FOREST FIRE AND ENVIRONMENTAL MANAGEMENT

– a technical report on forest fire as an ecological factor

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Cover: From a forest fire at Elverum, June 30, 1976 (Photo: Ivar Mysterud); inlaid two stages of succession after a fire in Sveio, June 2, 1992 (Photo: Bjørn Moe).

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SUMMARY

Bleken, E., Mysterud, I. & Mysterud, I. (Eds.). 1997. *Forest fire and environmental management. A technical report on forest fire as an ecological factor* Contracted Report. Directorate for Fire and Electrical Safety and Department of Biology, University of Oslo. 266 pp.

This technical report presents the fields of forest fire and environmental management in broad perspective. Forest fire as an ecological factor has been receiving increasing attention both in research and management due to its historic significance in developing forest ecosystems.

Fire ecology is a science based on physical, chemical and biological laws, which accumulates knowledge and analyzes the effects of fire on organisms and the environment. The terminology of fire research is presented, including the designation “fire regime”, which generally is used to characterize fires in an area by ignition sources, intensity, severity, fuel, climatic conditions, season, topography, conditions for spreading and frequency intervals. Fires ignited by lightning in Norway are defined as a “natural fire regime”, whereas those ignited by man represent an “anthropogenic fire regime”. Usually, they cannot be separated clearly, and therefore the designation “historic fire regime” is used to describe the sum of fires independent of ignition source.

Climatic and natural geographical conditions are important in shaping a country’s fire regime. Parameters such as topography, altitude, substrate, and the vegetation, which constitutes the fuel, are especially important. Vegetative changes resulting from climatic conditions after the last ice age followed an “undulating” pattern, and certainly caused considerable variation in the fire regime.

The highest frequency of lightning strikes in Norway occurs east of the watershed divide with the majority occurring in the forests north and east of Oslo. However, there is no simple relationship between the number of strikes and the number of fires started by lightning.

The Norwegian fire regime must be designated as cool, due first of all to the prevailing climatic conditions. To emphasize the regime’s distinctive characteristics, comparisons are made with natural geographical and regional conditions in Sweden and Finland. One feature of the Norwegian fire regime is that climate combined with the enormous topographical variation in Norway, can leave many areas unburned (“fire refugia”).

Among the challenges of fire regime research is securing better knowledge of the impacts of natural and anthropogenic ignition sources. It is easier for man to ignite fires, both deliberately and by accident, during the same dry periods in which natural fires occur. Cold periods with copious precipitation may, however, have resulted in bad years with crop failure and food shortage, this condition may have been compensated by more cultivation (“slash and burn”; Norw.: “svedjebruk”) and other anthropogenic open range burning. The different antropogenic burning activities are presented in chapter 4.

Man colonized Norway as soon as the ice sheet retreated. The question is how often immigrants burned the open range, and how comprehensive the different types of anthropogenic fires have really been. While lightning was the predominant igniting source in the least productive and driest forest types, anthropogenic burning primarily occurred on the most productive sites. Over the years, large areas must have been burned as part of different human activities or by careless ignitions connected with them. Some historical sources indicate that the amount of anthropogenic burning has been considerable, particularly during certain periods. Norway is a coastal nation that historically has had highly diverse coastal traffic. This may have led to considerable anthropogenic fire

impact on the coastal forests. One documented example of what we have called “tactical fires” was under the so-called “Hanseatic Period” during late medieval times when large areas of forest were burned as a competitive tactic in the timber trade.

As people settled the countryside, systematic burning on a large scale was undertaken to clear forestland for agricultural uses. Other important anthropogenic types of burning include swidden cultivation, which utilized the large nutrient stores in climax forest stands for production of crops, as well as burning to create and improve livestock grazing. Highly specialized burns for grazing improvement created the extensive areas of *Calluna* heath in Europe. These areas are maintained through a balanced cycle of burning, grazing and seasonal cutting. Principles from swidden cultivation were used by forestry, in the form of so-called “clear-cut-burning”, to stimulate regeneration, particularly in pine forests. Prescribed burning is also known to improve habitat conditions for certain game species such as grouse and ptarmigan. Nature conservation burning is the most recent type of anthropogenic burning. It is used to restore or improve biological diversity. The first prescribed burning of this type in Norway was undertaken in Hedmark county in 1996.

Anthropogenic contributions to the fire regime also include activities which indirectly affect the course of fire through changes and manipulation of fuel loads (Norw. “virke”). These activities include iron production (Norw.: “blestring”, “jernvinne”), charcoal production (particularly for mining purposes), salt boiling, potash production, tar burning, local harvest for house building and fuel, and the enormous extraction undertaken as part of commercial forestry and pulp industry. In some areas, the forest has disappeared completely due to human activities.

Anthropogenic sources of ignition have increased during the 20th century, both adjacent to large urban centers and in other parts of the landscape. These sources totally dominate the Norwegian fire regime today. However, forest fire history in Norway has not been systematically studied and is therefore not well known. Norwegian fire history is divided into three periods: older (long term perspective, back to the end of the last ice age), recent (short-term perspective, covering the last 500 years) and modern fire history (the last 200 years where records exist).

When a mapping of a country’s fire regime is conducted, all burning on open range that leaves carbon remnants in the soil, must be encompassed.

Scattered research up to now has indicated frequent occurrence of fires, especially in dry forest types. During certain periods, these areas burned frequently, separated only by short periods without fires. Fire refugia have also been found.

Research on recent fire history has been performed both in Finnmark county in northern Norway and in Østfold county in southern Norway. In Pasvik, Finnmark, fires had occurred at 26 – 100 year intervals on two thirds of the test plots, while one third of the plots had a fire interval of 100 – 200 years. In Østfold, a high frequency of fires was documented from ca. 1800 – 1850. Parts of the area may have burned every 20 to 30 years. An important periodic shift in the shaping of the Norwegian fire regime was introduced with the fighting of fires.

Systematic research to map the fire history and fire regime in Norway should be intensified. As a guide, the country can be divided into six “fire regions”: Hedmark (HMR), Southeastern Norway (SNR), Western Norway (VNR), Middle Norway (MNR), Northern Norway (NNR) and Finnmark (FMR).

Forest fire effects comprise an enormously complex field. Whether lightning or man ignites fires, they can have significant impacts both on species composition and cycling of materials over long periods of time. As an ecological disturbance factor they can represent everything from slight influence to profound alterations of whole ecosystems. Among short term effects are their surprisingly rapid elimination of larger or smaller parts of the biota, formation of mineralized nutrients and dead organic materials with high energy content, increase in soil pH and also in daily temperatures in the burned areas. Long-term effects are primarily associated with altered successions of species and changed nutrient regimes.

Certain species of fungi, plants and animals have evolved life history traits adapting them to fire, and may often be totally dependent upon fire, and are called “pyrophilic species” or “fire specialists”. Species without such adaptations, but which still react positively to fire and experience population growth are designated as “fire profiteers” or “fire winners”.

In higher plants, fire can affect among other things competition for light, nutrients and water, and plants can develop adaptations both in their vegetative phase, during flowering, fruiting or in resting stages (seeds). Fire can also profoundly affect animal societies. Some species, particularly meso- and macrofauna in the soil, can be directly affected during the fire. Most species, however, react indirectly through adaptation to new habitats.

Life history traits for which fire selects are best known in insects. Vertebrates are larger species with much better capacity for dispersal. They are less often affected by direct mortality, and have evolved few fire specialists. Some mammal species have developed “fire melanism”, i.e. a certain segment of dark colored genotypes surviving better in ash areas, thus having the capacity for population increases in burnt areas.

Forest fire can have profound impacts on soil, plants and animals, and significant effects on both energy flow and many different biogeochemical conditions in different ecosystems, i.e. nitrogen, sulfur and carbon cycles. This has important implications for environmental management.

The overriding principle in international forest fire management in the 20th and 21st century has been and still is suppression. Fire fighting has become so efficient during the last 100–150 years that unexpected consequences have contributed to changes in flora and fauna, i.e. loss of biological diversity.

Three important management strategies are available to cope with this: 1) management of already burned areas, 2) prescribed fires and 3) wild fire management. They are often characterized by combinations of conflicting arguments from scientifically based ecological criteria and economic management of resources.

The background and organization of modern fire management in Norway is also described. Measures against forest fires can be divided in preventive measures and suppression techniques. The preventive measures can again be divided into measures in the field and efforts towards early fire detection. Several actors today play a role in the preventive forest fire work in Norway. The basis for management is the Law of Fire Protection (Norw.: “Lov om brannvern”).

Key words: forest fire, ecology, fire regime, fire history, effects of fire, fire management

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GUIDE TO READERS

This technical report can be read in two ways. Those who only want a quick review of this document can get that by reading through the chapter summaries. Those who require more information are referred to the individual chapters. The chapters are organized so that they can be read as independent units.

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PREFACE TO THE NORWEGIAN EDITION

Today forest and range fires touch a number of topics in environmental management. Fires in coniferous forests can lead to large resource-economical losses for individuals and society. At the same time forest fire is a natural factor in the dynamics and development of the Nordic coniferous forests. Some species of plants and animals are actually dependent upon periodic fires for their survival. Such species are a part of the forest diversity, which there now is a consensus to conserve, and there are complex questions associated with how the future's fire management should take them into account. Future management of forest fires in Norway can therefore contain more than just complete fire suppression. A many-sided and nuanced view of fire management will demand information and knowledge at all levels.

During this contracted work we have borrowed support from both "local" literature, i.e. Norwegian and Swedish research, as well as relevant articles and books about forest fire written by international researchers. Several of the most modern accounts are written by fire researchers in Australia and Africa, thus from areas with a fire regime totally different from the Norwegian one. Good management builds on knowledge, so this technical report is attempted linked to international fire literature. In general, much research on forest fires has been conducted isolated from the mainstream research in ecology, a situation that is rapidly changing.

Fire management is today an extensive topic. However, presentations, which deal with such management, have often been characterized by incomplete discussion of the side effects of prescribed burning. Thus they have also avoided taking up much of the disagreement, which exists between forest fire researchers concerning the importance of fires in conserving natural diversity.

An important intention with this report was to deal with Nordic forest fire data to get an improved understanding of the forest fire conditions in the individual countries and undertake a comparison of these countries. This turned out to be quite difficult as statistical data both were of different kinds and partly insufficient. In spite of this we have evaluated a few conditions based on incomplete material to stimulate further research.

There is no international agreement about a basic terminology, and thus collection of data concerning forest fires is not standardized, and is incomplete and poorly suited for problem-based research. There are extensive problems concerning the importance of scale, and evolutionary conditions are very incompletely dealt with.

To get an updated review of forest fire and forest fire management, the Directorate for Fire & Explosion Prevention (Norw. "Direktoratet for brann- og eksplosjonsvern", DBE) initiated a contracted project to survey this topic. The work was carried out in cooperation with Department of Biology at the University of Oslo, and has been economically funded by the Directorate for Civil Defence and Emergency Planning (Norw. "Direktoratet for sivilt beredskap", DSB), the Directorate for Nature Management (Norw. "Direktoratet for naturforvaltning", DN), Skogbrand Insurance Company, the Ministry of Local Government and Regional Development (Norw. "Kommunal- og regionaldepartementet"), Department of Biology, University of Oslo, and the Directorate for Fire & Explosion Prevention.

The technical report aims mainly at reviewing current knowledge of the field, with particular focus on Norway. However, we wish to draw attention to the fact that many conditions concerning forest fires are still incompletely known, also in boreal coniferous forests and coastal forests. Therefore one has to be careful in transferring results from other countries to Norway. To a great extent this also applies to management plans and "introduced" knowledge of various kinds. Norway is subject to nature-geographical and cultural conditions so distinctively different from the areas further east that when future management plans are to be worked out, they should be based on special Norwegian surveys. The technical report was available in manuscript during December 1996, but was not printed due to a conference on the dynamics of burned areas in forest implemented by The Research

Council of Norway during January 13 and 14, 1997. The report was withheld to incorporate as much as possible of recent Norwegian literature concerning this topic.

We would also emphasize that the selection of results, concluding statements and evaluations included in this report must *not* be judged as complete compared with the enormous existing literature on this topic. However, it is our hope that this report can lead readers into relevant problem areas and literature concerning some important topics and that the report can be of value in future research and management of forest and range fires in Norway.

There is a large general need for information to attain an improved ecological understanding of the importance of forest fires both for actors in institutions and management departments in Norway as well as among the general public. Hopefully, this report may be a valuable contribution.

Erik Bleken   Ivar Mysterud   Iver Mysterud

PREFACE TO THE ENGLISH EDITION

This is an English edition of a technical report on forest fire ecology and environmental management presented in 1997. Many articles and books on forest fire have been published since then, but these are not incorporated here. **This edition is just a translated version of the 1997 Norwegian edition**, and only minor corrections and changes have been undertaken. The English plant nomenclature follows Clapman et al. (1962).

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1 INTRODUCTION

By Ivar Mysterud, Iver Mysterud and Erik Bleken

In this report, we are going to illuminate the topic of forest fire and environmental management. This is not possible without also describing forest fire as an ecological factor on a general basis and focus on both naturally ignited fires and human use of fire in a broad perspective. The view of forest fires depends both on our understanding of nature and of human's place in it.

1.1 Historic perspectives

Forest and range fires are the most general "disturbance" factor in terrestrial ecosystems behind anthropogenic activities such as establishment and construction of agricultural and urban areas (Clark 1989, Bond & van Wilgen 1996).

Forest fires have also been of significance over long periods of time in Norway. Studies of historically deposited carbon particles at a limestone stalagmite from a karst cave in Rana, Nordland county (Lauritzen et al. 1990) indicated fires in the interglacials during the period from 370 000 to 700 000 years back in time. Pollen and carbon dust from fires are moved by the wind far into such caves and deposited on humid surfaces of limestone little by little as these form and grow. There are 800–1 000 such caves in Norway (Lauritzen & Østbye 1994), offering unique possibilities for studying the forest fire history far beyond the last glaciation. If any of the oldest fires read in the grinded cut of the stalagmite from Rana were of an anthropogenic origin, they were ignited by the prehistoric human *Homo erectus*.

For millions of years, forest and range fires have been part of the normal climate of the biosphere. They have been naturally ignited by lightning, volcanic eruptions and sparks from rock slides long before humans evolved. Large changes occurred, however, with the appearance of humans.

Humans already knew how to use fire more than a million years ago, at the time *Homo erectus* left Africa and, among others, traveled northwards in Europe (Brain & Sillen 1988, Goldammer 1994). The cognitive processes and behavior of "taming" fire and burning, i.e. developing various forms of "fire culture", has been one of the earliest, most important and most radical contributions to human technology, a basic pillar in our civilization (Handwerker 1989, Goldammer 1994). Fire has been and still is a climatic factor that humans can control to far greater extent than other climatic factors.

Archaeological documentation indicates that anatomically modern humans were present on most continents with "torches in hand" at least 40 000 years ago, and probably earlier (Bird 1995). The ignition of fires made possible everything from large scale hunting operations and cultivation to war and defence actions (Goldammer 1994, Whelan 1995, Pyne 1996, Pyne et al. 1996). This deliberate use of fire marked the beginning of an enormous wave of global environmental change which still continues. More recently, numerous written reports became available from early European explorers about "natives" who ignited fires in Australia, Africa, North and South America and New Guinea (Mitchell 1848, Stewart 1956, McArthur 1970, Goldammer 1994). [1.1)]

Humans continue to burn also in our time. Both controlled and uncontrolled forest and range fires annually "consume" enormous amounts of plant biomass in all climatic zones of the world, from Arctic tundra and boreal coniferous forests to tropical grasslands and savannas. In the tropics alone, it has been estimated that 2 700–6 800 million Metric tons plant carbon has been burned annually, mostly in savannas in connection with agricultural production and rotation of crops (Crutzen & Andreae 1990, Levine 1991, Weiss & Goldammer 1994). Fire annually influences 20–40 million hectares of tropical rain forest in connection with agricultural utilization and various altered use patterns. The corresponding number for tropical and subtropical savannas and more open tree-covered landscapes is 500–1 000 million hectares annually (Weiss & Goldammer 1994). It is estimated that as much as 10–15 million hectares of the boreal and temperate forest and range areas are influenced by fire annually (Weiss & Goldammer 1994, Goldammer & Furyaev 1996). For comparison, it can be mentioned that the total Norwegian forest area is 11.9 million hectares.

During the last 50 years, ecologists have had to drastically reevaluate their opinions about fire as an ecological factor and about the important role humans have played in the development of the fire regimes on all continents.

What then is Norway's position in this perspective? What do we know about the Norwegian fire regime, and what have natural and anthropogenic forest fires meant for the development of our landscapes? These and similar questions are going to be the focus of this technical report.

1.2 Natural ignition and fire ecology

Lightning is the only known cause of natural ignition of forest fires in Norway, and in some dry years it can ignite many fires. We therefore first devote some attention to this part of the climate (ch. 2). Lightning is an important part of the global electrical processes. It is therefore pointed out that lightning has both direct and indirect effects on the ecosystem even when it does not ignite fires. The other important factor responsible for igniting forest fires is human activity. When we take into consideration the events after an ignition occurs, we will, however, proceed into the real fire ecology. In the first section (ch. 2), we therefore present some general elements about fires and combustion and some of the terminology scientists and managers use when describing fires.

1.3 Climatic and nature geographical conditions

Climatic and nature geographical conditons as they are defined by among others climate, topography and vegetation covers (Varjo & Tietze 1987) constitute important preconditions for the Norwegian fire regime (ch. 3). There have taken place considerable changes in climate and vegetation cover during the postglacial period, something that must be assumed to have influenced the fire regime.

The most important fuel for forest fires is constituted by a broad continuous belt of boreal coniferous forest stretching across the enormous Eurasian continent. Its western edge skirts the Atlantic Ocean along the coastal nation Norway, i.e. to Finnmark and Troms counties, including both the Trøndelag counties and a larger area at the eastern and southern part of south Norway (Østlandet and Sørlandet) (Sjörs 1987).

The most important topographic landscape feature in Norway is the Scandinavian mountain range (Varjo & Tietze 1987). Norway is more than 1 700 km long from north to south, but narrow, particularly in the northern part. Other topographic characteristics of great importance are the long and rugged skerries and fiords penetrating deep into the Scandinavian mountain range from the west. One of the most conspicuous features of the climate when considering forest fire is precipitation. Our coastal areas are among the wettest areas of the world (Varjo & Tietze 1987), and the Norwegian ecosystems and vegetation cover are among the most oceanic influenced on the Eurasiatic continent. These conditions result in a distinctive feature of the Norwegian fire regime, and are the reason why lightning as a natural ignition source is expected to have played, and play, a lesser role in Norway than in more continental areas. However, the conditions in Norway vary considerably. Climatically, we also have areas with more continental characteristics, for instance, in the forest areas furthest southeast towards the Swedish border. To put Norway in perspective and emphasize its distinctive features, we have compared Norway with the nature geographical conditions in Sweden and Finland (ch. 3).

1.4 Anthropogenic burning

Forest fires ignited by humans, and burning in outlying areas in connection with various anthropogenic activities seem to have been of great importance throughout the entire history over large parts of Norway (ch. 4). Because ignition of fires from lightning is less extensive in Norway than ignition from anthropogenic factors, does not, however, mean that such fires burned less in Norway than in our neighboring countries.

In this report, we emphasize activities associated with anthropogenic burning, both various burning types and how vegetation cover, i.e. the fuel, have been manipulated. Anthropogenic burning began with the first immigrants just after the last glaciation and has later varied in kind and extent through various time periods.

A basic historic feature is that movement and the first large traffic arteries in Norway followed the coast, with communication into the fjords and along large rivers. Settlements mainly began along the coast. It was not until a later time that large inland colonizations (Norw. "landnåm") appeared, and waves of immigrants colonized new land and gradually settled the inland areas permanently (Jokipii 1987).

While we know little about the first hunters' and gatherers' use of fire in the landscape, the later permanent settlements and agriculture in the Norwegian coastal areas formed the basis for exploiting the landscape. Farming was established and pastures were provided for an increasing population of domestic animals into ever larger parts of outlying areas.

The forests also became more utilized. Burning of forest to fertilize crops in various forms of swidden agriculture is the best known activity (Larsson 1995). Even the oceanic coastal forests were influenced by human use of fire. There are traditional stories told among local peoples of the western coast about coastal forests that were burned away in earlier times (Sandmo 1951).

Pasture lands for grazing animals helped create coastal heathlands across large areas of Norway. These are examples of fire-created ecosystems of purely anthropogenic origin. It was not, however, only the burning itself that was important in forming the Norwegian fire regime. Anthropogenic activities have also influenced the fuel in Norwegian forests by removing enormous amounts of wooden biomass. In some areas, the forest was cut so hard that it disappeared (Sandmo 1951). Thus, it is no longer possible to get forest fires in such areas. And, if lightning ignites a fire, there may be no "natural" course because the fuel configuration across large areas has been changed through anthropogenic activities.

Beyond the middle and especially towards the end of the 19th century, a profound change in the relation to forest fires emerged in many western industrial countries as one began to suppress forest fires far more efficiently. We know little about what consequences and changes this might have incurred in Norwegian forest ecosystems. This is one of the reasons that environmental management is now focusing on this.

1.5 Norwegian forest fire history

The fire history in forest and range landscapes is a basic part of the postglacial landscape history in Norway. We have divided the period into an *older* epoch, from the last glaciation until 500 years ago, and a *younger* epoch, which encompasses the last 500 years (ch. 5). There are, however, only a few fragments of "Norwegian forest fire history" which are known (ch. 5). We have, though, begun collecting the most factual information. There have been few historical forest fire surveys in Norway. However, those that exist have already emphasized a number of circumstances supporting the importance of uncovering the fire history of the landscape as a basis for future management.

1.6 Contemporary fire regime

Not before the modern forest fire statistics was initiated in Norway in 1913 could we establish a reliable picture of what lightning, compared to the consequence of human activity, meant for the Norwegian fire regime (ch. 6). After first exploring the development in number of fires in Norway during this period, we examined a number of conditions and mapped a few details in the general fire pattern.

1.7 Fire regions in Norway

Because climate and nature geographical conditions vary (ch. 3), the circumstances around forest and range fires cannot be generalized for the entire country. Norway does not only have one, but several different "fire regimes". We have therefore suggested a division of the country into six fire regions (ch. 6) that constitutes the basis for a more systematic exploration and future management of fires.

1.8 Effects of forest fire

Forest fires vary enormously and can lead to everything from sparse influences on the ground layer to severe impacts on entire ecosystems (ch. 2). The ecological effects can hardly be generalized, and knowledge about and evaluations of such effects constitute one of the most important fields of fire ecology. This is the background for why the presentation of ecological effects constitutes the largest part of our report (ch. 8). These can be subdivided into direct effects, where the fire kills organisms and converts biomass, and the indirect and long term effects, which change the environmental conditions and influence ecological conditions and processes over long time periods. Such knowledge is basic when developing fire ecology further in Norway. The effects are treated in general and also in reference to literature where comprehensive knowledge is known from other fire regions.

1.9 Management of forest and range fires

The most important reason for this report is the importance of forest fires as disturbance factors in national and international environmental management (ch. 9). It is internationally maintained as critically important to con-

serve biological variation, manage populations and partly maintain, restore, and in some places increase diversity and qualities in the landscape that in many industrial countries are lost as a consequence of fire suppression. Norway has never developed specific plans for conservation of plants and animals that have relations to fire, and current knowledge from domestic research to accomplish this is meager. We also emphasize that management of forest and range fires is a scientific field with considerable demands for specific competence.

Everyone involved with such issues and problems should be familiar with the broad discussion that has taken place internationally. For example, when we comment on the fires in Yellowstone National Park in the USA, it is not because this fire regime can be transferred to Norwegian conditions, but more so to highlight the importance Yellowstone studies have had in developing the present knowledge of fires. Research in this field has in fact contributed to our general understanding of nature. Theory formation and concept development in general ecology has only to a limited extent been influenced by the knowledge about forest fires. Models of forest fires and some of their effects actually do not agree with widely accepted general ecological theory (See Bond & van Wilgen 1996). Species changes over time, for example in succession, can to a certain extent in general ecology be predicted based on the positions of the species in a competition hierarchy. In communities that burn often, however, the succession is driven more by the life history traits of the different species than by their competitive abilities. [1.2)] Research has also extended our view of the relations between humans, forest fires and nature. This has been of far-reaching importance for environmental management.

Management of forest and range fires in Norway rest on two basic pillars; one is the international conventions and agreements which Norway has ratified to conserve diversity in nature (ch. 9), and the other is the country's own laws and regulations, for example the Law of Forestry, and others which regulate fire suppression and fire preventive efforts.

1.10 Fire preventive efforts

The overriding principle in international management in the 20th century has been and today still is suppression of forest fires. It is therefore necessary to have knowledge concerning the present practices. The opinion for steadily more developed and efficient fire suppression has been leading in Norway for more than hundred years. We have therefore devoted a separate chapter to this (ch. 10).

Efforts against forest fire can be divided into two main categories; forest fire prevention efforts and forest fire extinguishing, each containing many important topics. Many of these efforts may be assumed to be maintained as the most important basis for management in the future.

1.11 Organization of forest fire protection in Norway

The history of the development and organization of forest fire protection in Norway will be commented on in a number of situations throughout this report, but will also be treated in a separate account (ch. 10). Here, we survey which agencies participate and what resources are accessible both in the preventive work with forest fire and in the suppression of fires.

1.12 Laws and regulations

As already mentioned, a number of international conventions and agreements exist as a framework for the present management in Norway (ch. 9), but this also rests upon quite extensive Norwegian laws and regulations. These are applied in connection with all activities that influence or can influence forest fires. A rough choice of them is presented in an account at the end of this report (ch. 12). If it becomes necessary in the future to develop a better environmental management, it is at this juridical basis one must begin.

1.13 Objective

This technical report cannot cover in detail the enormous field comprised by forest and range fires in environmental management and as an ecological factor. It will, however, attempt to provide Norway with a first "fire ecological identity" in global, Nordic and Norwegian perspectives. The objective has also been to improve the understanding of forest and range fires for a broader public, and to make the literature in fire ecology and associated environmental management accessible for a larger audience.

2 NATURAL IGNITION AND FIRE ECOLOGY

By Iver Mysterud and Ivar Mysterud

Forest fires are today judged to be the ecological factor most significant for the development of the boreal coniferous forest (ch. 5). Knowledge of causes of fires and the various processes controlling the natural development of the vegetation after a forest fire, is therefore necessary if we are to understand the function of the natural forest under present conditions (Zackrisson 1977a,b, 1997, Schimmel & Granström 1991). In spite of this, fire ecology as a scientific discipline has earlier received sparse interest in Norway. [2.1)]

Fire ecology is concerned with the course of the fire “behavior” and its effects on organisms and environment based both on physical and biological laws (Fristrom & Westenberg 1965, Rosotti 1993). The first law of thermodynamics about conservation of (matter and) energy provides a superior perspective: Fires cannot destroy energy or matter, only change their forms (Komarek 1971a, Fuqua et al. 1972). The fire process itself may, however, influence almost every condition in an ecosystem.

Fire ecology is a large international research discipline (McArthur & Cheney 1966, McArthur 1967, Rothermel 1972, Cheney 1981, Vines 1981, Chandler et al. 1983, Pyne 1984, Goudie 1986, Trabaud 1987a, Fuller 1991, Johnson 1992, Weiss & Goldammer 1994, Whelan 1995, Goldammer & Furyaev 1996), and fire as a factor is important for all types of ecosystems that contain fuel (Wein & MacLean 1983, Goldhammer 1990, 1994, Goldammer & Furyaev 1996). The importance of fires is, however, highly different from continent to continent (and in various regions). The most extensive research has been conducted in areas where fires are of central importance, in Africa (Booysen & Tainton 1984, Cowling 1992, van Wilgen et al. 1992), Australia (Gill et al. 1981, Pyne 1991), USA and Canada (Wade et al. 1980, Mooney et al. 1981, Wright & Bailey 1982, Minnich 1988, Walstad et al. 1990) and Siberia (Goldammer & Furyaev 1996). Fires are also of great importance in many regions of Europe, for example in the Mediterranean area (Mooney & Conrad 1977, Goldammer & Jenkins 1990). Where this technical report focuses on the general aspect of forest fires, it builds on this international literature.

Two conditions are basic in the understanding of the course of fires. One is fire as a fast oxidation process, i.e. a reaction between organic matter and oxygen during the formation of water, CO_2, other gases and minerals (Rosotti 1993, Whelan 1995). The other is the physical source of ignition that is necessary for starting this fast oxidation. The most important source of natural ignition is lightning strikes. Lightning is a function of the steadily varying global electrical field. The importance of electric climatic processes (lightning and thunder) for living organisms, communities and ecosystems may be called “electrical ecology” (Malan 1963, Komarek 1964, 1968, 1969b, 1973, Uman 1969, 1973, Krider 1986, Orville 1986). Because of knowledge of sources of natural ignition are important for what is going to be discussed later in this technical report, we are as a start going to focus on a few conditions from this sparsely studied scientific field.

2.1 Lightning as the “prelude” to fires

“Electric ecology” concerns the relation between living organisms and electrical processes of the biosphere. Lightning discharges have also other ecological influences than the ignition of fires itself. Lightning may actually weaken and/or kill trees and other vegetation influencing the composition of the fuel regime; this has effects that holistically should be seen together with what later might happen after an ignition. [2.2)]

A generalized map (Fig. 2.1) shows that Norway has few thunderstorms compared for example with tropical areas. Norwegian thunderstorms may either enter from the ocean with wandering low pressures or they may be formed over inland areas, often in the afternoon on warm days during summer (Dannevig 1968). Lightning strikes connected to thunderstorms occurring due to the warming up of unstable air over warm land areas during the dry season, has the highest likelihood of igniting forest fires in Norway.

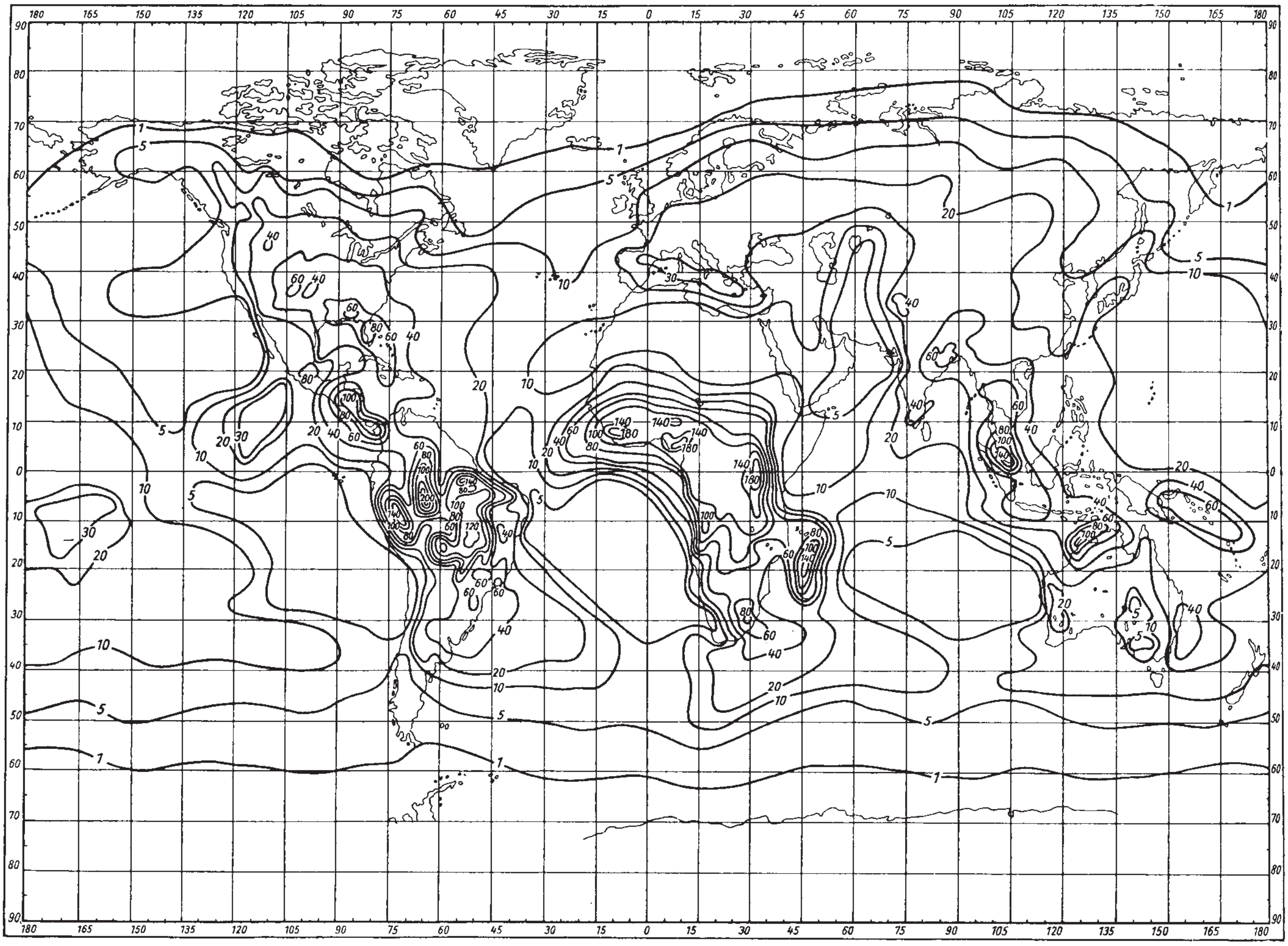


Figure 2.1. Global distribution of the annual number of days with thunderstorms. The thunderstorm frequency is low in North Europe and highest in South and Central America and in Africa (From Liljequist 1970).

Lightning discharges can be divided into positively and negatively charged lightning. The ignition energy from lightning is sufficient both in positive lightning and in the negative ones that have sufficient so-called “long follow-on current”. It is documented that the duration of a lightning is of greatest importance (Lundquist & Götschl 1995). Different types of fuel and their properties result in a highly variable risk of ignition by lightning. Ignition can occur both in the ground stratum and in trees, and lightning can create glowing combustion that can flare up as many as 8–10 days after the strike.

Lightning strikes can have both direct and indirect effects on ecological processes.

2.1.1 Direct effects

Direct effects are caused by lightning discharge at the moment of the strike itself. Many millions of trees are hit, damaged or killed by lightning around the globe each year, and a large number of these remain standing as dry trees (“snags”). In Florida in USA it is established that lightning annually hits at least one tree per 18 hectares forest land (Wilson Baker 1973). The hit trees are spread all over the forested area without any defined pattern. Some pine trees lived for a considerable time after the lightning strike, but most of them died within 1.5–2 years (Wilson Baker 1973).

The most common visible sign after lightning strikes in forest communities is effects on single trees. These vary from small structural and physiological influences to splintering and complete destruction (A.R. Taylor 1973).

Lightning strikes can give external damages like splintering, crushing, formation of a spiral shaped or straight “track” at the tree trunk as well as internal damages that are not visible on the outside (Murray 1958, Hauberg 1960, A.R. Taylor 1969, 1973). Lightning has been reported as one of the most important mortality factors in Ponderosa pine (*Pinus ponderosa*) and a number of other pine species. Lightning can, through splintering, remove old and ageing trees and in this way create gaps in closed stands.

Lightning strikes can also lead to considerable physiological damages on trees, for example reduction in resin secretion, changes of the water content in the inner bark tissue, lowering of sucrose levels and physiological damages to root systems. There has been measured an increasing loss of hydrostatic (water) pressure from the top and downwards along the trunk of trees that are damaged by lightning (A.R. Taylor 1973).

Some researchers think that a lightning strike can influence the root system of trees surrounding the hit tree (A.R. Taylor 1973). Others argue that lightning can hit several trees in a group at the same time, i.e. that it can pass on from trunk to trunk, while some think that discharges can transmit horizontally through the crown layer (A.R. Taylor 1973). There are documented instances where groups of trees gradually die around the tree that carries the physical damage after a strike.

Detailed information about effects of lightning discharge on soil and soil fauna is generally sparse.

2.1.2 Indirect and “hidden” impacts

In the extent that lightning kills and influences trees, it is a precursor for indirect effects like succeeding insect attacks, downing from wind influence and disease, and for plant and animal succession (Taylor 1971). The open spaces and gaps created by lightning, may result in invasion of plants, and thereby a larger species diversity of the vegetation in addition to changes in the micro-climate and other habitat factors, which again may influence the fauna (A.R. Taylor 1973).

In tree trunks killed by lightning where ignition does not occur, a succession of invertebrate animals and rot organisms is started. The invasion of species begins immediately after the tree is weakened or killed and continues until the tree is rotten and totally decomposed (A.R. Taylor 1973, Wilson Baker 1973). The fauna of such trees encompasses a number of groups of insects and other arthropods that are of importance in the ecosystem.

Especially bark beetles, for example the genus *Ips*, and related groups can colonize and attack trees that are killed or weakened by lightning strikes, in boreal coniferous forests. [2.3)]

Trees which are damaged by lightning can provide nourishment for a great variety of insects, which again can provide food resources for bird populations over longer periods of time. American research established six species of woodpeckers and a great variation of tits and other passerines that visited such sites through several years after lightning strikes (Wilson Baker 1973). The succession of animals connected to trees hit by lightning strikes is not further examined in Norwegian coniferous forests.

Dry trees formed by lightning strikes are used by woodpeckers (for foraging, resting, breeding and as “acoustics trees”), ducks (nesting), birds of prey and vultures (watch and observation posts, sitting sites), in addition to a great variety of other bird species (breeding and resting). Such trees offer good visual overview because of the dead branches (sitting trees). Stumps left standing when such dry trees crack, are also utilized as breeding and resting sites by a number of species requiring holes, for example woodpeckers (*Dendrocopos* spp.), different species of tits (*Parus* spp.) and nuthatch (*Sitta* spp.) (Wilson Baker 1973). In addition, several mammals, snakes and other animals can reside in such trees. Detailed surveys are lacking in many countries (See Samuelsson et al. 1994).

Effects of thunderstorms

Thunderstorms themselves can have ecological effects. During thunderstorms it is observed increases in the ozone content of up to 10 ppm (parts per million), and it is established that ozone concentrations of only 4 ppm can have ecological influences on plants. The impact on animals is still sparsely charted. The cause of the increased concentration of ozone close to the ground is supposed to be that the ozone is being transported toward lower levels by descending winds in the atmosphere formed by the storm. Thunderstorms can also be of ecological significance through an up- and down whirling of air currents spreading insects, spores and seeds.

Some researchers suggest that acoustic effects from the lightning flash itself with its accompanying shock waves can also influence both plants and animals.

2.1.3 Conditions for lightning ignition

To achieve ignition of solid fuel so much heat must be transferred to the fuel that it starts to form inflammable gases. The fuel must then be heated to a certain level. This demands a certain time determined by the heat conductivity of the fuel. In addition, moisture that is present must be evaporated.

The ignition is normally supposed to happen in the ground layer, which can consist of moss, lichen, heather and twigs, in addition to sprigs and leaves (A.R. Taylor

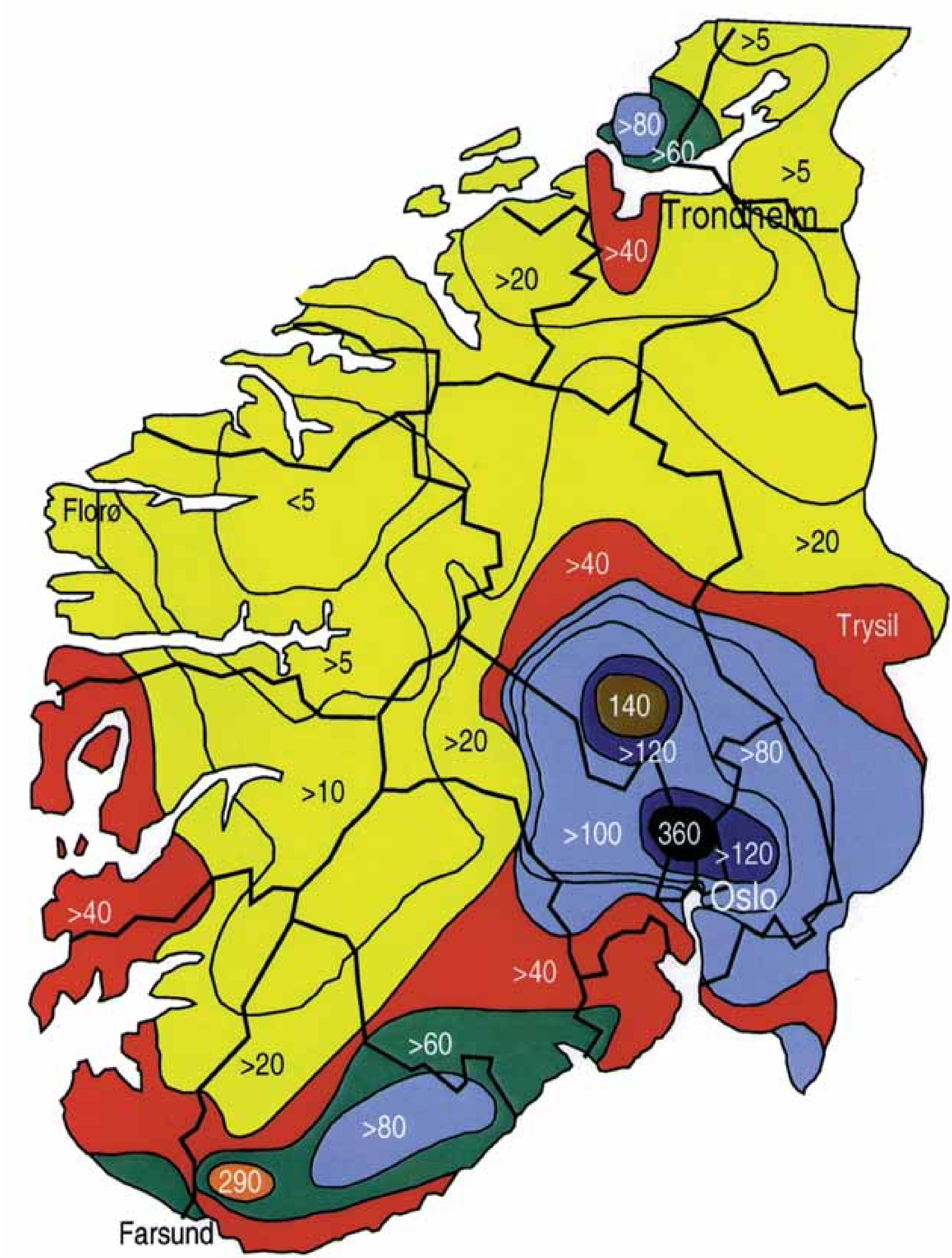


Figure 2.2. Map of South Norway with estimated number of registered lightning strikes per 100 km^2 throughout the ten-year-period 1982-92. (Printed with permission J. Huse, EFI).

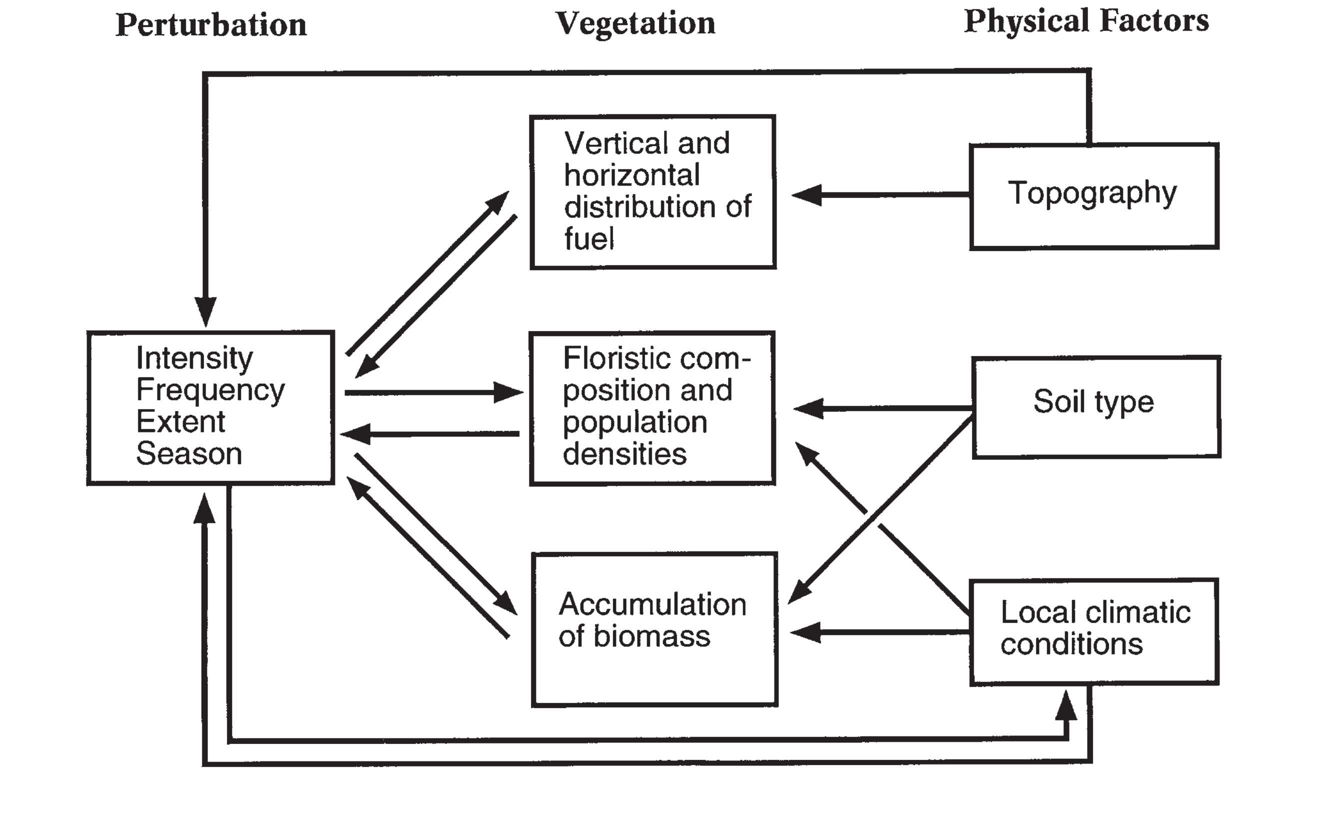


Figure 2.3. Schematic diagram illustrating interactions between fire, vegetation and physical conditions (Modified from Riba & Terridas 1987, redrawn after Whelan 1995).

1973). The depth of the fuel, the size of twigs and moss etc. plus moisture and porosity is of great importance. Of importance are also air temperature, sunshine and wind that can warm and dry the ground layer and accelerate a fire that has started, and rain which can withhold or extinguish a glowing combustion.

A single lightning strike can in certain cases start glowing fires at several sites in the ground layer. A lightning canal can spread out more than 100 m on ground with poor electrical conductivity characteristics, for example a thin ground layer on solid rock. Further lightning strikes can fork or branch so that various partial discharges have different impact sites with individual distances up to several kilometers (Lundquist & Götschl 1995).

Depending on the ground moisture and characteristics of the fuel, glowing combustion can continue for as long as 8–10 days. There may be great variations in the speed with which a running fire develops from a glowing fire.[2.4)]

Lightning strikes can also ignite trees. How easily living trees will be ignited by lightning is determined by bark structure, content and type of volatile chemicals, and by the moisture content of bark and surrounding air. This can explain observed differences in frequency and occurrence of forest fires ignited by lightning between different regions (A.R. Taylor 1973).

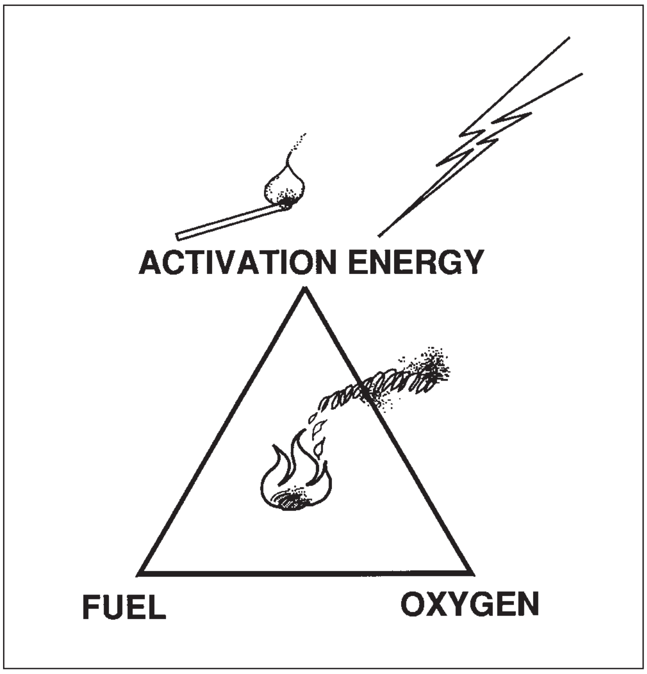


Figure 2.4. Necessary preconditions for ignition (From Lundquist & Götschl 1995).

2.1.4 Ignition and strike frequency

Each year approximately 182 million cloud to ground discharges occur over forest and grasslands in the biosphere. Of these approximately 50 000 cause forest fires, i.e. less than 1 % (A.R. Taylor 1973).

Lightning does not ignite fires in any evenly distributed pattern, but has to be seen in connection with climate and vegetation cover characteristics of various regions (See ch. 6). The frequency and the biological importance seems to be highest in the western part of North America (Fig. 2.1). We should also note that lightning strikes as source of ignition in most areas play a much less significant role than fires that originate from human activities. Even in the USA only roughly 100 000 of 1.1 million fires are supposed to be caused by lightning strikes annually (A.R. Taylor 1973).

2.1.5 Registration of lightning in Norway

In 1979–80 a system to register lightning came into operation for testing in Norway. It has later gradually been developed, and today a Nordic system is established. The aim is to achieve a running charting and registration of the lightning strike frequency of Norway, Sweden and Finland (Lundquist & Götschl 1995). This system has five registration units in Norway, located in Farsund, Florø, Oslo, Trysil and Trondheim, respectively. The central unit is located at Norwegian Meteorological Institute in Oslo (Huse 1994, Lundquist & Götschl 1995).

This system has given the first reliable strike pattern map of South Norway for the period 1982–92 (Fig. 2.2).

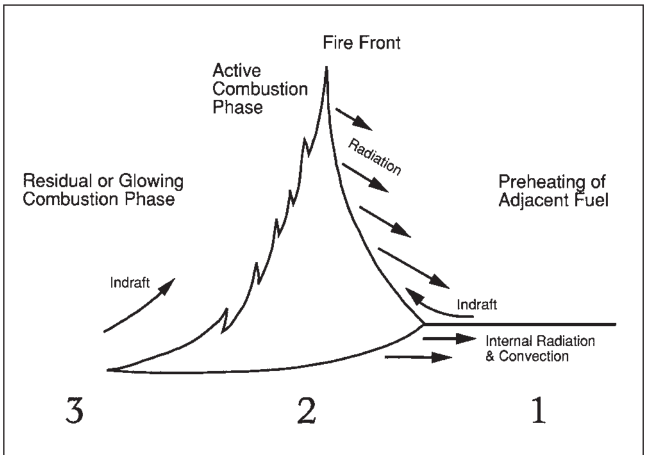


Figure 2.5. Fire front and flame profile of a fire in flat terrain without wind (Redrawn after Whelan 1995). The regions are indicated where matter is preheated (stage 1) and the flaming combustion (2) and glowing combustion (3) occur (See text).

Mean and lower values occur in the western part of Norway (Vestlandet). A coastal area close to the Trondheim Fiord shows somewhat higher values, likewise an area around Farsund. The highest values occur east of the watershed divide, peaking in the forested region north of Oslo and in adjacent areas to the north and east. A limited area with 360 lightning strikes per 100 km (the period 1982–92) in Southern Norway constitutes the Norwegian maximum. Another limited area with the value 140 is located somewhat farther north.

There is, however, no simple connection/association between the number of lightning strikes and the number of fires that are ignited by lightning in a region. When lightning ignites, however, the succeeding fire can spread in ecosystems and have considerable impacts both on species inventory and material cycles for a long time (See ch. 8).

2.2 Fire ecology

Fire ecology as a scientific field is here defined as the study of the relations between living organisms and fires, irrespective of ignition sources. In other words it embraces the study of all conditions concerning the occurrence of fire in the ecosystem.

As a basis for the further presentation an understanding of some elementary conditions concerning fire and combustion is necessary, plus knowledge of some of the terminology that is used. Particularly important is the notion *“fire regime”* (Section 2.2.5).

A forest and range fire is characterized both physically and chemically. The characteristics of the vegetation in an ecosystem and various conditions of the fires influence each other reciprocally (Fig. 2.3). The specific features of a fire will to a large extent contribute to determine the responses of the plant and animal species in the fire areas (ch. 8). [2.5] Such responses are in themselves highly variable, and predictions are difficult. A continued development of fire ecological theory and the understanding of forest fires are therefore dependent on thorough descriptions of individual controlled fires in experimental studies. [2.6]

Generally, the course of a fire will be modified through interactions with fuel (amount, distribution, flammability and energy content), weather, topography and factors influenced by the earlier fire history in the area. Basic conditions are determined by the amount of energy

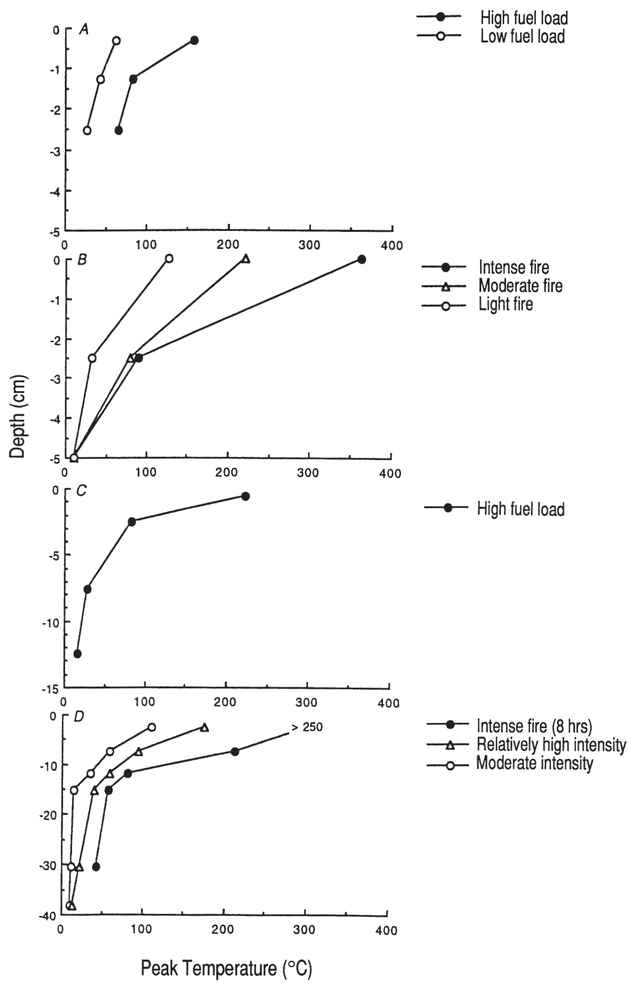


Figure 2.6. Profile measurements from fires where one has examined the relation between the peak temperature and depth influence of the soil profile. In all occasions the highest temperature declined with the depth (Redrawn from Whelan 1995)

A Fires in longleaf pine (*Pinus palustris*) forests in southeastern USA (From Heyward 1938).

B Fires in chaparall systems of California, USA (From DeBano et al. 1977).

C Temperatures under heavy slash fuels after logging in forest (From Neal et al. 1965).

D Fires in eastern Australia eucalyptus forest (From Beadle 1940).

stored as living and dead biomass per unit area.

We can divide fire development in two phases, 1) *the ignition* itself and 2) *the course of the fire's succeeding spread*. Different, but overlapping, groups of factors control the conditions in these two phases (Whelan 1995).

Table 2.1. Examples concerning fuel, which show that the elements influencing fires are often linked to each other in complicated ways (From Whelan 1995). The single variables will be more closely described in section 2.2.5.

Factor	Factor
Fuel load	• Determines maximum energy available to a fire. Arrangement of fuel can affect aeration (dependent on degree of packing), vertical spread (e.g. the likelihood of spreading into higher layers of the plant cover) and horizontal spread (patchy distribution of ground surface fuel) • Size distribution can affect likelihood of initial ignition • Chemistry of fuel can increase flammability (e.g. by means of resins and oils) or decrease it (e.g. because of high mineral content)
Overall climate	• Determines vegetation productivity and thereby rate of fuel accumulation
Rainfall and humidity	• Determines moisture of fuel. Increased water content combined with high relative humidity decreases likelihood of ignition, rate of combustion and rate of spread
Wind	• Causes drying of fuel. Increases oxygen available for combustion • Pre heats and ignites fuel in advance of the fire front, can contribute to spread of fuel through flying sparks and "torch spread", which again can produce ignition far ahead of front • Changes in wind direction can increase the breadth of the fire front
Topography	• Causes variation in local climate and thus the course of the fire, for example through fuel moisture, relative humidity, and interaction with wind • Permits better pre heating of fuel and thereby faster ignition and spread of fires burning uphill • Provides natural firebreaks. Determines quality and distribution of fuel through distribution of plant communities (fuel) of different flammabilities

2.2.1 Chemical-physical reactions

The understanding of the basic properties of a fire is dependent on insight in the physics and chemistry of combustion. To start a combustion, fuel, oxygen and sufficient ignition and activation energy [2.7] (i.e. "kindling temperature") must exist at the same place and time, here illustrated with the so-called "fire triangle" (Fig. 2.4).

Energy stored in biomass is released as heat when materials such as leaves, grass or wood combine with oxygen to form carbon dioxide, water vapor and large or small amounts of other substances (Whelan 1995). One can think of this reaction as a kind of "reversed" photosynthesis, in which carbon dioxide, water and solar energy are combined, producing a chemical energy store and oxygen. The two processes can be compared in the following equations (Trollope 1984, Whelan 1995):

Photosynthesis:
(1) $CO_2 + H_2O + \text{Solar energy} \rightarrow (C_6H_{10}O_5)_n + O_2$

Combustion:
(2) $(C_6H_{10}O_5)_n + O_2 + \text{kindling temperature} \rightarrow CO_2 + H_2O + \text{heat}$

In a simple form, the chemical equation for combustion can be illustrated with the complete combustion of a simple sugar, such as D-glucose (McArthur & Cheney 1972):

Combustion of D-glucose:
(3) $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 1.28*10^6 kJ$

Plant matter is, of course, chemically much more complex than glucose, and different components of fuel (e.g. dead leaf litter, dead wood, live foliage, twigs and wood) have energy stored in a great variety of forms. However, the principle of the equation is much the same as in equation (3) (Whelan 1995).

Phases of fires

The process ignition, pyrolysis (chemical decomposition by means of fire) and new ignition is a chain reaction. The initial ignition source provides the necessary activation energy that permits ignition and self-sustainability of a fire. Flaming combustion at the fire front then preheats adjacent fuel and provides the pilot flame to cause its ignition (Whelan 1995).

Three stages of combustion in a vegetation fire can be recognized in relation to the basic principles of combus-

Table 2.2. Categories of fires.

I Natural fires

Natural fires are fires that are ignited by lightning and other natural ignition sources in the ecosystem. Lightning is the only ignition source of this kind in Norway.[2.8] That a fire is ignited by lightning in our time will not necessarily mean that it gets any "natural" course as the fuel in today's forests is to a considerable extent manipulated by humans (Section 4.2), and because in addition the fire will be actively suppressed and extinguished as fast as possible (ch. 10).

II Anthropogenic fires

Anthropogenic fires are fires that are ignited by humans as part of conscious burning or by carelessness (ch. 4). Such fires may again be divided into a large number of different types (See section 9.1.1).

III Wildfires

Wildfires are fires that are ignited by natural and/or anthropogenic ignition sources which for a shorter or longer period are out of control (See ch. 9).

IV Management fires

Management fires are fires that are used in management of natural resources. In principle, they can be divided into two different subtypes.

One is ignited under control by humans as part of management (controlled fires, prescribed fires). An intention with prescribed fires can for example be prevention. This means fires that, by removing biomass (fuel), are ignited to decrease the likelihood for and/or the intensity/severity of possible future wildfires. Prescribed management fires can also be used to maintain vegetation types, halt invasions of unwanted "weed species" or manipulate the habitats of animals; the possibilities are numerous (ch. 9).

The other subtype consists in "taking over" or starting "directing" and/or "conducting" a wildfire which already is ignited and in progress toward a management objective or target that is established in advance (wildfire management). Such fires are treated in greater detail in connection with discussing management (ch. 9).

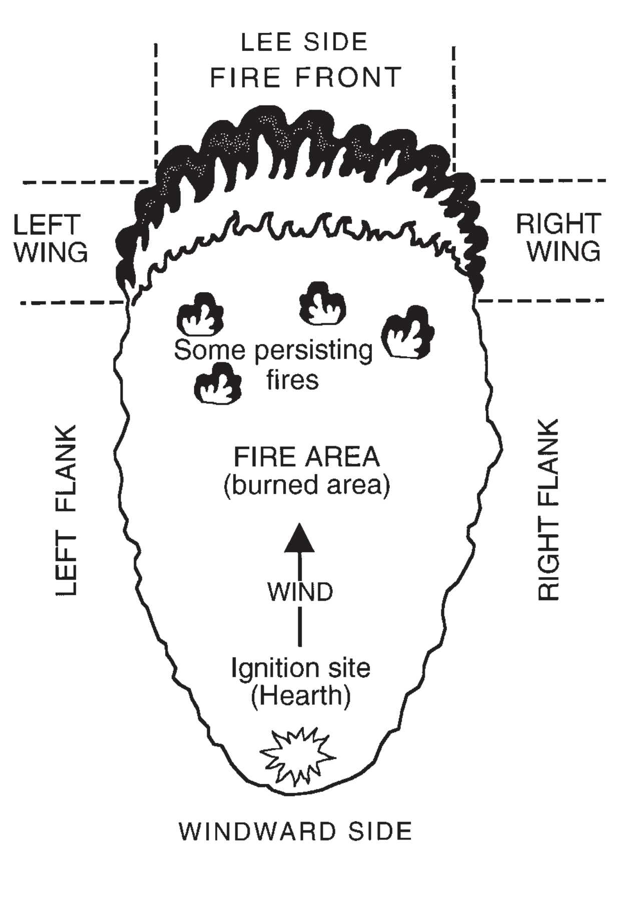


Figure 2.7. Terms used to describe forest and range fires (Redrawn from Anonymous 1987).

tion (Fig. 2.5). These are 1) *preheating stage*, in which the fuel just ahead of the fire front is heated, 2) *active stage* with flaming combustion which results from the ignition of the flammable hydrocarbon gases and 3) *stage with glowing combustion,* during which the remaining charcoal burns as a solid. The combustion of stage 3) takes place with oxidation on the surface leaving a small amount of residual ash (Whelan 1995).

Energy and intensity

The amount of energy produced by the combustion determines the intensity of the fire. The heat yield of a combustion reaction is determined by the difference between the total energy that potentially would be released by complete combustion of all fuel, minus what does not, influenced by various factors, become combusted. The more incomplete the combustion of the fuel is, the more it will reduce the energy output below the potential maximum (Whelan 1995).

The total liberation of heat from a fire can for example be highly influenced if the vegetation contains volatile oils and resins with high energy content. Even though the combustion is total, heat is lost to evaporate the water in the fuel (Whelan 1995).

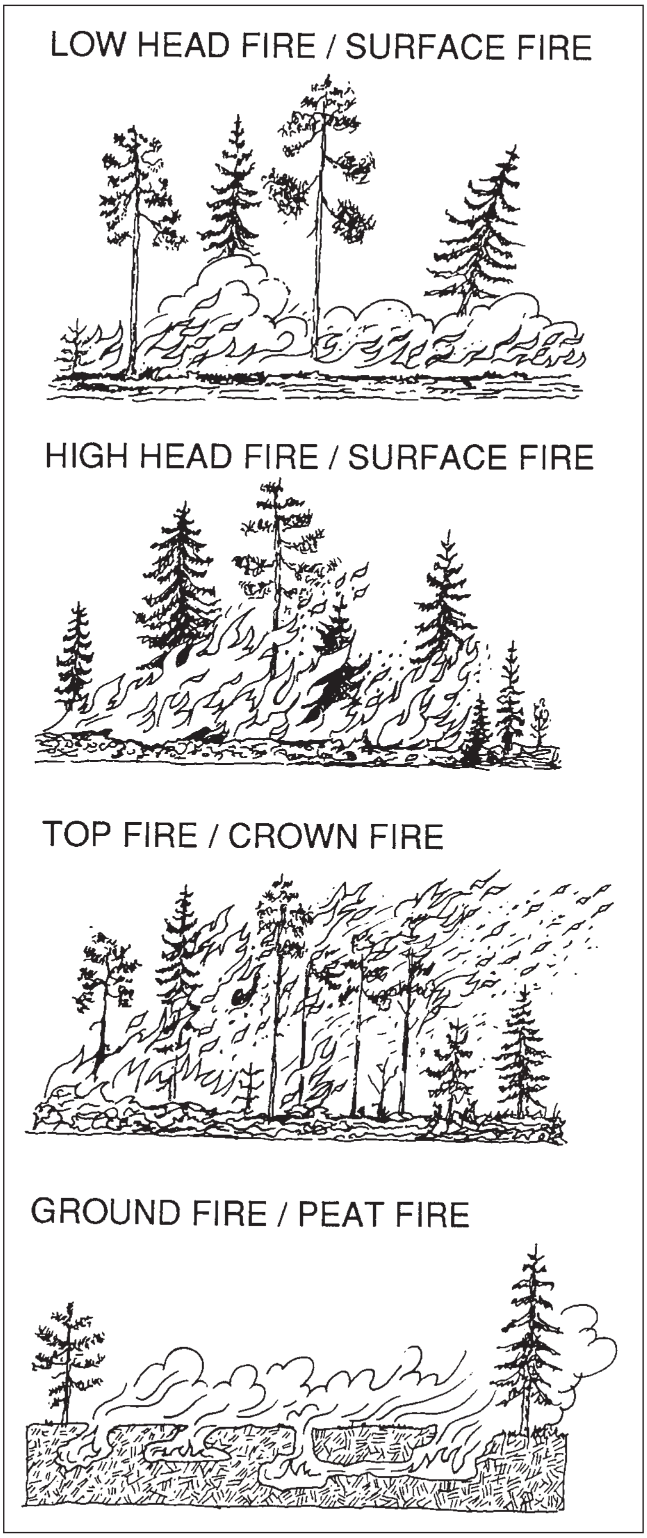


Figure 2.8. Terms used to describe course or patterns of forest and range fires (Redrawn from Anonymous 1987) (See text).

2.2.2 Temperature conditions

The intensity of a fire varies both horizontally and vertically, determined in part by the distribution of the fuel, wind speed and direction of the fire front, i.e. if the front moves as a head fire or back fire. It can for instance be measured on basis of the recorded peak temperature and the duration of a given temperature. The vertical distribution of temperature, both above and below the ground, is of particular significance for the survival of individual plants, plant parts and some animal groups (Whelan 1995).

Above ground temperature declines with height. Stronger winds may result in lower temperatures at a given height than if the fire were burning in calm weather. This decline in temperature with height may vary substantially among fires (Whelan 1995).

Soil is a good insulator (Beadle 1940, Whelan 1995), and measurements have established low penetration of heat downwards. The peak temperature already at 2.5 cm depth is likely to be well below 100 ˚C even when the fire is of very high intensity (Fig. 2.6). Ignition of post-logging slash at the forest floor may, however, raise the temperature of the soil profile considerably (Fig. 2.6).

Soil moisture appears to have some influence on the dynamics of heat transfer (Heyward 1938). Moist soil reached a higher peak temperature than air-dry soil at a given depth (Heyward 1938). In another study it was found that moist soil retarded heating (Beadle 1940). The resolution of these apparent opposing results may lie in temperatures applied at the soil surface. When the surface temperature does not reach 100 ˚C, water in the soil may facilitate conduction of heat. When the surface temperature exceeds the boiling point of water, however, evaporation in moist soil will delay heating of the underlying soil (Trollope 1984).

2.2.3 Range of variation in characteristics

Fires may be very different. A number of ecosystems on the earth, particularly in dry and temperate regions, burn so often that they are described as ”fire adapted” in ecological literature.[2.5] This indicates that they are ”dependent” upon fires to renew and maintain their particular species composition, structure and function. Both in such areas and where fires are less frequent, they occur in numerous forms. They vary in intensity, duration, frequency, distribution, form and degree of combustion of existing biological materials (severity). The effects (See ch. 8) are therefore different dependent on variations in

Table 2.3. The term “fire regime” is used as a notion for characteristics and conditions concerning all fires in a particular area or a climatic region. It can be characterized by a number of conditions and variables that are more or less closely connected (See text).

Ignition sources	• What ignites fires, causes of fires
Intensity	• Measure of the energy being developed by a fire front when it passes through
Severity	• Measure of a fire's total combustion/consumption of organic matter, for example in the ground layer (“burning depth”)
Fuel	• Amount, quality and distribution of combustible matter in the system (“fuel load”). The continuity and amount of fuel is among other things influenced by the time since the last fire
Wind	• Local and regional wind conditions are an important factor for spread and course of fires
Season	• When during the year the fires occur
Topography	• Landscape features are important to determine the distribution, size (extent) and mosaic form of fires
Spread factors	• The sum of the parameters which determine the spread of fires in an area
Frequency	• Concerning fire frequency, one often distinguishes between “fire interval”, which is the length of time between one fire and the previous fire, and “return interval” (or “return time”) which is average fire interval (frequency) for a longer period (i. e. “fire period”, sensu Whelan 1995)
Fire history	• Historic and chronological overview of all fires at a site or location, in a stand, in an ecosystem or in a landscape
Burned environments	• Characteristics of burned areas in an ecosystem or landscape formed through effects of fires

season, character of fuel, topography, soil, the age and species composition etc. of the system, and these elements are often tightly linked to each other (Tab. 2.1). In addition, great variation enters as a consequence of anthropogenic influence (ch. 2).

2.2.4 Definitions and terminology

Such an encompassing field as fires (in natural ecosystems generally and forest fires particularly) has promoted the development of a number of definitions and concepts. It may be a problem that such terminology is developed on different bases (Whelan 1995). We are therefore first going to clarify the terminology that will be used in this technical report.

Fires in ecosystems in the form of forest and range fires is an ecological factor on a par with temperature and precipitation, and as long as they are ignited by for example lightning strikes, are a *natural* part of the earth's climate. Fires may also, however, be ignited by humans, something which is an *"anthropogenic"* addition to the ones that are ignited by natural causes (See ch. 4).

Fire categories

Fires are often classified according to the type of vegetation that burns, for example *forest fire*, *heather fire* and *grass fire*. They can also as an example be called *catastrophic fire* based on the intensity and severity, or *prescribed fire*, for example hazard reducing fires that are ignited as part of risk management (See ch. 9). Fires may also be ignited consciously through *arson* ("evil will") or be ignited through carelessness linked to several human activities ("accidents", "not intentional").

Ecologically we have already mentioned fires that are ignited by *natural* ignition sources (lightning strikes) and the difficulties with keeping these separated from fires that are ignited by *anthropogenic* ignition sources. On many occasions one does not know the cause of the fire. It is generally purposeful during surveys to divide fires into some main categories based on background and causal conditions (Tab. 2.2).

Description of fire course

The course of forest and range fires is described by a number of terms (Fig. 2.7). The fire is ignited at an ignition spot or *hearth*, and as it progresses, a larger or smaller *burned area* is created, which on each side is limited by *flanks* (Norw. "flanker"). The advancing fire is called the *fire front* (See front cover). The front itself is limited by *wings* (Norw. "fløyer") (right and left) and in addition has a *leeward* and a *windward side*. Often persistent fires can develop at many sites in the burning area where there is accumulated combustible matter (Fig. 2.7). Particular fire courses or fire patterns can be described as high or low *head fire* or *surface fire, back fire*, *top fires/crown fire* and *ground fire* or *peat fire* (Fig. 2.8). Most fires are a combination of two or more different fire types. Below is an overview of some important terms that are used in this technical report.

Head fire/surface fire

A *head fire* or *surface fire* (running fire) is a fire that develops and spreads in the surface vegetation layer (Fig. 2.8). It usually characterizes the initial phase of a developing forest fire. A head fire may, dependent on the conditions, be *low* and stay on the forest floor and just *above* the ground layer, or *high* and touch somewhat more of the *lower* parts of the tree layer (Fig. 2.8). In treeless areas the head fire is also called heather fire or grassland fire. A head fire is most often a pure surface fire. In many ecosystems that burn regularly, most fires have the character of surface fire/head fire. This is also the most common form of forest fire in Norway.

Back fire

A *back fire* is a fire moving against wind direction. It therefore moves with low speed. "Back firing" has often been used as part of clear-cut burning (Anonymous 1987). Back fires are also often ignited at strategic sites as part of the suppression of wildfires. That method is no longer in use in Norway (See section 10.2.6). The use of the term "back fire" varies (See Chandler et al. 1983).

Top fire/crown fire

Top fire or *crown fire* is a fire that enters the tree layer and progresses through direct spread from tree crown to tree crown (Fig. 2.8). Such fires achieve much higher intensity and combust a far greater biomass than pure head fires.

Ground fire/peat fire

Ground fire or *peat fire* is a fire that burns more or less deeply in organic soil and peat layers, often as a *glowing combustion* without visible flame. Under Nordic conditions soil and peat fires occur particularly in extremely dry summers, when the humus layers and the organic soil are so dry that it may serve as fuel. Ignition and combustion of an organic peat layer, will, as for soil fires in general, depend upon extremely dry conditions. When such fires are ignited, however, they can often burn thoroughly and glow for a long time.

Such glowing fires can some places flare up on the surface and develop new head fires and even top fires. The whole upper organic soil layer can during certain conditions, for example at sites with shallow soils, become combusted and transformed so that the mineral sole is exposed. If wind or precipitation occurs just after the fire, the ash layer may be blown or washed away. If one reaches down to the morainic material or even barren rock, the whole landscape development in the area may be reversed to a considerable degree.

Whether a fire shall develop as a head fire, crown fire or glowing fire (Fig. 2.8), is determined by distribution of fuel and the conditions during fire spread. Under Norwegian conditions, where there is often moisture in the soil, forest fires are often gentle head fires where only the upper, dry layer is touched. In extremely dry and windy periods, fires may more easily enter the crown layer and escalate to fires of high intensity. Whether or not a fire "consumes" the organic soil layers and/or the vegetation and litter, is ultimately determined both by degree of desiccation and the composition of the organic soil layer in the area.

2.2.5 The notion "fire regime"

The term *fire regime*, which already is used in the introduction, has gradually come into use in everyday language in fire ecological accounts. A "fire regime" is the collective term for the *characteristics of all fires that occur at a location or in a region* (Tab. 2.3). Fires are neither equally common nor cause equally extensive ecological changes in all parts of the world. Temperate forests in Europe can experience a relatively high number of fires annually (167 fires per 10^6 hectare). These are usually small (mean 0.07 hectare), and the estimated return interval or return period (Tab. 2.3) of fire at a given location (average fire interval in a time period) is 6 000 years (Chandler et al. 1983). The contrast with respect to area can be seen in the conditions from the taiga of Alaska, where there are relatively few fires annually (2.7 per 10^6 hectare), but they are in average 1 800 hectares in size (Whelan 1995). The wet eucalyptus forest of southeastern Australia has an intermediate position concerning the occurrence of fires (66 per 10^6 hectare and year). These forests also have an intermediate size of the areas which burn (165 hectares) and a return period of 43 years. Thus it is not possible to directly transfer data from research that for example is conducted in North Sweden to Norway. This is an important aspect/ recognition when one is going to identify the fire regime of a particular region. It will be necessary to identify as many factors as possible describing characteristics of fires in various regions *in Norway* to characterize the *Norwegian* fire regime.

Figure 2.9. Natural and anthropogenic fire regimes can seldom be clearly distinguished, and in practice we here operate with the term historic fire regime, i.e. characteristics defined by the total number of fires regardless of cause of ignition (See text).

The term has been used in at least two ways. The first concerns the characteristics of all fires in a particular climate region, within a vegetation unit or a geographic area (region, country etc.) (Whelan 1995) (Tab. 2.3). The second use of the term originates from fire management where it denotes a "prescription" or a blueprint/general arrangement for fires that is going to be used managing an area.

The first use expresses that fires, from an ecosystem perspective, should not be viewed as single events. One should rather view the pattern they form in time and space (frequency, causes etc.). The fire pattern in a region may be characterized by a number of features (Tab. 2.3), among others fire intensity, severity, the interval between fires (frequency), season(s) when fires occur, the extent and form of the burned areas ("patch formation" of unburned islands) and the type of fires that occur (Gill 1975, 1981a,b). In sum this defines the aforementioned "fire regime", which is a collective term for all characteristics of fires that appear at a location or in a region (Tab. 2.3).

The other use applies in environmental management. A manager who is working out a strategy to preserve diversity in an ecosystem, can express this by saying that he imposes a given "fire regime" on the system which can be specified in detail (intensity, duration, time etc.). Used in this way "fire regime" indicates that all important ecological aspects (Tab. 2.3) concerning a fire are taken into consideration.

A complication with respect to use of the term fire regime is the fact that human activity continuously has changed various aspects of the "natural" fire regime. Fire frequencies may for example have been reduced as a consequence of direct forest fire suppression from economic interests or motives. On the other hand, the number of fires can have increased as a result of higher frequency of ignitions around population centers. Changed intensities must be expected to follow changes in frequency. Because the vegetation structure is also important for determining the intensity of a fire, forests, where one has conducted forestry and removed wood, would not burn "naturally" either. A number of such influences from human activity lead to changes in the fire regime (ch. 4), it is difficult to keep the causes apart.

In this technical report we have taken the consequence of this, and speak about a *historic* fire regime as the sum of the natural and anthropogenic fire regimes (Fig. 2.9).

The climate of earlier times influences present fires by having contributed to determining development, distribution and amount of biomass of present plant communities (fuel). The present climate determines the conditions for natural ignition sources (e.g. lightning strikes) and the course of potential succeeding fires until they possibly are actively extinguished. Additional factors influence the climatic basis, which again creates variation in the fire regime. Variations in the course of fires have been emphasized as one of the main causes of small-scale heterogeneity in boreal coniferous forest (Van Wagner 1983, Johnson 1992). With background in Table 2.3 we are here going to comment upon some of the elements of the fire regime.

Ignition sources

Ignition sources are everything that ignites fires (Tab. 2.3). The most important *natural* ignition sources of forest fires are lightning, volcanic activity and sparks from land- and rockslides. Natural fires can also start spontaneously (Vogl 1974). In some ecosystems compressed plant matter that is rotting and fermenting, can produce sufficient heat for self-ignition. Whether this can happen in nature in Norway is not known. [2.8)]

Even though volcanic activity and sparks from slides may be important in local situations (Booyson & Tainton 1984, Cope & Chaloner 1985), lightning is by far the most common natural cause of ignition of fires (Stewart 1956, Komarek 1965).

Even if lightning is important as a cause of natural fires, some land areas are often exposed to a considerable percentage increase of fires through anthropogenic ignition sources (Komarek 1965, 1968, Gill 1981a, Kruger & Bigalke 1984). While lightning strikes caused approximately half of the fires in forest areas in western USA (Brown & Davis 1973), almost all fires in Bouches du Rhone in France are caused by human activity (Wright & Wanstall 1977, Goudie 1986). Anthropogenic ignition sources can thus locally be from less important to totally dominating. We will later return to the conditions in Norway (ch. 4).

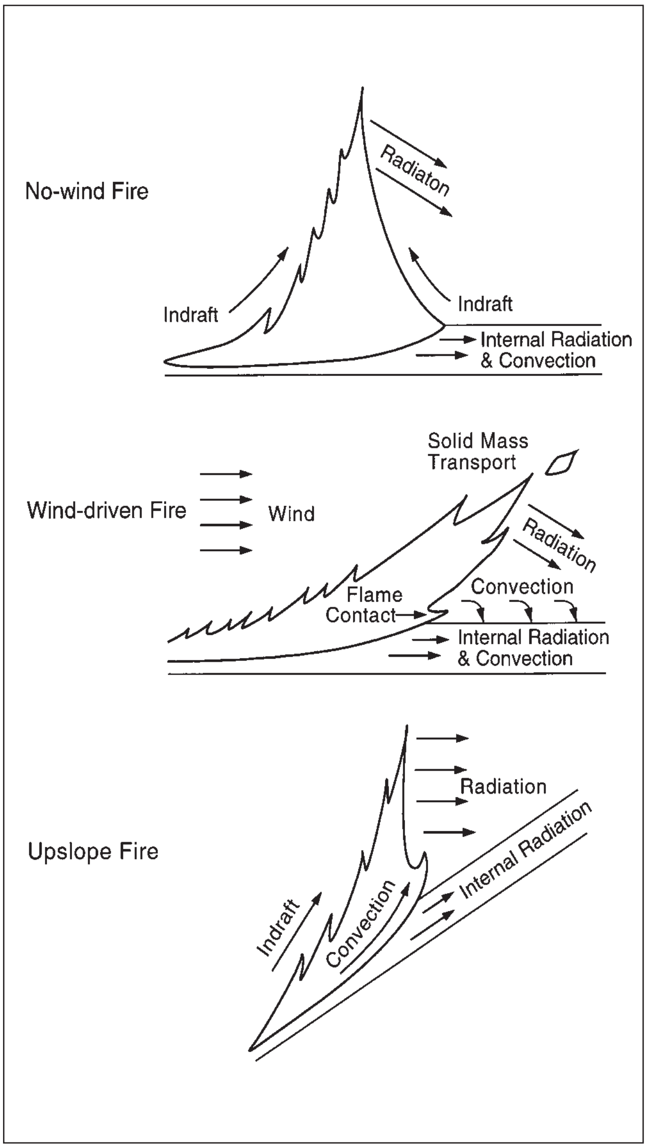


Figure 2.10. Fire front and flame profile in flat terrain without wind (upper) compared with a fire front with wind (middle) and one which moves upslope (lower) (Redrawn from Whelan 1995).

Intensity
The intensity of the fire is as previously mentioned a measure of the energy developed by the fire front itself when it passes through (Tab. 2.3). The height of the flames and the spread speed of the fire front are measures that are easy to observe with respect to this important variable. The survival of the trees is to a great extent controlled by the intensity. Fire intensity is influenced by a number of factors like climate, topography (slope and aspect), fuel load, fuel type and chemistry, and vertical and horizontal distribution of fuel (Whelan 1995). The intensity of forest fires varies within broad ranges between various fires as well as between various sections of one and the same fire.

The climate and weather in the time before and during the fire will have a strong effect on the fire intensity. This is because the combustion speed in cold, humid fuel is slower than in warm and dry fuel. The local climate will determine relative air humidity, drying of fuel prior to the fire and prevailing winds when it burns. A plant community can exert considerable control over the local climate: A dense, closed vegetation cover reduces the evaporation and maintains humid fuel for some time after rain, and shade from the vegetation reduces the temperature of the fuel.

The fire history of a location may as mentioned have a marked effect on the intensity of a fire through having influenced the availability of fuel during earlier fires. The vegetation communities of a location that has recently burned, will not be able to produce and accumulate enough fuel to support another fire of the same intensity as in comparable areas where the last fire was long ago. Thus there is a close associated link historically between fire intensity and fire frequency in any ecosystem. There is a clear connection between the time since last fire and the ability of the vegetation to support a fire (Schimmel & Granström 1991). The re-colonization of the most important moss species at surveyed burned areas in Sweden is apparently a slow process, which first got properly started after 10–20 years. During the first post-fire years the ground flora is instead dominated by fast colonizers among the mosses.

Severity
Severity is a measure of the total consumption or combustion of organic matter by the fire (Tab. 2.3). It is important to distinguish fire severity or burning depth from the intensity of a fire front. Severity measures for instance the total influence of the fire on the ground layer (Schimmel & Granström 1991), that is how much of the organic matter of the ground layer is consumed or combusted by the fire. The burning depth varies relatively independent of fire intensity and is first of all dependent on to which depth moss, humus and other organic matter have dried up. The mortality of the organisms increases when the severity increases. This is of great importance for the future structure and appearance of a forest stand.

Fuel
The most important factor determining the intensity of a fire, is the amount of energy stored in the fuel. The amount of fuel, or “fuel load” (Tab. 2.3), i.e. total dry weight of fuel per unit of surface area in an ecosystem, is an indicator of this. There is a high positive correlation between different measures of fuel load and fire intensity. The dry weight should as mentioned earlier be viewed as *potential* fuel. Few fires actually cause total combustion of the biomass above the ground of all measured size classes of fuel. A more realistic estimate called *available* fuel is usually also estimated where the size and configuration (e.g. compactness) of the fuel are taken into account (McArthur & Cheney 1972). It is important to separate the concepts potential (=total) and available amount of fuel. Practically, it is very difficult to undertake a reliable estimation of how much of the fuel is really going to burn. This has been clearly demonstrated both during clear-cut burning and burning for game production in Norway (See ch. 4 and 9). The condition will vary with a number of parameters (wind, humidity etc.) prevailing at the time the fire passes (Whelan 1995).

A continuous distribution of fuel is an important precondition for the spread of a fire, especially in the phase just after ignition. Once a fire has started, the continuity of the fuel will decide the “patch formation” of unburned areas. The continuity of fuel is, as previously mentioned, among other factors influenced by time since the last fire (See above).

The fuel of Swedish ecosystems and the Norwegian ones that it is natural to compare with, consists mainly of lichen and mosses associated with stored litter in the ground layer. The field layer can also contribute fuel if it consists of heather. For the field layer to be able to support a fire by itself other than during extreme winds, it has to be very dense and consist of fire prone species like heather and crowberry (*Empetrum* spp.). Herbs and grasses on the other hand usually retard the fire through

their high water content. A continuous coverage of lichen and mosses in the ground layer is of decisive importance for the possibilities of spreading a fire (Schimmel & Granström 1991).

Plant communities vary in their ability to support flaming combustion, and less combustible plant communities can occur mixed with more flammable ones. Some plant communities, for example with great elements of deciduous trees, may thus appear as firebreaks in the same way as topographical features (See section 8.3.8). The composition of the communities can also influence the spread of fires in another way. Plant species have quite different characteristics with respect to causing or producing "torches" which can blow away and set off new fires in front of the main fire (Chandler et al. 1983).

Wind

Local and regional wind conditions are an important factor in the spread and course of fires (Tab. 2.3). One major effect of wind is to provide more oxygen to the fire front. Although this can increase the rate of combustion, the nature of the vegetation has some control over

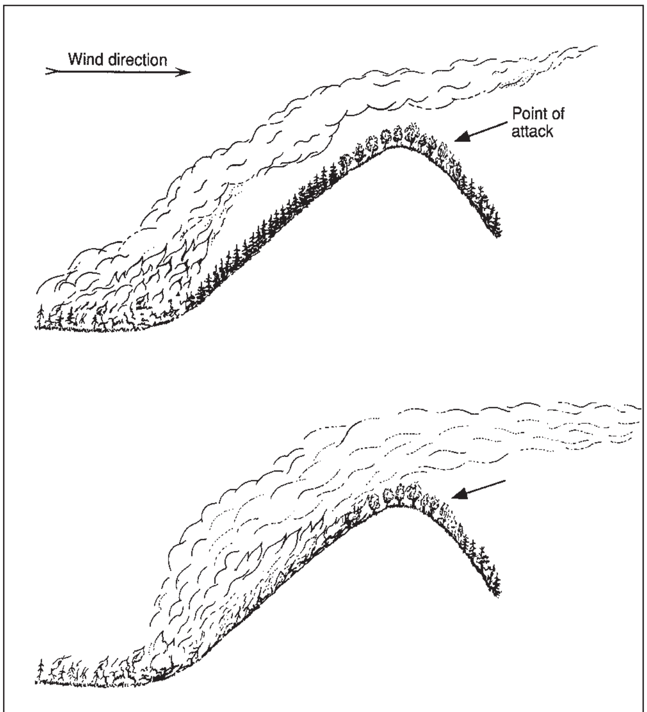


Figure 2.11. Convex formations may often act as firebreaks. Steep uphill fires are often difficult to suppress, but easier to extinguish when they reach convex landscape forms (indicated with arrow), they often die out by themselves. Point of attack for forest fire extinguishing is shown in the figure (Redrawn from Anonymous 1987).

the magnitude of the effect. Fuels that are densely packed and layered do not permit access to oxygen and therefore constrain combustion. Changes in wind direction can convert one side of the initial circle of flames from a back fire to a head fire, or can, some time after a fire has been burning, convert the flank of a fire into a new front (Whelan 1995). [2.9)]

The angle of the flame front, compared to the ground layer, is determined by the wind, and a more acute angle causes more rapid combustion of the fuel (Fig. 2.10). In the right sort of fuel and with the appropriate winds, the head fire may as mentioned also produce burning fragments ("torches") that blow away and set off "spot fires" ahead of the main front. Studies in some ecosystems have reported spotting as far ahead of the fire front as 25 (Foster 1976) and 30 km (Vines 1981).

In the absence of other constraints, fires generate their own winds. The convection of heated gases upward draws in air from around the burning nucleus and the fire front will spread outward, as a back fire, into this self-generated wind. The radiation from the front preheats the adjacent fuel and thereby prepares it for ignition, and so the fire spreads due to its own dynamics (Whelan 1995).

Fire often leads to increased wind speed in the burned field after the fire has passed. Ecological consequences of this may include more rapid desiccation, increased erosion and greater dispersal of some seed types (Whelan 1995) (See ch. 8).

Season

With season is meant when fires take place during the year (Tab. 2.3). The climate is often the most important factor that determines the fire seasons, i.e. when ignition sources appear in combination with dry vegetation. [2.10)] Air temperature and humidity, fuel temperature and suitable fuel must all be at a favorable level if a fire is to start.

There are strong associations between season and fire severity or burning depth. The degree of desiccation during the period before a fire is important. Types of fuel with high content of resins (e.g. from pine), can ignite at a moisture content up to 35 %, while high mineral content in for example leaves reduces the flammability (King & Vines 1969, Cheney 1981, Whelan 1995).

The occurrence of oils and resins in fuel that has begun to burn, increases the heat production during the reaction because of its higher energy content. Fuel that contain concentrations of such chemicals, must be expected to burn with higher intensity. Conversely, relatively high concentrations of mineral elements in wood and leaves can reduce the flaming combustions of some plant species (See ch. 10). Research in an oak-chaparral community in Arizona, USA, has indicated that increased phosphate content of the fuel directly decreases the speed of spread of fires in this type of ecosystem (Lindemuth & Davis 1973). This has lead to the hypothesis that there is a great potential for modifying fires by promoting spread and development of plants with high phosphate content. This must be seen associated with the experiences one has achieved with the use of di-ammonium phosphate as “fire retardant” during ordinary fire extinguishing operations (Foster 1976).

The burning depth, i.e. how much of the ground layer’s organic matter of mosses and humus that is consumed by the fire, varies to a certain extent with the fire intensity, but mainly it depends upon how deeply the moss and humus layer is dried up (Schimmel & Granström 1991). These factors can vary more or less independently of each other and also influence vegetation in different ways (Rowe 1983, Klingsheim 1996).

Topography

The landscape features are important in determining the distribution, size (extent, outer delimitation) and mosaic form of the fire. Firebreaks like knolls, ridges, gullies, rivers, lakes, bogs and swamp forests form a mosaic in the landscape which gives great variations at the forest floor. The appearance of such a fire mosaic will, as mentioned, depend on times of earlier fires. [2.11)]

The effects from slopes or steep hillsides on a fire front are similar to the effect of wind. In an uphill fire, the flames are brought closer to the ground and therefore pre-heat more of the fuel ahead of the front (Fig. 2.10). A fire ignited on a hilltop or ridge is likely to take hold slowly as it burns downhill, whereas a fire ignited in a gully will start more rapidly and gain momentum as it burns uphill (Whelan 1995).

Another effect of topography is its interaction with local climate and the patchwork of plant communities. For example, gully vegetation is likely to be somewhat different from hilltop vegetation – it is perhaps more mesophytic (adapted to growing under medium moisture conditions), denser in canopy and therefore less flammable. On a smaller scale, the litter beneath some tree species is likely to differ in flammability, degree of aeration and moisture content. This may produce large local variations in fire intensity (Williamson & Black 1981, Whelan 1995).

Studies in various parts of the world have examined vegetation islands that may be protected by rivers, lakes or terrain formations (See Whelan 1995). In Lake Duparquet, at the northern end of its range in Canada, red pine (*Pinus resinosa*) is restricted to island habitats. These islands provide a fire regime that is more similar to those further south, while the mainland in the northern region suffers large-scale, intense forest fires that have eliminated this pine species (Bergeron & Brisson 1990). A fire ecological understanding of such complex connections with topographical structures and other features of the landscape, is important for Norwegian conditions with its high density and variation of natural firebreaks (Section 3.2.2).

When in the season a fire influences an area, also creates variation in the characteristics of the fires. Fires outside the real fire season, when the vegetation still is moist and/or the climatic conditions are cool, will be of lower intensity and also develop more as a mosaic than fires during time periods where the vegetation is bone dry. The distribution and form of the vegetation mosaic that is created is also influenced by wind strength and direction, which may change the course of the fire and thus *the burned area that is created* (Fig. 2.11). Burning fragments may as mentioned also be blown ahead of the front and set off new fires. There are thus a number of factors that control and influence the mosaic formation of the vegetation on burned areas after a fire. Formation of “islands” of unburned vegetation in an otherwise burned area constitute important “refuges” for plants and animals, so-called fire refuges (Section 9.2.3).

Spread factors

A number of factors are important with respect to determining the spread of fires (Tab. 2.3). The three most important natural factors that determine their direction and speed are the heat suctioning, the so-called “ground draught” and the wind conditions (Strømsøe 1961). *Heat suctioning* is the air current which originates in the vicinity of powerful heat development, as warm air, which is light, will rise and colder air will be drawn in from the sides (Fig. 2.10). During calm weather, in undulating terrain there will in addition to the heat suc-

tion be the *ground draught* that determines the direction of movement. Forest fires spread with very high speed uphill, but progress or travel very slowly downhill (Strømsøe 1961).

Many of the same factors that influence the intensity of fires will also determine the spread. For example, fires during dry, windy conditions in areas with much fuel will spread faster due to higher combustion speed. Higher intensity at or in the fire front will pre-warm adjacent fuel ahead more quickly, and the wind will to a larger extent influence flame length and angle. Sparks or spread of burning organic material ("torches") will also start more forest fires.

Frequency
With respect to the fire frequency, one often distinguishes between *fire interval* and *fire period* (Tab. 2.3) (Fox & Fox 1987). Fire interval is defined as the length of time between one fire and the previous fire in one and the same area, and fire period is defined as the fire interval averaged over a number of fires (See Johnson 1992).

The potential fire frequency at a given location will in principle depend on two important factors: (1) amount of time needed to produce sufficient biomass and build up a "load" of available fuel after last fire and (2) the frequency of ignitions [2.12] associated with the occurrence of annual "seasons of ignition" due to variations of the climate, the precipitation factor, lightning frequency, human activity etc. [2.13] In chaparall systems in California it is now supposed that the main factor for determining the "return period" of fires is the accumulation of fuel. It is in other words supposed that the ignition sources earlier have been frequent enough to secure fires when the amount of fuel has been sufficient (Minnich 1983).

It must be supposed that suppression of fires both of the ones that are ignited by lightning strikes and the ones that are caused by human activity, have led to increased accumulation of organic matter. When fires then hit, they may attain larger dimensions than they would have during earlier historic time without such fire suppression (Whelan 1995). This approach to the problem is also relevant for Norwegian conditions (Section 4.3).

2.2.6 Fire history
Fire history denotes a historical and chronological overview of all forest and range fires in a given area, in a stand, in an ecosystem or a landscape (Tab. 2.3).

Charting of the fire history of a location can provide important understanding of the prevailing biotic connections in an area. [2.14] Activities connected with immigrating agrarian cultures and settlers generally seem to have increased the anthropogenic ignitions significantly, and Europe with its old agrarian cultures constitutes no exception. The importance of anthropogenic ignition sources is therefore important in the evaluation of the postglacial fire history in Fennoscandia (ch. 4). The fire historians must also examine the importance of increasing human influence on the landscape itself. The extent of fires has been reduced as roads, cities and agricultural areas have been developed, and in many areas the fire seasons have changed as a consequence of anthropogenic burning (ch. 4).

Knowledge of fire history can be of particular importance when one is going to define strategies and management objectives for burning in particular reserves and protected areas. [2.14] A recent fire historic survey of a national park in South Sweden (Page et al. 1997) has suggested what we have termed *management based on fire history* (See ch. 9). A substantial number of studies of fire histories appear to have been carried out to cover management requirements (Whelan 1995).

Many techniques are available for making estimates of a historical fire record of an area (Mutch 1980, Stokes & Dieterich 1980, Battson & Cawker 1983, Johnson 1992, Ortloff 1994, Whelan 1995, Håkonsen 1996). These among others encompasses:

- sampling fire scars on trees [2.15] for evidence of a sequence of fires in the growth rings (See e.g. Houston 1973, Dieterich & Swetnam 1984, Goudie 1986). This is the most commonly used method in the Nordic countries (Zackrisson 1976, 1977a,b, Johanson & Schneede 1995) and North America (Stokes & Dieterich 1980, Ortloff 1994)
- sampling of sediments in lakes and swamps or peat in bogs for pollen and/or charcoal fragments (See e.g. Singh et al. 1981, Cope & Chaloner 1985, Johanson & Schneede 1995, Håkonsen 1996, Korhola et al. 1996)
- sampling lake and reservoir sediments for extreme or unusual runoff events (See e.g. Clark & Wasson 1986, Goudie 1986)
- collection of historic data from written or oral sources (See e.g. Lorimer 1980)
- extrapolation from current patterns of weather, fuel build-ups and lightning fires

Fire cycles have been estimated, by using such and similar techniques, for a large number of plant community types in different regions (Whelan 1995).

Trees have long lifetimes and can contain several fire scars and signs of a considerable number of fires. If a sufficient number of trees with fire scars can be examined, the picture of a historical fire frequency can also be expanded to concern extent of the fires. Another method is to study and date ash and other partly combusted charcoal fragments in soil profiles (See Håkonsen 1996).

Studies of natural soil profiles are basic for studying fire history. Forest fires can have highly variable effects on the productive capacity of the ground layer (ch. 8). Depending upon the combination of the strength of the fire and the characteristics of the growth site the effect can vary from what can be characterized as good soil preparation to total soil destruction (Lundmark 1986).

In the process of podzolisation of forest soil a thick horizon of bleached soil can only form if also the humus layer is relatively thick. This again demands absence of frequent and/or extreme fires. Through studies of the relation between the thickness of the humus and the bleached soil horizon we can therefore make rough judgements of the frequency or extremeness of earlier forest fires and draw some conclusions about the potential or latent production capacity of the growth site prior to the fire. Forest fires during earlier times can have been so severe and extreme that a large part of the humus layer has been combusted. This might also have happened at growth sites where well developed forest stands with their litter earlier built a thick humus layer, which again with its acidic constituents has caused a powerful leaching and a well developed thick bleached soil horizon. Such patterns both testify to an earlier high production at the site and to the fact that the fire must have extensively combusted the former humus horizon. One expresses this as if the ground has “degenerated” as a consequence of the fire. It requires a long time to develop a new and adequate humus horizon, during Nordic conditions often many hundred years (Lundmark 1986).

Modern remote sensing, as for example with the LANDSAT satellite, has today opened new possibilities for characterization of the fire regime in an area. The method with use of satellites makes possible charting of for example return periods, areas and seasons (See Minnich 1983, Press 1988, Weiss & Goldammer 1994, Whelan 1995).

2.2.7 Burned environments

Characteristics of burned environments of an ecosystem or landscape are formed by effects from the fires (Tab. 2.3). The ruling physical conditions in an area after a fire are usually very different compared with those that have been ruling before the fire (ch. 8). Many of those differences will be of importance for how the living community is restored after the fire. There is relatively little information about this part of ecological fire processes in the literature (Whelan 1995). What we know is mainly results from fires in heather and grasslands (Old 1969, Knapp 1984, Mallik 1986, Ewing & Engle 1988). These studies indicate that fires often lead to increased maximum temperatures at the soil surface, increased light intensity and increased wind speeds. Fires also create a declining water vapor pressure (pressure deficit) in the areas. Such and similar effects of forest fires are thoroughly treated in chapter 8.

2.3 Summary

Forest fires are believed to be the single most important ecological factor in the development of the boreal coniferous forest. Therefore, knowledge concerning the course of fires and the various processes that control the natural development of vegetation is necessary in order to understand the function of natural forests under our conditions. Fire ecology is the scientific field that studies the course of fires and effects on organisms and the environment based on physical, chemical and biological laws.

Fires can be ignited by natural sources or by people. Lightning strikes are definitely the most important sources of natural ignition. Throughout millions of years, lightning is the factor that has ignited ecosystems and has played an important part in their shaping. In a way, we can say that lightning theory represents the “prelude” of forest fire ecology. That is why a discussion of this natural phenomenon is the first factor addressed in this report.

Lightning discharges are divided into positively and negatively charged lightning. The strikes that ignite forests are thought to be lightning with so-called long follow-on current. Different types of fuel and their prop-

erties result in a highly variable risk of ignition by lightning. Ignition can occur both in the ground stratum and in trees, and lightning can create glowing combustion in the soil that may flare up as many as 8–10 days after the strike. We have called the scientific field that studies lightning and the relationship of the electrical processes to organisms and the environment "electric ecology." This comprises far more than just the ignition of forest fires. Lightning can have both direct and indirect effects on ecological processes. When we write about direct effects in this report, we mean the effects caused by the lightning at the moment the strike occurs. Lightning damages or kills many millions of trees around the world each year, and a great many of these remain standing with roots as dead trunks ("snags"). They increase the risk of ignition and provide fuel for future forest fires. Indirect effects can be that trees damaged by lightning may rapidly be invaded by microorganisms, insects and fungi, and may gradually attract higher animal life that will exploit this production. The lightning can thereby influence the course of the succession by contributing to changes in the vegetation that in turn can affect the fauna, i.e. create a greater diversity of species.

The strike pattern for lightning varies considerably around the world, and there are also substantial variations in the lightning strike frequency in Norway (Fig. 2.2). The highest values occur east of the watershed divide, peaking in the forest regions north of Oslo and in the regions to the north and east of Oslo. There is no simple connection between the number of lightning strikes and the number of fires ignited by lightning in a region, nor does lightning ignite fires in any evenly distributed pattern. The pattern must instead be viewed in context with the climate and the vegetation cover in the various regions.

When ignition occurs, whether caused by lightning or people, the subsequent fires can spread throughout ecosystems and cause significant long-term effects both as regards species inventory and material cycles. The process is described using general knowledge linked to fundamental physical and chemical reactions in combustion and through a presentation of the various phases of a forest fire. Important key words in this fundamental understanding of fires are energy, intensity and temperature factors. Simple terms are presented to describe the course and type of forest and field fires. The fires can be divided into categories according to cause of fire or source of ignition. Fires ignited by lightning strikes, volcanic eruptions and sparks from rockslides are called *natural* fires to distinguish them from the anthropogenic fires that are ignited by people. Fires that are out of control for shorter or longer periods of time are called *wildfires*, while prescribed fires used in nature management or other controlled activities (see ch. 9), are called *management fires*. The course of forest and field fires is described by a number of terms (Fig. 2.7). The same applies to the fundamental pattern of the fires. They can be characterized as *head fires* or *surface fires* (running fires), *back fires*, *top fires/crown fires* or *ground fires/peat fires*, depending on which strata the fire occurs in. *Fire regime* is an important term used in fire ecology theory and which has two meanings. The first type of usage states that, based on an ecosystem viewpoint, fires should not be viewed as independent events. The other usage is used in fire management to describe a "prescription" or a "system" for fires that one wishes to utilize in a special area, for example, a national park.

The use of "fire regime" as a collective term for the characteristics of all fires occurring in an area or region can be approached through descriptions of a number of elements that are more or less linked together. These elements are ignition sources, fire intensity, fuel (quality and quantity), prevailing wind conditions, season of the fires, topography and spread factors, fire frequency, fire history and properties of the burned environments in the relevant area (Tab. 2.3). To recapitulate, we can say that the behavior of fires in a given location depends on quite a number of factors that must all be favorable at the same time.

With regard to the first definition, a clear distinction can rarely be made between *natural* and *anthropogenic* fire regimes, and in practice, we operate here with a *historical* fire regime (i.e. total fires regardless of cause of ignition).

The same factors that promote ignition will, to some extent, also influence the course of the fire. For example, dispersed fuel that contains a lot of air will be easy to ignite and will also burn more intensely and spread the fire more rapidly. Intensity is a measurement of the energy developed by the fire front itself. The fuel load (amount of combustible material) in the system increases proportionately with the time that has passed since the last fire, and its capacity for flaming combustion (flammability) varies according to both qualitative and quantitative changes in plant life.

The type and distribution of fuel and appropriate climate conditions at the time of ignition can vary randomly (stochastically), and make it difficult to predict when a fire will occur at a given location, as well as the severity of the fire. Severity is a measurement of the fire's total consumption of organic material. Factors such as topography, fire barriers, soil type and size of given vegetation will all vary in space, even though they may be relatively constant over time.

The features of the landscape play an important role in determining the spread, size (extent), outer limits and mosaic form of a fire. With regard to fire frequency, a differentiation is often made between "fire interval" and "return interval". The fire interval is the period between a fire and the previous fire in a given area, while the return interval is the average fire interval and describes the frequency (see Tab. 2.3).

"Fire history" denotes a historical and chronological overview of all fires in a given area, in a stand, an ecosystem or in a landscape. Charting a location's fire history can provide important understanding of the prevailing biota in an area. The significance of anthropogenic sources of ignition in Fennoscandia will, for example, be important in the evaluation of the fire history for the period after the Ice Age because this area has been invaded by agrarian cultures which have largely burned forested areas. Factors such as changes in the landscape that are not the result of direct burning are also included under the fire history. The extent of fires has been reduced gradually as agricultural areas, cities, roads, etc. have been built up. In many cases, fires also have different courses because vegetation, i.e. the fuel, has been manipulated. Knowledge of the fire history may have particular importance when we define strategies and management goals for burning in special reservations and preservation areas, what we have called "management based on fire history" (ch. 9). A number of methods are available today to chart an area's fire history.

It emerges from the above that a number of properties of burned environments in an ecosystem or landscape are formed by fires. The likelihood of a fire being ignited is a product of the simultaneous variation in a number of individual components. The many variables involved in determining course and properties make it generally difficult to predict the consequences of fires.

3 CLIMATIC AND NATURAL GEOGRAPHIC CONDITIONS

By Ivar Mysterud og Erik Bleken

It is well known that natural fire regimes follow the climate, and that lightning strikes can ignite more easily in drier periods resulting in higher fire frequencies (ch. 2). Thus, the frequency of fires caused by lightning strikes has probably been influenced both by long-term and regional climatic changes, as well as shorter dry weather periods with many thunderstorms (Franssila 1959, Nichols et al. 1978, Tolonen 1983, Jørgensen et al. 1995). According to a meteorological reconstruction of the postglacial climate (Lamb 1977), common identifiable climate factors have been operative both in Central and North European countries. Similarities between Canada and Northern Europe in some important climate factors from approximately 6000 B.C. until the present has been pointed out by many researchers (See Tolonen 1983).

Climate fluctuations influence the fuel composition, i.e. produce the vegetation communities including the species of forest trees that dominate the stands. Therefore, the paleoecological development of the forests at any time is an important condition for interpreting possible variations in a fire regime. The history of the vegetation can be studied by pollen analyses or dating of old wood (Börset 1985).

In this chapter, we are going to present an overview of the natural historical periods and some of the climatic and natural geographic conditions that framed the vegetation development after the last Ice Age.

3.1 Postglacial climate periods and vegetation conditions

During the Quaternary period, there were large climatic changes with several glaciations. During the most recent glaciation, the ice masses had a maximum distribution approximately 30 000 years ago. Only fragments along the western coast of Southern and Northern Norway were likely free of ice. At these isolated locations, some alpine plants and tough deciduous species survived the glaciation (Krohn 1982, Börset 1985).

The contemporary Norwegian vegetation has thus developed postglacially (Fig. 3.1). The ability of the trees to settle on new soil and react to ecological factors, combined with human impact, has shaped the forest pattern observed in Norway today. Typically, a first succession promotes shade intolerant and modest plant species with efficient seed dispersal. Thereafter, demanding species follow the lesser light, and finally the typical climax tree species characteristic of acidic soil may invade (Börset 1985).

13 000–14 000 years ago, a large ice sheet had retreated such that an outer coastal brim from Jæren and northwards had become free of ice. For some time, birch (*Betula* spp.) occurred at Jæren, but otherwise the vegetation was characterized by alpine plants. A significant climate change occurred approximately 10 000 years ago, commonly regarded as the end of the glaciation. After the quick retreat of ice, birch (*Betula* spp.) invaded and developed the first forests (Larsson et al. 1994).

The individual plant species makes various demands both to summer and winter temperature, length of the growth season and humidity. These factors also influence the competitive condition among species. Climate changes are the key to understanding the dispersal of various plant species and their possibilities for survival. Roughly, one can say that the development of the postglacial climate has followed a “wavelike” pattern (Fig. 3.1). The first, approximately 2 000 years after the withdrawal of the ice, were characterized by increasing warmth. An intermediate period lasted approximately 4 500 years with warm and favorable growing conditions (annual mean temperature was approximately 2 ˚C higher than today). Finally, there was a 3 500 years long period with declining warmth, increased moisture and longer winters (Jørgensen et al. 1995).

The last 15 000 years of earth history is often divided into a *late glacial* or *subarctic* period (13 000–8 000 B.C.), when ice was still over much of Norway, and a *postglacial* period (8 000 B.C.–present), when the major part of the inland ice sheet had melted (Börset 1985). While the invading plant species have a very old fire history that can only be understood by thorough studies

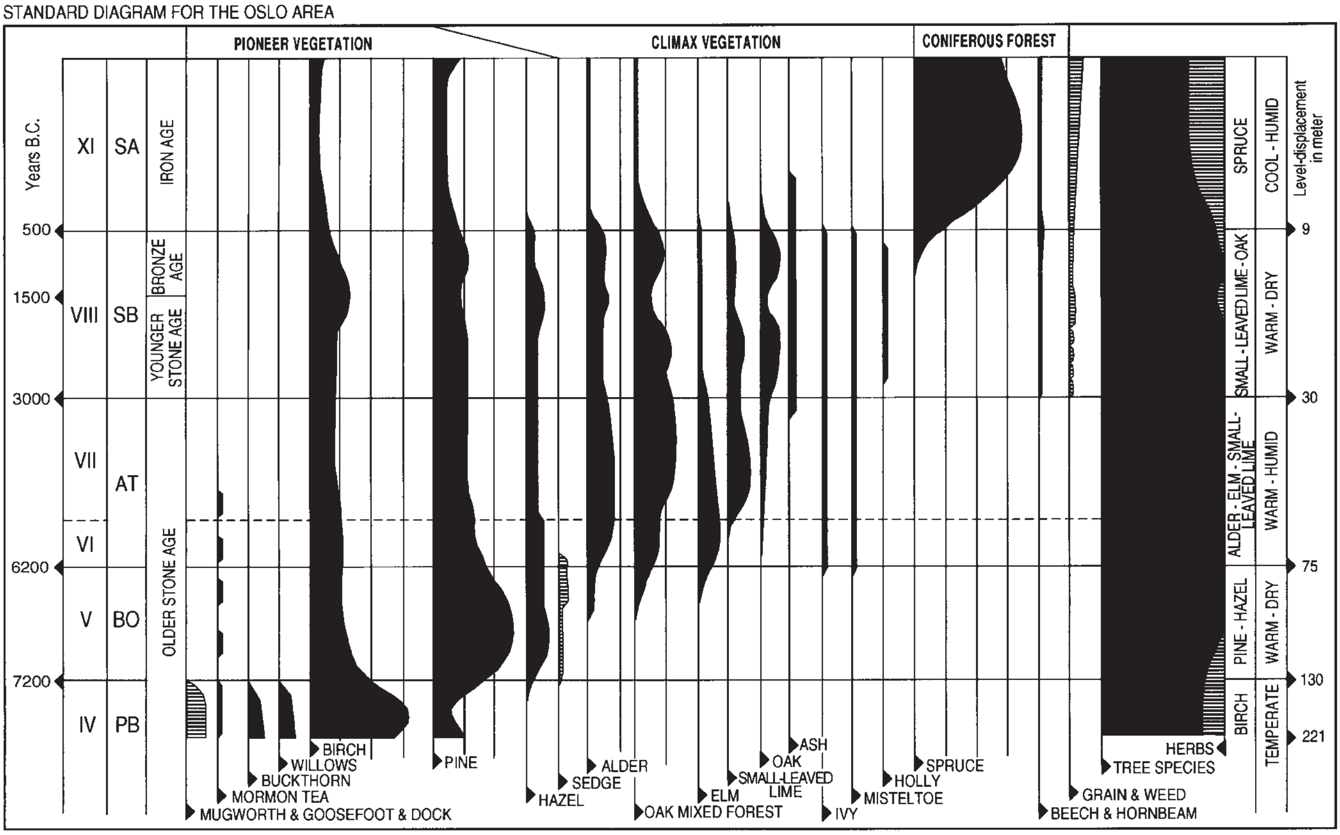


Figure 3.1. Pollen diagram from the Oslo area showing the main developmental features of the forest in this area after the last Ice Age. Information concerning the climate development, agricultural history and shore line heights at different borderline periods is also presented (After Börset 1985).

of their prehistory and refuge conditions, the actual fire historic epoch for our Norwegian forests is only 8 000–9 000 years old. The two long late glacial and post-glacial epochs are further divided into shorter time periods with varying climate conditions where important tree species invaded. A division into archaeological periods is also developed for this long time frame to date cultural historic epochs and human use of the landscape (Tab. 3.1). This is also important for fire-history (ch. 4).

The subarctic period was characterized by a cool climate along the edge of the ice exceeding in a *preboreal* time characterized by better developed birch forests and a subsequent *boreal* time with pine forests. *Atlantic* time was characterized by a more pronounced oceanic climate and is called the oak period. During the next *subboreal* period, the pine was also to a large extent expelled by oak. The postglacial warmth period (Boreal, Atlantic and Subboreal Time) lasted for a total of 6 500 years (Tab. 3.1). Judged from climate and vegetation, this was likely an important fire historic period in the Nordic countries, especially because human use of the landscape became more pronounced.

Table 3.1. The postglacial invasion of trees and dominating tree species during various climatic periods in Norway, with an evaluation of the natural fire frequency (After Börset 1985).[1)]

Year . B.C.	Climate period	Dominating tree species at respectively		Natural fire frequency
		Jæren	The Oslo area	
	Subatlantic	Heathland	Spruce	Low
500	Subboreal	Broadleaved deciduous trees	Broadleaved deciduous trees	High
3 000	Atlantic	Birch and alder trees	Broadleaved deciduous	Low
5 500	Boreal	Birch, pine and hazel	Pine, birch and hazel	High
7 000	Preboreal	Birch	Sea buckthorn and birch	Low
8 000	Subarctic	Tundra Birch	Ice covered	Moderate

[1)] Note that the division of time periods in this table from Börset (1985) does not completely coincide with Table 4.1 (ch. 4) based on Hagen et al. (1980).

3.1.1 Subarctic Time

In Subarctic Time (13 000–8 000 B.C.), there was a quite cool climate along the edge of the ice (Fig. 3.1). The entire eastern part of South Norway (Østlandet) was still covered by ice. It was only on the west coast that vegetation in the form of dwarf birch (*Betula nana*) and hardy willow species (*Salix* spp.) had begun developing. Birch (*B. pubescens*) and silver birch (*B. verrucosa*) invaded Jæren at that time. Toward the end of this period, the climate became cooler and the timber line retracted somewhat south- and westwards. In light of the cool climate, one would expect moderate or low frequency of natural fires (Tab. 3.1).

3.1.2 Preboreal Time

Preboreal Time (8 000–7 000 B.C.) was characterized by relatively quick melting of the inland ice sheet, while at the same time the land rose (Börset 1985).

Birch colonized large areas during this period, both from the southwest across the North Sea Continent, from the southeast through Sweden and Denmark and from the east across Finland. Birch invaded first together with aspen (*Populus tremula*), willows (*Salix*) and juniper (*Juniperus communis*). Thus the Preboreal period is often called the *birch period*. The invasion of aspen has been more difficult to chart because aspen pollen is less durable and more difficult to analyze.

The more warmth demanding silver birch also spread in Preboreal Time. Broadleaved deciduous species also seem to have colonized the ice-free areas relatively quickly after they became available. Because of a forest development with stands characterized by various species of deciduous trees, one would expect that the natural fire frequency was still low, even though the climate was more fire compatible compared to the preceding period.

3.1.3 Boreal Time

In the Boreal Time period (7 000–5 500 B.C.), the thousand year old birch period in the Oslo area was followed by pine (*Pinus silvestris*), hazel (*Corylus avellana*) and grey alder (*Alnus incana*). After expelling deciduous tree species that had previously invaded, pine gradually became the dominant tree species for a long period of time. Thus, Boreal Time is often called the *pine period*. Toward the end of Boreal Time, broadleaved deciduous tree species such as elm (*Ulmus glabra*), black alder (*Alnus glutinosa*) and oak (*Quercus* spp.) also began immigrating. The natural fire frequency during this dry and warm period with large elements of pine forests is expected to have been high (Tolonen 1983). This is documented through examinations of increased supplies of carbon, both in lake sediments and bogs in Finland.

3.1.4 Atlantic Time

At the transition to the Atlantic Time period (5 500–3 000 B.C.), the ocean broke through the North Sea Continent, and the climate became more oceanic (Börset 1985).

During this period, the broadleaved deciduous trees invaded the Oslo area, first and foremost oak (*Quercus* spp.). This period is therefore called the *oak period*. Simulaneously, alder, elm (*Ulmus glabra*), ash (*Fraxinus excelsior*) and small-leaved lime (*Tilia cordata*) expanded, and luxuriant deciduous forests gradually covered large areas in the eastern part of South Norway (Østlandet). Pine was expelled to poorer growth sites.

The Atlantic and the subsequent Subboreal Time periods are therefore regarded as the time for luxuriant broadleaved deciduous forest. The climate was warmer than at present. In the Oslo area, winter temperatures may have been approximately 2 ˚C higher and summer temperatures 1.5–2.0 ˚C higher than today.

For the western part of South Norway (Vestlandet), the climate improvement was somewhat delayed. More hardy species, like birch and alder, characterized the forest here also during this period. Pine, elm and oak appeared more dispersed. Pine and birch still dominated the northern part of Norway and in the highest elevated areas, and hazel reached further north and higher up than the present. Atlantic Time coincides with the archaeological period that is called the *Older Stone Age* (Börset 1985).

Examinations of carbon samples from lake sediments and bogs have documented high fire frequencies both in the continental North Europe and North America from Atlantic Time and onwards (5 000–6 000 B.C.). During the same time, only seldom fires have been registered in more oceanic areas (K. Tolonen 1983). On the British isles, clear differences between highland areas and lowland districts characterized by a maritime climate have been established (A. Smith 1970, Jakobi et al. 1976, K. Tolonen 1983).

From the increasing oceanic impact on the climate in Norway, one would expect that the relative frequency of natural fires declined. From research other places in Fennoscandia, carbon supplied to Finnish lakes were

also very low during the period before 4 000 B.C. (M. Tolonen 1978, Huttunen 1980, K. Tolonen 1983).

After spruce (*Picea abies*) became common in this Finnish area (4 000–3 000 B.C.), however, the carbon supplies to the examined locations increased by a factor of 33. Fires were commonly distributed throughout the examined areas, something which is confirmed through many stratigraphic pollen examinations in Finland (K. Tolonen 1983). Thus, there are indications that also during certain periods of the Atlantic Time, parts of Fennoscandia may have been characterized by a dry climate type.

3.1.5 Subboreal Time

During the Subboreal Time period (3 000–500 B.C.), pine was to a large extent expelled by oak that created forests of considerable extent in the southern part of Norway. In the eastern part of South Norway (Østlandet), oak had wider distribution than today, and also ash and maple expanded during this period. Even though the oak forest expelled the pine forest in the south, pine still expanded northwards and towards the mountains, where it gradually established a wide distribution. The timber line for pine was 200–300 m higher at that time than the present (Börset 1985).

It is assumed that pine constituted the timber line during Subboreal Time. The present reaches of the deciduous forest (subalpine birch forest), may be related to changes in the climate towards maritime situation. This climate change emerged when the Subatlantic period began. Birch may survive cool summers as long as the vegetation growth time is long enough, while pine is dependent on higher warmth during summer (Börset 1985). The present vertical elevation of the birch belt in Norway is largest in the west and decreases eastwards. In the further east and most continental areas in Norway, for example in North Gudbrandsdalen, some areas lack a birch belt.

While the Atlantic period climatically was the most favorable for the eastern part of South Norway (Østlandet), the Subboreal Time seems to represent an optimum for the western part of South Norway (Vestlandet), with high summer temperatures. The climate was mainly dry and warm during the Subboreal period (Jørgensen et al. 1995), but there were also fluctuations during this period (Fig. 3.2).

Spruce (*Picea abies*) quickly invaded Scandinavia during the last half of the Subboreal period and reached the Oslo area. The expansion of spruce happened at the expense of birch and pine forests. The deterioration of the climate led to difficulties for pine at the timber-line where mountain birch (*Betula pubescens* f. *tortuosa*) began taking over (Börset 1985).

The first part of Subboreal Time coincides with the archaeological period of the *Younger Stone Age* and the last part with the *Bronze Age*. From general considerations of the dry and warm climate and the large distribution of pine forests, one would expect high natural fire frequency. In accordance with this, research in Finland shows that during the period 5 000–2 000 years B.C., the forest fire frequency was high in some areas (Tolonen 1983), and many fires burned in the Finnish bogs over considerable areas.

3.1.6 Subatlantic Time

The Subatlantic Time period (500 B.C.-present) began with a powerful climate deterioration with falling temperature and increasing precipitation. This led to a general withdrawal of the forest. Pine did not manage to maintain its distrib-

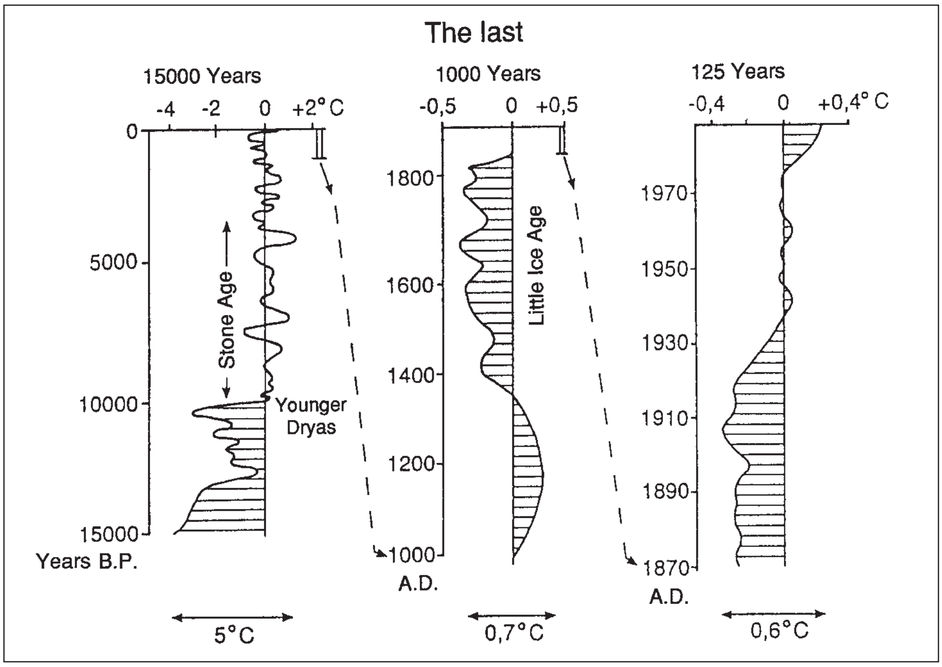


Figure 3.2. Temperature fluctuations during the last 15 000, 1 000 and 125 years (The Black Death in Europe in 1350) (After Jørgensen et al. 1995, originally based on Williamson 1992).

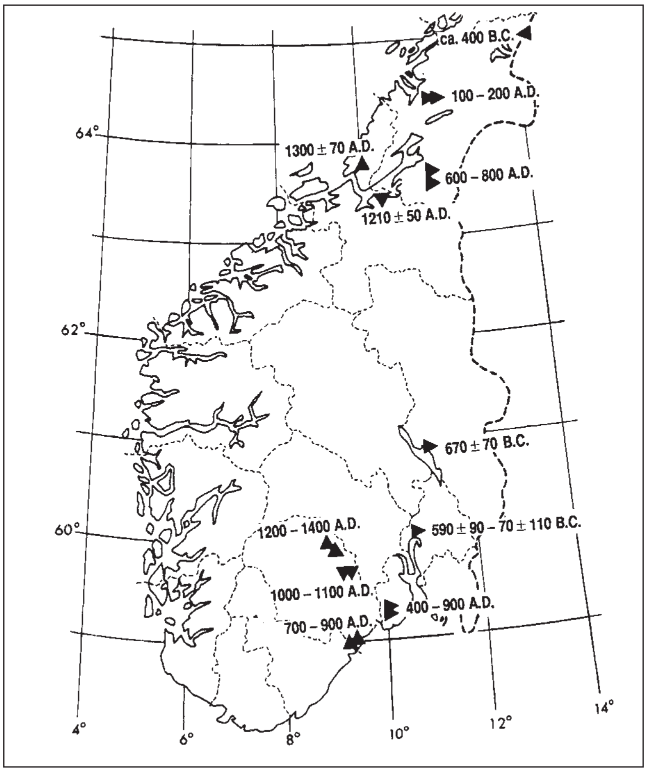


Figure 3.3. The immigration and establishment of spruce in South Norway based on carbon datings (^{14}C). Double triangles indicate the age variation for two or more dated locations (After Börset 1985).

ution at the outer edges toward the mountains. In the south, the broadleaved deciduous forest retreated (Börset 1985), partly because of the climate deterioration itself, but equally much because it was outcompeted by spruce (Larsson et al. 1994). In Norway, the present occurrences are limited to the parts of South and Mid-Norway which have a particularly favorable climate.

At Jæren and in the outer coastal areas along the entire western coast, the forest disappeared in many areas and was followed by heathlands. Natural conditions like climate deterioration influenced this, but it is presently maintained that this first and foremost was, and is, due to human activity (Section 4.1.6).

Subatlantic Time is often called the *spruce period*. Spruce probably came to Norway already during Subboreal Time, but it was not until Subatlantic Time it established an extensive distribution. The humid and cool climate made spruce particularly competitive, and it colonized most of the eastern part of South Norway (Østlandet) and Mid-Norway (Trøndelag). Both at the southern (Sørlandet), western (Vestlandet) and in the mountain valleys of the eastern part of South Norway (Østlandet) and in Mid-Norway (the Trøndelag area) it is still expanding.

It is of common opinion that spruce spread almost “explosively” across the whole of the eastern part of South Norway (Østlandet) and Mid-Norway (Trøndelag) approximately 2 500 years ago. However, more recent radio carbon dating has shown a varied invasion pattern (Hafsten 1956, 1962, 1986, 1991, 1992, Börset 1985).

To the southern parts of Vestfold and Telemark counties spruce seems to have invaded 700–800 years A.D. and to northeastern Telemark county not until 1 200–1 400 A.D. It has in other words taken a relatively long time for spruce to immigrate from the Oslo area to the inner parts of Telemark county and towards the southern part of South Norway (Sørlandet) (Börset 1985). Something similar is seen in Mid-Norway (Trøndelag), with early invasion to Namdalen across Lierne (approximately 400 B.C.), and not advancing to the Trondheim area until 1 200–1 300 A.D. (Fig. 3.3).

Spruce seems to have had a quite uniform immigration speed from Russia through Finland and Sweden to Norway. It still spreads westwards in several areas, both at the southern part of South Norway (Sørlandet), in the valleys of the eastern part of South Norway (Østlandet) and in Mid-Norway (Börset 1985). The invasion and distribution pattern of spruce from stratigraphic analyses of pollen is, however, still being adjusted. Analysis of subfossil wood fragments has recently shown that spruce occurred in an area of Sweden as early as approximately 8 000 B.C., more than 5 000 years earlier than its presence has been established in pollen data (Kullman 1996a).

Another late invader, beech (*Fagus sylvatica*), is vital and regenerates easily in Vestfold county, where it is now distributed (Larsson et al. 1994). The beech is the last invader among the forest trees. It immigrated to Vestfold during the beginning of Subatlantic Time.

In a period of approximately 6 500 years after the last Ice Age (the postglacial warmth period), we had a far better climate than today (Jørgensen et al. 1995). The forest was then spread across areas that it could not manage to retain when the climate deteriorated. The forest has had to withdraw at three fronts: from north toward south, from west toward east and from the mountain and toward lower elevations (Börset 1985).

During the last 1000 years, the annual average temperature has not varied by more than 1 ˚C (Fig. 3.2). *The little Ice Age* is the term of a 500-year period with poor climate in the northern hemisphere that lasted from approximately

1350 to 1850 (Fig. 3.2). Before the Little Ice Age it was relatively warm in Europe (Jørgensen et al. 1995).

The cooler and more humid conditions in the Little Ice Age have influenced the fire frequency (See Bradshaw & Zackrisson 1990). The fire cycle seems generally to have been shorter in the northern boreal coniferous forests during this period (Kohn 1975, Zackrisson 1977a, Engelmark et al. 1993, Kullman 1996b). This cool period was a hard time for Scandinavia. The human population number of Finnmark county declined 30 % because of emigration, famine and freezing to death (Jørgensen et al. 1995). The glaciers of Norway increased considerably during this period, reaching their maximum in 1750. It must be expected that swidden agriculture for grain production has been carried out much more extensively during periods with crop failure and difficult food situation. During such periods, anthropogenic burning in forested areas may therefore make it difficult to correlate the fire dynamics to *natural* fluctuations in climate conditions only.

We have had a relatively cool period over the last 125 years up until 1930, followed by a relatively warm period (Fig. 3.2). The increase in temperature during the last years may be connected with the increasing content of carbondioxide (CO_2) in the atmosphere. During the last 100 years, the CO_2 content of the atmosphere has increased by 30 %, the methane (CH_4) content is doubled and the earth's mean temperature has increased 0.5 ˚C (Jørgensen et al. 1995). This may have consequences for the fire regime, but so far it does not seem to have manifested itself in any increase in the fire frequency (See section 6).

In spite of damaging consequences of human utilization of the forest in the mountain areas (Section 4.2), Börset (1985) still assumes that the climate deterioration that occurred approximately 2 500 years ago has been the most important cause of the forest decline. The land rise during the last approximately 7 000 years has also contributed to the extinction of forest (Börset 1985). There is, however, no agreement as regards the interpretation of these complicated conditions.

3.2 Nature geographical and regional conditions

In this section, we are going to have a look at the present situation. While there is considerable uncertainty associated with the description of the historic periods during postglacial time, the basis for the contemporary fire regime is considerably easier to interpret. The reason that we have made some comparisons between Norwegian and Swedish and Finnish conditions is that the distinctive features of Norway then emerge more clearly.

3.2.1 Contemporary climate

The climate in Norway in its entirety falls within the cold (boreal) climate zone. A long contact zone toward the ocean and very variable mountain formations produced a very fluctuating climate.

Two main types of climates are the so-called *coastal climate* (oceanic or maritime) and an *inland climate* (continental). Langfjella forms the most marked division between these two climate types in Norway. In the coastal climate, the winter is mild, but unstable, often with an average temperature as high as 0 ˚C even during the winter (Krohn 1982). The summer is not particularly warm, and the transition periods spring and particularly fall are long. The inland climate has a cold and stable winter, a warm summer and quite short transition periods. In the inland, marked drought periods may now and then occur, where the forest is more fire prone, while along the coast it is mostly very humid. There is also marked differences in wind conditions between the coastal and inland climate.

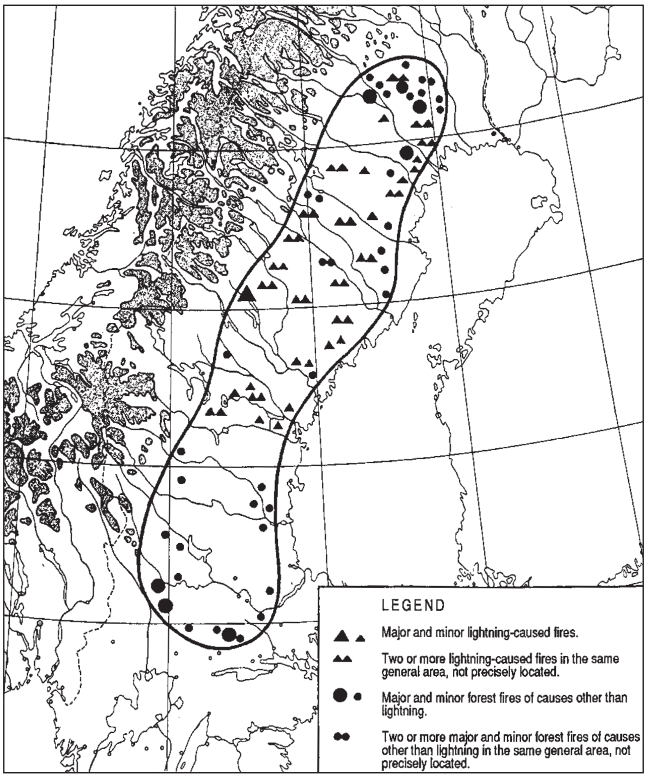


Figure 3.4. Fires ignited by lightning in Sweden during the period between July 3 and 12, 1933 (After Högbom 1934).

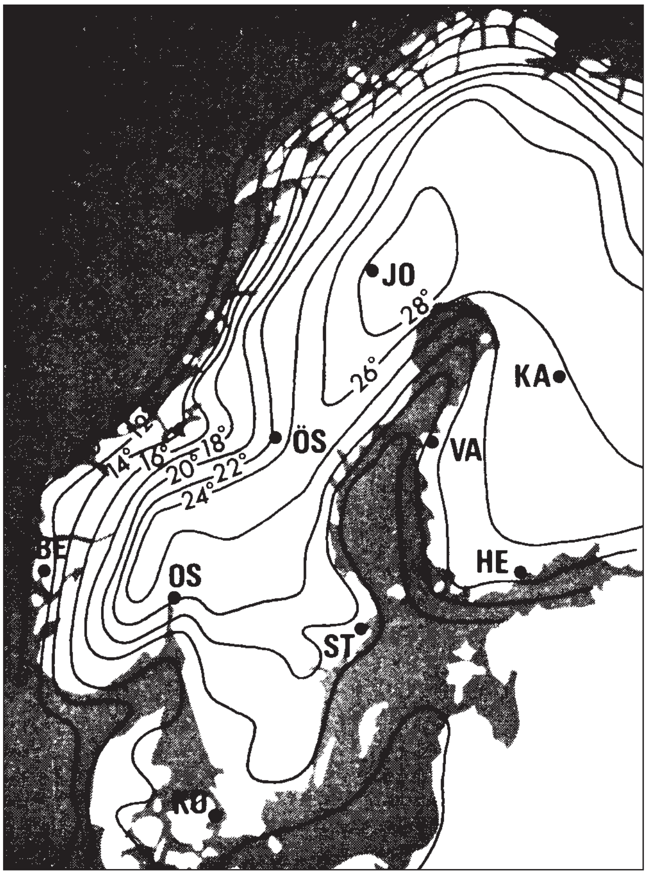


Figure 3.5. The continentality of the climate in the Nordic countries expressed as differences in mean temperatures between the coldest and warmest month (After Abrahamsen et al. 1977).

This is also of importance for the course of forest fires, especially the prevailing winds during the drought periods. In the middle and inner fiord areas, in the west and in the north, the climate is so special that it may be characterized as a specific *fjord climate*. There are also areas in Norway with a *mountain or high alpine climate*, with very low summer temperatures, short summers and much wind (Börset 1985). In these areas, fires are of little influence.

Temperature

In spite of its northern latitude, Norway has a favorable temperature, particularly during winter. This is in part due to the warm Gulf Stream (The Norwegian Atlantic Sea Current) flowing northwards along the coast, and to the fact that mild air streams from the south. At the central eastern part of South Norway (Østlandet) the monthly average temperature in July is approximately 17 ˚C, while on the west coast it is 14 ˚C, and on the Finnmark coast 11 ˚C.

With rising altitude above sea level the temperature drops (0.6 ˚C per 100 m elevation). The undulating topography leads to large local variations in temperature, between warm sunny slopes and frost exposed depressions (Börset 1985). This is of great importance for the regional shaping of the Norwegian fire regime (See ch. 6).

It is in the drier and warmer continental areas of Norway that lightning strikes ignite most fires, and thus where one gets the largest element of “natural” fires. In Sweden, where the continentality of the climate is more prevalent, it was documented during the large fire year of 1933 how important thunderstorms may be as a cause of forest fires (Högbom 1934, Kinnman 1936). During a relatively short period between July 3 and 12, 1933 with extensive thunderstorm activity, lightning ignited forest fires scattered throughout the northern part of the Swedish forest area (Fig. 3.4).

The continentality of the climate, for example expressed as differences in average temperature between the coldest and warmest month, shows that Norway clearly distinguishes itself from both Sweden and Finland. It is only the northeastern parts of eastern South Norway that are continental enough to be very vulnerable to fires. This region in many ways is characterized by the same conditions as in adjacent areas of Sweden (Fig. 3.5).

Precipitation

The amount and distribution of precipitation throughout the year is an important variable in the fire regime. There can be large variations from year to year, or from month to month, and often a change between drought years and years rich in precipitation. The conditions may be very unequal in various parts of the country during one and the same year: A drought year in the eastern part of South Norway (Østlandet) may coincide with a year particularly rich in precipitation in Mid-Norway (Trøndelag). There may, however, be dry conditions across large parts of the country at the same time combined with extensive thunderstorm activity, something that by experience is decisive for the number and extent of fires ignited by lightning. During years with extraordinary large amounts of precipitation the vegetation becomes so soaked that natural ignition is difficult (Section 2.1.3)

Figure 3.6 shows the precipitation in the Nordic countries. The essential part of the precipitation falls west of the Norwegian mountain range, and Norway as a whole has more precipitation than Sweden and Finland. There are large amounts of precipitation along the coast and partly in the mountain range of Norway, actually over most of the country, compared to Sweden and Finland (Fig. 3.6).

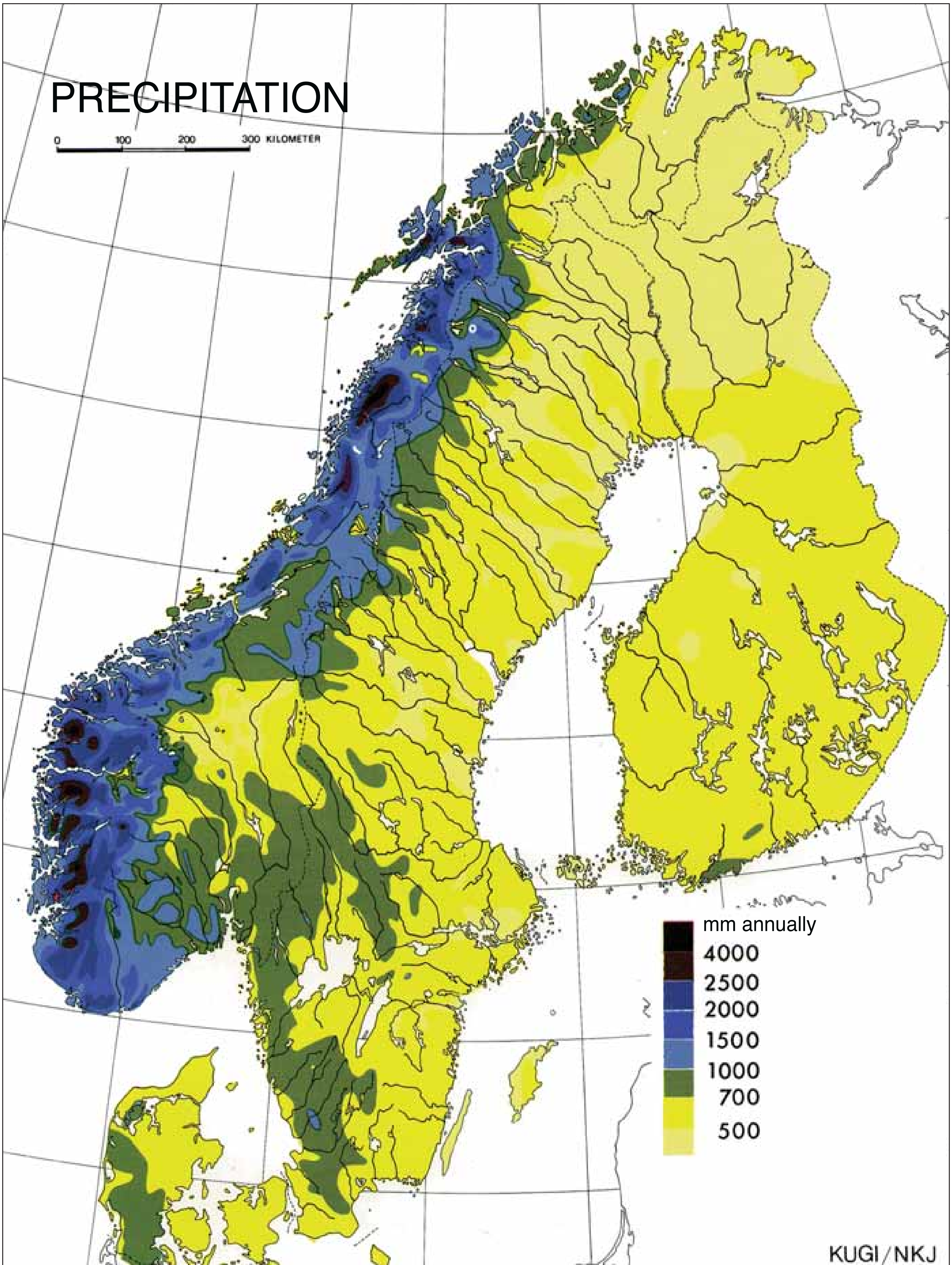


Figure 3.6. Precipitation map of the Nordic countries. Pay particular attention to the low precipitation areas in the inland of Norway and the northernmost forest areas in the southeast (Østlandet) of Norway (After Abrahamsen et al. 1977).

Table 3.2. The climate type throughout large areas of Norway must be characterized as humid, here characterized by humidity figures based on Hesselmann's scale (After Börset 1985).

H [1)]	Types of climate	Areas of Norway
<30	Subarid	Øvre Gudbrandsdal
30-34 35-39	Continental Transitional area	Valleys in the southeastern part of South Norway (Østlandet); inner parts of Troms and Finnmark counties
40-49 50-59	Subhumid Humid	Most of the south eastern part of South Norway, (Østlandet), lower parts of Mid-Norway (Trøndelag) and the rest of Troms and Finnmark counties
>60	Superhumid	Ridgy areas in the south eastern part of South Norway (Østlandet), the southern and western parts of South Norway (Sørlandet, Vestlandet); Nordland county and higher elevated areas of Mid-Norway (Trøndelag)

1) Humitidy expressed by humidity figures after the following formula: H=N/(T+10) where H is humidity figure, N is average annual precipitation in mm and T is average annual temperature in ˚C.

For example, the coastal forests of several counties dominated by pine with large amounts of fuel, lie in areas that have more than 4 000 mm average annual precipitation (Fig. 3.6) and therefore have a low likelihood of being ignited by lightning strikes. In such areas, one must a priori assume that natural ignited fires occur in far lower frequency than in more continental areas. From a low natural ignition frequency one cannot, however, deduce that it necessarily has burned less in such areas (See ch. 4). In contrast to such humid areas, we have the protected inner part of eastern South Norway (Østlandet), with average annual precipitation below 300 mm.

The amount of snow may vary a lot, but normal snow depths are for the most part of the country quite moderate. The melting of the snow cover means much for the soil moisture during spring and early summer and therefore for the extent of the drought periods. Where the snow melts early and the soil and ground vegetation dries quickly, the likelihood of ignition may become very high. When the drought period ends and the vegetation has become green, the inflammability again decreases.

Humidity

The moisture content of the fuel is as mentioned important both for ignition and the course of forest fires. The considerable precipitation and relatively low average temperatures (See above) provides in general high humidity figures and a predominantly humid climate (Tab. 3.2).

Conclusively, we can say that temperature conditions, precipitation and moisture regime gives Norway a humid and cool fire regime where the likelihood of naturally ignited fires is highest in the continental transitional areas and subarid inland regions.

3.2.2 Topography and elevation factors

Landscape features like topography and altitude may be of decisive importance for the course of fires (Section 2.1.5).

Topography

The terrain in Norway also varies much from county to county. It gets steeper and more varied toward the west. This is of great importance for the local fire regime.

Both the steepness, shape and levelness of the terrain may be of decisive importance for the course of forest fires. Hillsides and convex landscapes are particularly vulnerable to fires (Zackrisson 1977a, Foster 1983, Engelmark 1987). Fires, as we have seen (Fig. 2.11), also spread more easily up a slope than level or downhill (Romme & Knight 1981, Hörnberg et al. 1992). Valley bottoms, depressions and various concave formations are to a larger extent assumed to escape fires (Zackrisson 1977a, Foster 1983, Engelmark 1987, Hörnberg 1995, Hörnberg et al. 1995). More recently, Norwegian research at Totenåsen (Håkonsen 1996) has shown that also this may vary. The connection and interaction between topography and hydrology contribute to increase the variability of local fire regimes. Håkonsen (1996) assumed that quick changes in slope and humidity through forested areas at Totenåsen was the actual basis for a fine-grained mosaic of fire regimes, including fire frequencies. Forest fires around and in concave formations without an outlet are interesting because runoff from the fire areas may lead to a local accumulation of nutrients (“nutrient traps”). This development of exceptional qualities contributes to diversity in the landscape (variation on a small scale).

Natural fire barriers may also be found in terrain with even topography. For example, it has been documented

Table 3.3. Norway's forest area distributed by percent on steepness categories. The forests of Troms and Finnmark counties are not included (Landskogstakseringen, after Börset 1985).

Steepness, slope	Even terrain	Terrain with large rocks and knolls	Boulder- and scree-areas	Small cliffs and clefts/crevices	Wet forest ground	Sum
<10	22.5	2.8	-	0.1	1.0	26.4
10-20	26.1	8.6	0.1	0.4	0.4	35.6
20-33	13.6	8.5	0.2	1.1	0.1	23.5
33-50	4.6	4.2	0.3	1.7	-	10.8
>50	1.2	1.0	0.3	1.2	-	3.7
Sum	68.0	25.1	0.9	4.5	1.5	100.0

that bogs constitute barriers (Engelmark 1987, Håkonsen 1996). Microtopographic variation is generally of larger importance in Norway that has a much larger part of its forested area in steep, uneven and difficult terrain than its neighboring countries. "Uneven terrain" is in this connection meant areas with large rocks or ridges, characterized by boulder- and scree-areas, small crevices or clefts and cliffs with steeper and less sloping sites in an ever uninterrupted variation. Many parts of such rugged terrain may be stagnated and swamped (Tab. 3.3). Up to approximately 15 % of the productive forest area are situated in terrain steeper than 33° (Börset 1985). The percentwise distribution of the forested area on different steepness categories of Norwegian areas is shown in Table 3.3.

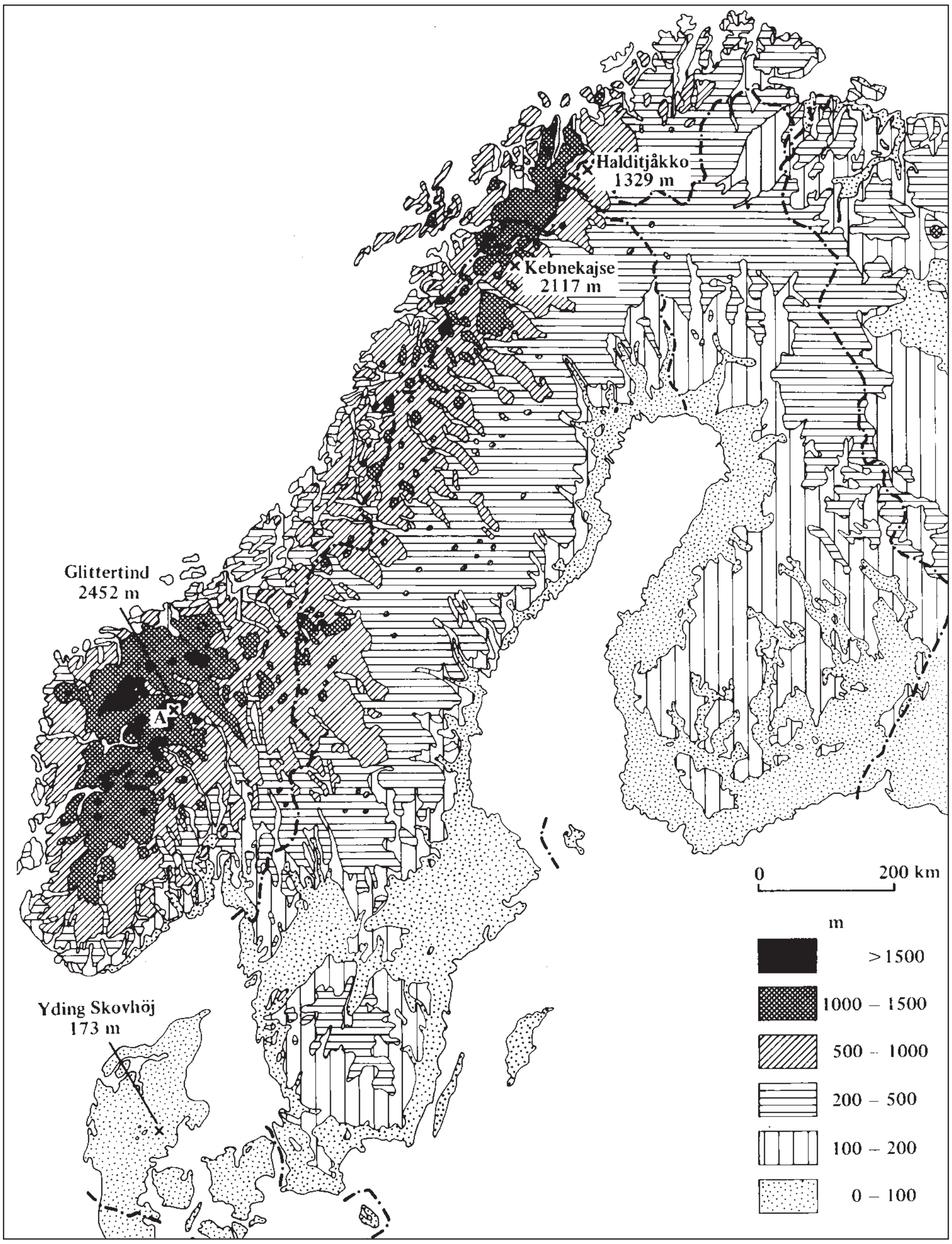


Figure 3.7. Height contour map of the Nordic Countries highlighting the areas above 1 000 m. Because of the low atmospheric pressures coming in from southwest and west, the high altitude topographical formations in Norway result in large areas of Sweden being in a "rain shadow" (After Rudberg 1987).

Elevation factors and relieff

The large topographic differences between the Nordic countries clearly emerge on a map of the *altitudes* (Fig. 3.7). Norway has the largest proportion of high-elevated areas. Tree species which contain much resins (coniferous trees) and other good fuel with accompanying surface litter layers and field layer vegetation occur at much

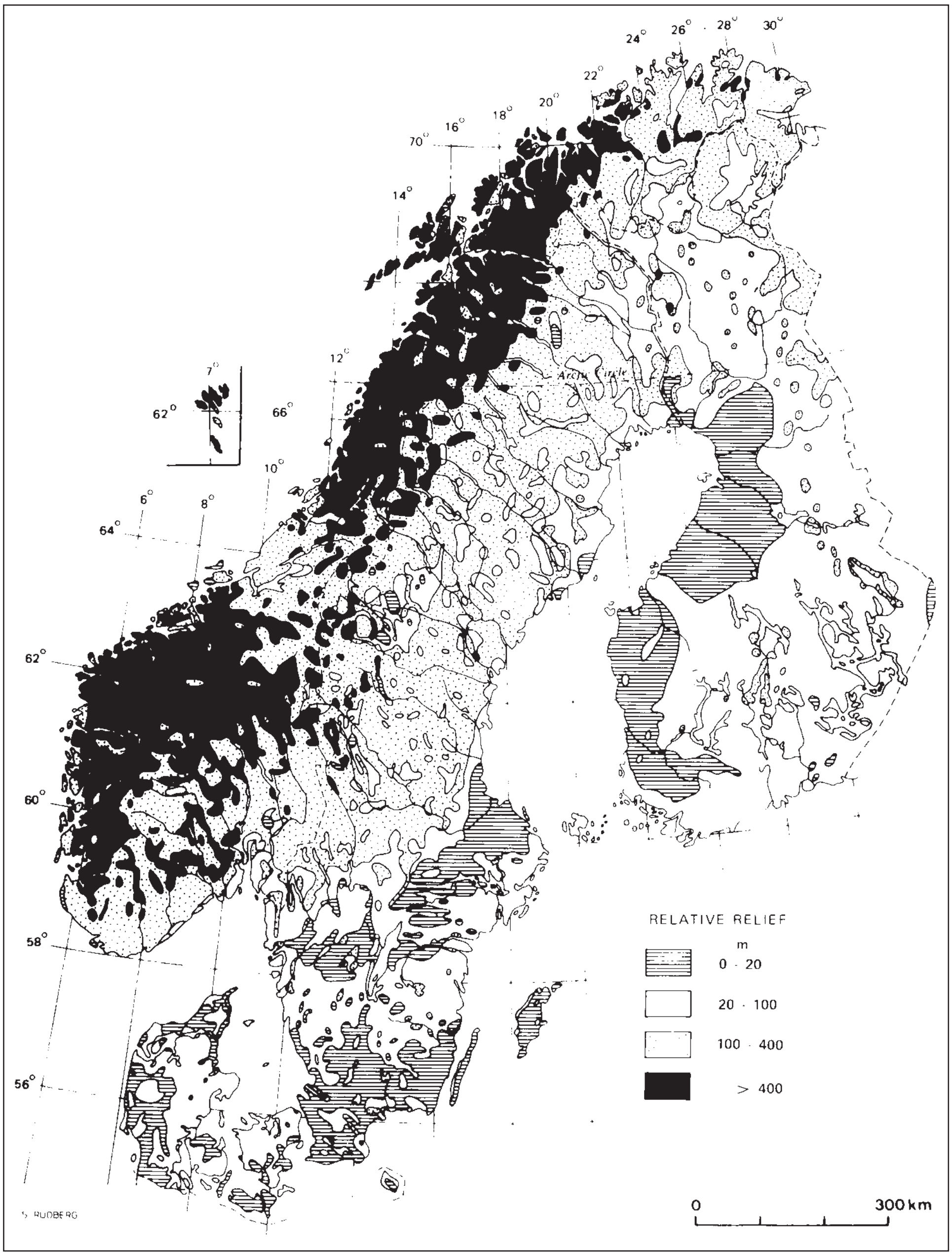


Figure 3.8. Relative relief of Norden. Pay attention to the large flat areas of Sweden and Finland below 20 and 100 m, respectively (After Rudberg 1987).

higher altitudes in Norway than in the neighboring countries. Considering the quality of the fuel, in forests at higher altitudes one would assume that the conditions were present for naturally ignited fires here. The altitude is, however, in itself of direct importance for the course of fires. It is documented in Sweden that mountain forests at higher altitudes have fewer signs of fires than forest at lower elevations. Colder climate at higher altitudes induces less transpiration and poorer decomposition of organic matter, thicker raw humus layers, more humid conditions and thereby reduced impact of fire (Hörnberg 1995, Hörnberg et al. 1995). Because of the topography, the precipitation and some other conditions (Section 2.2.5) one would therefore expect that the natural ignition frequency is lower in large parts of South Norway than north- and northeastwards in Sweden and Finland. These countries have a more favorable combination of vegetation cover rich in fuel, and dry periods, and thus increased risk of ignition by lightning strikes. In these areas the natural conditions are more homogeneous such that one could expect that they have been more exposed to naturally ignited fires. However, here we are faced with uncertainty about the extent of anthropogenic burnings in the Norwegian mountain forest. The question is therefore, to what extent can information and knowledge from North Sweden be extrapolated to the mountainous areas of South Norway? It seems to be evident from historical sources that the forest vegetation resources at higher altitudes, for example around Hardangervidda, have been heavily utilized (Warren & Mysterud 1995), and that anthropogenic activities associated with burning may have been common. The importance of anthropogenic activity and possible wild fires ignited by humans in high elevated and mountain forests in Norway should receive closer examination (ch. 5).

The inland portion of Southern Norway represents the most extensive high elevation area in all of the Nordic countries. It is divided from the continuous high-elevated areas of Northern Norway by lower elevated areas around the Trondheim fiord. In comparision, Finland has the largest lowland areas: Most land is located below 200 m a. s. l., and no area is above 500 m a. s. l. (Fig. 3.7). Sweden is intermediate with some high elevated areas between 500–1 000 m and more varied topography northwards, particularly along the Norwegian border (Fig. 3.7).

Compared to Sweden and Finland, Norway therefore has much more high-elevated forest areas where the proba-

bility of forest fire is low. In addition, Norway is characterized by more fire barriers in the form of various convex and concave structures than the less elevated landscape of Sweden and Finland (Fig. 3.8). Finland has another type of fire barrier in the large number of lakes and bogs. This distinguishes parts of Finland from the conditions in Sweden.

Differences between the countries can be seen clearly on particular relief maps, where the distribution of peaks, high elevated hills, ridges and plateau edges and adjacent sea level, sea shores, valley bottoms and flat country are highlighted (Fig. 3.8). The relief map emphasizes the mountain range of Fennoscandia itself and the compactness of the areas at higher elevations. Norway has the majority of all area above 400 m (Fig. 3.8).

3.2.3 Geological substrate and edaphic conditions

Approximately 30 % of Norway's rock base is bedrock, formed during the Earth's earliest history. Granite and gneiss are the dominating species of rocks from this time period. The bedrock weathers slowly and leads to relatively coarse grained, acidic soil poor in nutrients (Börset 1985).

The Eocambrian species of rocks (sparagmite) are also old formations, rich in feldspar and quarts that for the most part produces coarse grained and poor soil. Together with Devonian species of rocks, they cover approximately 15 % of the total Norwegian area.

Species of Cambrosilurian sediment rocks are younger. They cover considerable parts of the eastern part of South Norway (Østlandet), Rogaland and Hordaland counties, Middle (Trøndelag) and North Norway. They consist for a large part of clay schists and phyllite that weathers much easier than the bedrock species.

The younger eruptives in the Oslo area also provides a better basis material for soil formation than the eruptive species of rocks from the Earth's earliest history.

The nutrient poor bedrock is not as dominating in Norway as in Sweden and Finland (Börset 1985).

Table 3.4. Designations of various types of humus and soil in Norway (After Larsson et al. 1994).

Podzol is the generic term of a group of soils particularly common in Norway. It consists of a raw humus horizon above a horizon of bleached mineral soil and another horizon with acidic precipitate (Norw. "utfellingslaget"). Podzol formation and podzol profiles are typical for cool-humid climates and soil poor in nutrients. The bleached horizons and the horizons with acidic precipitate get thicker and more pronounced with increasing amounts of precipitation and raw humus. Podzol is the most common profile type in boreal coniferous forest.

Humus is a common term of more or less decomposed organic material in the soil. Humus may be sharply delimited from the mineral soil, or it may be partly mixed with it.

Raw humus is slightly decomposed humus horizon where one may recognize biological structures, and lies as a layer above the mineral soil. It is poor in nutrient and forms during cool-moist conditions of surface litter poor in nutrient. In a raw humus horizon the humidity conditions are highly variable. Raw humus is divided into several types (Larsson et al. 1994).

Mull is a further decomposed, more mineral mixed and more nutritious humus, normally with a gradual transition to mineral soil. The germinating conditions in mull are good.

Peat is a very poorly decomposed humus which is deposited during moist, oxygen poor conditions. Soil with more than 30 cm height of peat is denoted as peatland. In peatland, the humidity conditions for germination are usually good. Peat is found in bog and swamp forests.

Brunisol (Norw. "brunjord") is a soil type that has a more or less thick horizon of mull or mull-mixed soil at the top. Brunisol is formed where there is good access of nutrients in the soil. There may also be high biological activity of organisms that transport humus within the profile and mix soil from various horizons. Brunisol is typical in broadleaved deciduous forest and spruce forest rich in herbs.

Peat soil forms during conditions with high water content and lack of oxygen, which inhibits the decomposition of organic material. The designation is used for wet forest sites, characterized either by a thick, peat-like humus horizon above dark gray-colored mineral soil, or by pure peat.

Soil

Covering the rocks in Norway we find predominantly moraine soil and sedimentary soil. The soil formation is of basic concern from a landscape ecological perspective, and soil and humus are divided into several types (Tab. 3.4). The soil depths vary greatly. The soil layers are usually thin or absent such that bare rock is exposed. This influences the intensity and continuity of fires and is important when evaluating the fire regime.

Soil material, particularly the added layering of humus

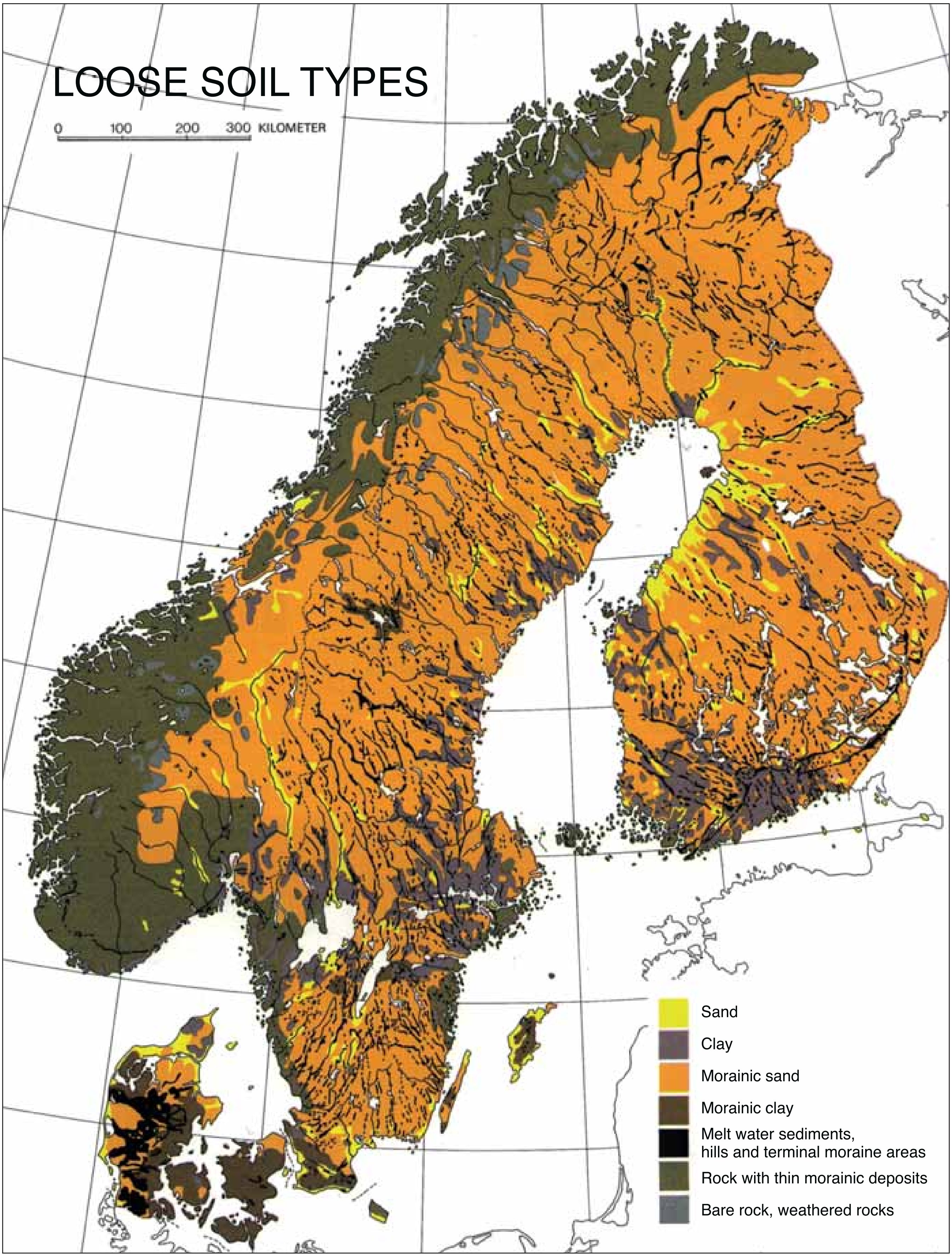


Figure 3.9. Map of quaternary geological conditions in Norden. Norway is a country with small areas suitable for agricultural production with permanent tillage (After Abrahamsen et al. 1977). This may indicate that swidden agriculture (Section 4.1.5) during some historic periods has been of particular importance.

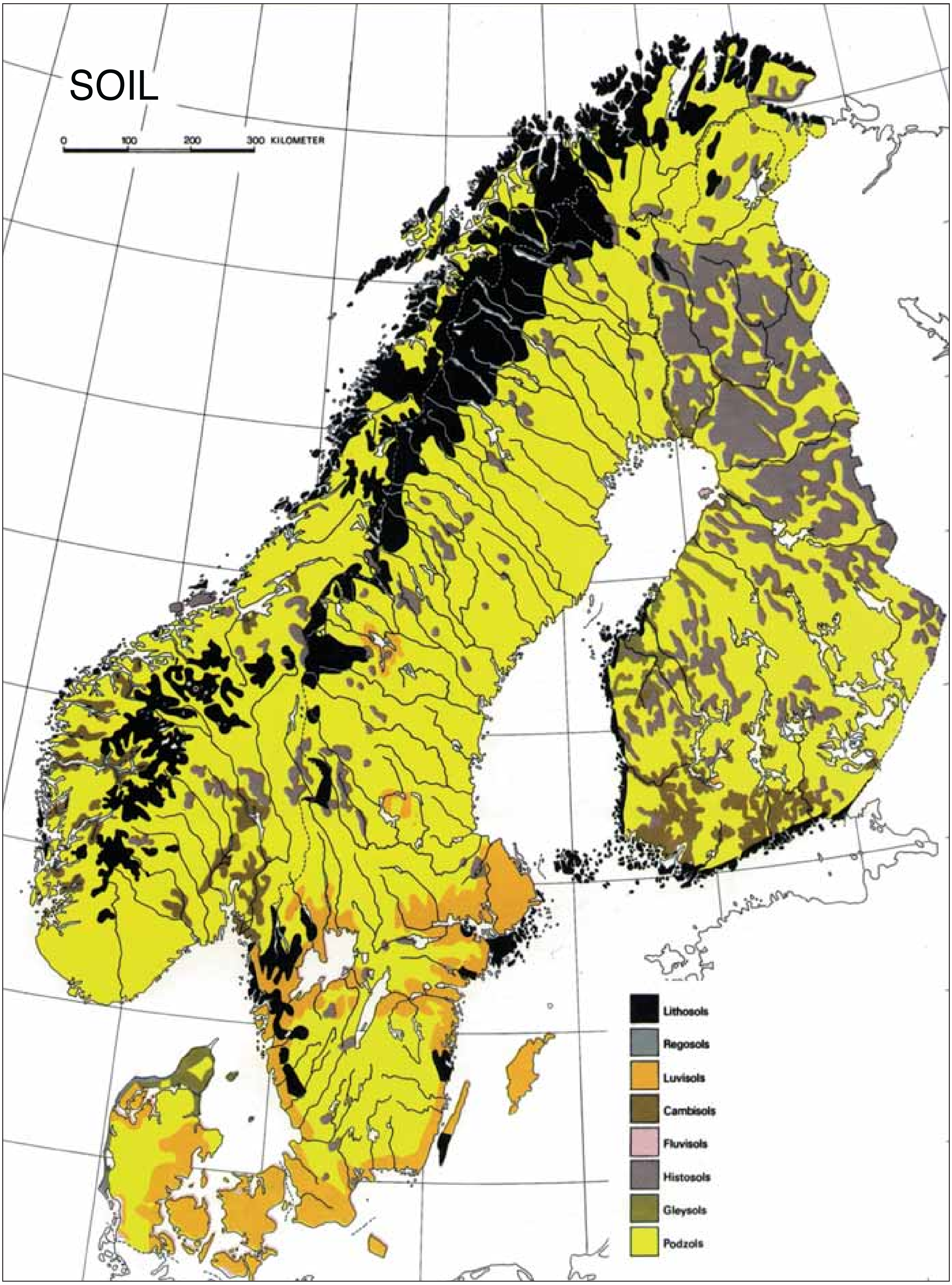


Figure 3.10. Map of edaphic conditions in Norden illustrating the considerable differences between Norway, Sweden and Finland (After Abrahamsen et al. 1977).

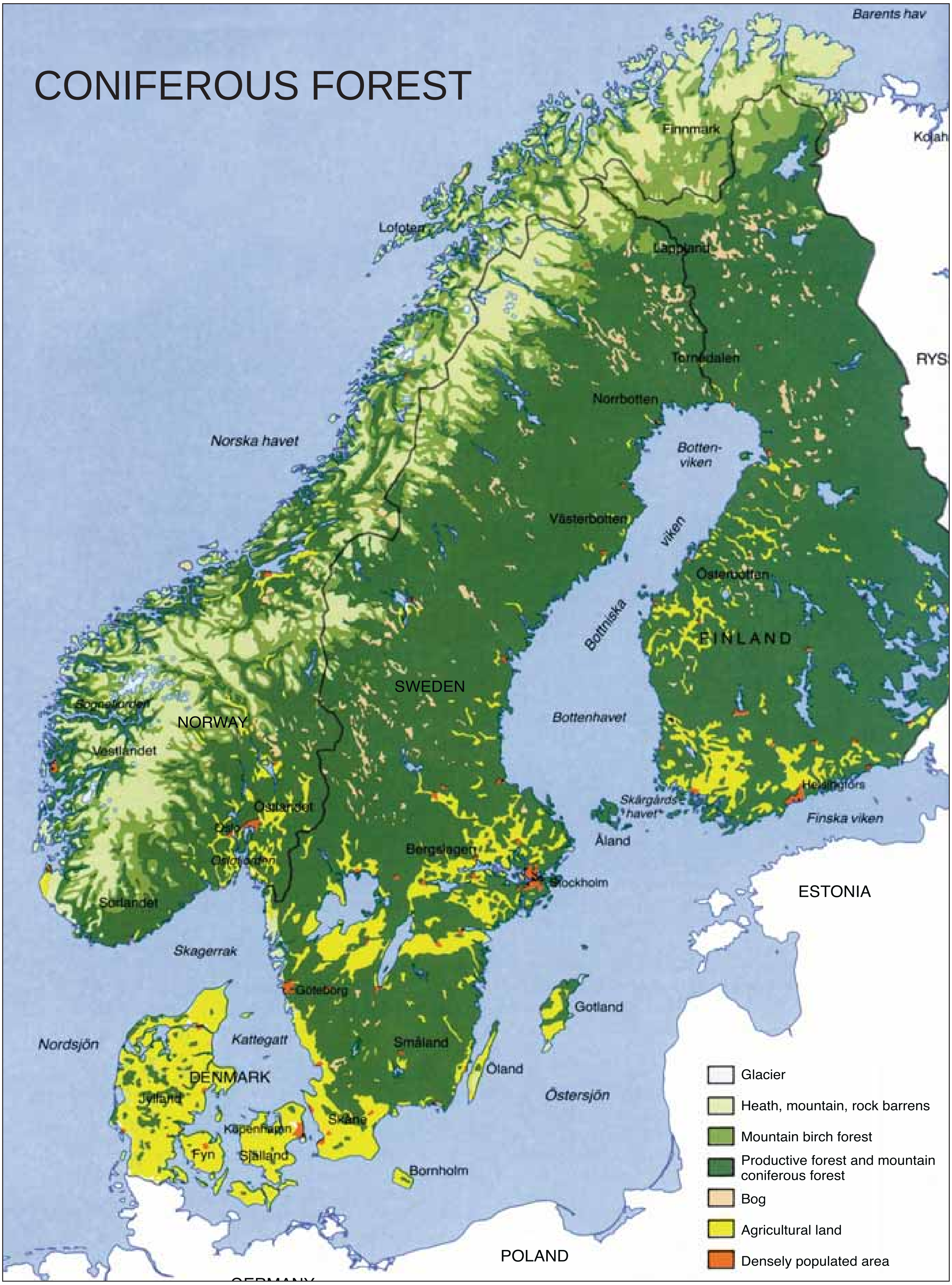


Figure 3.11. The distribution of coniferous forests in the Nordic countries (After Bernes 1993).

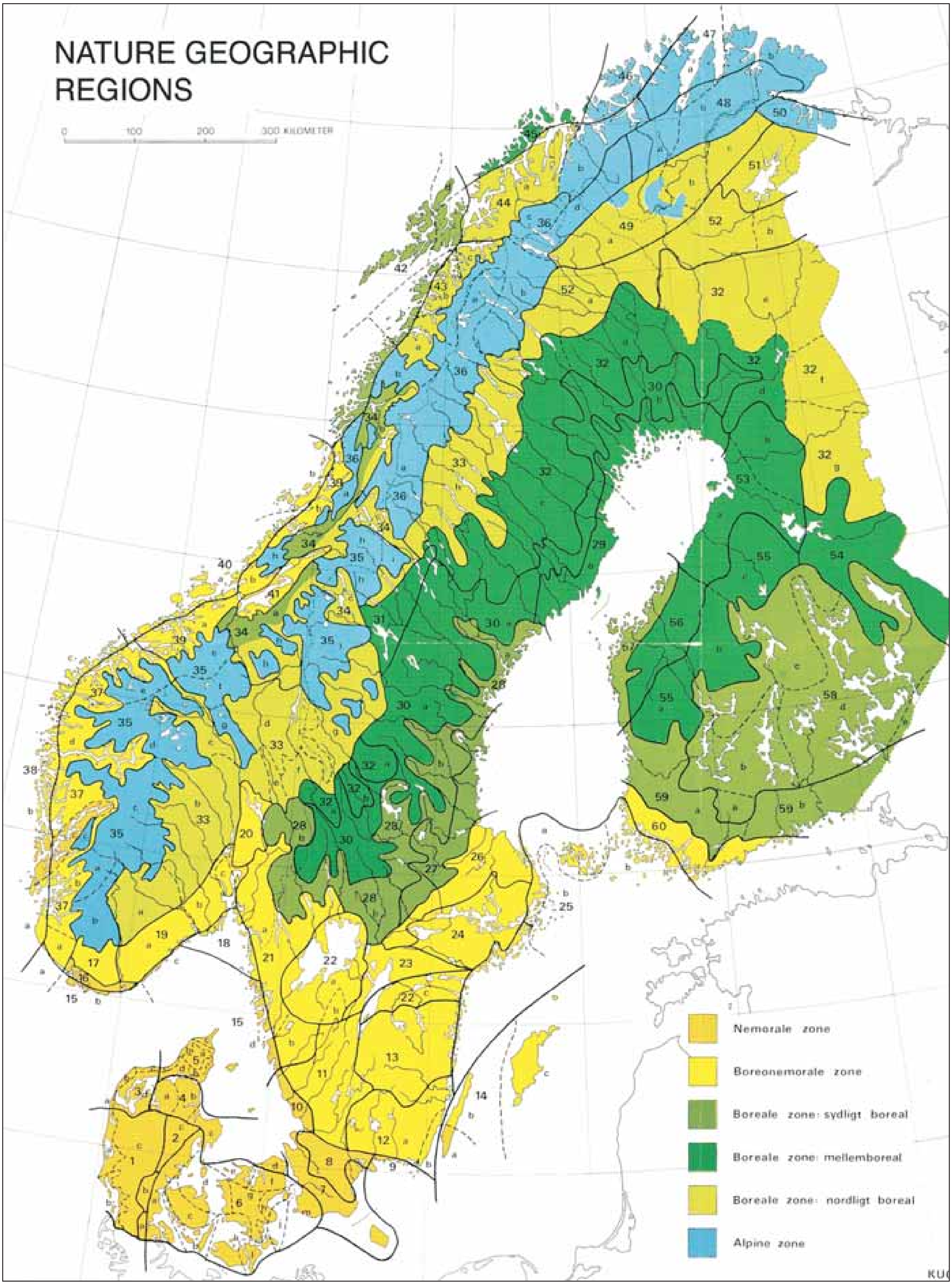


Figure 3.12. Vegetation regions of Norden. Solid lines indicate regions and subregions (See Tab. 3.5) (After Abrahamsen et al. 1977).

Table 3.5. Regional vegetation conditions of Norway and the Nordic countries (After Abrahamsen et al. 1977, Dahl et al. 1986, Larsson et al. 1994), which due to climatic conditions and composition of vegetation, constitute a suitable foundation for identifying potentially different fire regions on a large scale.

The ***Nemoral Region*** or the *Southern Deciduous Region* includes the southernmost areas of South Norway (Sørlandet) with a climax forest of oak, and the area around the Hardanger Fiord. Spruce and gray alder are absent as natural tree species. Summer drought and deciduous oak bushes discourage the establishment of coniferous forest. The region is heavily influenced by human activity and the landscape has been transformed over large areas by burning and other anthropogenic influences associated with agriculture.

The ***Boreonemoral Region*** or the *Southern Coniferous Forest Region* (the Mixed Forest Zone) covers the lowland areas along the coast up to Mid-Norway (Trøndelag) and Nordland county and the valleys east of the divide in South Norway as far as oak occurs. Broadleaved deciduous forest and plant species demanding high temperature are common, but usually coniferous forest dominates. In the eastern and southern parts of South Norway (Østlandet and Sørlandet), pine dominates on sandy soil and other poor sites while spruce dominates on more humid and richer sites. Most deciduous tree species also occur here, but to a lesser extent than in the Nemoral Zone. The Boreonemoral Region is heavily influenced by earlier and contemporary human activity. Data from test plots conducted indicate that it has often burned.

The ***Boreal Region*** or the *Northern Coniferous Region* lies north of the Mixed Forest Zone that is a western fringe of the taiga. Here, various types of spruce and pine forests dominate. The zone is further divided into a Southern Boreal, Middle Boreal and Northern Boreal Subregion. Spot tests conducted indicate that the region has been most prone to forest fires in the south, and that the frequency declines northwards. The importance of human activity varies. In many instances, the extent of anthropogenic fires is undetermined.

The *South Boreal Subregion* (Low Boreal) includes lowland areas and valleys in South and Mid-Norway associated with the distribution of the silver birch. Deciduous forest may occur patch-wise at the richest sites. The Southern Boreal Subregion seems to have been considerably influenced by forest fires.

The *Middle Boreal Subregion* constitutes the “real” coniferous forest that cover large expanses of the hilly landscape east of the divide in South Norway and the valleys northwards. Here, silver birch and broadleaved deciduous trees are absent. Small herb spruce forest and lichen pine forest are gradually replaced by small fern spruce forest and bog whortleberry pine forest. Grey alder may still form stands. The Middle Boreal Subregion seems to be considerably influenced by forest fires.

The *Northern Boreal Subregion* includes thinly spaced coniferous forests at higher elevations, with a large component of birch and the mountain birth forest itself (Subalpine Birch Forest Region). It is characterized by a quite open forest with components of mountain vegetation like mat-grass (*Nardus stricta*) dwarf birch, mountain juniper (*Juniperus communis*) and willow species. Towards the mountains swamp forests gradually become scarce and are replaced by willow bush. The Northern Boreal Subregion is supposed to be the subregion least influenced by forest fires.

The ***Alpine Region*** constitutes treeless mountain areas. The limit of the birch forest constitutes the transition into this region. Here, parts of the field layer species of the coniferous forest continue further upwards towards the mountain as heathland. The Alpine Region is the region that is least affected by fires.

and surface litter, together with surface vegetation constitute important fuel. Which type of soil that is going to be formed is to a large extent dependent upon the underlying geology. From the information below one will see that the soil conditions vary strongly in different parts of Norway. A survey of the loose soil types shows that bare rock dominates in large parts of Norway and adjacent parts of northernmost Sweden (Fig. 3.9). Moraine material in most instances lies directly on the bedrock, and will over large areas constitute the base for carbon containing soil types. Bedrock covered by a thin layer of moraine constitutes a considerable part of the Norwegian area. There are mostly moraine sands in the border areas toward Sweden and parts of Mid-Norway (Fig. 3.9).

A map of the soil conditions of Norden is shown in Figure 3.10. The mountain range of Norway and adjacent regions of Sweden are dominated by a solid rock base where the edaphic development is so poor that the depth of the profile is less than 10 cm. The edaphic conditions after the passing of fires are strongly influenced by terrain slope and soil depth. Steep terrain with little organic soil and high precipitation is, as mentioned, par-

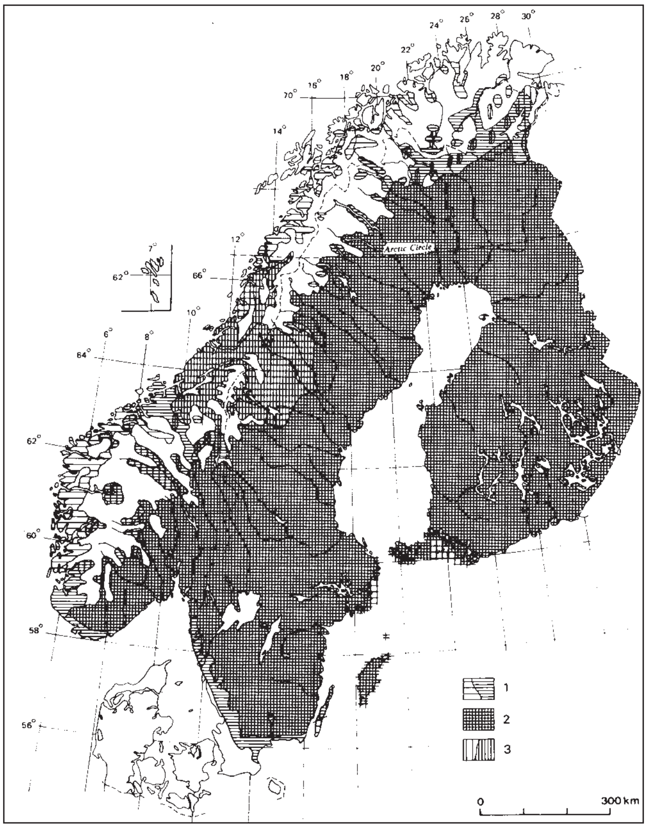


Figure 3.13. Distribution of pine, spruce and mixed coniferous forest in Norden (After Sjørs 1987).

ticularly susceptible to erosion after fires. The large areas with steep slopes, particularly in the coastal areas of Norway, are particularly exposed.

In the forest areas of Norway, Sweden and Finland, the soil is often characterized by *podzols* (Section 3.2.3) that contain a relatively thin organic, and thus relatively inflammable, layer.

In some smaller areas in Norway and Sweden, there are also *peatland* (histozols) with more than 40 cm thick top layers containing 20–30 % organic matter. In Finland, the peatlands dominate over large areas, particularly in the northern half of the country. Especially in such areas, the distribution of glowing fires may become considerable in extremely dry seasons (Section 2.2.4).

In areas with poor soil, the fire severity is of crucial importance in the perspective of productivity. [3.1)]

While the dry types have been most fire prone in a natural fire regime, it is the nutrient rich types on brunisol and forests on well-developed podzol profiles with rich humus resources which have been most prone to anthropogenic burning. What this may have meant for a marginalization of the nutrient rich types is little known (See section 4.1.5).

Effects of forest fire on the organic part of the soil are also of utmost importance concerning impacts on lakes and water systems in the catchment area of the fire (ch. 8). Norwegian hydrology is due to climate and topography very different from the ones in our neighboring countries. Nevertheless, comparative research of what this means for the landscape after larger fires is absent.

3.3 Vegetation regions

As mentioned in the introduction, the primary factor concerning the present distribution, quantity and quality of fuel in the ecosystems is the historic development of the vegetation cover under shifting conditions. There are great differences between the Nordic countries in the distribution of coniferous forests (Fig. 3.11). The total productive forest area constitutes 74 000 km^2 (23 %) of the land area in Norway, 225 180 km^2 (55 %) in Sweden and 200 320 km^2 (59 %) in Finland. The forests in the medium and southern boreal zones are continuously distributed from Finland through Sweden and across the eastern part of South Norway (Østlandet). Along this gradient, the conditions get ever less continental and gradually more oceanic as one proceeds into Norway and approaches the coast.

Therefore, the basis for delimiting regions with possible well-defined fire regimes (Section 2.2.5) in Norway partly depends on the vegetation conditions.

The Nordic Council of Ministers (Norw. “Nordisk Ministerråd”) has on the basis of climatic, biotic and historic conditions divided the Nordic countries into regions with different natural environmental traits (Fig. 3.12).

The Nordic terminology defines a Nemoral, Boreonemoral, Southern, Middle and Northern Boreal and Alpine Zone (Tab. 3.5). The distribution of zones clearly shows the similarities in precipitation, continentality, edaphic conditions etc. which associates Hedmark county and parts of the Norwegian border areas more to the conditions in adjacent areas of Sweden, than for example to the more fragmented forests in the rest of Norway.

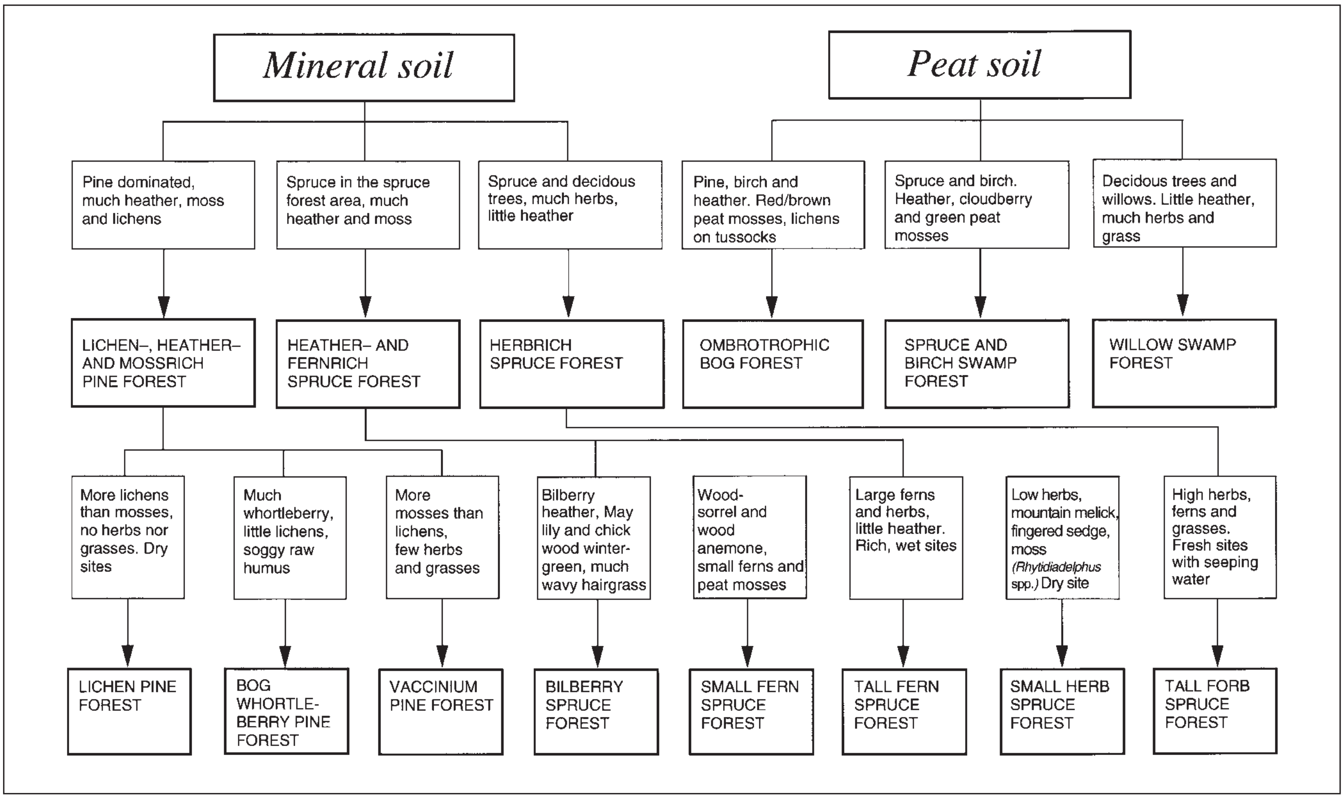


Figure 3.14. Flow chart showing characteristics and distribution of forest types on upland and peatland (After Larsson et al. 1994).

3.4 Forest types and plant communities

The forest of Norway constitutes approximately 120 000 km^2 or 37 % of the land area. Of this, 74 000 km^2, or 23 % of the forested area is productive forest area. The remaining area is deciduous forest above the coniferous forest line and wooded bogs or other wooded sites, so-called impediment, below the coniferous forest line.

Of the productive, manageable forest area, coniferous forest constitutes 52 000 km^2 (70 %) and deciduous forest 19 000 km^2 (25 %), while the remaining 2 900 km^2 (5 %) is newly harvested sites (cutting class I). In Norway, there are only two coniferous tree species, spruce and pine, which are economically important. On a coarse scale, the distribution of these may be used as an indicator of the distribution of the most inflammable fuel (Fig. 3.13).

Plant communities are more closely defined species combinations or vegetation types adapted to particular growth sites (Fremstad & Elven 1987). The different forest plant communities are often called *forest types*. [3.2)] An easy system for evaluating forest fires on a local scale is to connect fire history to divisions of plant communities and forest types.

The forest types have different qualities in regard to forest fires because of, among other things, differences in location (climate), composition of fuel (vegetation profile) and humidity content (hydrology) (Fig. 3.14). It is particularly the presence of coniferous trees that contributes to high inflammability (Fig. 3.13). The driest forest types, Lichen, Heather and Moss Rich Pine forests together with several mixed coniferous types to the left in the diagram (Fig. 3.15), are most easily ignited. Because pine easily survives fires (Bonan & Shugart 1989), it will gradually come to dominate in areas that burn often (See ch. 8). Forest stands and surface litter at dry sites provide drier fuel, and hence, higher risk of ignition and increased spread rate of a new fire. Pine is, however, not dependent of fires to survive. In fire free periods, pine also has a competitive advantage compared to spruce in dry soil with shallow or coarse geological deposits. Thus, in a succession process, pine may prevail independent of fires. The distribution of dry Lichen-Pine-forests is considerable in Norway (Fig. 3.16, pie diagram).

It seems reasonable to predict something about the potential for natural fires in Norway by studying the distribution of such dry forest types. However, such types are more or less distributed as a mosaic along the whole

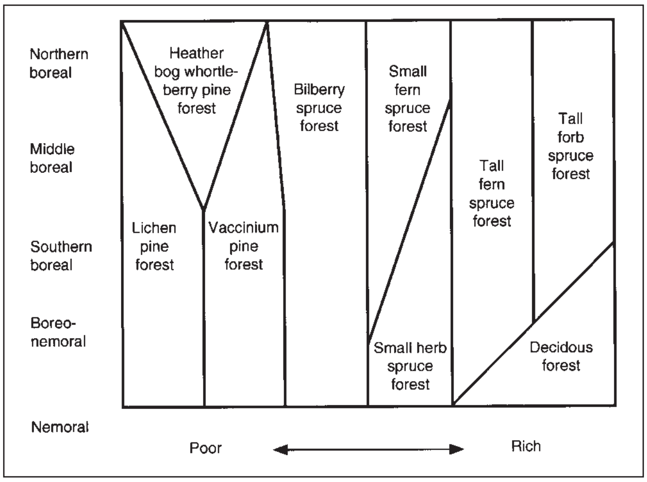


Figure 3.15. The distribution of the vegetation types in relation to elevation and vegetation regions, with a general description of the vegetation types' requirement for climate and demand for nutrient resources (After Larsson et al. 1994).

gradient from the Nemoral Region to the Northern Boreal Subregion (Fig. 3.15).

Because of the considerable fluctuations in topography and macro- and micro-climatological conditions in Norway, large variation in fire frequency will exist even among the dry type sites (ch. 5).

3.4.1 Differential fire frequency

From general considerations, one would expect that Bilberry and Small Fern Forest sites are moister than the previous mentioned sites (Fremstad & Elven 1987), and therefore, generally less fire prone. Least vulnerable are spruce swamp forests at wet sites. It has generally been assumed that these sites rarely or never burn (Zackrisson & Östlund 1991), and that they belong amongst the forest types that have very low fire frequency (Zackrisson 1986, Hörnberg et al. 1992). Another reason for this is that swamp forests as a rule are located in depressions, valley bottoms and other concave terrain structures characterized by high level of ground water and moist conditions (Zackrisson 1986). They are therefore rarely exposed to ignition from lightning strikes.

Surveyed swamp forests in Northern Sweden show long continuity (200 years) compared with forest at medium moist and drier sites with natural fire cycles of 80–120 years (Zackrisson 1977a) and the common rotational age of 70–120 years in modern even aged management (Tryterud 1995). Rare fires in spruce swamp forests will normally not destroy the structural continuity of the forest (Hörnberg et al. 1992).

In the Nordic landscape, pine competes with spruce, which in various types of successions is a climax tree. With a competitive advantage, spruce will replace the pine and gradually dominate on more moist locations where both tree species have good growing conditions.

Thus, spruce could profit from moist conditions that may also reduce the probability for naturally ignited fires (ch. 8), while it loses the competition with pine in areas that burn frequently (See above). It has been documented that the spruce stand in an area of Sweden was excluded because of frequent fires (Bradshaw & Hannon 1992).

There are, however, several conditions that complicate the evaluation of a forest types' relation to fire, based only on consideration of such "natural" conditions. Firstly, studies in both Sweden and Norway have implied that we need to expand our view of the fire history of the spruce swamp forests (Segerström et al. 1994, Hörnberg 1995, Hörnberg et al. 1995, Tryterud 1995). Secondly, it is the spruce dominated forest types that have constituted the most important basis for swidden agriculture (Section 4.1.5) because they are the most nutritious. Swamp forests, even bogs, may also have served as basis for various forms of swidden agriculture (Section 4.1.5). Also concerning a number of forms of anthropogenic burning, one can discuss "fire cycles" and "frequencies". For example, in the modern "huutha" swidden agriculture (Section 4.1.5), it was common first

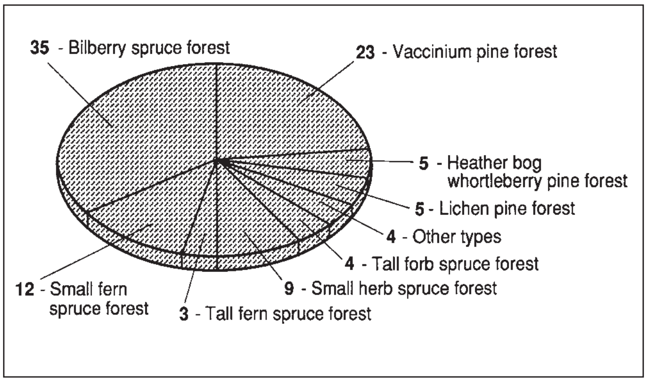


Figure 3.16. Fractions (%) of vegetation types of productive coniferous forest (Finnmark county not included) based on the registrations of the National Forest Survey (Norw. "Landskogtakseringen"). "Other types" are mainly bog, swamp forests and deciduous forests (After Larsson et al. 1994).

to burn and harvest the succeeding crop, and thereafter to return and burn once more after 80–100 years (Tvengsberg 1995b). The vegetation, which constitutes the fertilizer basis, thus needed time through a succession or rotation to develop sufficient fuel for a new fertilization. The crops of such “secondary” burned forest were not as successful as that from burning untouched forest. After the second burning the location was often considered so poor in nutrients that it was judged as unsuitable.

Another scenario occurred when the climate worsened. In cooler and more humid periods when the natural ignition frequency declined, the same factors may have brought about an increase in the anthropogenic burnings. Norway has always had low amounts of soil suitable for agriculture. Periods with crop failure and famine probably lead to increased efforts to increase the production. During earlier periods, this would mean more swidden agriculture and larger burned areas (ch. 4). Tvengsberg (1995b) claims that the huutha burnings were maintained as long as there was spruce forest available to burn.

3.4.2 Swamp forests

In a long-term perspective, some of the contemporary spruce swamp forests of the Northern Boreal Subregion have functioned as fire free refugia after the invasion and settling of spruce (Hörnberg et al. 1995). It is, however, also established that in areas where spruce settled approximately 1 700 year ago, fires have repeatedly suppressed spruce and favored birch. One of the studied spruce swamp forests was actually more disturbed by fire than forest stands on surrounding morainic sites (Segerström et al. 1994, 1995). In research conducted in Sweden by Hörnberg et al. (1995), three out of ten swamp forest stands lacked macroscopic carbon fragments in their soil profiles. Thus, no signs of fire was established in the three stands which were located farthest north/northwest. The age of the surveyed stands varied from approximately 1 800 years to approximately 3 600 years. This may of course be related to lower frequency of lightning strikes in this region (Zackrisson & Östlund 1991, Granström 1993). It could, however, also be caused by less intense anthropogenic activities in the northernmost part of the forest areas due to marginal conditions for conducting swidden agriculture.

Recently, Tryterud (1995) presented a hypothesis that through its removal of vegetation and considerable hydrologic impact on the local flow of water, forest fires may actually be the factor which determined the development of a spruce swamp forest examined at Nordmarka north of Oslo (See section 5.4.2). He also established a long continuity without fire disturbances in this swamp forest stand, where climate and an inner dynamic were assumed to have been the most important developmental factors after the stand settled.

3.4.3 Fire refuges and continuity areas

It has long been assumed that species that are judged to have great demands for continuity in tree layer and dead wood would invade areas that are rarely affected by catastrophies (Zackrisson & Östlund 1991). This may be true in general, but the first long-term fire historic research in Norway indicates that coniferous forest having continuity characteristics do not show tendencies of having been burned more infrequently than other spruce forest sites (Håkonsen 1996).

Important questions regarding a stand’s history are therefore connected to how “the continuity species” disperse and settle during present landscape ecological conditions. A possibility is that indicator species linked to continuity areas may have had possibilities to invade from nearby areas that were cut later on (Segerström 1992, Håkonsen 1996). A reason that some areas have developed continuity characteristics and others have not, may also be that surrounding areas in addition to extensive cutting may have been influenced by other disturbances like windfellings, fungi and insect attacks (Patterson & Backman 1988, Engelmark et al. 1993, Håkonsen 1996).

Another possibility is that the high diversity, which for example can be seen in old swamp forests, may be due to variation of microhabitats in such stands, rather than to long continuity (Ohlson 1990, Håkonsen 1996). At this stage, it seems clear that spruce dominated forest types may develop a character of “primeavel forest” structure far quicker than earlier assumed. More specifically, it is the conditions and prospective encroachments during the last 300 years, i.e. the last rotations, which are responsible for this.

Developmentally, swamp forests, when they have first settled, may also be maintained by a “dynamic stability” which encompasses continuous regeneration and death of individuals (Tryterud 1995). This would mean a continuous process where an internal dynamics of small-

scale disturbances (local stand factors) determine the structure through the falling over of single trees making the development of younger and suppressed trees possible. The Norwegian material is very limited (Section 5.4), but it has clearly proved the need for forest history surveys to demonstrate the development in certain areas. There is a need to examine the whole series of Norwegian forest types (Fig. 3.15) with respect to fire history conditions (See ch. 5).

3.5 Summary

Climatic and natural geographic conditions are important in the framing of a country's fire regime. The natural fire regime is determined by lightning strikes as sources of ignition and the prevailing climatic variations at any given time, in interaction with parameters such as topography, elevation factors, as well as the substrata and the vegetation that constitutes the fuel. It is well known that the natural fire regime follows the climate and that lightning strikes will more easily cause ignition in drier periods, thereby resulting in a higher fire frequency.

The immigration of vegetation, and the conditions during the paleoecological climate periods after the last Ice Age, have clearly imposed considerable variation on the natural part of the fire regime. An overview of these periods is provided in Table 3.1.

The frequency of fires started by lightning has probably been influenced by both long-term regional climate changes, as well as shorter, dry weather periods with many thunderstorms.

It is, however, difficult to acquire reliable knowledge concerning the natural part of the fire regime because of potential influence from anthropogenic ignition sources.

It is easier for people to start fires during the same dry periods when natural fires occur; however, anthropogenic burning can also follow quite different patterns (see ch. 4). Cold periods with significant precipitation may, for example, cause crop failure, bad years and food shortages. This can lead to more swidden cultivation and burning of outlying fields.

The broad outlines of climate development after the last Ice Age have followed a "wavelike" pattern, where approximately the first 2 000 years after the withdrawal of the ice were characterized by increasing warmth. During an intermediate period of about 4–500 years, there was a warm, favorable growth climate followed by approximately 3 500 years of declining warmth, increased moisture and longer winters. Over the last 1 000 years, the average annual temperature has not varied by more than 1 ˚C. We have had a relatively cool period over the last 125 years up until 1930, followed by a relatively warm period.

What characterizes Norway is easily apparent when you compare the natural Norwegian geographical and regional conditions with those of Sweden and Finland. The countries are quite different, and the natural geographical form of Fennoscandia, with its substantial differences in climate, indicate that fires resulting from natural sources of ignition have had a quite different influence and significance in these three countries. The climate in Norway in its entirety falls within the cold (boreal) climate zone, but the climate changes a lot. Two main types within this climate are the so-called coastal climate (oceanic or maritime) and the inland climate (continental). Langfjella forms the most marked division between these two climate types in Norway. An overview is provided showing the most important features of temperature, precipitation and humidity conditions in the various parts of the country. The climate type for large areas in Norway must be characterized as both cool and damp. In Norway, the continental Hedmark particularly distinguishes itself. Here, climatic and natural geographical conditions have so many similarities with adjacent Swedish areas that the fire regime must be expected to be fairly similar to the Swedish areas near the border.

Landscape features such as topography and elevation may also have crucial significance for the course of fires. Both elevation, steepness, and the form and evenness of the terrain can affect fires. Hillsides and convex landscape formations are particularly vulnerable to fires, while concave hollows and bogs can form fire barriers. Macro- and micro-topographical variation generally have far greater significance in Norway, which has a much greater portion of forests in steep, uneven and difficult terrain than both Sweden and Finland. Terrain conditions in our country become steeper and more varied in terms of topography as you move farther to the west. The inland portions of Southern Norway represent the most extensive high elevation area in all of Scandinavia. About 30 % of Norway's mountains are bedrock formed during the Earth's earliest history. Covering the rocks in Norway we find moraine soil and sedimentary soil as the dominant

features. Together with field vegetation, the soil material, particularly the layering of humus and litter, constitute important fuel. Mountains with thin moraine coverings make up a significant part of the Norwegian area compared with Sweden and Finland. Soil development is often so poor that the profile depth is less than 10 cm. The broad outlines in climatic, biotic and historic conditions are reflected in the vegetation regions (Fig. 3.12). Therefore, they are an appropriate basis for describing the zoning of the fuel on the macro scale. A suitable system for evaluating forest fires on a local scale is to link the fire history to classifications of forest types and plant communities. Forest fires have contributed to the shaping of these types, which have completely different qualities both vis-à-vis naturally ignited and anthropogenic ignited forest fires. The driest types, pine forests rich in lichen, heather and moss are most easily ignited by lightning strikes while the more damp and characteristic spruce types are more difficult to ignite. Nevertheless, the distinction between what can be attributed to natural and anthropogenic forest fires respectively, is difficult. The characteristic spruce and most nutrient-rich forest types have constituted the most important basis for cultural activities such as swidden cultivation. Therefore, as we have already mentioned, an overview of the fire regime also requires an extensive overview and knowledge of the anthropogenic burning in this country. Comprehensive studies of all of the forest types in Norway are necessary in order to chart fire dynamics and historical factors. Important landscape ecology factors will also be revealed through a survey of fire refuges and self-perpetuating forests that burn little or not at all.

Norway, with its cool and wet climate and enormous topographic variations, must also be expected to have areas that have never burned (see ch. 5).

4 ANTHROPOGENIC BURNING AND IMPACT

By Ivar Mysterud

Anthropogenic fires mean forest fires ignited by humans. In this technical report we emphasize the conditions and activities linked to anthropogenic burning in forests, both the various types of burning, which directly contribute to accumulation of carbon in the soil, and the manipulation of fuel. An understanding of the extent and use of fire and its impact on forests is closely linked to the colonization of the country and its demographic, economic and political history.

Therefore, it is necessary to recapitulate certain elements of Norwegian history to gain a perspective on anthropogenic burning; we also comment on a few Swedish and Finnish conditions. To survey and specify this part of the Norwegian fire regime, it is necessary to summarize the extensive research on forest history that was recently initiated in Norway.

4.1 Processes of anthropogenic change

It is presumed that the aborigines (Norw. "urbefolkningene") were the most important source of ignition of range fires in the circumboreal area after the ice sheet retreated and the forest invaded (Stewart 1956, A. Smith 1970, 1981, Jakobi et al. 1976, Mellars 1976, K. Tolonen 1983). [4.1)]

Traits from burning practices of prehistoric aborigines are mapped through studies of carbon remnants and culturally determined pollen in soil profiles in many countries including Northern Europe (Dimbelby 1961, 1962, Berglund 1969, 1991, Simmons 1969, A. Smith 1970, Iversen 1973, Asheim 1978, Göransson 1977, 1995, M. Tolonen 1978, 1987, K. Tolonen 1983, Dodson & Bradshaw 1987, Clark et al. 1989, Berli et al. 1994, Larsson 1995, Tinner & Amman 1996).

Some of the burning activities had universal characteristics, for example the use of fire in connection with cooking of food, hunting, fishing and travelling. Increased human traffic led to increased fire burning, which again increased the risk of negligent ignition of forest and range fires. Other burning types were linked to certain activities that supplied large amounts of carbon to forest soils. A number of indirect impacts of the fire regime are linked to range businesses; this led to an extensive harvest of wood and thus to local and regional changes in the amount and configuration of fuel. There is an extensive literature about the cultural history of several of these activities (Sandmo 1951, Tenow 1974, Liljewall 1996).

4.1.1 Historic epochs

In the survey of the anthropogenic part of the fire history through the last 12 000 years we have used Norwegian historic chronology to characterize the time epochs (Fig. 4.1, Tab. 4.1).

The postglacial period of approximately 10 000 years may be roughly divided into two equally large parts. From what is known, the first period was characterized by a use of landscape linked to hunting, fishing, and gathering (Berglund 1970). The other period was characterized by cultures with a mixed economy using various combinations of pasturing, agriculture and some horticulture; cultural forms that may be characterized as *fire cultures*. The use of fire in various forms was such a self-evident prerequisite for cultural development, expansion and settlement, that it was rarely mentioned in general historic accounts.

Historically, agriculture reached Middle Europe around 4 000 B.C., and Scandinavia approximately 1 000 years later (Stenberger 1969). The colonization of the land areas took place in so-called "settlement waves" (Norw. "landnåm"). [4.2)] These were periods where the development was of an expansive character concerning the occupation and use of new areas (Berglund 1969). Clearing land and settlement led to periodic burning of forests across areas where light demanding species, like oak and particularly ash, became more common (Iversen 1973). For a long time swidden agriculture was the only possible basis for agricultural production. These pastoral cultures burned the forest to open the landscape, to found settlements, and to create pastures and new grazing opportuni-

ties. Pasture burning, i.e. burning to create and renew pastures, spread slowly across heathlands, forests, bogs, natural meadows and to many outlying ranges as the human population increased (Section 4.2.6).

The mixed agricultural practice of the central-European type that became common later on, was impossible in the absence of sufficient amounts of manure from domestic animals (Asheim 1978). Ash, the earliest form for “manure”, came from the burning of forests. *The absence* of frequent natural fires in Norwegian ecosystems created large amounts of fuel and made possible extensive anthropogenic burnings (kap. 5).

Under Norwegian conditions the growth season is short, the possibility for burning *less* than in continental areas and the capacity to change the landscape limited by the dynamics of weather conditions and the availability of fuel. As areas suited for agriculture were limited, one had to provide the animals over large areas with forage from outlying areas.

During this long colonization period there were periods with war and times of social unrest where tactical use of fire also is documented (Section 4.2.2).

The indirect impact through manipulation of the fuel may be indicated by steadily more extensive encroachment in the forest ecosystems. We know that various types of forestry and wood harvest influences the ignition frequency through changes in distribution, composition and configuration of fuel. A dense, closed forest vegetation will, for example, reduce the wind speed and maintain high moisture at the surface for some time even after a period with warm and dry weather conditions in the region. Forests where cuttings and/or extensive grazing were conducted dry out more quickly than older and intact primary stands (Uhl & Kauffmann 1990).

After industrialization there was a period of aggressive suppression of forest and range fires as forests became of greater value. This suppression has been the major influence on today’s fire regime. In recent years a broader ecological understanding has led to changes in the view of forest fires; at the end of the 20th century there has developed a new type of conservation fires (Section 9.2.4).

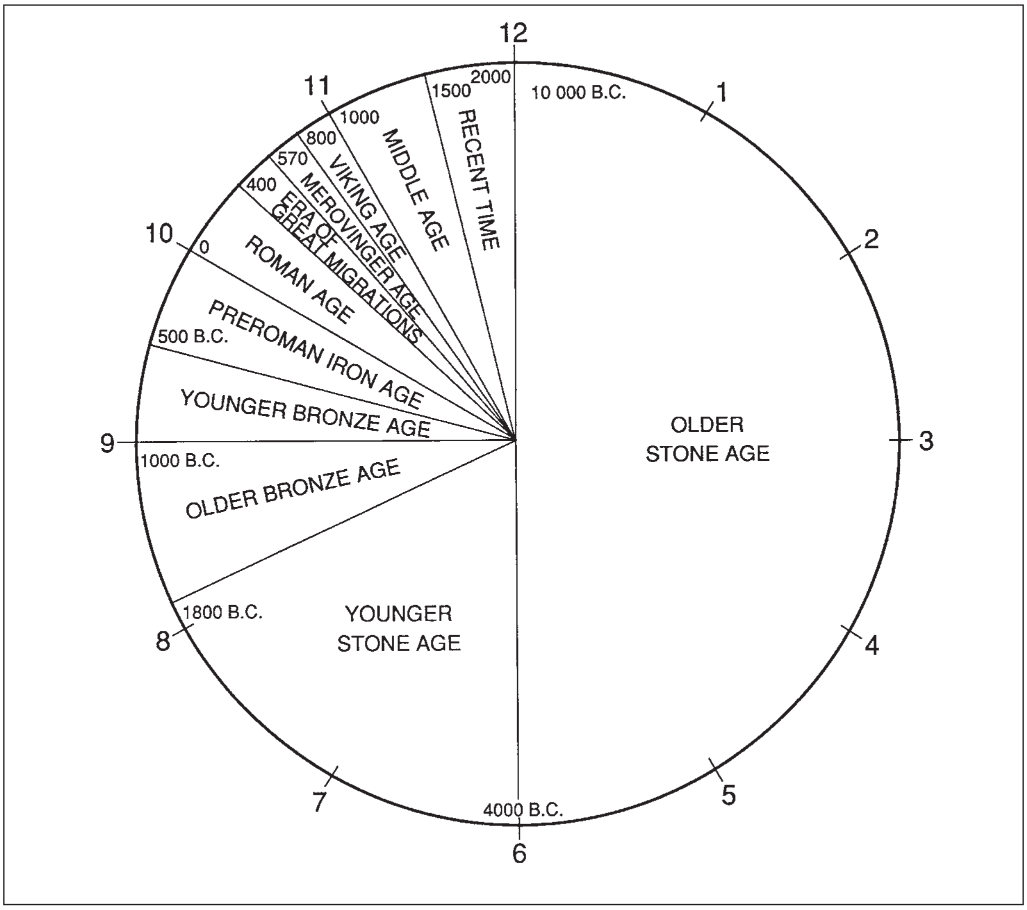


Figure 4.1. Pie diagram showing the chronology and relative length of the cultural periods in prehistoric and historic times in Norway during the last 12 000 years (After Hagen et al. 1980).

4.1.2 Increase of anthropogenic ignition sources

An important condition in the anthropogenic fire regime is linked to population development and the steady increase in human use of forests and outlying areas. Today’s rural population reflects the colonization of the Nordic forest by immigrating peasants (Fig. 4.2). Even though parts of these areas are still sparsely populated, the human travel and traffic has increased in the whole area.

Cities also increased both in population size and distribution (Fig. 4.3). This led to high travel and traffic and increased fre-

Table 4.1. Chronological overview of the cultural periods in prehistoric and historic times in Norway synchronized with the climatic periods in the same time intervals (After Hagen et al. 1980).

	CLIMATE PERIOD	CULTURAL EPOCH
Ca.16 000 B.C.	OLDEST DRYAS	
Ca.11 000 B.C.	BØLLING PERIOD	
Ca.10 000 B.C.	OLDER DRYAS	OLDER STONE AGE
	ALLERØD PERIOD	
Ca. 9 000 B.C.	YOUNGER DRYAS	
Ca. 8 000 B.C.	PREBOREAL TIME	
Ca. 7 000 B.C.	BOREAL TIME	
Ca. 6 000 B.C.	ATLANTIC TIME	
Ca. 4 000 B.C.		

CLIMATE PERIOD	CULTURAL EPOCH			
SUB-BOREAL TIME	YOUNGER STONE AGE		OLDER PART	Ca. 4 000 B.C.
			MIDDLE PART	Ca. 2 800 B.C.
			LAST PART	Ca. 2 400 B.C.
	BRONZE AGE		OLDER BRONZE AGE	Ca. 1 800 B.C.
			YOUNGER BRONZE AGE	Ca. 1 000 B.C.
SUB-ATLANTIC TIME	IRON AGE	OLDER	PREROMAN IRON AGE	Ca. 500 B.C.
			ROMAN IRON AGE	C.
			ERA OF GREAT MIGRATIONS	Ca. 400
		YOUNGER	MEROVINGER AGE	Ca. 570
			VIKING AGE	Ca. 800
	HISTORIC TIME		MIDDLE AGE	Ca. 1 050
			RECENT TIME	Ca. 1 536
				1 814
				Recent

quency of anthropogenic ignition sources in and around such sites. This trend is reflected on all continents in connection with increased activities generally and recreational activities particularly. This is an important element in the contemporary Nordic fire regime. Better communications has slowly facilitated the spread of such traffic in Norway to nearly all outlying areas. Today the main characteristics of the Norwegian fire regime are dominated by these types of anthropogenic ignition sources (See ch. 6). The population pattern also is an important part of the explanation of why the activities and the fire frequency have been highest in the south.

4.2 Types of anthropogenic burning

There is no thorough and uniform terminology connected with the various burning types and fire cultures in the Nordic countries (Larsson 1995). [4.3)] Burnings may be categorized and termed based on *what* burns, by *the objective* of the burnings, or *how* the burning is undertaken (Myrdal 1995). Examples of these three are “heather burning” (common on the large heathlands along the coast), burning to clear land, clearing burning (to clear arable land), or “huutha” (a particular form of swidden agriculture, see Section 4.2.5), respectively. In this technical report we chose to categorize and name the types of anthropogenic burning based on their objective (Tab. 4.2); this seems to be most pedagogical in anticipation of a more explicit terminology (See Myrdal 1995). The burning types and relevant activities are described, ordered chronologically in Table 4.2.

Figure 4.2. The distribution of rural populations in Norway, Sweden and Finland in 1970. 1=1 000 inhabitants, 2= ≦1 inhabitant, per 1 km^2 (After Myklebost 1987).

4.2.1 Burning by hunters and gatherers

Throughout prehistoric times hunting, trapping, fishing and gathering (berries, mushrooms, roots etc.) constituted the subsistence base, followed later by agriculture and trade (Hagen et al. 1980). The use of fire was used

concomitantly as part of the development. The motives for conscious burning in prehistoric time are discussed by several researchers who think that systematic burning strategies were used by prehistoric hunters and gatherers (See Mellars 1976). One Norwegian researcher has proposed the radical hypothesis that the first humans who immigrated, brought with them a primitive form of swidden agriculture, and that there was never a post-glacial culture in Norway based only on hunting and gathering (Tvengsberg 1995b).

Humans have probably known and used fire for more than a million years, and increasing documentation from various continents shows that fire, along with the axe, may have been the oldest and most important technology. Aborigines seem to have had considerable insight into ecological processes and how fires could be used actively to open the landscape and improve its production ability, for example for valuable game species, long before the time of husbandry. [4.4)]

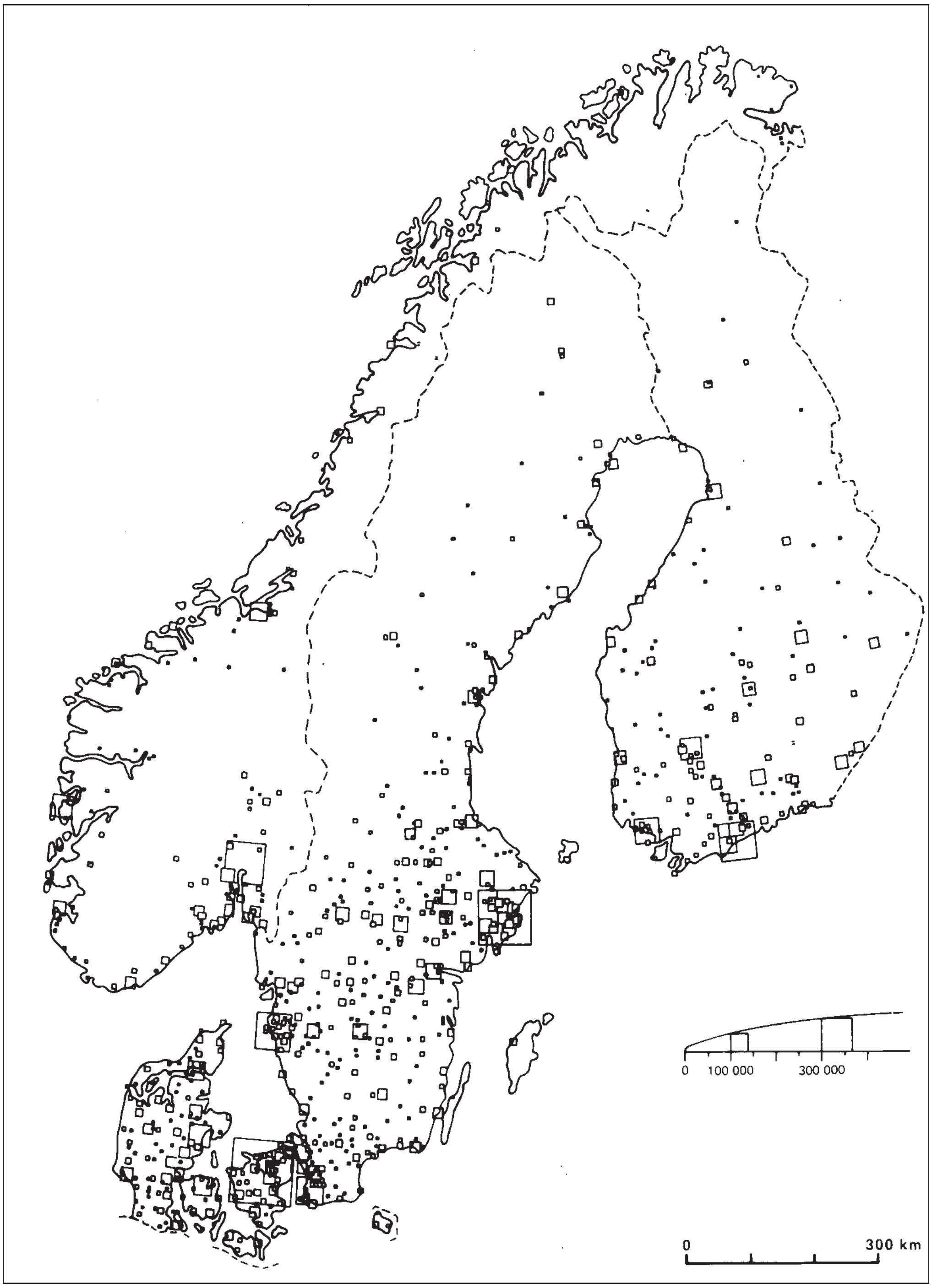


Figure 4.3. Distribution of urban populations in Norway, Sweden and Finland in 1970 (After Myklebost 1987).

It seems evident that hunting people routinely made campfires in outlying areas and that they accidentally or on purpose ignited fires that burned large areas.

Use of fire and also smoke from fires was used in various ways in boreal areas in connection with hunting. [4.5)]

It also was possible to burn to stimulate flowering and production of certain species of forest berries and herbs (See Høeg 1976). From Finland it is also known that people burned to produce mushrooms (Pyne 1996). Today, systematic studies of prescribed fires under various conditions may be used to study the situations that may have been present historically.

In Eurasia boreal forests were burned to open travel corridors and trail systems; this made for easier access through the landscape (Pyne 1996). However, nothing is known about how old or how widely distributed such practices were. However, it was common practice among

Table 4.2. Keywords for important types of burning and other impacts of the anthropogenic fire regime in Norway (See text).

ANTHROPOGENIC BURNING TYPES

- Burning by cultures of hunters and gatherers
  - Game production?
  - Berry production?
  - Mushroom production?
- Tactical burning
  - Warfare
  - Trade competition
  - Revenge actions
- Prophylactic burning
  - Plague abatement?
- Burning to clear land
- Swidden agriculture
- Pasture burning
- Other agricultural burning
  - Shoot forestry burning (Norw. “skuddskogsbrenning”)
  - Burning to clean pastures
- Forestry burning
  - Clear-cut burning
  - Patch burning
- Game management burning
  - Game production
- Nature conservation burning
  - Diversity burning

ANTHROPOGENIC IMPACT OF FUEL

- Tree coal burning and mining
- Salt boiling
- Potash burning
- Tar burning
- Wood harvest for fuel and home purposes etc.
- Commercial forestry
  - Timber and sawmilling
  - Pulp wood and pulp mills

ANTHROPOGENIC REDUCTION OF FIRES

- Suppression of fires
  - Forest fire insurance

white pioneers in Alaska into the 20th century to burn the forest along travel corridors to stimulate grass vegetation around campsites as forage for horses, to create standing dead trees (“snags”) for firewood and to fight mosquitoes and flies (Kirchhoff 1993).

However there is no archaeological information that documents the use of fire by the first immigrants onto the Norwegian landscape.

4.2.2 Tactical burning

Tactical burning is arson and use of fire during warfare and competition for resources, and in revenge actions.

Tactical burning in war and times of social unrest is well known from many areas in Europe (cf. “the burnt soil tactics”). Fires might be started as part of war actions themselves or indirectly through use of fire weapons. Known fire weapons were fire sledges, fire ships, fire arrows and even “fire bombs” thrown by catapults. Forest areas and wooden buildings were particularly vulnerable for tactical ignition. Blackmail was often initiated by so-called “fire tax”, money paid by people under the threat of arson (Pyne 1996).

Trade wars and conflicts

Use of tactical fires in Norway was used in times of peace, in the competition for the timber market during the Late Middle Age. Urbanization, ship building and the deforestation in Western Europe in the so-called “Hanseatic Period” of the Late Middle Age created an ever larger need for timber in many countries, among them the Netherlands, England, France and Portugal. In two separate periods members of the Hanseatic League set fires to forest and used them as a trade-political weapon; the activity was extensive (Sandmo 1951). [4.6)] Members of the Hanseatic League evidently judged the Norwegians to be future competitors at sea, and consciously destroyed forests which constituted the timber basis for ship building (Sandmo 1951).

Also swidden agriculturists from Finland, which immigrated into Eastern Norway from the 1620s and beyond (Fladby 1977, Tvengsberg 1995a,b), made use of tactical burning.

Swidden agriculture was an agricultural technique that entailed high risk of ignition of forest by negligence (See section 2.4.5). In the southeastern part of Norway (Østlandet) political conflicts developed between permanent residents and other legitimate peasants and Finnish swidden agriculturists in this period (Østberg 1978). In the conflicts that periodically took place in southeast Norway (Østlandet), forest fires were occasionally set tactically.

> "It was insecure times in the Finn forest areas (Norw. "Finnskogene") at that time. To set themselves free the Finns ignited the forests, which became the victim of the flames. Almost the whole of the Finn forest area were devastated, burned and deserted ..."
> (Translated from Lindtorp 1943, p. 159).

It is reported from Sweden that swidden agriculture was one of several sources of conflicts between peasants who colonized the forest areas in Pite Lappmark and the Samii population (Tenow 1974). Swidden agricultural practice and accompanying forest fires impacted and destroyed the reindeer grazing plants (lichens) that constituted the resource base of the nomadic Samii. Intended forest fires in these areas were applied as weapon against the Samii people (Tirén 1937, Bylund 1956).

Along the coast of Nordland county there are old accounts about islands covered by large forests that were burned. Even though the causes were evidently many, we also found examples of tactical burning. [4.7] On one island ("Roløen") primarily densely forested to the coast line, a forest fire was deliberately raised by a "Finn" as pure revenge (Skogdirektøren 1909).

It was common that "forest Finns" (Norw. "skovfinner") and nomadic reindeer herders (Norw. "flytlapper"), often were blamed for having raised forest fires. [4.8] In one instance it was observed that peasants actively raked out remnants from a campfire at a site which the Samii had left (Skogdirektøren 1909). Thus the hearth for such fires could later be "traced" to the reindeer herders' campfire and the "question of guilt" would be easy to settle.

4.2.3 Prophylactic burning

The response to the outbreak and spread of plague according to Pyne (1996) resulted in what is called "prophylactic burning". This was not only used to burn infected houses, but whole regional societies (Pyne 1996). In the latter instances outlying areas may also have been influenced. It is not known if such burnings were practiced in Norway, for example during the Black Death. [4.9]

4.2.4 Burning to clear land

Burning to clear land (clearance burning) can be defined as all burning linked with the preparation and development of home fields and particular agricultural areas in connection with building of farms and settlements. [4.10] Such burning is one of the largest and most extensive elements of anthropogenic burning.

Clearance burning evidently varied in prehistoric time, and was linked to population development and cultural progress; such burnings were made with existing technology, organization and knowledge. However, all stratigraphic indications of anthropogenic burning before the large colonization waves are disputed (K. Tolonen 1983).

The first people in Norway for which fire has been documented being used to undertake extensive changes of vegetation communities were the first colonists who practiced agriculture. [4.11]

The extent of such burnings is sparsely known. However, the historic epochs of current interest will be discussed. It will be up to archaeologists to fill the void about such fires. [4.12]

Older Stone Age

Humans may have lived in Norway between 11 000 and 10 000 B.C. (the Bølling period), but we do not have definitive evidence of the presence of people in Norway before the ice had retreated. During the Older Stone Age (Boreal Time), approximately 7 000–6 000 B.C., the whole coastal area was inhabited. [4.13] Settlement around 4 000 B.C. varied, with open dwellings and caves and rock slabs in use at the same time. The extent of possible burnings made by these humans is not known.

However, stratigraphic profiles taken from early postglacial time from old lakes in South Sweden (Nilsson 1967) established a considerable amount of macroscopic and microscopic wood carbon from Mesolithic cultures from early Boreal until early Atlantic time (See Tolonen 1983). Carbon remnants were found in distinct peaks in various cultural horizons. These findings indicate that burning to clear land was undertaken at these times. [4.14]

Younger Stone Age

Some historians think that the impact of the cultures on the vegetation in the first part of the Younger Stone Age (4 000–1 800 B.C.) was modest (Magnus & Myhre 1976). However, agriculture became a dominant business in South Norway during the last part of the Younger Stone Age (late Neolithic time, approximately 2 400–1 800 B.C.) and the beginning of the Bronze Age. As a consequence of herding and tillage or grain cropping

this resulted in changes and led to extensive burnings. According to Tenow (1974) swidden agriculture (See section 4.2.5) was well established in Scandinavia at that time even though herding still dominated in some areas. Both at the southeastern (Østlandet) and southwestern (Vestlandet) part of Norway the oak mixed forest declined significantly during this extensive settlement wave in inner areas. Small communities that existed inland were now considerably expanded (Magnus & Myhre 1976). That these first Neolithic peasants used burning to clear land is well documented through paleoecological research in our neighboring countries, among others in Denmark (Iversen 1973).

During the Younger Stone Age the inland of South Norway also became settled. In the last part of this period it appears that people along the coast moved inland to parts of the landscape that had better conditions for agriculture. In North Norway the settlement spread from the coast and inland along the large rivers Alta, Tana and Pasvikelva (Hagen et al. 1980).

Bronze Age

During the Bronze Age, approximately 1 800–500 B.C., there was likely more stable settlement in South Norway early in the period. However, there are no signs of permanent farms with permanent fields until the Iron Age. The predominant tillage technique at that time probably made it necessary to establish new fields after a short time. People were not aware of any kind of specific fertilization such as animal manure, and the nutrients in the soil were quickly depleted. In South Norway and along the coast tillage and/or husbandry slowly became important industries in addition to hunting and fishing (Magnus & Myhre 1976). During this period in early Bronze Age forests in some areas of Europe that had burned earlier, were burned once more. This resulted in forests in many areas degenerating into heath vegetation (Tolonen 1983). The development of coastal heathlands across large areas in Norway is reported in section 4.2.6.

Era of Great Migration and Merovinger Age

Not until the year 300 B.C. to present do we find evidence of real farms in Norway. During this period individual farms or composite farms (Norw. “sammensatte gårder”) became common in large parts of the country. Farms were probably made by means of clearance burning in connection with a shift to agriculture associated with the development of home fields.

During the Merovinger Age, i.e. in the first part of the Younger Iron Age, from approximately 570–800 A.D., the settlement south and west in Norway shrank. Farms were abandoned and the settlement also in caves and rock slabs came to an end. The decline may partly be explained by previous population increase and land clearing resulting in an overharvesting of the resources that resulted in small crops, famine and decline in population size. To the extent that one was dependent upon swidden agriculture (Section 4.2.5) at that time, increased burning to increase the crops was likely during such periods.

Stratigraphic evidence does not seem to exist from Norway that can be evaluated more closely. However, in an area in Finland local fires increased as a result of swidden agriculture also during the Iron Age; this form of agriculture evidently still dominated the economic activity (Tolonen 1983). In Sweden spruce could not spread effectively before the forest was opened by clearance burnings (Göransson 1977). The beginning of the dispersal of spruce presumably began after burnings as far back as approximately 2 500–2 000 B.C. (Göransson 1977).

Viking Age

After the reduction in the settlement south and west in Norway during the 7th century, a new expansion wave occurred in the 8th century; this expansion reached its peak in the Viking Age. Contrary to the large fluctuations in the settlement pattern in the southern and western parts of South Norway (Sørlandet and Vestlandet), a firm definitive expansion of the settlement areas occurred in the eastern part of South Norway (Østlandet), in Trøndelag and in North Norway all through the Merovinger Age. New farms were steadily cleared, and the population size increased (Hagen et al. 1980).

Older Iron Age was a time of agricultural expansion. Steadily larger areas of fields and meadows were cleared, and the forest retracted considerably. Not until early Viking Age did the swidden agriculture begin to be outcompeted by tillage and grain cropping (Tvengsberg 1995b). All over the country the settlement was most dense in the best agricultural areas. During the whole Iron Age farming became intensified, and more manure was used increasingly from domestic animals on the homefields.

In the Merovinger Age and the Viking Age (younger Iron Age) it is thought that mountain and forest (sum-

mer) dairy farming was initiated where the conditions were suitable (Hagen et al. 1980); this may have intensified pasture burning (See section 4.2.6). The Viking Age appears as the largest and most important prehistoric expansion period in the whole of the Nordic countries. At the end of the Viking Age the farm and rural landscape emerged in parts of this area where it may be studied on land register (Norw. "landmatrikkel") maps from the 17th and 18th centuries (Stenberger 1969, Berglund 1970, Tenow 1974). Anthropogenic burnings that followed in the wake of this development were supposedly extensive.

Middle Age

Seen together, the Viking Age, early Christian Middle Age and the high Middle Age in Norway was an expansion period both concerning population, economy and politics, and pioneer clearing by means of burning became more extensive. In parallel with the growth in population size, inland settlements expanded. New farms were cleared, even in marginal areas. There was not any reduction in settlements of larger extent until the Black Death (Hagen et al. 1980).

Tillage and grain cropping, i.e. agriculture on permanent fields, was most important in the flat rural areas in the eastern part of South Norway (Østlandet) and in Mid-Norway (Trøndelag). Seen together the growing of grain was the most important part of agriculture until the 14th century, and agriculture was the most important industry throughout the Middle Age. However, as late as the 16th century a new type of eastern swidden agriculture was introduced by Finnish immigration; these settlers (See section 4.2.5) burned large forested areas in the eastern part of South Norway (Østlandet) up until modern time.

Recent time

From more recent times (after the year 1500, fig. 4.1) written sources exist in which colonization may be studied in more detail. Some of these descriptions make it possible to survey the considerable dimensions that anthropogenic burning has had in the Norwegian landscape.

Farmers who wished to become permanent residents, had to open up previously forested areas (Section 4.2.4). Fires that opened the landscape, were often the precondition for colonizing new areas to establish new farms and develop suitable pasturage for husbandry animals. Susendalen in Nordland county exemplifies this (Skogdirektøren 1909). Susendalen was, after unsuccessful attempts in the preceding years, not colonized until after a large forest fire had burnt through the area.

> "Not until a terrible forest fire had cleared and burnt through the large spruce forests, the valley was covered with luxuriant grass growth, which tempted some farmers, mostly from Meraker, to settle there. Their example tempted others, some from even as far away as Gausdal. Already in 1856 30 farms were cleared." (Translated from Skogdirektøren 1909, p. 189).

In Vefsn and side valleys in Nordland county the more recent fire history from the previous century is partly known. For example Hattfjelldalen more than any other area was ravaged by fires that influenced large streches of forest (Skogdirektøren 1909). In the previous century, the land properties in Hattfjelldal and Vefsn belonged to large landowners from which farmers and settlers leased their farms. At that time forests were still of low economic value, and people were generally not careful with the use of fire. A farmer who complained to the landowner that the forest was dense and that he lacked pasturage to his husbandry animals, was simply advised that he could "just burn the forest" (Skogdirektøren 1909).

In sum, these areas of Nordland county were burned extensively by farmers who settled there permanently. In 1830 the forests in local areas (Pantdalsli, Kampli, Mikkeljord and Ørjedalsskogen) burned; in size and extent the largest of all known forest fires in Hattfjelldalen. In 1831 and 1832 again considerable stretches of forest burned. These last fires were caused by a farmer who used swidden agriculture to produce turnip. In 1953 another large "fire summer" occurred in these areas. Even though the making of fires in Norway was strictly forbidden by a decree of 12 May 1683 (Skogdirektøren 1909), it appears clearly that these regulations were not strictly enforced in this area. This may also have been the common pattern in many other parts of Norway. Therefore, one must raise the question as to how the regulations were practiced in local areas a long time after it was strictly forbidden to set forest fires intentionally. The climate and character of the naturally ignited fires in this area cannot be assumed to have been particularly different from today; the ignition frequency from lightning is low (ch. 6).

During earlier periods conflicts between cultures with

Table 4.3. Four important cultural periods based on examinations of pollen where settlement waves and land occupations (Norw. "landnåm") had large impacts on the forest areas in South Scandinavia. We also assume the influences involved extensive anthropogenic burnings (After Tenow 1974, based on Berglund 1969).

Climate period	Archaeological period	Time period	Resource utilization
Subboreal Time	Younger Stone Age (Mesolithic Time)	3 300 – 2 300 B.C.	Herding of extensive character Swidden agriculture?
Subboreal Time	Older Bronze Age (Neolithic Time)	2 200 – 1 000 B.C.	Herding Swidden agriculture Grain cropping
Subatlantic Time	Older Iron Age	200 B.C. – 450 A.D.	Herding Grazing Swidden agriculture Increased grain cropping
Subatlantic Time	Viking Age Younger Iron Age	800 – 1 100 A.D.	Herding Grazing Swidden agriculture Increased cultivation

varied landscape use may have led to many arsons which both then and now would be difficult to uncover, even through detailed studies of historic documents.

The colonization and settlement waves in Norden
Settlement in Norway took place in phases or waves, partly due to increases in the population. These "waves" reflect cultural trends that according to Tenow (1974) may be identified more or less over the whole of Norden. It is possible to reconstruct how the cultural landscape emerged stepwise both in the southern and northern parts of Scandinavia. Tenow (1974) identified, among others based on Berglund (1969), four important prehistoric expansion periods in southern Scandinavia (Tab. 4.3).

The forest retreated due to burning for clearing and cultivation, but during intermediate periods recovered only to be cleared again, burned and grazed. The most extensive openings of the landscape, which established the main basis for today's rural agricultural system, came during the Viking Age.

All the anthropogenic burning in the postglacial period must have supplied the soil with enormous volumes of carbon remnants and inorganic ash. The problem with distinguishing the archaeological and the cultural historic aspects in Norwegian fire history from natural fires is first and foremost linked to the difficulty of providing documentation. Even though carbon remnants in stratigraphic research of soil profiles and cultural layers are frequently documented, at present we have no accepted method for determining the specific origin of carbon remnants (See section 2.2.6). If some form of swidden agriculture was based on growth of particular cultivated plants, carbon remnants are often accompanied by pollen and other remnants from such plants. The burnings only to clear land constituted a part of the impact and were continuously associated and overlapping with burnings for swidden agriculture. This must also have entailed many forest fires that were ignited through negligence up to modern time.

4.2.5 Swidden agriculture

The notion "swidden agriculture" or "swidden cultivation" is used in this technical report as a collective name for agricultural techniques that used or still use fire as its most important tool. The basis for all swidden agriculture is utilization of the large stores of nutrients bound up in trees and humus layers in the climax forest. When these nutrients are converted and released by burning, they may be used for crop yields of a great variety of useful plants (Arnborg 1949, Asheim 1978, Tvengsberg 1995a,b). Swidden agriculture was not exclusive to the Nordic countries. This technique developed and became a continual agricultural practice over large parts of the boreal region where long winters and small amounts of forage made it difficult to keep large herds of husbandry animals and thus get enough manure (Asheim 1978, Tvengsberg 1995b, Pyne 1996). This lack of manure is in fact a problem that was not "solved" in marginal pro-

ductive regions until the industrial revolution made possible the production of chemical fertilizers (Pyne 1996).

There is no agreement among either archaeologists or culture historians about the semantic content of the term "swidden agriculture", or in what periods the different techniques implied in such agriculture may have been practiced.

Various forms and definitions

Swidden agriculture is generally the most primitive and area-demanding form of agriculture (Asheim 1978). It can occur in varying forms and has been studied in a number of different cultures around the globe (Tvengsberg 1995b); this has led to problems regarding terminology (See Myrdal 1995).

In the historic terminology of common Norwegian culture swidden agriculture is often called "bråtebruk". The "bråtebruk" consisted in clearing and burning forest, followed by sowing grain, especially rye, in the ash. This technique also was a means to expand the cultivated home fields of Norwegian farms. A "bråte" was an intermediate stage in the transition from forest to cleared and fully cultivated soil. While the word "bråtebruk" is still alive in oral Norwegian tradition (Asheim 1978), the notion "swidden agriculture" (Norw. "svedjebruk") is used in the scientific literature when one talks about agriculture of this type.

A more precise definition of swidden agriculture is "burning of forest to cultivate crops during a period of a few years" (Myrdal 1995). The technique in Fennoscandia may also have been developed as various types adapted to different ecological conditions of this region. A Finnish historian delimited and defined swidden agriculture adapted to Nordic conditions as a method based on clearing of forest with fire, involving moving the crop area from site to site (Raumolin 1987) (see later about the "huutha" form).

However, there are different opinions about how extensive the swidden agriculture was in the Nordic countries during prehistoric time, what forms it had, and in what time periods the various forms were in use (See Larsson 1995). It is known that bogs were used for swidden agriculture (Asheim 1978, Larsson 1995). Swidden agriculture as a fire dependent agricultural technique changed slowly as knowledge and experience successively adapted the technique better to local conditions.

In some epochs and areas swidden agriculture played an important role and was a main factor in the agricultural economy. In other epochs it may have had the character of a subsidiary industry where the main purpose was to open the landscape to create pasturage (Myrdal 1995). Crops on the burned sites could be large the first year, the second year they were only tolerable, and thereafter it hardly paid to sow. However, old swidden agricultural land could provide both good pasture and meadows (Asheim 1978), and was associated with the use of outlying ranges for grazing (Section 4.1.6).

During some periods Swedish swidden agriculture was undertaken as much for the creation of pasturage as for grain cultivation. Differing from this, Finnish swidden agriculture primarily was conducted to grow rye (*Secale cereale*), turnip (Norw. "nepe" and "turnips", both cultural varieties of the same form *Brassica rapa* var. subsp. *rapa*) and swede (Norw.: "kålrot", *Brassica napus* var. *napo brassica*). Swidden agriculture was also utilized to produce turnip (Norw. "roer") for example, even in the northern part of Norway (Skogdirektøren 1909).

"Fire cultures"

The use of swidden agriculture is the basis for denoting the earliest agricultural people in Scandinavia "fire cultures". Swidden agriculture in Norway may be traced to Younger Stone Age or Subboreal time (Fig. 4.1). This was a period with dry and warm climate and wide deciduous forests composed of broadleaved tree species such as ash, elm, lime, oak and hazel. As a technique for production swidden agriculture implied a shortterm and intense drain of the nutrient capital in the biomass of the forest through a long period of time. If one considers precipitation patterns and topography, it is probable that ash through runoff deposited slowly in lakes and water systems. In earlier times one has to imagine an extensive use of the landscape. Slowly distances to walk increased more and more from the temporary settlements (Norw. "boplassen") to find a suitable area of forest to burn. Therefore, it paid off to move. A culture based on swidden cultivation therefore did not permit any permanent settlement, but was linked to a nomadic or seminomadic way of life (Asheim 1978, Tvengsberg 1995b).

In prehistoric times swidden agriculture originally meant burning standing forest. This was the simplest and easiest way because forests were full of dry trees and twigs that provided good fuel. Live trees were rossed in advance to dry and burn better. Thereafter the seed was

hacked down into the soil mixing with the ash. Later an improved practice developed where trees were first cut, dried and then burned (Arnborg 1949, Asheim 1978).

Written sources with descriptions of the swidden agriculture has been recorded from past history. The forest was cut in the middle of the summer and left to dry until the next year. Then it was ignited, and burning logs were rolled back and forth across the site until the humus layer was burned. Anything left of the logs was used to fence the burned site to keep animals out, and later transported home as firewood (Asheim 1978).

"Huutha" swidden agriculture

During the 16th century, Finnish swidden agriculturists immigrated to Norway through Sweden. They settled down farthest east in forests toward the Swedish border (Asheim 1978, Tvengsberg 1995a,b). The Finns brought with them a highly specialized swidden agriculture that is called "huutha". The technique utilized spruce forests of good quality. As a rule, the site demanded preparation for 2–3 years prior to burning and sowing, and the crop was a particular type of rye (*Secale cereale*), so-called "tussock rye" (Arnborg 1949, Bladh 1995, Orrman 1995, Sarmela 1995, Tvengsberg 1995a,b).

During the period of Finn immigration the estate pattern in the large stretches of forest in the eastern part of South Norway (Østlandet) were often unclear; existing regulations concerning swidden agriculture was hardly known among the common people. A letter written to the king as a report from "the Ordinary Land Commission" in 1661 stated:

> "The whole local community complains about the damage the Swedish eastern Finns (Norw. "østfinner") cause on his majesty's commons (Norw. "allmenninger") and large forests. Because, in addition to being a barbaric people who resides in almost desolated forests and remote tracts, they often move and successively occur in new places, where they afterwards burn the forests, and move when they themselves find it appropriate, they spoil even the largest forests with their burned sites and swidden land" (Translated from Østberg 1978, p. 130).

During the burning more careful people had enough manpower to prevent fire to spread outside the sites intended. But many were careless and the fire got out of control and spread to surrounding forests (Østberg 1978). Sometimes fires that originated in connection with careless burning burned farms and people died (Østberg 1978). It was not surprising that permanent residents in rural areas during such conditions feared to lose their "timber resources".

Also, the huutha technique practiced by these immigrants changed over time. Finnish researchers established that "huutha" denoted something different in the Late Middle Age and in the 16th century than during the 18th century when one got the first detailed descriptions of this phenomenon (Orrman 1995). One should probably consider the "huutha" burning technique a particular form based on high quality spruce forest. The method was steadily improved, and the descriptions from the 18th century described the most advanced form (Myrdal 1995). [4.15)]

The huutha swidden agriculture introduced to Sweden and Norway from Finland during a later period, thus had older roots in the colonization of the forested boreal areas. Such areas were once burned to produce an array of cultural plants using a variety of techniques (Tvengsberg 1995b).

"Swidden landscape"

Where extensive swidden agriculture was undertaken, distinctive landscape types were slowly developed. The swidden landscape was complex and formed a mosaic, with some sites with newly cut forests, some recently burned, some with various crops, some used as pasturage, some burned again, and some lying fallow. The soil preparation in the burned sites was done with hoe or pick, and roots, pebbles and rocks were pulled loose and often gathered in small heaps. If development of meadows on the burned site were used for haymaking, it was important to remove surface rocks. In outlying areas numerous signs of old burned sites are found (Fig. 4.4). However, as already discussed, it may be difficult to determine whether such sites were swidden agricultural land or fields burned for haymaking (Asheim 1978), and it is also difficult to separate such sites from ordinary forest fire areas. [4.16)]

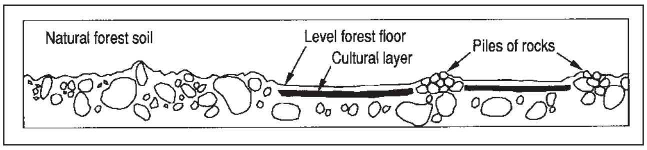


Figure 4.4. Section through a forest floor that has old signs of swidden agriculture (After Asheim 1978).

Table 4.4. Productive forest area (percent distribution) in Norwegian counties according to quality classes (National forest survey, after Börset 1985).

County	Quality class				
	1	2	3	4	5
	Distribution %				
The forest counties	5.3	13.4	34.6	30.6	16.1
Østfold	11.1	17.8	30.2	26.5	14.4
Akershus and Oslo	12.9	22.3	38.4	20.4	6.0
Hedmark	4.3	12.2	38.2	31.4	13.9
Oppland	5.4	13.3	34.6	33.7	13.0
Buskerud	7.3	15.7	33.8	28.6	14.6
Vestfold	17.7	27.5	32.3	16.2	6.3
Telemark	4.7	13.7	33.1	28.8	19.7
Aust-Agder	2.3	14.0	39.3	26.8	17.1
Vest-Agder	5.9	15.0	38.2	25.6	15.3
Sør-Trøndelag	1.5	7.8	29.8	37.5	23.4
Nord-Trøndelag	1.5	8.3	28.0	36.6	25.8
Nordland (southern part)	0.5	5.4	31.7	41.4	21.0

Attitudes towards swidden agriculture changed between various periods. During the 16th century swidden agriculturists in Sweden were favored by the state; the state generally accepted burning of areas to obtain new crops. After the turn of the century, this attitude changed, and for a long period in the 17th and 18th centuries swidden agriculture was suppressed. Swidden agriculture was seen as destroying forest resources better needed for coal production, tar burning and other forms of economic utilization. Even if swidden agriculturists used “controlled” burning as an agricultural technique, the risk of starting wild fires in the surrounding areas was at times high. Still, in Sweden a new “wave” of swidden agriculture occurred during the 18th and 19th centuries with a considerable expansion of crop area (Myrdal 1995). Similar conditions were also manifested in Norway. Swidden agriculture was practiced to produce rye in Norway until around 1800. However, in the last period all usable lumber and wood was removed from the site before it was burned (Asheim 1978).

Swidden agriculture ceased in many local areas as the knowledge of fertilization of permanent fields improved, [4.17] and swidden agriculture slowly got a subordinate position compared to grain cropping (Asheim 1978).

Impact on quality classes?

Classification of quality in forestry is a measure of the ability of the growth site to produce wood and timber (Börset 1985). The quality class therefore provides an expression for the collective impact of growth factors, both climatic and edaphic. National forest survey’s (Norw. “Landskogstakseringen”) oldest quality class system designates productive forest into five classes (1–5, 5 most productive). Table 4.4 shows the distribution (%) of the productive forest into these classes for the most important forest counties.

The “quality class” is considered as relatively stable, even though it may fluctuate periodically with the climate. However, it may become heavily influenced by fires (Börset 1962b, Beese & Divisch 1980, Lundmark 1988). Swidden agriculture was above all a shortterm consumption of the mobile nutrient capital of the forest. The nutrients that were not bound and harvested in the crops were often transported through runoff as ash into streams and lakes or deposited in concave landscape structures (valleys, hollows etc.). Because swidden agriculture may have been in use for such a long period, this activity likely converted enormous amounts of humus, wood and timber to ash and carbon remnants. Then one could ask if the quality class conditions in the burned areas were influenced. [4.18]

How much were the quality classes reduced through the considerable anthropogenic burning? How much of the bilberry-spruce forest of medium quality we today see in Norway (Tab. 4.4), is created through burning of earlier higher quality sites?

Swidden agriculture in many areas implied a disintegration of brunisol or brown soil (Norw. “brunjord”) into

podzol (see Tab. 3.4). Swidden agriculture slowly limited the distribution of the broadleaved trees such as ash, elm, lime, oak, maple and hazel, and in many places has led to a permanent change from broadleaved trees to forests of less demanding tree species such as birch, aspen and coniferous trees (Asheim 1978). Where forests were burned repeatedly or where the mobile nutrient capital was depleted because of high precipitation, the result could become open heathlands.

In addition, swidden agriculture is supposed to have strongly influenced the distribution of some rare plants. Today rare plants and remnants of broadleaved forests are strikingly associated with sites that were not suitable for swidden agriculture and grazing by husbandry animals: precipices, landslide areas, and ravines with boulders (Selander 1957, Stålfelt 1960).

4.2.6 Pasture burning

Pasture burning is defined as use of fire to establish and maintain pasturage for domestic animals (See Myrdal 1995). This encompassed burning to remove forest, open up landscapes and develop a vegetation that was suited for grazing animals, and to maintain and improve conditions for husbandry.

Burning to provide grazing was common in the boreal coniferous forests in circumpolar areas through periods of several thousand years. [4.19)] Burning to improve pasturage was both widespread and important in the old Norwegian rural culture and was continuously part of the long development which we commented on earlier (Section 4.2.4). We must assume that this knowledge followed the first herding cultures that immigrated. They later spread and increased in the boreal areas as the pressure on husbandry from human population increased.

Extensive burning practice in outlying areas

There is little specific information about grazing conditions in both prehistoric and historic time in Norway. We assume that burning in connection with grazing of husbandry animals was common almost everywhere.

The above assumption is based on the fact that extended husbandry was an important part of a mixed economy during periods when there was pressure in Scandinavia to increase the husbandry yield and thus to provide enough pasturage. Grazing animals provided basic resources such as meat, clothes (sheep) and manure. During periods of scarce food, all available outlying pastures were grazed. Managing husbandry animals during some periods were totally dominant in Scandinavia compared with other agricultural industries (Tenow 1974). Especially important grazing lands were bogs, naturally irrigated land, shores along lakes and water systems, open, grass-covered slopes and old swidden agriculture areas (Asheim 1978). There often were a maximum number of animals allocated to forest pasture, swidden land, grazing home fields and meadows (Tenow 1974). Large parts of the forested moraine areas lacked grazing plants like herbs and grass. To stimulate the necessary growth of grass, burning was conducted wherever possible (Tenow 1974). For an overview of the Nordic grazing literature, we refer to Myrdal (1994).

During the period of transition from extensive husbandry practices to settlement on permanent farms, a combination of tillage on homefields and husbandry animal grazing was developed in outlying areas (or close to the home field) (Mysterud & Mysterud 1995). Adjacent to farms and on homefields both cattle, sheep, goats and horses were grazed in enclosures with well cleared pastures (Asheim 1978). The establishment of such pastures close to farms with a vegetation type characterized by grass and deciduous trees was the premise for all farming where peasants became permanently settled (Asheim 1978). The possibilities for developing pastures for husbandry animals in the farm vicinity were limited, and the outlying areas represented the only possibility for improvement of the forage situation. Summer diary farming was developed during the Viking Age where usable summer pastures were so far away from the farm that cows did not have time to eat and walk to and fro within one day (Malmström 1951, Tenow 1974, Asheim 1978).

Agriculture on uncultivated soil (outlying area) where the domestic animals graze during summer, and winter forage is collected on homefields (Hagen et al. 1980), remained an important form of usage through the Middle Age; this was particularly true in rural areas along the coast and in mountains where conditions for grain cropping was not good. Grazing plants on large portions of the landscape were also cut to provide additional winter forage; this included natural meadows, bogs and shore areas along water systems. [4.20)] Burnings to provide pasturage “followed” in the wake of this activity throughout outlying areas.

Keeping husbandry animals also brought about the development of grass- and heathlands in Western Norway and southwestern Sweden. These ecosystems were almost purely formed by human activity and “created by fire”; at first this occurred in the coastal areas.

There the climate was so mild that outdoor grazing was possible all year (Tenow 1974, Kaland 1986, Skogen 1989, Fremstad et al. 1991).

The *Calluna*-heathlands in Western Europe

In oceanic and temperate coastal areas in Western European *Calluna*-heathlands were created on large parts of the landscape with a vegetation developed on acidic substrates (Brüne 1948, Goudie 1986).

In some areas these heathlands were formed naturally, but at low and medium elevations in the western parts of Europe between Portugal and Scandinavia heathlands over large areas were created by humans (Fig. 4.5). The origin of these is disputed (Kaland 1974, 1997, Skogen 1974, 1997, Gimingham & de Smidt 1983, Brekke et al. 1990, Fremstad et al. 1991), and has been the subject of extensive research regarding both vegetation and soil (Allen 1966). For a summary see Fremstad et al. (1991), Aarrestad et al. (1996) and Goldammer et al. (1997). Stratigraphic pollen analyses have shown that most heathlands of this type are located in areas which earlier were forested. Heathlands developed 4 000 years ago, i.e. during the Younger Stone Age in Subboreal Time. The creation and expansion of heathlands started in Older Iron Age at the time just before our current era (Subatlantic Time) and accelerated during the Roman Iron Age when agriculture expanded significantly (Kaland 1974, 1979, 1986, 1997, Paus 1982, Brekke et al. 1990, Fremstad et al. 1991, Aarrestad et al. 1996). The presence of human artifacts and carbon remnants found in archaeological excavations, and the fact that the forest was burned and replaced with heathlands at different times between the Neolithic period (Tab. 4.1) and late 1900s, indicates that impacts from humans established and maintained most of these heathlands.

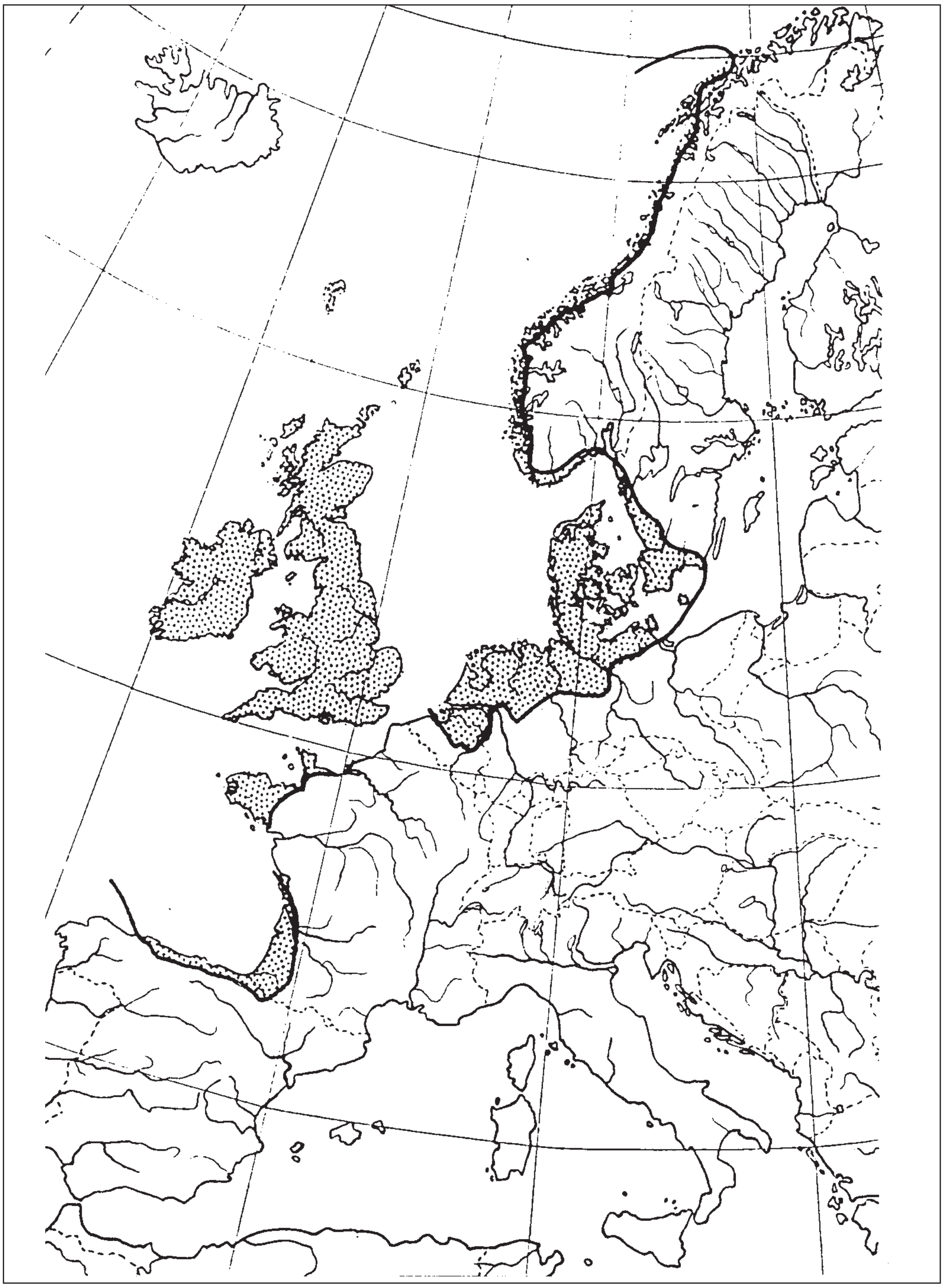


Figure 4.5. The distribution of Atlantic coastal heathlands in Western Europe (After Skogen 1974).

Advanced "fire culture"

Peasants are presumed to gradually remove the forest by intentional fires followed by intensive grazing and regular burning of heather; this created the heathlands through a "balanced" cycle of grazing,

burning and cutting (Fig. 4.6). Thus, they constitute an example of a cultural landscape that is a fire-created ecosystem (Brekke et al. 1990).

By keeping the forest cut optimal possibilities were created for growth of heather (*Calluna vulgaris*) which was the most important forage plant for domestic animals during the winter. Heather burning required good experience concerning the judgement of conditions of the vegetation cover, soil, topographical structure and weather. It was important to conduct a burning that would remove the vegetation without igniting the humus layer (Kaland 1997), i.e. a fire that was not too severe or "hard".

In Norway an extensive examination of how heathland was managed was undertaken in Nordhordland through the Lindås project (Norwegian Research Council for Science and the Humanities, 1971–76). This project documented that heathlands are among our oldest cultural landscapes, and have been in continuous use up to the 1960s (Kaland 1997). [4.21)]

A primary objective with this burning was to create and maintain forage production for sheep (Norw. "utegangarsau") and other livestock which could graze in outlying areas all year due to mild winters. Heathland burning is an important indication that the Stone Age culture in the Subboreal period used fire strategically in the landscape to produce desired resources. However, the heathlands are only a special case of a general practice in Norway.

Burning as "pastoral behavior"

Throughout the Middle Age "summer pastures" in the commons with free access to summer diary farms played an important role in providing forage in the annual cycle of the farm (See earlier). Summer diary farming slowly became an important part of husbandry and expanded over most of Norway. Husbandry was particularly important along the coast and in fiord areas south, west and north in the country, and in rural areas in the mountains (Hagen et al. 1980), but was also important in the forests. Up to the modern era pasture areas for domestic animals were cleared and maintained by cutting of forest, use of mattocks and burning. In this way coniferous forests were removed and grassy meadows created and deciduous trees that provided improved pasturage (Asheim 1978).

A number of different burnings were conducted on the forest floor vegetation to maintain the pasturage both in pastures close to the farms and in outlying areas. They were implemented as burnings to clean off twigs and slash to improve accessibility ("clean burnings")

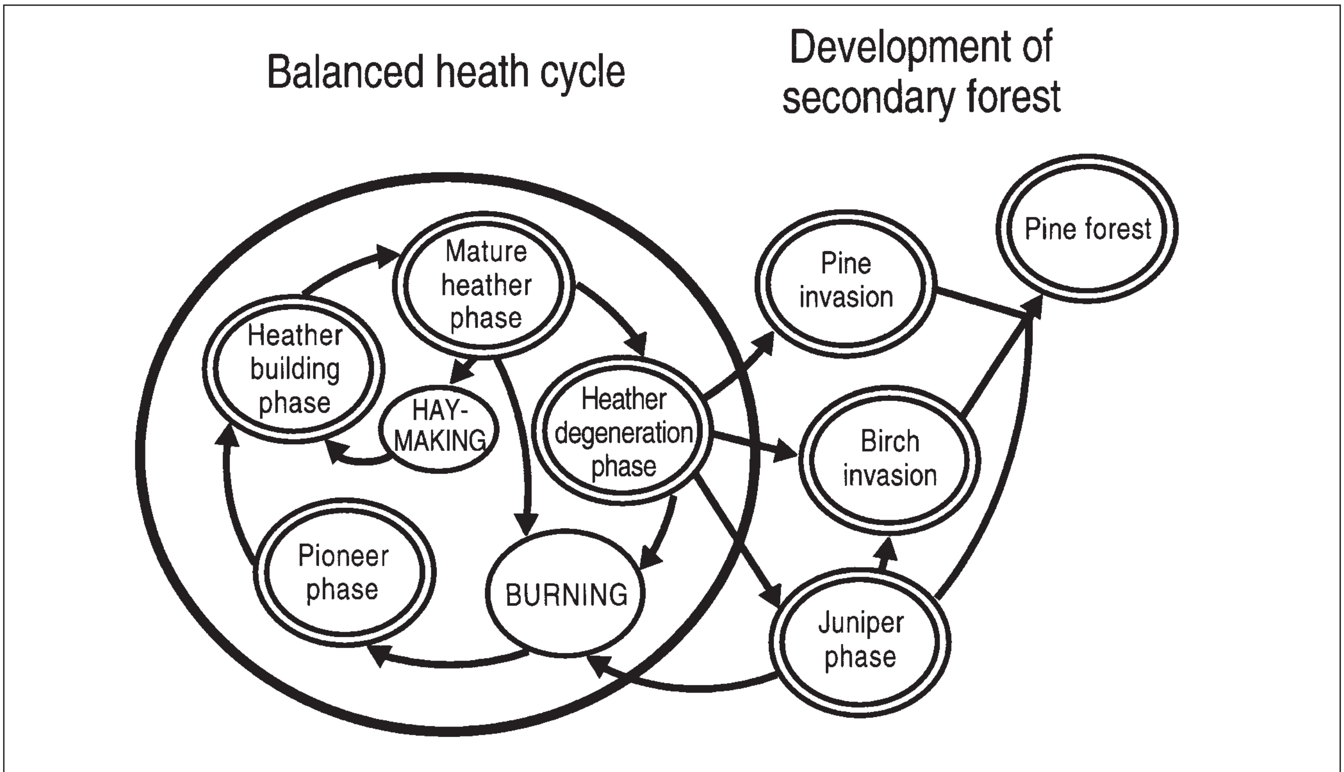


Figure 4.6. The dynamics of the coastal heathlands was maintained as a balanced cycle of burning, grazing and cutting. Central in this process were the four developmental phases of *Calluna*-heather (Redrawn after Fremstad et al. 1991).

(Section 4.2.7), or “spring burnings” in which only old grass was burned to stimulate early and luxuriant growth of grass. Burnings were also common in outlying areas far above the tree line, and were a widespread activity among professional herdsmen (Norw. “heiekarer” and “driftekarer”) and shepherds up to the present time (Eikeland 1966).

> “During herding in the old days they had lots of time to detour and burn a hill or a valley. Particularly in the spring when there were a lot of snowfields that prevented the fire from spreading, grass burning was a regular activity on their daily schedule. Several old people told us about that. In the spring with frozen soil the grass roots do not get damaged. The sheep thrive well in burned areas; all people working with sheep have observed that.” (Translated from Eikeland 1966, p. 281).

Shepherds who undertook this extended forest floor burning, had a multi-purpose task. Eikeland (1966) points out that they removed heather and “unwanted” vegetation to improve growth conditions for grass species. Secondly, considerable ash was produced during the burnings. This was concentrated mineral fertilizers and first class fertilizers on humid soil [4.22] because of the nutrient content and because of its alcalic properties which neutralized acid soil. However, the ash did not contain nitrogen (Eikeland 1966, p. 281). [4.23]

The permanent lack of home fields and cultivated agricultural areas already mentioned in connection with burning to clear land (Section 4.2.4) periodically pressed and spread husbandry grazing over outlying areas; this is a pattern that still can be observed in today’s use of outlying areas (Mysterud & Mysterud 1995). Burning to create and improve pasturage has to some extent encompassed all of Norway: The widespread heathlands are only specialized and locally adapted forms of a general practice of burning for pasture in outlying areas. The pasture burning was such an obvious part of the annual cycle of the farm that it often was not mentioned in written sources.

4.2.7 Other burning for agricultural purposes

Shoots and smaller twigs from deciduous trees were used as forage for domestic animals. Deciduous trees are powerful shoot developers (Norw. “skuddannere”), and new shoots quickly grow from the stumps.

From the southernmost parts of Sweden a so-called shoot or coppice forestry (see Tab. 4.2) is described (Tenow 1974, Göransson 1977, 1995) which also demanded burning. In the Younger Stone Age (Mid-Neolitic Time) and up to the end of Older Bronze Age, and most probably also during the Younger Bronze Age, deciduous trees were used for animal forage production in the form of so-called “sprout” or “shoot forests”. This practice was carried out on patches where the forest was cut such that shoot production was promoted from stumps for a certain period; the field was then abandoned and the production moved to a new patch (See Göransson 1995).

At the cleared sites with the “shoot field” (Norw. “skuddåkeren”) a “mild” burning of branches and twigs was undertaken, after removing the trunks. Göransson (1977) raised the hypothesis that such an advanced shoot forestry was used througout northwest Europe, and gives arguments for this through research on stratigraphic pollen diagrams (See Göransson 1995). It is unknown if this form of forage production was ever applied in Norway, but from the importance of husbandry in Norway, it cannot be ruled out.

Burning to clean pastures

On meadows and fields it was common to burn piles of branches, twigs and slash to improve the quality of the pasturage, and through better accessibility increase the degree of utilization. This burning is suggested denoted as burning to clean pastures (Myrdal 1995); it should not be confused with the burning to clear land (Tab. 4.2).

4.2.8 Forestry burning

To regenerate pine on clear-cuts in the Nordic countries foresters expanded and modified the swidden agriculture technique to clear-cut burning. Below we are going to present clear-cut burning, and the so-called “patch burning” as two important forestry techniques.

Clear-cut burning

Swedish and Finnish foresters discovered early that forest fires and “wildfires” from the time of swidden agriculture created the basis for the best stands in their forests. Burning eased seeding and regeneration of plants through removal of slash and thus lowered the regeneration costs (Söderström 1981). Therefore, the positive effects from application of fires to mimic natural disturbances in the boreal forest landscape, was emphasized (Hallsby 1995). Foresters started to burn clear cuts in Sweden from the middle of the 1920s

(Hallsby 1995) to ease natural regeneration; over time this technique was used more and more. The most intensive period for use was at the end of the 1950s. Earlier the method was mostly applied at inactive, moist and raw humus sites, particularly in areas at higher altitude in Swedish Norrland (Uggla 1958). In 1947 in these landscapes a clear-cut of between 100 000 and 150 000 decare was burned (Strømsøe 1956).

However, clear-cut burning demanded a lot of personnel and because of the dependence of weather, was difficult to plan. There also was considerably uncertainty about the long-term effects of such burning on forest production. When the first reports indicating growth reduction emerged (Huss & Sinko 1969), they had a lot of impact. Experiments conducted at new sites with heather forest, documented that the lower the quality class of the forest soil, the more the growth on burned sites was reduced (Lundmark 1988). In the earlier 1960s, the mass occurrence of the fungus *Rhizina undulata* that killed the seedlings was apparent on burned clear-cuts (Hagner 1960); after this, the method lost popularity. During the last three years of the 1960s clear-cut burning ceased almost totally in Sweden (Hörnsten et al. 1995). However, at the beginning of the 1990s interest in clear-cut burning in Sweden resurrected. This renewal was motivated by increasing pressure from nature conservation groups argumenting that certain plant and animal species are favored at burned forest sites and on burned trees. Forest fires and probably also burning of clear-cuts are the source of a structure and mosaic variation in forested landscapes that may be difficult to maintain without the help of fires (ch. 8).

Today there are considerable data about clear-cut burning as a management technique (Hörnsten et al. 1995, Weslien 1996). Information about the influence of clear-cut burning on wood production in boreal coniferous forests is reviewed by Hallsby (1995).

Clear-cut burning in Norway

Clear-cut burning based on methods introduced from Sweden and Finland was also practiced in Norway. It was originally applied to enhance soil to make it better suited as germination and growth sites for trees (Skinnemoen 1969). Burning of clear-cuts also made soil preparation, sowing and planting cheaper on burned than on unburned sites (Strømsøe 1956, 1962, 1964, Skinnemoen 1969).

The first report on methods for clear-cut burning in Norway was published in the 1930s (Opsahl 1935). Interest in clear-cut burning increased during the following period. In the 1940s and 50s, when clear-cut burning was considered an inevitable part of forest management over large parts of Sweden and Finland, a corresponding degree of utilization did not occur in Norway. However, after the Second World War some teaching on clear-cut burning was conducted in Norway. Approximately 15 000 decares have been burned annually since 1952; slightly more than half of this in Hedmark county (Strømsøe 1964). Interest declined thereafter. The broken relief and rough terrain in Norway made clear-cut burning more difficult and expensive, and the fragmented estate pattern and the mosaic variation of soil and forest quality classes often entailed that individual sites were too small to accomplish cost efficient burning (Strømsøe 1962, 1964). Where it seemed most logical to burn in clear cuts in Norway there was often too little slash. Dry weather and low humidity are required to set the forest vegetation on fire on such sites for a considerable period. Relative humidity during burning was recommended to be around 30 % and not above 50 %. Therefore, clear-cut burning often was accomplished during periods of high risk of forest fires; this again presupposed a number of safety actions and large work effort to control the fire (Strømsøe 1962, 1964, Skinnemoen 1969). For additional comments on clear-cut burning, see chapter 9.

Patch burning

"Patch burning" means a patch-wise burning of vegetation to support regeneration and improve settlement of seedling plants for forest trees (Øyen 1996a, 1997). It is launched as a current effort in forestry to establish new forests (Øyen 1996a,b). This is a new method in Norway, and there are no experiments with patch burning to rely on from Nordic forests. The method is simple and relatively safe: The possibility for the spread of fire beyond the target patch is expected to be low. [4.24)] Therefore, the method may be applied during most parts of the snow-free period, but must be limited to periods with good humidity in the ground layer.

The method is expected to be of focal interest on medium quality soil and good quality sites, particularly in areas with luxuriant "weed vegetation" and thick layers of inactive raw humus. Patch burning may be used to develop multi-storied stands, and it is expected to be a supplement to mechanical soil preparation (Øyen 1996a,b, 1997).

Small scale burning may also be of interest for nature

management. Studies of the effect of fires on a small scale in the form of re-vegetation surveys of campfire patches are now undertaken in all the Nordic countries (Arnesen 1989). The physical and chemical effects of bonfire burning have much in common with larger fires, and small scale burning may become an important method in areas where it is not possible to burn on a large scale (See ch. 9).

4.2.9 Game management burning

Burning to produce game or as part of game management, has old historic roots (Gossow 1978), and is still used to favor some species. Some countries in Europe have old traditions of burning heathlands and outlying areas as part of game production; this is often called "heathland burning" (Norw. "heibrenning") or "heather burning" (Norw. "lyngbrenning") (Myrberget 1988). Areas in Scotland have been improved for the production of willow grouse (*Lagopus lagopus scoticus*) for several decades through periodic burning of *Calluna*-heathlands which provides the main food for this grouse species (Lovat 1911, Miller 1964, Jenkins et al. 1970, Miller et al. 1970). High population densities may be maintained when the heathlands are burned regularly in narrow stripes or as points in rotational periods of 3–7 years (Miller 1963) or 10–12 years, particularly if this is combined with fertilization (Miller 1964, Picozzi 1968, Miller et al. 1970, Bendell 1974). This kind of game production has been undertaken in Germany (Klaus 1993). For an overview of the literature we refer to Goldammer et al. (1997).

Burning in Norway

Since the 1970s in Norway, there has been interest in burning outlying areas to produce game related to an increased focus on utilization of the country's outlying area resources; this is particularly true for burning of alpine heath vegetation for willow grouse (Pedersen 1991). The heath burning was inspired by the research and positive experiences from Scotland (See above).

The largest and most interesting experiment is undoubtedly the Sletthallen project in Numedal, Buskerud county (Aalerud & Phillips 1984, Phillips et al. 1992); this project was initiated in 1978.

Even though the causes are uncertain, there is agreement that breeding populations and harvest have increased in areas where burning was undertaken (Phillips et al. 1984, Myrberget 1988, Steen 1988). Most of the uncertainty is linked to the simultaneous removal of carnivores from the area (Pedersen et al. 1992).

At Gausdal Vestfjell in Oppland county research revealed did not establish a corresponding increase in the postburning breeding population of willow grouse (Solbraa 1992). Compared with Scottish conditions where burnings entailed fertilization effects lasting up to 8 years (Pedersen 1991), results from both Sletthallen and a smaller experiment at Kvikne in Hedmark county showed that the effect disappeared two years after burning (Råen 1989, Andersen et al. 1990). See chapter 9 for further discussion on use of this type of burning in management.

Internationally there has been much discussion about the use of fire in the production of ungulates (See section 9.2.4). It is uncertain if the first immigrants set forest fires as part of tactical hunting operations or carried out such game production in Norway. Drive hunting may have demanded massive ignitions in patterns determined by the season where conditions were suitable. By intentionally starting forest fires the conditions may have been improved for production of larger populations of typical "fire followers" such as moose (*Alces alces*) and roe deer (*Capreolus capreolus*). [4.25] It is well documented that fires may increase both the quantity and the quality of forage for large ungulates. Better nutritional conditions increase body weights and thus reproductive rates. Mellars (1976) postulated that burning of suitable areas may increase the general productivity of the ungulate population by a factor of 10. [4.26] Such discussion has no relevance for ungulate management in Norway today (Section 9.2.4). Forest fires may also affect some species of ungulates negatively. An increasing distribution of anthropogenic forest fires in the boreal areas connected to colonization and settlement was presumably the cause of local decline of the population of American woodland caribou (Cringan 1957) (See ch. 8).

4.2.10 Nature conservation burning

The most recent type of anthropogenic burning in Europe is burning for nature conservation (Goldammer et al. 1997). This type of burning has developed after it became clear that fires were involved in the evolution of species almost requiring periodic fires to fulfil their life cycles (ch. 8). Management to maintain diversity (biodiversity) of flora and fauna must necessarily take this into account. In Sweden [4.27] and Finland burning for purposes of nature conservation has been in use for some time. A primary motivation for this technical report is to develop a scientific basis to evaluate the necessity of such fires in Norway (ch. 9).

Modern pc-technology and Geographic Information Systems (GIS) are used in several Swedish projects started to require as *model areas* for general landscape planning utilizing nature conservation burning, while some projects specifically have developed *action plans* for target species, for example white-backed woodpecker (*Dendrocopos leucotos*). Each pair of white-backed woodpecker is supposed to need approximately 1 000 hectares of broadleaved dominated forest of a certain mix and quality. One of the largest forest companies in Sweden has decided to create breeding habitats of 100 new pairs on their estates (Stora Skog AB 1995b).

Both stands and clear cuts are burned in Sweden, mostly the latter. “The nature forest” is burned to conserve diversity, while cut areas are burned both for soil preparation, regeneration and biological diversity. The intention is that burning of the standing forest in the future is to be an integral part of Swedish forest management (Sundkvist 1995).

Sweden also emphasizes the importance of education and information about this topic. In 1996 a course in management burning was arranged as a cooperative effort between the forest companies AssiDomän and Skogforsk (AssiDomän 1996). Such courses are to be continued and expanded (Herman Sundkvist, pers. comm.).

Nature conservation burning in Norway

Interest in nature conservation and fires set off to increase biological diversity is now increasing in Norway (ch. 9). Much of the conceptual framework concerning such planning is imported from Swedish management.

On the estates owned by the forest company Borregaard Skoger AS plans now exist where fire is incorporated as a management technique (Foss 1995). With the company as a contractor for World Wildlife Fund (WWF) so-called “key habitats” (Norw. “nøkkelbiotoper”) were registered at the company’s estates at Gravberget district in Hedmark county to evaluate the potential need for diversity fires. [4.28)]

The need for burning is justified by the fact that many species, both vascular plants, lichens, mosses, fungi and insects, are linked to burned substrates. These species are adapted to disturbance and have wide dispersal capacity. Håpnes (1995) supposes that conditions for such species have worsened at Gravberget, because of forest fire suppression in an area “which probably earlier have had relatively high fire frequency” (Håpnes 1995, p. 23). [4.29)]

There are many pine-covered islands in bogs characterized by earlier fires in the northern and western parts of the Gravberget forest. The intention is to burn small patches at various sites during different years to make establishment of new stands possible. It may be necessary to let some patches burn harder than others. It is presumed that if small stands are created every fifth year, this frequency will be satisfactory for creating various age successions distributed throughout the landscape (Håpnes 1995). On the basis of the above the first nature conservation burning in Norway was undertaken on 13 August, 1996 where a 14 000 m^2 standing forest was burned (Frode Hjort, pers. comm.).

The importance of biological diversity and use of burning was realized by the administrators of the forests of Løvenskiold-Vækerø north of Oslo and brought into their strategy for conservation. This forest estate is 430 000 decare, with 340 000 decare productive forest; 7 % of the area is secured through protection (Løvenskiold-Vækerø 1996). In connection with initiating a more ecological forestry through cooperation with the project “Levende skog”, smaller areas of standing forest are planned to be burned (Anonymous 1996). The first burning was to be conducted during spring 1996 (Rolf Hatlinghus, pers. comm.), but was delayed until 2 June 1997 where an area of 8 000 m^2 at Trehørningen in Bærum municipality was burned (Aftenposten June 3, 1997, Levende Skog 1997). However, comprehensive examinations are emphasized before extensive plans for systematic burnings of this type are undertaken (See ch. 9).

4.3 Anthropogenic impact of fuel

The Norwegian fire regime is not only influenced by direct anthropogenic burning. Manipulation of vegetation covers in the ecosystems during activities that removed or changed the composition and configuration of fuel has affected the fire regime and greatly influenced the course of forest fires (Tab. 4.2). Some ways of using the forest brought about total deforestation and thus made forest fires impossible, while others entailed considerable displacement of tree species composition or removed wood in a way that resulted in large changes in fuel configuration. A good example of qualitative impact in modern times may be a lack of preference by forestry for mineral rich deciduous trees that burn poorly, or stated another way, the high preference for fuel rich coniferous trees that burn well. Historically different ways of use have entailed harvest of wood that changed both quality and density of fuel. Some encroachements entailed large and massive

wood harvest, others were smaller, more diffuse and therefore difficult to quantify. An example of the latter may be a steady removal of standing dead wood ("snags") and fallen trees for firewood during one succession after another over long periods. The fuel of the Norwegian landscape has been manipulated to an extent that makes it almost impossible today to determine what is meant by the "natural" course of a forest fire. We will describe these harvest activities and future research that must quantify and clarify more closely what importance the removal of wood may have had on the fuel regime.

4.3.1 Iron melting

The first wood consuming activity is iron melting (bloomery) and tree coal burning. Coal (carbon) is bioenergy that most civilizations throughout the world have used for heating, cooking and for running both simple and complicated technical processes. Signs of coal burning are found everywhere in the country where there has been sufficient supplies of wood and timber. All tree species have been used for coal burning. Much of this burning has been connected with iron production from bog ores in bloomery furnaces (Fossum 1992a). Iron melting in Norway can be traced back to the year 100 B.C.

The impact on the forest through removal and burning of wood for local iron production from bog ores has played a far larger role than the real mines (Sandmo 1951) (See later).

Signs of iron production are found in valley and mountain areas in South Norway, particularly in the inner parts of southeast Norway (Østlandet) and in Mid-Norway (Trøndelag). There are large concentrations in Telemark county and Setesdalen and more scattered occurrences toward the coastal areas at Møre (Fossum 1992b).

In the southern part of Norway most mountain rural villages exhibit remnants of the old bog ore melting activity (Sandmo 1951).

Iron melting seemed to develop into a large industry in areas adjacent to mountains during the transition to the Younger Iron Age. The production peaked in the beginning of the Middle Age (Magnus & Myhre 1976); the first ironworks started their activities just after it (Sandmo 1951).

In some local areas, for example in Østerdalen, bog ore melting lasted until the 19th century (Sandmo 1951, Fossum 1992b).

This activity demanded enormous amounts of wood. The most interesting feature of bog ore melting related to forest history is that its sites of main activity are within areas that have no forests today (Sandmo 1951).

4.3.2 Tree coal burning and mining

An increased need for wood came with the development of mining that encompassed other metals than iron (silver, copper etc.). Mining as a new economic activity in Norway fully emerged during the last part of the 15th century (Benedictow 1977), while organized mining in Norway can be traced to the 1520s (Fladby 1977). Large amounts of wood were needed for this complex industrial activity, mostly for the production of charcoal. This type of coal was made by burning charcoal kilns everywhere in forested areas, but was also produced through use of wood wasted from the sawmill industry (Dyrvik 1978).

Even though there are no good surveys of the wood consumption of the tree coal burning itself, it must have been large. This can be seen indirectly through the number of sites that were used for operations and specifications of what they have produced. Peasants in the area from the lower part of Drammensvassdraget were obliged to deliver charcoal to the silver mine at Kongsberg, the largest and best known of the Norwegian mines. During peak production around 1770 the annual production was up at 35 000 "mark" or approximately 9 metric tons of silver (Dyrvik 1978).

There were 17 ironworks in Norway in 1720, all situated in a belt from Nedenes to Odalen. An additional 7 factories were established later during the 18th century (Dyrvik 1978). The production at these ironworks was increased throughout the century, from around 6 000 metric tons annually in 1720 to 9 000 metric tons in the 1790s. The value of the production increased considerably because of higher prices towards the year 1800, and then the value decreased.

Copper mines or copperworks exhibited a similar trend. In addition to the older works at Røros, Løkken, Årdal, Kvikne and Selbu during the 18th century, two new factories were set up: Folldal and Mostadmark. During the first part of the century the annual production was around 400 metric tons annually. In the 1770s this had increased to 750 metric tons, and then the production declined (Dyrvik 1978).

Also in Sweden extensive burning of charcoal occurred for mining purposes (Tenow 1974). [4.30)] Of the various

parts of mining activity the handling of iron was the oldest and during later times without comparison the most important one. During the period 1600–1720 the iron production doubled fivefold; something that corresponded to an equally large increase in the consumption of wood (spruce and pine) for this purpose. The consumption of charcoal in Sweden had a marked culmination during the last half of the 19^{th} century. After 1920 a decline in the consumption occurred. During the peak year 1885 the consumption of wood was 6.5 millions m^3f or 20–25 % of the nation's total cutting. In local areas, for example at Bergslagen in Sweden, the total consumption from mining activities during the 1740s, was estimated to be as much as 54 % of the growth (Wieslander 1936, Arpi 1959). Political interests associated with the development of mining led to laws and regulations against swidden agriculture (Tenow 1974). The forest was harvested so hard locally in Norway that new stands did not reappear. A well-known example is the district surrounding the copperworks at Røros.

4.3.3 Salt boiling

Salt boiling was undertaken along the Norwegian coast and was supposed to contribute considerably to the decline of the forest at the southwestern part of Norway (Vestlandet) (Sandmo 1951, Tveite 1964). To get seawater evaporated over open fires or at particular salt boiling factories, there were high demands for fuel. If this took place over open fire, it is estimated that 3 fathoms of firewood were needed to produce one barrel of salt. Older reports in Fosnes parish indicated that to produce 800–900 barrels of salt annually, thousands of fathoms of firewood were removed from the forests (Sandmo 1951).

Because salt was an absolute necessity in any household, it was common that people who lived in the inland got rights to burn salt at the coast. Salt burning activity is old in Norway. This technique appears in Harald Hårfagre's saga, where a particular class of workers is denoted as the "salt guys" (Norw. "saltkarlene") (Tveite 1964). Salt was also prepared for export. Salt boiling was one of the most important industries during a period in Norway. During the 16^{th} century several foreigners arrived who founded salt factories at various places in the country (Sandmo 1951).

In the 17^{th} century the salt boiling activity gradually declined. During the 1650s a salt company was founded in Copenhagen that monopolized the salt trade in Norway. However, the salt boiling continued for 200 hundred more years, until the 19^{th} century, in spite of the import of a large amount of salt.

One of the factories that was used for the longest period was Vallø salt factory outside Tønsberg in Vestfold county. Around the year 1800 this factory switched from wood to peat as firewood, since sufficient amounts of wood were not available.

4.3.4 Potash burning

Another activity consuming wood was potash burning. Potash, or potassium carbonate K_2CO_3, was made from ashes of deciduous trees, particularly birch. The production took place by lying the ash ("in pots") with water and then evaporated the water by boiling the lye. Potash was used in the production of washing powder, dyes and certain sorts of glass, in the treatment of fish ("lye fish", i.e. dried codfish prepared in a potash lye) and as fertilizer (Rugsveen 1989).

In connection with glass production, potash was produced in large quantities in Norway (Rugsveen 1989). Glass consists of various chemical compounds, the main constituent being silicic acid. In nature it occurs as the mineral quartz in the erosion product sand. To ease the smelting of this parent material a flux (Norw. "flussmiddel") is added. Potash was used for this process. [4.31)]

There was high demand for potash. For Norway to become as independent of import as possible, it was necessary to establish specific potash factories. One of the first potash factories was built at Minne by Minnesund in Eidsvoll; this was operative from 1741–42 and was the largest in Norway.

The development of potash cooking or boiling in organized forms accelerated from the end of the 1760s through privatization of the factories. Production of potash in Norway remained stable at a high level by the use of fixed prices. From 1787 the potash cooking became free; this led to the establishment of many small potash factories in rural areas. However, it was in forested areas in the southeastern part of Norway (Østlandet) that most of the potash cooking occurred. Large amounts of potash were burned throughout the 1870s after the privatization of the industry, and in many rural districts the potash cooking was an important and profitable industry. Potash was a very important export good from Skjåk, where it was stated:

> "To get enough ash, one partly used to gather firewood in the mountains for large fires which were burned to get ash to lye. The mountainous forests were ruined in this way. The wood from forests at high eleva-

> tions was expected to give a more clear ash lye than that from the valleys." (Translated from Rugsveen 1989, p. 306).

The same source relates that the activity during the 19th century gradually influenced the mountain forests considerably by removing large amounts of wood for this burning.

There are relatively detailed surveys of potash burning from some areas in Sweden [4.32]; these tell much about the extent of such activities (Tirén 1937).

Potash was burned at the cutting site, and the location of the potash fires in the terrain and their age is possible to determine based on spruce regeneration at the site, and fire scars [4.33] on trunks near the fires. Tirén (1937) surveyed where the fires were located at a Swedish forest estate and showed that they were common (Fig. 4.7). The figure only shows the fires that were possible to date; the total number was many times larger. There are no full descriptions of potash burning in the Nordic countries during historic time (Östlund 1996).

4.3.5 Tar burning

Tar burning is another wood demanding activity that took place throughout Norway where pine occurred. [4.34] Production of tar can be traced to prehistoric time. Throughout the Middle Age and until the 20th century, tar burning was an important way of utilizing the forest (Fossum 1992c). Tree tar was used for impregnation and tightening of wooden structures, particularly in houses and boats (Tveite 1964, Tenow 1974, Fladby 1977).

During the period of peak production tar was a bulk product in Norway. The activity took place on a large scale during the Middle Age, and tar existed among the payment goods from the peasants early in the 16th century (Fladby 1977).

In the 12th century the Gulating Law stated that tenant farmers must not burn more than they needed to tar their boats (Fossum 1992c). This production was subject to restrictions. Tar was a popular export product during the Middle Age. Tithe (Norw. "tiende") was introduced in 1277 on tar (Fossum 1992c).

In Sweden raw materials for tar burning became scarce. Consequently, production, due to local depletion, was moved from area to area to get access to raw materials (Tirén 1937, Borgegård 1973, Tenow 1974). However, the largest tar production occurred in Finland (Kaila 1931, Alho 1968, Heckscher 1968).

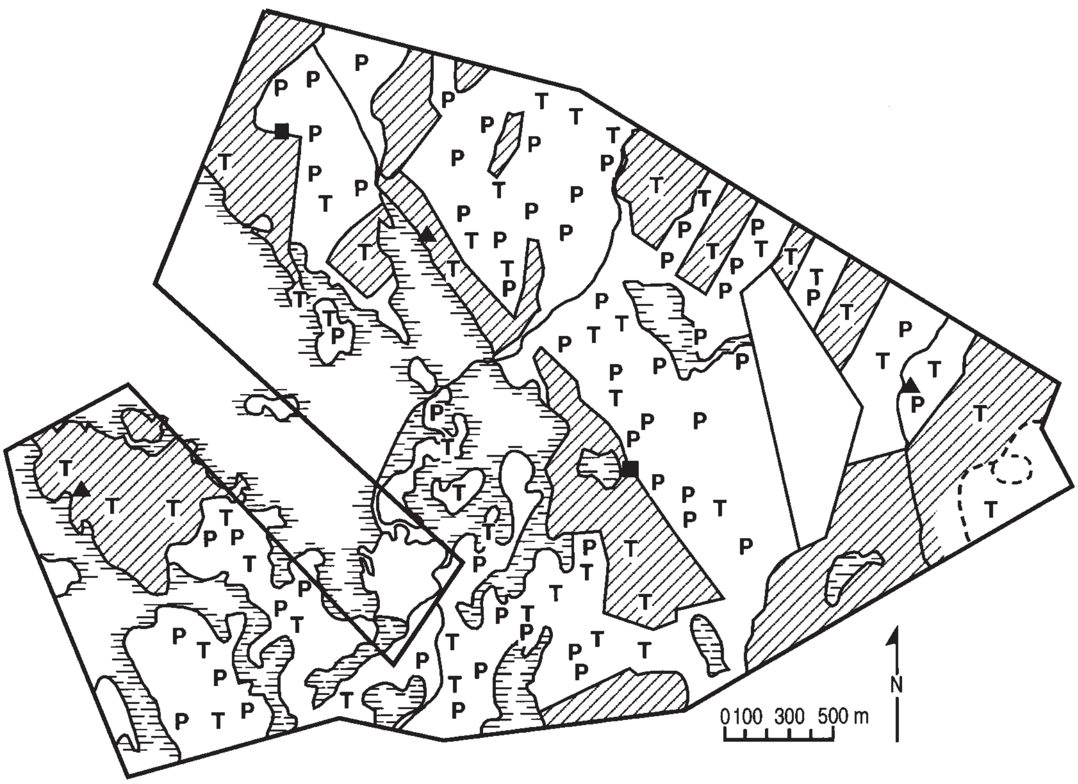


Figure 4.7. Locations for burning of potash (P) and tar (T), respectively, on a forest estate in Sweden are depicted to illustrate how densely such burnings could occur. Hatched areas denote clear cuts (Redrawn after Tirén 1937).

For some time tree oil was produced in Norway; it was distilled in large factories. This production also yielded other important products such as the resinous pinewood (Norw. “tyri”) roots that were later burned to common tar, and the remains to charcoal. At a factory in Sør-Odal municipality in Hedmark county founded in 1863 it is denoted that 150 fathoms of firewood and 200 cubic fathoms of resinous pinewood produced 15 000 pots of raw oil and 255 barrels of tar (Try 1979).

4.3.6 Wood harvest for fuel and home purposes

In connection with summer dairy farming in Norway during the postglacial period large amounts of wood was harvested for different purposes such as fuel and later construction activities (particularly lumber for house building). [4.35)]

The unsystematic cutting initiated by peasants gradually developed into various forms of forest utilization of a more commercial nature. Lumber was first cut with axe (later with saw) or split. Slowly a considerable sawmill industry developed in Norway; this industry exported planks and other wood products. This production was before the industrial era counted as a subsidiary income of agriculture (Tenow 1974). [4.36)]

4.3.7 Commercial forestry

Commercial forestry has harvested enormous amounts of wood for centuries and has been one of Norway’s most important industries.[4.37)] Cutting and harvest methods used in forestry have changed forest succession and tree species composition across large areas; this also changed the quality and configuration of the fuel for forest fires.

Timber and sawmilling

Historically, the export of timber and other wood products by commercial forestry, has old roots in Norway. As early as the Viking Age timber was cut and shipped from Norway to Iceland; since that time timber has been exported from Norwegian harbors. There was easy access, with short distances to timber resources (Sandmo 1951, Tveite 1964).

Even though the saw is an old hand tool, the axe was the tool of choice. For a long time timber was processed with axe. Logs were split lengthwise and one plank made from each half; in Norwegian this is called “huggenbord” (“hoggenbord”). A breakthrough came with the development of the first water-driven saws, in Norwegian called “oppgangssager”. Introduction of water-driven saws was one of the most interesting developments among new impulses to economic growth emerging during the last part of the 15th century (Benedictow 1977).

As early as the 13th century timber export from Norway was considerable. During later periods Norwegian timber trade dominated, occasionally controlling the market (Sandmo 1951). The sawmill industry of Scandinavia developed relatively quickly during the 17th and 18th centuries, where the export from Sweden doubled several times (Tenow 1974).

The next important step in the development came in the middle of the 19th century, when large sawmills based on steam-powered saws emerged and produced for export.[4.37)] The two first in Norway were operative in 1859 (Try 1979). Thereafter, technical changes appeared successively. From the turn of the century a gradual transition to the use of electric power started in the industry; the transition was not completed until the end of the interwar period (Fuglum 1978). Postwar electrification of the sawmills and the use of circular saws again implied a new inland decentralization of the production through the use of small saws in local areas (Tenow 1974).

Pulp wood and pulp mills

Building of factories for production of pulp, chemical (wood) pulp and paper was an activity that speeded up forestry from the end of the 19th century (Eknæs 1975). 4.37) Pulp mills were built in quick succession from the middle of the 1860s (Try 1979); by 1887 55 pulp mills were in operation. In 1863 the first paper fabric based on pulp was built in Oslo (Try 1979). Production based on pulp wood at first proceeded slowly, then accelerated at the end of the 19th century. In 1920 the value of paper, cardboard, and pulp constituted more than a third of Norway’s export (Fuglum 1978). The historic development of commercial forestry in Norway can roughly be summarized into four important time periods (Tab. 4.5). [4.37)]

4.3.8 Fuel structural changes

Treatment of forests during the last 100 years, especially the introduction of modern forestry and its focus on forest stands, has entailed massive changes in the forest structure. In addition to undertaking extraction of timber modern forestry also has conducted extensive silvicultural efforts that have resulted in a buildup of more biomass (more fuel) in many areas earlier characterized by hard cutting and overharvest. [4.38)] To demonstrate this

Table 4.5. Important time periods in the development of commercial forestry where anthropogenic activities have "manipulated" the biomass of fuel in Norwgian forests through the removal of large amounts of wood (Adapted and translated from Aanderaa et al. 1996).

Time of "axed planks" (the years 1100–1500)
The population size increased considerably until the Black Death in 1349. At that time approximately 300 000 humans lived in Norway. Lumber or planks processed with axes ("axed planks") were exported, particularly to England and the Netherlands. Adjacent to important harbors in the western parts (Vestlandet) and in South Norway available forests for exploitation were scarce. In comparison, there was lesser impact on inland forests.

Time of sawmills (the years 1500–1650)
The first water-driven saws were important to forestry development. Combined with river transport of timber through driving, these saws made it profitable to cut lumber across large forested areas. During the period 1520–1620 this led to a large expansion of the timber export. The timber export from harbors in South Norway was doubled 16 times during that period.

Time of wood conversion (the years 1870–1950)
The steam saw replaced the early water-driven saws of the 1850s, and during the 1890s the timber conversion industry emerged. This led to the selling of new products on the market. Also, small trees could be utilized for "pulp wood". In many forested areas additional stands were cut during this period. Agnar Barth, a Norwegian professor of forest management, estimated in 1917 that the cutting was 30 percent higher than the regrowth.

Time of modern forestry (from 1950 until today)
With introduction of modern stand-related forestry a new era followed. Through systematic care of forest stands, Norway's forest resources were to be renewed after several hundred years of "mismanagement". Modern forestry built on biological knowledge adequate at that time. Clear-cutting was undertaken to allow light and warmer temperatures to penetrate to the forest floor. Cuts were to be planted and the regrowth was to be cared for based on scientific principles. In this way modern forestry managed to renew and rebuild timber resources.

anthropogenic impact on fuel we will look at the stratification or storying of stands.

A forest stand is structured in storys or strata. The trees constitute the *tree stratum*. Closer to the ground is the *bush stratum* (Fig. 4.8); this often consists of bushes and scrubs of willow, juniper, bog myrtle or other species. *The field stratum* is developed close to the ground of grass, heather and herbs. At the bottom on the ground several species of moss and lichen grow which constitute the *ground stratum*. The plant species and therefore composition of fuel in the various strata are important concerning how fires progress (Schimmel & Granström 1991). Cool fires in Norway most often develop as light surface fires (See fig. 2.10) in the field/ground strata and in the upper humus layers. The changed configuration of the fuel may be demonstrated by a visualization of the story patterns (Fig. 4.9).

In *one-storied stands* all tree crowns appear in nearly the same height. Such stands are open in the vertical section (seen from the side), so that horizontal air currents may find easy passage between soil surface and crown roof. However, in many dense stands there is sparse forest floor vegetation to support surface fires (Fig. 4.9, A).

In *two-storied stands* where there is a layer of smaller trees under the dominant trees, the stand may be relatively well closed both vertically and horizontally, and surface fires will increase their probability of reaching higher layers.

Multi-storied stands have trees mixed at "all" heights. In its best-developed form virtually the entire air space between the soil surface and tree tops is filled with branches, twigs and assimilation organs. Here surface fires may reach higher layers much easier.

As the modern stand focused forestry consciously has created many even-aged stands through clear cutting, it indirectly influences the progress of forest fires. At the same time one has for a long period systematically removed or reduced the element of deciduous trees that burns relatively poorly.

4.3.9 "The cutting class landscape" (Norw. "Hogstklasselandskapet")

Forest composed of one and the same tree species, with trees of various age, will have highly variable combustibility and thus also have different risk of burning (Van Wagner 1978, 1983, Foster 1983, Bonan & Shugart 1989, Granström 1991a, Schimmel 1993). Various successional stages are in addition to tree age also characterized by differences in forest floor vegetation and tree species composition. In the recent period with fire sup-

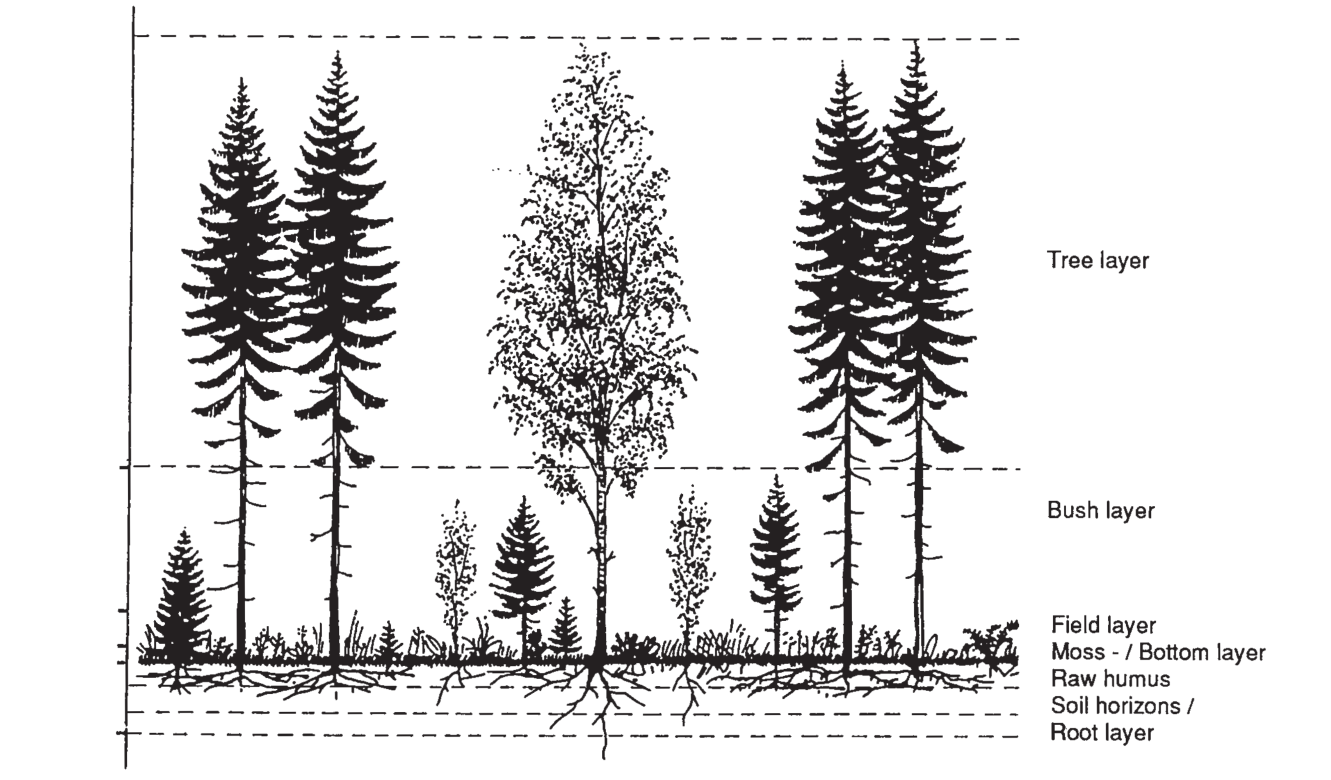


Figure 4.8. Terminology for stratification of forest (Combined from Börset 1985, Larsson et al. 1994).

Table 4.6. National Forest Survey's (Norw. "Landskogstakseringens") traditional classification of cutting classes (roman numbers I–V).

I	Forest under regeneration (clear cuts, seed tree stands etc.)
	1. Satisfactorily regenerated/cleared
	2. Not satisfactorily regenerated/cleared
II	Regenerated sites and young forest
	Young forest before the age when it normally should be thinned. This is further subdivided into several subgroups where developmental stages or phases, origin (cultural or natural regeneration) and density are decisive factors.
III	Younger production forest
	Younger forest that has reached such a development that it should be thinned or already is thinned.
IV	Older production forest
	Middle aged and older forest that judged only on the basis of age is not characterized as mature enough for cutting.
V	Old forest
	Older forest. Judged from age this forest would normally be judged as mature for cutting.

pression the successional conditions are almost totally conducted or dictated by forestry. It has been created a "cutting class landscape" where it is almost impossible, based on contemporary stand conditions, to have any opinion about how stand stratification and the age distribution of forest trees would have been in a "nature forest" at that site if lightning ignited fires were allowed to develop freely (See Van Wagner 1978). An aid to assist the description and classification of forest conditions with respect to development and maturity is the so-called *cutting classes* (Tab. 4.6).

The condition today may be illustrated by viewing the contemporary distribution of cutting classes in Norwegian forests (Tab. 4.7). After initiation of surveys of the forest structure by these kinds of statistical tools, the impact of forestry on the fuel regime may be concretized in a totally different way than earlier. By means of the cutting class

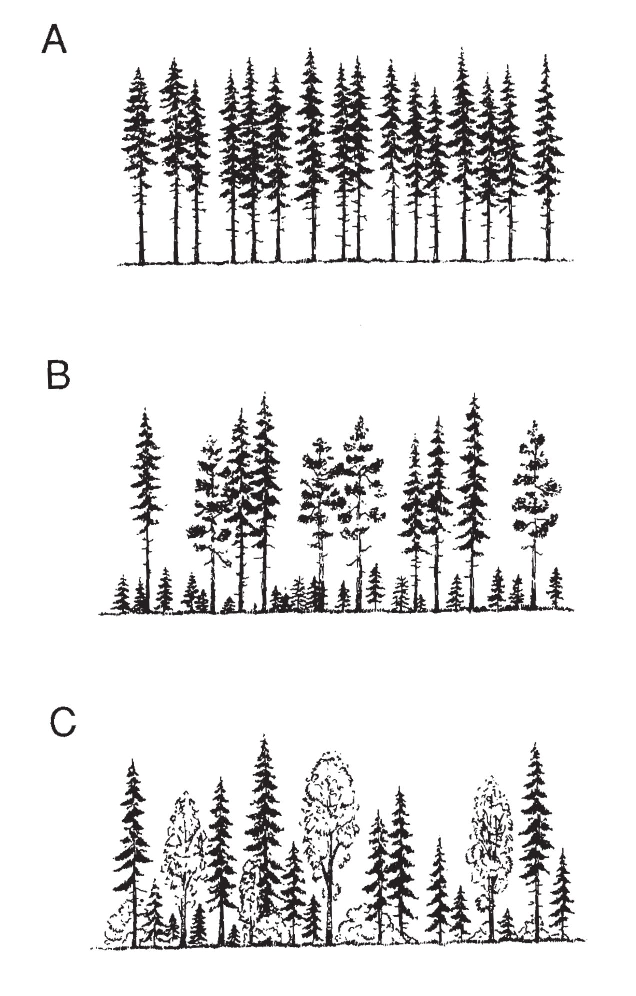


Figure 4.9. Storying of forest. One-storied spruce stand (A), two-storied, mixed stand (B) and multi-storied, mixed stand (C) (Redrawn after Börset 1985).

development and the cutting history the variation of the fuel at the individual location may be quantified over time in a far more detailed way than was possible earlier.

The structural shape of today's forest is the result of a long historic process, where conditions of succession, tree species composition and age distribution are predominately influenced by forest treatment during the last century.

Anthropogenic configuration

Wild fires which occur where modern stand-focused forestry and forest fire suppression has been undertaken, will often burn with another, higher temperature regime than in comparable areas where fires have not been suppressed. The above is due to the combustion of large amounts of slash accumulated on the forest floor in some areas of the first type. Another anthropogenic effect in areas where one has for a long time practiced suppression, also a larger load of fuel in the form of many standing dry trees ("snags") and fallen trees which influence the progression of fires.

Therefore, the situation in most Norwegian forests is that if one wants to study the "natural fire regime" and let lightning ignite a fire, the interpretation of the result will become problematic because the composition and configuration of the fuel across large areas is determined by humans. The fuel in the forested Norwegian landscape is, through systematic cutting and silvicultural efforts from forestry, manipulated to an extent that makes it almost impossible to mean anything further about what is a forest fire's "natural" course. The above insight will be used when we later discuss objectives in fire management (ch. 9).

4.4 Anthropogenic reduction of fires

The growth of the forest industry and high demands for pulpwood led to trees of smaller dimension becoming valuable. Commercial forestry and industrial timber cutting brought about huge changes. Forest roads were built which fragmented earlier continuous fuel complexes and created artificial fire barriers. Besides, roads eased the access to extinguishing and controlling forest fires. The extraction of wood was accompanied by silvicultural activities and management efforts which led to continuous changes in distribution, composition and configuration of fuel through changes in tree species frequencies, age, tree dimensions, tree densitiy, edaphic and regeneration conditions.

Through a long period modern commercial forestry stimulated and aimed for economically important, but also highly combustible species like spruce and pine in even-aged and as homogeneous stands as possible. However, an increased tolerance for deciduous species has quite recently begun to prevail.

From the middle of the 19th century the industrial and economic development has led to increased suppression of forest fires. Insurance arrangements also were slowly developed for forests in Norway.

4.4.1 The emergence and expansion of forest fire suppression

At the time of king Kristian the fourth (1577–1648) laws were established to protect the forests against fire (Strømsøe 1961). The Forest Commission (Norw. "Skogordinansen") of 1683 referred to these laws and

Table 4.7. Countywise survey of the cutting class distribution in Norwegian forests 1994. Percent is presented in brackets (For definition of cutting classes, see table 4.6) (After Tomter 1994).

County	Cutting class				
	I	II	III	IV	V
Østfold	8 (4)	56 (24)	42 (19)	56 (25)	64 (28)
Akershus/Oslo	16 (5)	89 (28)	75 (23)	75 (23)	67 (21)
Hedmark	72 (5)	315 (24)	307 (23)	272 (21)	354 (27)
Oppland	39 (6)	153 (21)	125 (17)	148 (20)	258 (36)
Buskerud	25 (4)	126 (22)	106 (19)	126 (22)	189 (33)
Vestfold	11 (9)	27 (22)	23 (19)	30 (24)	32 (26)
Telemark	26 (5)	109 (21)	79 (15)	119 (23)	188 (36)
Aust-Agder	18 (5)	59 (19)	42 (13)	96 (30)	104 (33)
Vest-Agder	12 (5)	45 (18)	42 (17)	70 (29)	74 (31)
Rogaland	21 (16)	22 (17)	29 (22)	28 (21)	32 (24)
Hordaland	37 (15)	39 (15)	53 (21)	66 (25)	61 (24)
Sogn og Fjordane	27 (11)	35 (14)	44 (18)	44 (18)	98 (39)
Møre og Romsdal	25 (9)	52 (19)	55 (19)	70 (25)	79 (28)
Sør-Trøndelag	21 (6)	67 (19)	62 (17)	105 (29)	107 (29)
Nord-Trøndelag	27 (5)	162 (29)	67 (12)	104 (18)	202 (36)
Nordland	28 (5)	110 (20)	89 (16)	143 (27)	175 (32)
Troms	22 (6)	55 (14)	58 (15)	114 (29)	175 (36)
Finnmark	-	-	-	-	-
The whole country	435 (6)	1 521 (21)	1 298 (18)	1 666 (24)	2 259 (31)

decided among other things the following (Cited and translated from Strømsøe 1961, p. 173):

> "Because cutting of sites, and forest fires by people who burn forests, cause damage in Norway, even if it is forbidden by many laws and regulations; then, if someone is met having committed this, anybody must attack him and if he is a forest Finn, who lives in the forest, or is vagrant, he should have death penalty, and priests and country police ("sheriff") should with eager look thereafter, and when they get such knowledge the bailiff should be informed; but if the priest in whose parish the damage has happened, does not warn the bailiff about it within 3 weeks after it has burned, he has to give to the next hospital 30 Rdlr. (Eng. "hist"=Rdlr=riksdaler, old Norwegian money) for each time, it happens, but if he agrees with it and hides the guilty, then he loses benefice (Norw.: "prestekald, kald")". (original version is in oldstyle language and is not translated in detail).

Modern law and regulations began in 1893 when "Law of restrictions in use of fires in forested outlying range etc" (Norw.: "Lov om indskrænkninger i brug av ild i skog og mark m.v.") was passed. The law of 1893 forbade the use of fire during periods of dry weather and strong winds and during any conditions when forest fires could break out. Burning to improve pasturage and heather burning in June, July and August was forbidden. The law gave permission for local councils to pass rules about prevention and extinguishing of forest fires (Strømsøe 1961). How serious the government viewed forest fires at that time, will be illustrated with some quotes from the regulations that gave authority to the local network responsible for extinguishing fires, viz. § 4 and § 6 of "Skogbrandsregler for Hemsedals Herred" [Eng.: Forest fire rules for Hemsedal municipality] submitted in a royal resolution of September 17, 1900 (document borrowed from the archives of "Skogbrand Insurance Company, Oslo"):

> "§ 4 Any adult and capable man settled within the municipality, who is fit to take part in the extinguishing work and has no legitimate reason for being absent, is obliged after being called for by a local foreman (Norw. "brandrodemester") to meet at the fire site bringing suitable tools, such as axe, spade or pick and there carry out whatever duties the foreman instructs him to do. The extinguishing work is to be judged

as an aid, which in general should be given without payment."

"§ 6. To stop or delimit forest fires the foremen of the extinguishing task force, without respect to objections from the landowners, judged from the circumstances might cut adjacent forest, dig ditches, tear down fences, start counter fire and any other necessary actions to extinguish the fire. However, he should, before he undertakes serious actions of mentioned kind, to the extent time and circumstances allows for, seek advice from other fire foremen or members of the municipal council, who happen to be present."

4.4.2 Steadily improved laws and regulations

In 1921 the law was revised. It became mandatory to establish permanent committees in all municipalities to be responsible for carrying out the rules. Each municipality was thus expected to have a forest fire chief, and the municipality to be divided into fire districts, each with a responsible fire officer. Each municipality should make sure that the regulations in the law were followed and accomplished, and they had to warn immediately when a fire broke out. Rules were subsequently established to increase the efficiency of forest fire prevention. For details we refer to Strømsøe (1961, 1987) and Kaafjeld (1987).

As with other forms of fire it is important that forest fires are discovered and reported as early as possible. This fact resulted in immediately building fire watch stations in Norway. These were established on elevated sites and activated during dry periods. Thus in 1907 as many as 12 fire watch towers operated in Hedmark county. In spite of the fact that forest fire laws in this first period did not specify who had the responsibility for the building and maintaining of forest fire watch towers, different institutions with contribution from "Det gjensidige norske Skogbrannforsikringsselskap" managed to keep this state of readiness intact (Strømsøe

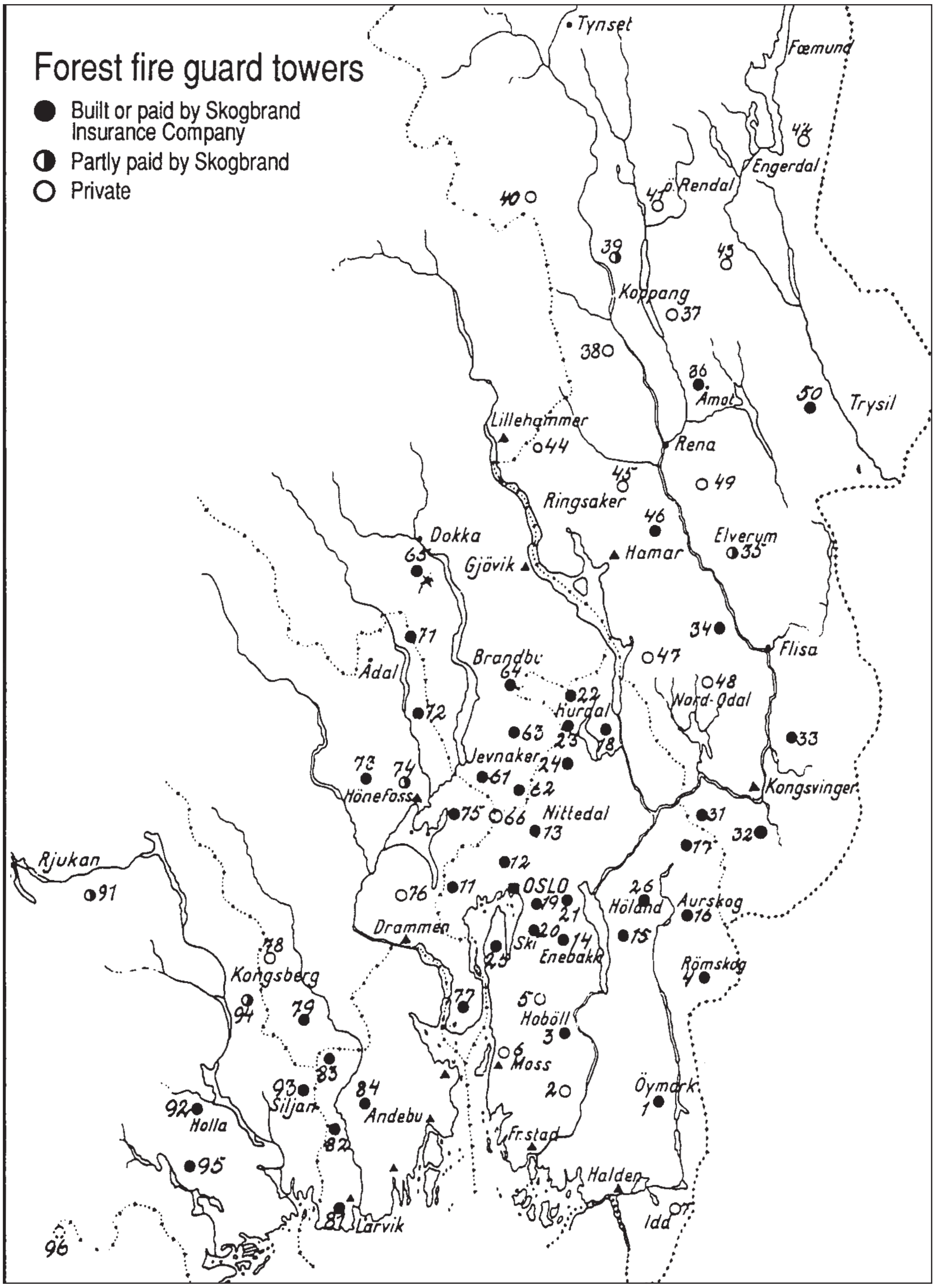


Figure 4.10. Forest fire guard towers in Norway 1942 (After Vevstad 1987).

1961). In many districts the number of watch towers was not sufficient, nor the towers sufficiently equipped. With the introduction of a forest fire warning service using airplanes and more efficient extinguishing methods, a new era in the organization of forest fire prevention developed in Norway. Contemporary forest fire suppression efforts in Norway are described and discussed later (See ch. 10), also the modern law and its regulations (ch. 12).

4.4.3 Introduction of forest fire insurance

The task of forest fire insurance is to render compensation for forest damaged by fire. It was the dry summer of 1899 that initiated serious thoughts and consideration of forest fire insurance in Norway (Strømsøe 1961). During 1912 "Det norske gjensidige Skogbrandforsikringsselskap" ("Skogbrand") was founded. As the name signifies (Norw. "gjensidige" = "mutual"), the company is a mutual forest assurance company where any forest owner, private or municipal, public or semipublic, may become admitted as a member with all forest estates. As a result of the company's mutuality, prospective profit could be allocated to funds with the intent of regulating the fees (Strømsøe 1961).

The company's objective is first and foremost to cover losses that might hit individual forest owners, and to prevent forest fires or prevent existing fires from spreading.

In 1923 an "all future insurance" (Norw. "allfremtidsforsikring"), so that a fee could be paid on a one time basis, was introduced. Since 1955 forest owners have had access to cover the one-time-fee for forest fire insurance from available investment means (Norw. "investeringsmidler").

Estimation and adjustments of post-fire damage are undertaken according to common rules for estimating forest value. For earlier estimation of fire damages in forests and the development of such damages in Norway, we refer to Strømsøe (1961).
Skogbrand [4.39)] is today the only insurance company that offers forest fire insurance in Norway. Comprehensive materials about forest fire prevention and forest fire insurance in Norway are found in publications from this company (Skogbrand 1937, Vevstad 1987a).

4.5 Summary

Under the key words anthropogenic burning, we have presented the most important activities that are regarded as having significance for fires in forests and outlying fields.

Historians and other researchers have long pointed out the significance of thunderstorms and lightning strikes as causes of fires in northern areas, and have emphasized that they have played a "dominant role" in the "virgin forest" before human beings colonized the boreal coniferous forests. However, human beings colonized the land as soon as the ice withdrew, so that there has never been any postglacial "history" in Norway without human beings.

The question is how much these immigrants burned in the Norwegian landscape, and how extensive various forms of anthropogenic burning have actually been. The answer to such questions may be an important aspect for understanding the development of the landscape in emphasizing distinctive features associated with the fire regime in Norway after the last Ice Age. Fires can be traced as remnants of coal and ash in the field profiles, however, older traces tell us little or nothing about whether the cause should be attributed to natural or anthropogenic ignition sources. However, lightning strikes will most easily ignite fires on the poorest quality classes (1 and 2), which have the driest types of forests. This stands in contrast to anthropogenic burning for agricultural purposes, which has been carried out on the best quality classes (3, 4 and 5). Human colonization and increased use of forest regions in Scandinavia led to an increase in fires from clearing of grazing lands, swidden cultivation, burning of bonfires and other activities in ancient times. Large areas have been deliberately burned off as a step in pasturage and grain production. Negligent ignition following this use of fire must have caused wildfires in substantial outlying areas. However, the extent of the area affected by fires started through negligence in ancient times is unknown. Certain historical sources indicate that the extent has been significant, particularly in certain periods.

The cultural contribution to the fire regime partly originates from activities that are directly connected with burning, and partly from activities that have altered the fuel and thereby, indirectly, the course of fires, as well as increasingly effective methods to combat fires during the most recent period.

Norway has historically had lively traffic and diverse transportation along the coast, with a corresponding increase in cultural influence on the coastal forests through fires of a different character than those that we must assume have been typical to the inland areas.

A documented example is what we have called "tactical

fires" in Norway. During the so-called "Hanseatic Period" in the Late Middle Ages, many forests were burned as part of an economic trade competition for lumber. Forests were also burned for tactical purposes in other areas, including Finnskogen in Eastern Norway.

Systematic burning on a large scale arrived with the first so-called clearing fires, which followed the great occupations of land, in which people gradually spread out over the country in order to establish settlements and cultivated areas. The use of fire in this connection has been such a self-evident matter that it is hardly mentioned in written sources. Another important type of burning is the various agricultural techniques that are included under the collective term swidden cultivation. The swidden cultivation exploits the climax forest's large stores of latent nutrients in the tree layer and humus mats that were transformed through burning and released for production of useful plants. The most famous historical swidden cultivation came from the east during the 1500s with Finnish immigrants. This was a highly specialized swidden cultivation ("huutha"), which burned spruce of a high quality and sowed rye (*Secale cereale*) in the ashes. Distinctive landscapes gradually developed in areas where swidden cultivation was used extensively.

Other important types of burning have been various forms of pasture burning, which have been used to create and improve pasturage for domestic animals. Highly specialized pasture burning lies behind the formation of the so-called coastal heaths that were developed throughout large areas in Europe. They are ecosystems created purely by means of culture and fire. These areas were maintained through a balanced cycle of burning, grazing and cutting. Pasture burning has been carried out as field burning everywhere in outlying field areas. A hypothesis has been proposed in Sweden to the effect that so-called "shoot" or "coppice forestry" was carried out earlier to produce branches and twigs as food for domestic animals, but which has also required burning ("sprout forest burning"). There is, however, no information that this form of forage production was ever applied in Norway, but the possibility should be investigated.

Experiences from swidden cultivation have been continued in forestry as so-called clear-cut burning. Felling areas have been burned during periods to stimulate regeneration of forests, particularly pine. This came to Norway from Sweden and Finland, but never became as widespread a management method as it was in our neighboring countries. Another and new form of forest burning is the so-called patch burning, i.e. a patch-by-patch scorching of vegetation as an aid in the regeneration phase for forest trees. Burning to improve the conditions for certain types of game such as willow grouse and black grouse is also familiar. The experiences from such burning here in Norway have been mixed.

The newest form of anthropogenic burning is conservation burning or diversity burning, i.e., burning to protect and enhance biological diversity. The first burning of this kind in Norway was carried out in Hedmark in 1996.

Culture-related activities that have changed and influenced the fuel in Norwegian forests have primarily been activities that have entailed the removal of substantial amounts of wood (Table 4.2). Among the most comprehensive of these are the old iron melting (Norw. "jernvinna") and charcoal burning, the latter particularly in connection with mining operations. Many areas were worked so intensively that the forest disappeared. Other uses such as salt boiling, potash burning, tar making and extraction of significant resources for fuel and household needs have also demanded hard exploitation of the forest areas. Commercial forestry has ancient roots, but the forestry industry really accelerated with the inception of sawmill operations. The cultural influences that arrived with stand-related forestry after 1950 have been most important with regard to setting their marks on today's forest scenario and structural changes in the fuel.

The cultural changes have now progressed so far through the harvest techniques, extraction of wood and silvicultural activities that the configuration and composition of the fuel has been completely changed in large areas. Therefore, the situation in many Norwegian forests is such that, if you want to study the "natural fire regime", it will be difficult to interpret the result because the configuration of the fuel is culture-dependent. It has become impossible to have an opinion regarding what the "natural course" of a forest fire is in today's "cutting class landscape". An important cultural history development came a little more than a hundred years ago with increasingly effective methods to fight fires. Moreover, the number of anthropogenic ignition sources has increased, both around the major urban centers and otherwise in the landscape. Today the anthropogenic ignition sources totally dominate the Norwegian fire regime.

5 FOREST FIRE HISTORY

By Ivar Mysterud and Erik Bleken

The fire history of forests and outlying ranges is a basic part of the history of the landscape. This history may also teach us much about resource use in outlying areas in various periods. There is, however, no collective account of the fire history of Norway, and the fire history seems both extensive and difficult to track. In addition, few stratigraphical soil surveys are conducted in outlying areas with primary emphasis on dating and interpreting carbon remnants and other signs of fire. Therefore, mainly fragmented information is presented in this technical report.

We will address three historic epochs: the older, newer and modern fire histories. The older fire history concerns a long-term perspective in postglacial time, the newer history a relatively short-term perspective (approx. 500 years B.P.) and the modern history from the last 200 years. From the latter it is also possible to study conditions through written sources, which are relatively easily accessible (ch. 6).

5.1 Older forest fire history

The shaping of the boreal coniferous forest belt is generally determined by climatic, soil (edaphic), topography and biotic conditions (ch. 1). The forest structure in individual stands has constantly changed both in time and space as a result of disturbances like wind fellings, snow breakage, fungi, insect attacks and fires which have occurred individually or in concert (Hunter et al. 1988, Bonan & Shugart 1989, Bradshaw & Hannon 1992, Engelmark 1987, Engelmark et al. 1993). Forest fires have supposedly played a decisive role in shaping the spatial structure of the boreal coniferous forest belt in the postglacial period (Bonan & Shugart 1989, Schimmel 1992), and have in many places probably been the most important single factor in this respect (Zackrisson 1977a,b, Schimmel 1992). Fires have in many areas created and maintained a landscape mosaic with considerable variation within and between stands, and have thus maintained the diversity and dynamics of the forest system over long periods (Zackrisson 1977a,b).

In some areas, fires have shaped the coniferous forest over large areas, while disturbances like wind fellings and pest/diseases have been decisive elsewhere. Some stands have of course also developed completely without influence from fires.

It is impossible to establish the older fire history of an area solely through studies of the current vegetation. The vegetation today has mainly developed through recent succession, and is rarely more than 300–500 years old. The soil itself must therefore be examined, for example by studying humus layers and soil profiles (e.g. podzol formation or by taking core samples to survey pollen and carbon remnants (ch. 2).

Such examinations have already revealed past patterns of frequent small fires in both Norway and Sweden that have been characteristic for large parts of the landscape. Many of these small fires were presumably caused by active anthropogenic burning in connection with various commercial activities (See ch. 4), or by carelessness in connection with these or other activities (Tenow 1974). Forest fires have thus varied in size locally, while large fires may have occurred with highly variable frequencies (Tenow 1974).

5.1.1 Regional and historic trends

One can already see some historic trends in the performed examinations. The frequency of fires generally seems to have been high in the southernmost areas of Scandinavia where human activity has been most extensive. This is consistent with what one may indirectly deduce from population development and historic colonization of the landscape (ch. 4). In Sweden, even within areas that today are national parks, the present forest structure may have been determined by past frequent burnings linked to human activity (See Page et al. 1997). Such studies are lacking in Norway.

A central question that steadily emerges is how much the forest fire regime is influenced by humans. It is easy to underestimate the importance of total human activity in the boreal coniferous forest, because some important

anthropogenic burning types leave, besides carbon, few (e.g. only pollen) or no permanent signs that may be registered and properly identified (See e.g. Tvengsberg 1995b). Even though core samples have been taken in forests, which today are outlying areas, to survey pollen and carbon remnants, determining the burning types from which the remnants descend may be difficult. That a certain locality or a forest stand has poor soil today, does not guarantee that swidden agriculture has not been practiced there earlier, as previous burnings may have reduced soil quality (See section 4.2.5).

It is therefore uncertain which elements of today's climatic and ecological conditions may be used to evaluate hypothetical scenarios from older times, and how these conditions are to be evaluated.

Based on current climatic conditions, we would suppose that inland areas also previously have had a higher fire frequency than coastal areas, due to frequent thunderstorms and a continental climate in the former (ch. 3). Lightning for example caused 20–30 % of all forest fires in North Sweden in the period 1900–50 (Zackrisson 1977a). These numbers are of the same magnitude as today's fire regime in Hedmark county (23 %) (ch. 6). If we estimate that the lightning has caused 30 % of the fires in the last century in the areas where this natural source of ignition is most prevalent (Hedmark), 70 % therefore originate from anthropogenic ignitions in these parts of Scandinavia in this period. Thus, important questions are on one hand associated with how much "natural conditions" have changed (ch. 3), and on the other, what are the "natural" fires' share of the total fires throughout prehistoric time when the changing role of humans is taken into account (ch. 4).

Several researchers assume that lightning has been the most important cause of ignition in areas of sparse human activity (Romme & Knight 1981, Foster 1983, Engelmark 1987, Granström 1991a, 1993). The question is, however, on what basis the degree of "human activity" in such areas has been documented. As mentioned, all burning types do not leave permanent signs (in addition to carbon remnants) that make it easy to identify them today. Such a working hypothesis should therefore not be transferred to Norwegian conditions without reservation, given the country's considerable coastal areas, where anthropogenic burning is known to have been of great importance. Another hypothesis to which we have placed much emphasis, is that human activity associated with burning may have been of especially great importance in Norway, where the population growth has occurred in far more limited forest areas than in the wider and more continental forests of Sweden and Finland.

Documentation of even the most basic traits of our older fire history is still lacking.

5.2 Newer forest fire history

It is far easier to survey the newer fire history. Regardless of the uncertainty about the relative importance of natural and anthropogenic ignition sources, there is today general agreement that the fire regimes influence plant communities and their distribution in the landscape (Zackrisson 1977a, 1997, Romme & Knight 1981, Foster 1983, Van Wagner 1983, Bonan & Shugart 1989, Zackrisson & Østlund 1991, Schimmel 1993, Granström et al. 1995). This is documented through extensive research into how forest fires lead to changes on relatively recently burned sites, and how the vegetation colonizes such areas. Such research has traditions back to the 1930s in Sweden (Högbom 1934, Wretlind 1934, Kinnman 1936, Tiren 1937, Uggla 1958, Tenow 1974).

Classical Swedish studies of fire damage ("fire scars") on old trees have been carried out in limited areas to elucidate the fire frequency. Certain stands in Muddus National Park in North Sweden have for example been affected by as many as 3 to 4 forest fires. Some trees had probably burned even more, while others had never been exposed to fire over the last 400 to 500 years, maybe not even during the last thousand years (Arnborg 1963). A 550-year old pine from the so-called Sarkavare fire in Sweden in 1933 bore signs of "several" forest fires (Arnborg 1941), while a dozen forest fires were registered on a 500 years old pine from Øvre Dalarne (Högbom 1934).

Such studies in our neighboring countries, which are based on dendrochronologial examinations of stumps and trees with old fire marks (See Zackrisson 1977a), have served as models and initiated examinations of newer fire history in Norway (See section 5.4). The Swedish studies give a solid basis for regarding forest fire as the most important natural factor in boreal succession of coniferous forests, especially in the most continental areas (Engelmark 1984, Engelmark et al. 1993, Hörnberg 1995, Hörnberg et al. 1995, Schimmel 1993).

Table 5.1. Burned area (ha) in years with high and low forest fire frequency on Swedish state forest 1878–1955 (Summarized by Tenow 1974 based on Högbom 1934, Uggla 1958).

Years with high fire frequency	Area (ha)	Years with low fire frequency	Area (ha)
1878	27 000	1881	510
1888	11 650	1885	380
1901	10 475	1892	59
1914	6 450	1898	78
1918	3 140	1913	90
1920	3 830	1922	26
1926	1 384	1931	20
1933	11 002	1951	29
1955	1 520	1952	35

Forest fires will in such areas influence species composition over long periods of time (Kohh 1975, Sunding 1981, Schimmel & Granström 1991). According to Sunding (1981), regeneration of the vegetation will be slowest in areas where dry and poor vegetation types dominate. In Norway, this was for example indicated through studies in a forested area in Østfold county (Johansen & Schneede 1995). The short-term perspective and newer fire history may therefore be studied on the basis of succession patterns and the vegetation present in the stand today.

5.3 Modern forest fire history

In addition to forest history studies of the types mentioned above, historical documents are possible sources of information about fires in the last centuries. The modern fire history from the most recent period may also be based on statistical information (See ch. 6). Towards the middle of the 1800's the view of fires, and, little by little, also the management of fires changed a lot throughout the Nordic countries, and a steadily more efficient forest fire suppression led to a decline in the size of forest fires (See also ch. 6). All the while, there have still been great variations from year to year both in number and size of fires, and even recently fires of considerable size have occurred in the Nordic countries (Tenow 1974).

Among documented large fires in our neighboring countries a single fire of 100 km^2 at Österbotten in Finland, and another, also in Finland in 1933, had a 20 km wide front (Högbom 1934). The size of burned areas has, however, as mentioned clearly declined, also in these countries. This is exemplified in material from Swedish state forests for the period 1878–1955 (Högbom 1934, Uggla 1958). The survey shows total size burned areas (ha) on state forestland (Tab. 5.1).

Such a declining tendency as shown in Table 5.1 seems to be typical for all of the Nordic countries after fire suppression became ever more effective. The modern fire history of Norway is described in more detail in chapter 6.

5.4 Forest fire history studies in Norway

Pioneer studies of forest fire history with a long-term perspective based on core sampling have begun quite recently in Norway by forest ecologist Mikael Ohlson and co-workers (Tryterud 1995, Håkonsen 1996, Ohlson 1997). Examination of forest fires with what we have called a newer fire history perspective have among other things been carried out in pine forest with primeval features in Pasvik, Finnmark (Huse 1965, Korsmo 1997) and also in a pine dominated forest area in Østfold (Johansen & Schneede 1995). The examinations in question will be commented relatively thoroughly in the following.

5.4.1 Regional studies at Totenåsen

Håkonsen (1996) examined core samples from 23 bog and forest locations in Oppland and Akershus counties, more precisely in the municipalities of Østre Toten and Hurdal at elevations between 500 and 800 m a.s.l. The samples were examined for remnants of macrofossil car-

bon (> 0.5 mm) and collected in several groups of 2–5 locations, and samples were dated by pollen analyses. Two locations were also dated by ^{14}C analysis (Håkonsen 1996).

The sampled localities represented a wide spectrum of nature types in this large belt of coniferous forest and also encompassed two nature reserves (Fjellsjøkampen 812 m a.s.l., Torseterkampen 841 m a.s.l.) with continuous old spruce forest. At Fjellsjøkampen, a spruce swamp forest was also examined (Håkonsen 1996).

Håkonsen (1996) has pointed out several uncertainties associated with such studies. Carbon remnants that have been lying on the surface after fires, may have been exposed to water transport and thus have been displaced. Carbon in concave sites may originate from runoff from fires in the surrounding areas. Håkonsen (op.cit.) citing Clark (1988) assumes that this effect has been of minor importance in the Totenåsen studies because rain water is most often absorbed by the soil (infiltrated) allowing new vegetation, which decreases runoff, to be quickly established. Specific studies will probably be needed to examine carbon transport in burned areas under various topographical and precipitation conditions in order to accurately evaluate this.

Another uncertainty is associated with the relatively few datings that have been conducted. Håkonsen (1996) points out that extended studies of far more extensive datings and with more fine-grained division of profiles are necessary. The problem is that the surveying of larger samples that may be analyzed statistically, demand large resources. [5.1)]

Frequent fires during earlier eras

Håkonsen's (1996) examinations of the amount and distribution of carbon from the Totenåsen core samples indicated that there have been many fires in this forested area during the postglacial period. Signs of fire in the core samples were documented at all sampling sites except one. The fires at the individual locations have occurred with uneven frequency, and none of the profiles showed an identical fire pattern (Håkonsen 1996).

Some fires had been of limited extent, and the pattern at some locations which lay only 100–400 m apart, showed distinct differences. In some areas, it was possible to correlate carbon "peaks" in the profiles from different locations, which indicates fires of larger regional extent. Today's pine forest localities, dry soil sites with *Calluna-Vaccinum uliginosum*-heather, had burned more often than those covered by spruce forest. This is also established in Swedish studies (Zackrisson 1977a, Engelmark 1987). Of the bilberry-spruce forests in this area it was first and foremost hillsides that had burned (Håkonsen 1996).

With one exception, no clear time pattern with periods with high and low fire frequency was found in the Toten studies. The exception was the time just *before and during the invasion of spruce*, which seemed to have been "fire characterized". The profiles from most of the locations indicated more fires at the time just before the invasion of spruce. Håkonsen (1996) assumed this to be connected with the dry and warm climate in Subboreal Time, a period with some of the highest temperatures during the last 3 500 years (Håkonsen 1996).

The period after the invasion of spruce

Six of the locations studied at Totenåsen were generally characterized by having few fires. This was unexpected in three of the locations, in view of the local topography (Håkonsen 1996). One location (Skålåsen 741 m a.s.l.) totally lacked any sign of fire (Fig. 5.1).

The interpretation of the samples indicated, however, large variations in fire frequencies between locations that today have spruce forest. Some locations actually showed increased fire frequency in the period after the invasion of spruce. The last 2 500 years have been characterized by a comparatively cool and humid climate (ch. 3). Such a fire pattern is therefore not supported by a climate hypothesis.

Håkonsen (1996) assumes, with reference to Foster (1983), that local variations in parameters like vegetation, topography and hydrology may have been of greater importance than regional climate changes in this period. This may of course be correct, but the fire pattern can also be a result of anthropogenic influences (ch. 4). [5.2)]

An unexpected result from Håkonsen's (1996) studies at Totenåsen is that spruce forest locations which today are characterized by continuity, and which recently have been designated as forest reserves, show no tendency of having burned more rarely than other spruce locations. This is important new knowledge for management (ch. 9). Håkonsen (1996) has made an important contribution to the understanding of landscape ecology in Norway.

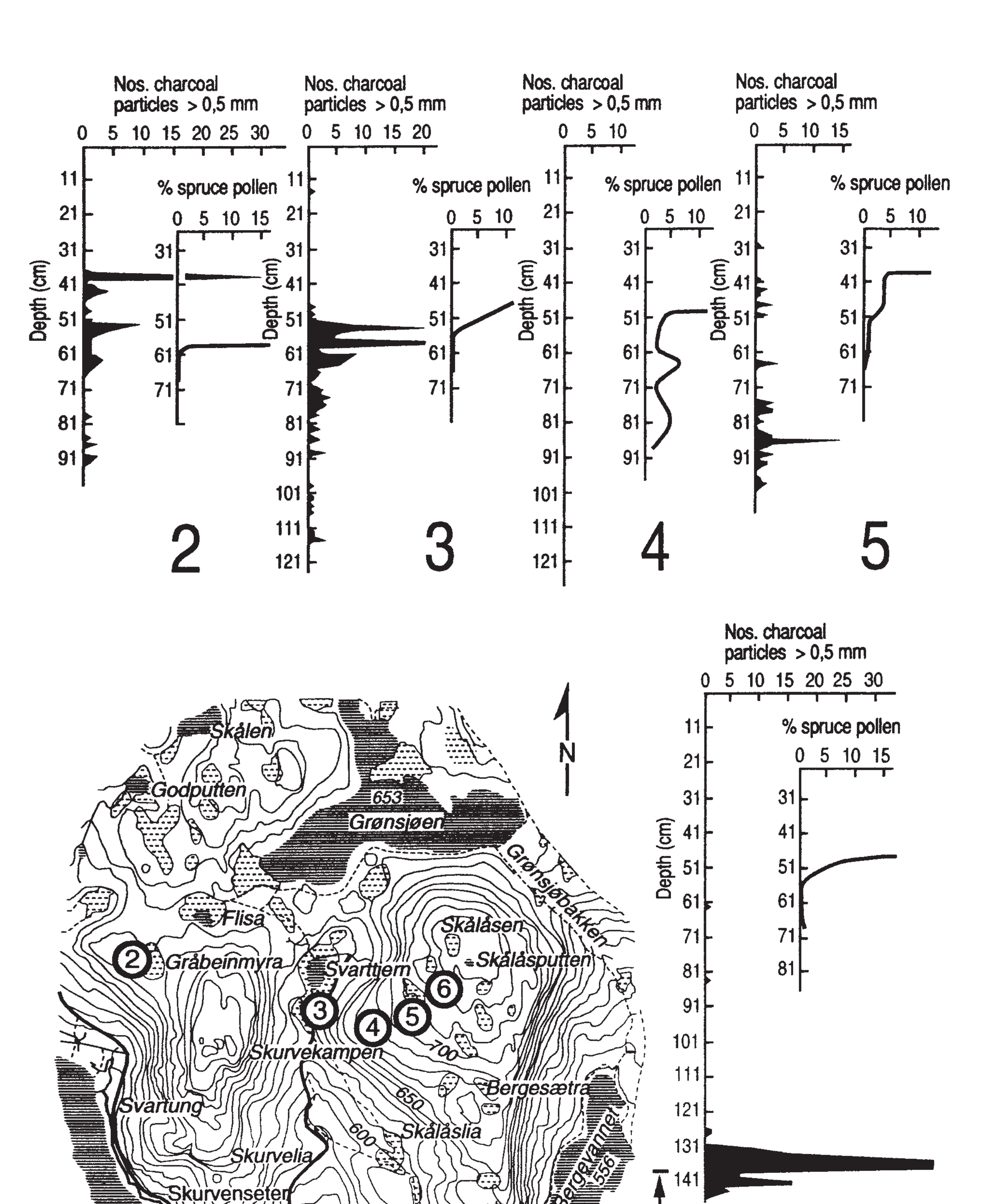


Figure 5.1. Diagram of number of carbon fragments and spruce pollen shares compared to pine pollen in five core samples from Skålåsen, Oppland county (The pollen curve interprets spruce invasion as the period when the portion of spruce pollen in the samples exceeds 2 % pine pollen) (Redrawn from Håkonsen 1996).

5.4.2 Spruce swamp forest in Nordmarka

Tryterud (1995) has recently presented the results of a forest fire history study of an approximately 4 500 year old spruce swamp forest site at Oppkuven in Nordmarka near Oslo (600 m a.s.l.) (Fig. 5.2). The examination is based on a single core sample (Tryterud 1995).

Throughout the whole postglacial period only two distinct fire periods were noted in this area, interrupted by a long period without fires. The periods occurred from 3400–3300 and 2700–2600 B.C., in Subboreal Time and the oldest part of Younger Stone Age, respectively (Fig. 4.1).

Tryterud (1995) assumed, with reference to Tolonen (1985) and Bradshaw & Hannon (1992), that climate rather than anthropogenic activity has been responsible for the extensive distribution of fires in the subboreal forest. [5.3] The size of the carbon material in the Oppkuven profile indicated that the fires were of local origin, and mineral grains in the profiles indicated that today's wet stand location at that time was a drier soil site (Tryterud 1995).

New fire period in the Iron Age

The other fire period in the Oppkuven stand was dated to 100–0 B.C. to 400–500 A.D. After this fire, a period up to the present has followed without any influence from fire, a period characterized by development and dominance of spruce (Tryterud 1995).

Tryterud (1995) considers it likely that the fires in the last period may actually have induced the establishment of the Oppkuven spruce swamp forest. Spruce invaded around 500 A.D. and has since totally dominated the stand. [5.4]

Tolonen (1983) emphasized the importance of clarifying if and when humans have been responsible for the local spread of spruce. It is assumed that repeated fires and the increased thinning of the pine forest in some northern areas of Russia has promoted a general spread of spruce and actually caused its domination (Vakurov 1975). Also Göransson (1977) has indicated that spruce could not spread efficiently before the forest was opened by clearance burnings. In his Swedish study area the spread of spruce began after burnings in Swedish Pre-

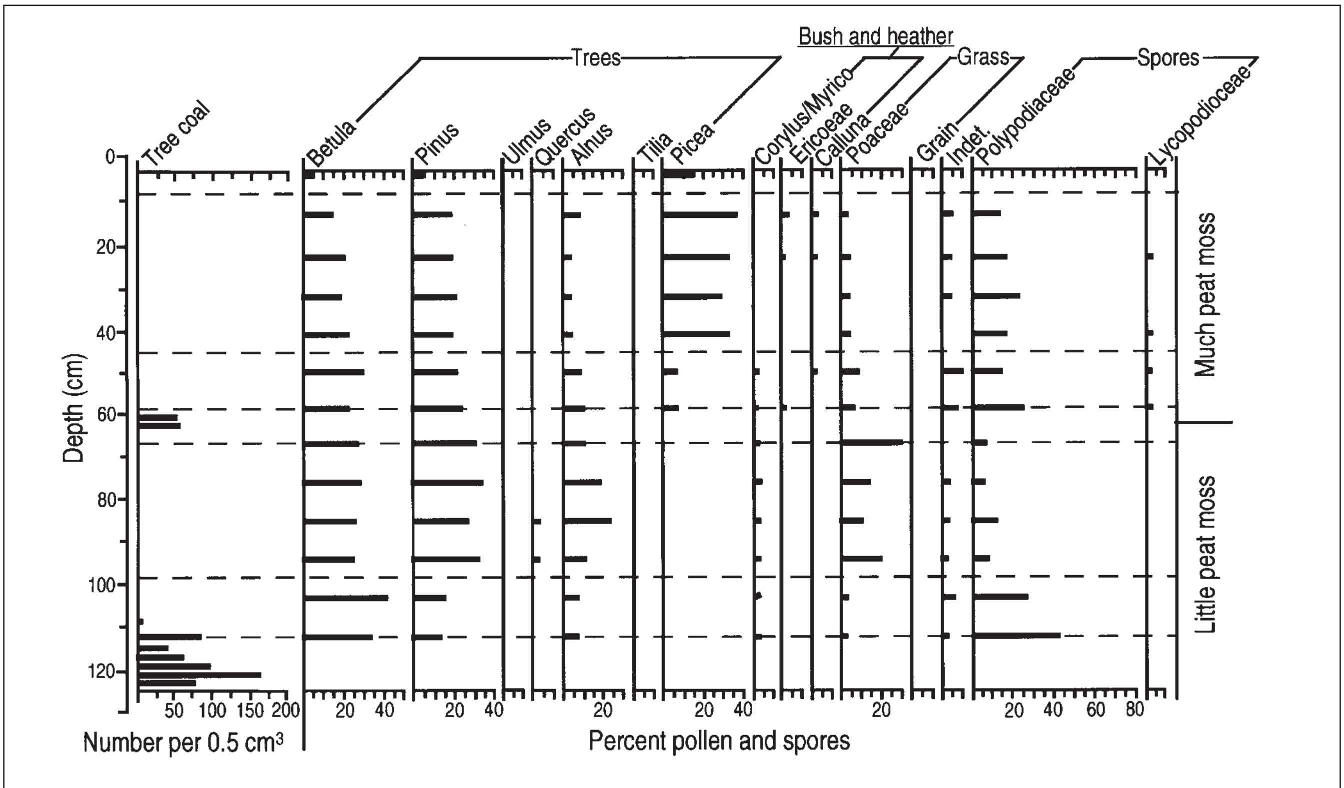


Figure 5.2. Diagram showing carbon remnants ("char coal", approx. number per 0.5 cm^3 wet peat) and the content of pollen and spores (in percent of the sum of pollen and spores) for the plant groups in the Oppkuven study. Peat bog remnants are subjectively denoted based on main impression. Dashed lines show the transition between different vegetation periods (Redrawn from Tryterud 1995).

Roman Iron Age (approx. 2500–2000 B.C.) (Göransson 1977).

The association between forest fires and spread of spruce is not, however, a simple one. In areas of Sweden swamp forest communities may develop after fires have caused a decline of the spruce stand with a subsequent increase of birch (Segerström et al. 1994).

It is then possible that the spruce swamp forest at Oppkuven was created by fire 1 500 years ago (Tryterud 1995). An interesting feature from the Oppkuven sample is the indication of only two distinct postglacial fire periods despite the stand's location in an area that today has one of Norway's highest frequencies of lightning strikes per square kilometer (Fig. 2.2). It is also striking that the two fire periods coincide with two of the most expansive periods of human use of the Norwegian landscape (Tab. 4.1).

5.4.3 Forest fire history studies in Finnmark

Forest fire history studies which cover the last centuries, have been conducted in Øvre Pasvik National Park, Sør-Varanger municipality in Finnmark county (Korsmo 1997).

Øvre Pasvik National Park was established in 1970 and covers 63 km^2. Of this, approximately one fourth consists of almost equal shares of lakes and bogs. The forest in the national park has primeval features and consists mainly of pine (*Pinus sylvestris f. lapponica*) with elements of silver birch (*Betula pendula*) on poor mineral soil and birch (*B. pubescens*) on humus-rich soil. Along streams there are also bush-formed grey alder (*Alnus incana*).

Forest fire has been an important ecological factor in the establishment of new stands (Huse 1965). Korsmo (1997) has examined the frequency of forest fires on four different test sites. Together they cover a climatic gradient ranging approximately 50 km northwards toward the arctic forest line.

The field work consisted of surveys and observations conducted on plots of 2.5 decares systematically placed in *Empetrum*-pine forest with 1 km mutual distance except in the area farthest north. In addition, observations of more recent fire sites were made during the surveys. Fire years were judged by means of a growth-measuring drill bit on pine trees with old fire scars. A sample of 123 drill cores from 81 test sites were used in the analysis to identify the different times of forest fire at the sites.

Korsmo (1997) found highest forest fire activity in the Øvre Pasvik National Park itself, but more than 80 % of the sample sites had been exposed to at least one forest fire. The forest fire frequency declined as one proceeded northwards in the Pasvik valley. Korsmo (1997) attributes this to increase in elevation (See Engelmark 1987, Zackrisson 1977a) and an increased element of birch forest that moderates forest fires. Most of the sample sites had signs of only one fire. In one instance signs of four different fires at the same site were registered (east of Sortbrysttjern). The first of these occurred approximately 280 years ago and the last approximately 80 years ago (Korsmo 1997). In 1946, there was a larger forest fire at Muotkevarri (Krokfjellet), which today lies within the Øvre Pasvik National Park. The fire stopped towards bogs and lakes and covered an area of approximately 3 700 decares. This is the largest fire in Øvre Pasvik in many years. After 1946, there have been several smaller forest fires.

Several fires in Øvre Pasvik could be dated as far back as to the 1550s. The accuracy of the examination method used, however, varies considerably (See Korsmo 1997).

To identify periods that show particularly high forest fire activity, the material was divided into 25-year intervals and the periods in question, evaluated as percent of all samples with fire scars. The oldest forest fire was registered west of Ellenvann, from approximately 1554. One could also establish that the same sample site burned 217 years later. Korsmo (1997) found a peak in the fire activity in the last half of the 18th century. A tendency of more forest fires was again established for the period 1876–1900. Korsmo (1997) assumed that these events may be associated with larger fluctuations in the climate. Most of the examined area (66 %) showed intervals from 26 to 100 years between each fire, while approximately 30 % varied between 100 and 200 years between fires (Korsmo 1997).

5.4.4 Forest fire history studies in Østfold

Johanson and Schneede (1995) have recently examined forest structure and dynamics in a southeastern Norwegian coniferous forest, which is heavily influenced by fire; the Lundsneset Nature Reserve (protected 1993) in Halden and Aremark municipalities in Østfold

county. The reserve covers 2 335 hectares. It is located 166–262 m a.s.l. within the bedrock area with dry ridges and pine forest surrounded by bogs and lakes, criss-crossed by depressions and concave sections characterized by mixed coniferous forests, often including stands of deciduous trees. The main part of the forest in the area is less than 150– 200 years old. The area is characterized by cutting in some parts, and there are old settlements both within and just outside the area. The area is located in the Boreonemorale zone (ch. 3) and was judged as representative of the most common vegetation types in this part of southeastern Norway (Johanson & Schneede 1995).

Forest fire history was mapped by means of dendrochronological examinations of trees damaged by fire, and the "compass direction of fire scars" was surveyed over a large area to identify the direction of fires. In addition the distribution of carbon layers in core samples from nine bogs were evaluated in the field.

Johanson and Schneede (1995) concluded that the coniferous forest in this area had been frequently exposed to forest fires, particularly the dry pine forest types on the ridges. Pure pine stands seem to be maintained by repeated fires. With increasing age and with suppression of fires, spruce began to invade below the pine stands. A clear connection was established between forest fire history during the last centuries and forest structure in the area today (Johanson & Schneede 1995). The *Cladina* lichen-pine forest in the Lundsneset Reserve may have burned as often as every 20–30 years [5.5)]. The lichen-pine-berry heather-mixed-coniferous forest and bilberry-spruce forest (see Section 3.4) have had a relatively high fire frequency in the 19th century. Also the bilberry-spruce stands seemed to have burned quite often.

Four different fires in the area, in 1816, 1821, 1838 and in 1852, were identified through examination of annual rings. Fire frequency has probably been high earlier also. This seems to be supported by the number and distribution of carbon layers in bogs (Fig. 5.3). In one area, as many as nine carbon layers in a bog profile of 130 cm depth were identified, the mean number of carbon layers in bogs measured 0.5 m from the edge of firm forest soil was 4.7. The real number was probably higher, because some layers/horizons were difficult to identify with the present method (Johanson & Schneede 1995).

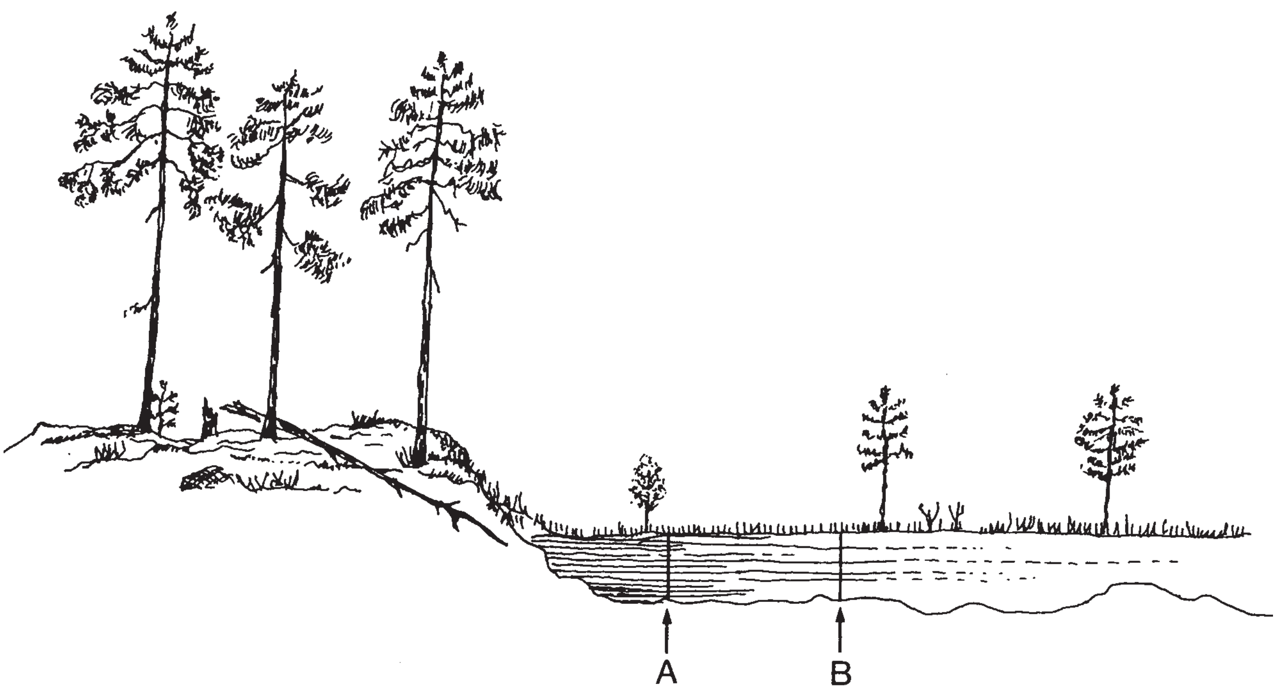


Figure 5.3. Sketch showing two sections (A and B) in a bog at which the number of carbon layers decrease with increasing distance from the edge of firm forest soil (After Johanson & Schneede 1995).

The particular topography, in addition to the prevailing wind direction during summer, had made the fires spread in a northerly direction through the nature reserve. Individual fires in the area seemed to have influenced relatively small areas, a consequence partially of the characteristic topography in the area. The fires had created a mosaic with large variation in ages of stands, species composition, and fire history (Johanson & Schneede 1995).

It was considered difficult to judge how anthropogenic activities had influenced the fire frequency, if at all (Johanson & Schneede 1995). [5.6)] No information about large fires within the central part of the nature reserve is known from the 1900's. A smaller fire occurred in 1958. In spite of high fire frequency earlier, the area has had infrequent fires during the last 150 years, presumably due to fire suppression and a general decline in use of the area (Johanson & Schneede 1995).

5.5 Historical sources

In addition to research results there are several written sources from the last centuries that clarify the most recent part of Norwegian forest fire history. (The task remains for historians to compile a more complete review.) *The historic fire regime* (Section 2.2.5) can be much better elucidated in such written material because it is possible to judge the importance of the relative shares of the natural and anthropogenic ignition sources.

Forest fire has generally been an important factor in regeneration of the coniferous forests in Norway to this day, and a part of the material concerning this is already collected and discussed (Strømsøe 1961, 1987, Vevstad 1987b):

> "Forest fire has through the eras caused tremendous destruction within the country's forests. In the old days, with scattered settlements and difficult communication, no claims for or attempts to suppress the fires were made within the large forested tracts – in many instances there was little more to do than let the fire ravage until it was extinguished, either by heavy rain or by lack of fuel (Skogdirektøren 1909, p. 175).

Sandmo (1951) assumed that the largest part of the known and unknown forest fires "which through time have occurred in Norway were initially ignited by humans, usually without intending to cause any damage. Forest fire started by lightning, is in reality quite rare" (Sandmo 1951, p. 32). Thus it is emphasized that throughout the 1800's large areas burned, and that the importance of anthropogenic ignition has been great. The historic material indicates that the fire frequency has changed periodically, and that there are regional differences (Strømsøe 1961, 1987) (See ch. 6).

5.5.1 The transition between old and new eras

Strømsøe (1987) assumes that even though the peasants in the Middle Age used fire somewhat carelessly, the percent of wild fires ignited by accident and carelessness was still modest compared to the controlled burning that took place in outlying areas. Strømsøe (1987) assumes further that most people knew where and how one should "mitigate" and suppress both self-initiated wildfires and other fire in the forest.

As long as swidden rye agriculture, bog ore iron melting and charcoal and tar production were a natural and necessary part of the seasonal activity of farmers (See ch. 4), there was a certain control of wildfires. The farmer, who had limited areas in the forest suited for rye swidden agriculture, had to ensure that he did not burn more than intended. The same was true with respect to the raw materials needed in other wood-demanding resource use (Strømsøe 1987).

In the years around and just after 1800, much of the old and traditional activity in the outlying areas stagnated. Iron melting (ch. 4) had culminated long before, and little by little, as the potato in the beginning of the 19th century played a steadily larger role in the household, the turnip and grain growing on burned fields and sites in the forest became less important. At the same time, coal burning declined because most ironworks were outcompeted one by one by a more efficient steel industry. Gradually, this caused people to lose experience and become less careful with fire in outlying areas. Numerous and sometimes very large forest fires in the period between 1810 and 1890 clearly tell of a marked decline in the ability and willingness among rural people to suppress forest fires (Strømsøe 1987). As we have pointed out (ch. 4), a new development ended this period, which had been characterized by large forest fires, at the end of the 18th century. It coincided with timber as an export product becoming of such economical value that Norwegian authorities put ever more effort into suppressing wildfires.

5.5.2 Hedmark in the 1800's

As late as at the beginning of the 1800's relatively large areas in the heavily forested Hedmark county still burned, and could cover areas of thousands of hectares. This was due to scattered settlements, lack of communication, and to the fact that local populations were often not motivated to extinguish fires if the settlements were not directly threatened.

As late as during the 1840s and 1850s and in the beginning of the 1860s large forest fires still burned in several municipalities in Østerdalen (Sjølie 1907).

Causes of fires in this period include in addition to lightning, careless cooking, heather burning to improve pasture, sparks from locomotives (from the 1860s) and ignition due to other railroad activities, herders' campfires, fishermen and river drivers, tar production, bog burning and swidden agriculture. The cause of some large fires remained unsolved, however (Sjølie 1907).

One can estimate that of a total forest area of 12 540 km^2, approximately 1 000 decares burned annually in a 35 year period around the middle of the 19^{th} century (Sjølie 1907).

In the years 1898–1900 the municipalities began passing a new set of regulations to enforce stricter suppression and prevention of forest fires (See Strømsøe 1987). In some municipalities, forest fire work gradually become systematized (Sjølie 1907).

5.5.3 Stor-Elvdal at the turn of the 19th century

Stor-Elvdal is one of the municipalities in Hedmark county that has kept the most careful review of forest fires since the forest fire rules were introduced (Sjølie 1907). During the period 1899–1907 lightning ignited 12 out of 24 fires (50 %). Anthropogenic fires were of three types: from train and railroad activities (n=7, 29.1 %), forestry (n=4, 16.7 %) and leisure activities (n=1, 4.2 %). Even though the fires ignited by lightning constituted half of the incidents, they caused less burned area, in all approximately 460 decares (da), as compared to approximately 1 720 decares due to railroad activity and 2 300 decares due to supposed ignition by fishermen.

5.5.4 North Norway in the 1800's

Examples from North Norway show the same tendencies with extensive fires as has been described from Hedmark county. Here valuable observations are made by skilled forest people.

Nordland and Troms

From many areas in Nordland county, examples of good regrowth on burned sites and fine stands after forest fires have been reported. There are, however, also examples of the forest floor itself being so deteriorated by extensive washing out of minerals and organic nutrients that the soil class quality is considerably influenced. Open plains and heathland were formed in many areas that earlier were heavily forested. Further, because seeding years were rare, especially in the mountainous forests, conditions in higher-lying areas were often heavily affected. In many areas the birch forest dominated successions on burned areas.

Also in Troms county large forest fires have burned up to around the turn of the 19^{th} century (Hagemann 1905, Skogdirektøren 1909). Forest fires in Troms during the 19^{th} century have been recently systematized and commented on by Dahl (1997). Of 25 registered fires which covered 3 034 hectares in Målselv, Bardu, Nordreisa and Skibotn in Troms during 1760–1902, as many as 19 were suggested or documented to be caused by human activity. [5.7)] For six fires the cause was not specified. Lightning is not mentioned as the cause of a single fire.

Finnmark

From Finnmark county many forest fires are described in older time. Fires were also here able to develop freely until they stopped by themselves or reached rivers, lakes or other natural fire barriers.

> "Throughout almost all of the Finnmark region (Norw. "Finmarken", an area larger than the present Finnmark County), actually reaching down through Nordland, fire has ravaged in the old forests." (Hagemann 1905).

Hagemann's descriptions leave no doubt that the ecological influence of forest fires has been extensive, also in this region:

> "Never have blows from axes sounded in the forest. Old and gray the pine heath trees stand with bending trunks, snags and fallen trees, but everywhere only small dimensions. It is as though the forest has lost its power. Because it is not the altitude, not the northern latitude, that prevails here. In between one can once more find primeval forest,– clumps of huge pine trees. Many places one

> can follow large gravel deposits along the rivers of Finnmark, covered by poor mats of lichens and even poorer thickets of birch. Many places one can wander on slopes and mountains distances of tens of kilometers, where the birch carry on a marginal existence, sick and stunted, one does not know, if one is to call it forest or thicket. Many places, if not everywhere, there are effects of old forest fire, which manifests itself" (Hagemann 1905, p. 26). (Original language in old style not translated in detail).

Hagemann (1905) notes that there have been large forest fires "until our own times." Even during the 1830–40s nobody in Finnmark county even considered trying to extinguish forest fires. Here as in Troms and Nordland counties, the population lived scattered, transport and travel was difficult and the forest had little economic value.

In his survey of the forest fires in Finnmark Hagemann (1905) mentions that much forest burned particularly during the summer of 1831. In Anarjokka at least 20 km^2 pine forest and more than 100 km^2 birch forest burned. At another locality in the same area, 50 km^2 birch forest mixed with lichen heath burned. Hagemann (1905) thereafter treats the period chronolocially up to 1894 which was the last large fire summer in Finnmark county.

Landscape-ecological importance?

In the discussion of causes of fire in Finnmark county both careless use of fire and lightning are established as important (Hagemann 1905). It is emphasized that both Norwegians, Samii people (so-called "Lapps") and persons of Finnish stock (Norw. "kvener) may be careless with fire when they camp in outlying areas. It is, however, assumed as improbable that the Samii population in the area intentionally ignited the forest. The forest offered the Samii people shelter and firewood during their movements, and was important to them as a producer of game as well (Hagemann 1905).

Not only the inner parts of the county, but the entire Finnmark coast, also the islands

> "have been ravaged by the fire, to the extent it has found anything to consume." (Hagemann 1905, p. 27).

As mentioned, Hagemann (1905) strongly emphasizes the importance of fires in the impoverishment of the ground layer, which for long periods after an intense fire may remain exposed to precipitation and wind, and therefore exposed to either leaching, erosion or stagnation (peat formation) (See ch. 8). Even though fine pine stands emerged on many burned sites, the new forest, which gradually developed in many areas, could not be compared to the site's original stand. Often a change of tree species occurred in burned areas, in which birch stand took over (Hagemann 1905). The long-term effects of forest fires on nutrient turnover, biomass production and vitality of the boreal forest ecosystems are, however, less well known and still disputed (Lundmark 1986, Zackrisson 1997), and examples of degeneration of the type Hagemann (1905) mentions, are not documented by research (Zackrisson 1997). See the presentation of effects of forest fires for further discussion (ch. 8).

5.6 Summary

In this report we have divided the history of forest fires into three periods: older (long-term perspective back to the end of the last Ice Age), newer (short-term perspective, cycles during the past 500 years) and modern (the past 200 years where the conditions can be studied based on written sources including relatively reliable statistics (see ch. 6). The fire history has developed on a background of a combination of natural (lightning strikes) and anthropogenic (induced by humans) ignition sources that are unique to each country. Consequently, the history in e.g. Norway cannot be interpreted merely by transferring studies and information from forest fires in other countries. Over a long-term perspective, the occurrence and frequency of forest fires is partially determined by the climate, where summer temperatures and number of lightning strikes are important factors. It is particularly emphasized that the anthropogenic and historical use of the landscape must be given far more weight in the assessment.

Few long-term forest fire history studies have been carried out in this country, but those that have been performed to date have already established several important factors. These studies have been carried out partly in the coniferous forest areas in Totenåsen and partly in Nordmarka near Oslo. They provide comprehensive documentation of fires, particularly in the drier types of forests. Certain distinct periods have also been established when there have been many fires, separated by periods without fires.

Fire refuges have been identified, i.e. areas that have burned little or not at all during the period after the last Ice Age. Based on the samples taken to date, it is not possible to state how many such areas we have in Norway. There are clear indications that coniferous forests that currently exhibit typical perpetuating characteristics, and that have been set aside as reserves, do not show a tendency to have burned more rarely than other spruce forests.

Studies of stands from the period we have called newer fire history have been carried out both in Sør Varanger, Finnmark in northern Norway and in Østfold in southern Norway. Both are locations in areas characterized by pine forests. In Pasvik it was found that two-thirds of the examined test sites had 26 to 100 years between each fire, while about one-third varied between 100 and 200 years between fires. The studies in Østfold showed a high fire frequency in the 1800s up to the middle of the 19th century. Parts of the area may have burned as often as every 20–30 years. These spot tests conform with the pattern discovered in Sweden, i.e. that the fire frequency is lowest in the boreal areas in the north and highest in the southern areas. However, the studies are far too fragmented to draw reliable conclusions regarding the causes of this.

In addition to the historical forest fire studies, local historical material regarding forest fires over the past 200 years in Norway has also been collected. The information gathered to date indicates that humans as an ignition source have been a far more significant cause of forest fires than lightning strikes, and that the number and extent of fires has declined after the introduction of fire fighting.

Forest fire history studies that analyze selected stands over a long-term and short-term perspective should be intensified in Norway. Such studies will be valuable in increasing the knowledge about stand dynamics and the processes that form the forest structurally, and they will be necessary to ensure a more well-founded management of Norwegian coniferous forests in the future.

6 THE FIRE REGIME IN THIS CENTURY

By Ivar Mysterud, Iver Mysterud and Erik Bleken

Forest fires in earlier times were most often impossible to extinguish because of scattered settlements and poor communications. They burned until they reached barren mountains, bogs or lakes, or were extinguished by rain (ch. 3). There are, as previously mentioned, no statistics of how large areas have burned in earlier times. (ch. 5). In “Skogvæsenets Historie” [History of Forestry] (Skogdirektøren 1909) it is indicated that in the period 1800–1900 an area of 250 000 decares burned just within the borders of Rendalen Statsalmenning in Hedmark. The general view of forest fires became greatly improved some time after the turn of the 20th century.

Collecting of forest fire statistics in Norway was started in 1913. The Director of Forestry (Norw. “Skogdirektøren”) requested forest fire statistics from the municipalities. These results were published for a period in the accounts from the Director of Forestry. From 1924 the statistics was transferred to Statistics Norway. In this first phase the bureau published “Forest Statistics 1952”, “Forest Statistics 1953–56” and “Current Statistics” with detailed information about forest fires in Norway (see Strømsøe 1961).

The following are descriptions and comments on the fire history in the 20th century. Reference will also be made to some conditions from the period 1913–59 and the Norwegian fire regime today in more detail, based on data from the period 1975–89. The whole statistical material about forest fires in Norway is thus collected in a period where intense fire suppression was carried out.

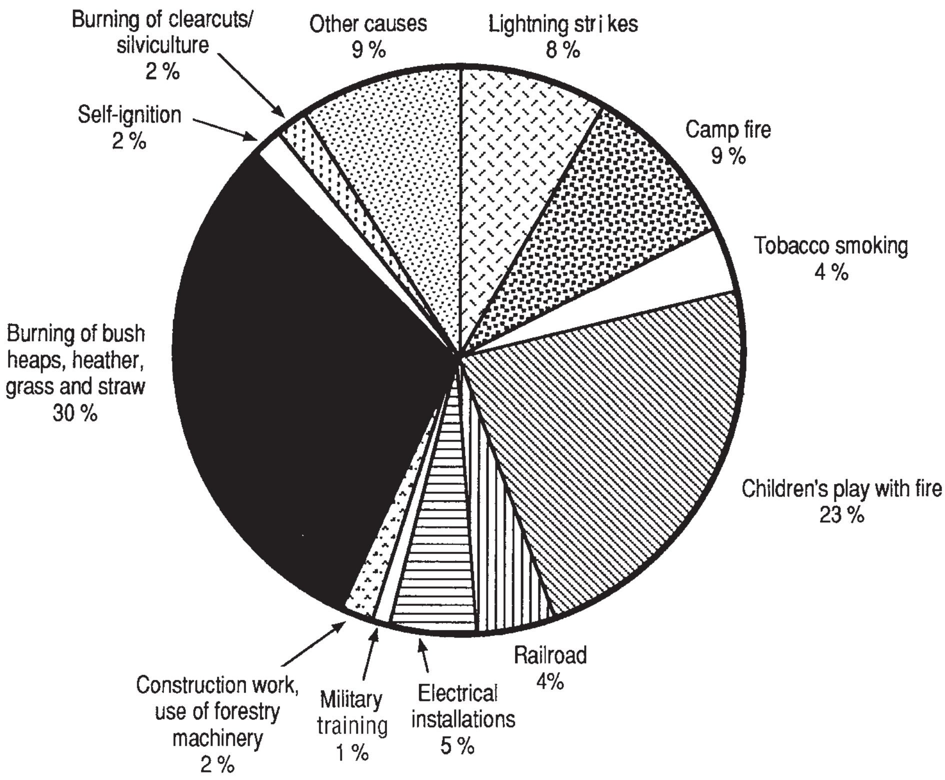


Figure 6.1. Causes (%) of fires in forests and outlying areas in Norway 1975–89 (After Statistics Norway) (See text).

6.1 New types of ignition sources

An important feature concerning the general development in the 19th century is the emergence of a number of completely new ignition sources (Section 4.1.2). Population growth, industrialization, increased leisure, and improved communications contributed to more utilization of the forests (Strømsøe 1961). The construction of roads and railways gradually contributed to an “invasion” of fishers, hunters and other tourists. These “invaders” were not always careful in their use

of fire. The construction of the railway network along flat riverbanks and valley bottoms with bone dry forest floor vegetation gradually had large consequences for the frequency of forest fires. The Norwegian State Railway over the years caused many of the largest forest fires in Norway, in spite of considerable efforts to reduce such fires, such as installation of spark catchers on the engines, establishment of deciduous forest belts, digging of fire ditches and line surveys with rail tricycle patrols. This condition lasted as long as steam engines were used in the locomotives (Strømsøe 1987).

Short circuits caused by trees falling over electrical wires also became an ever more frequent cause of fire as the network of wires and power lines was gradually developed. Extended use of outlying areas for various activities such as military training operations also increased the risk of ignitions (Strømsøe 1961).

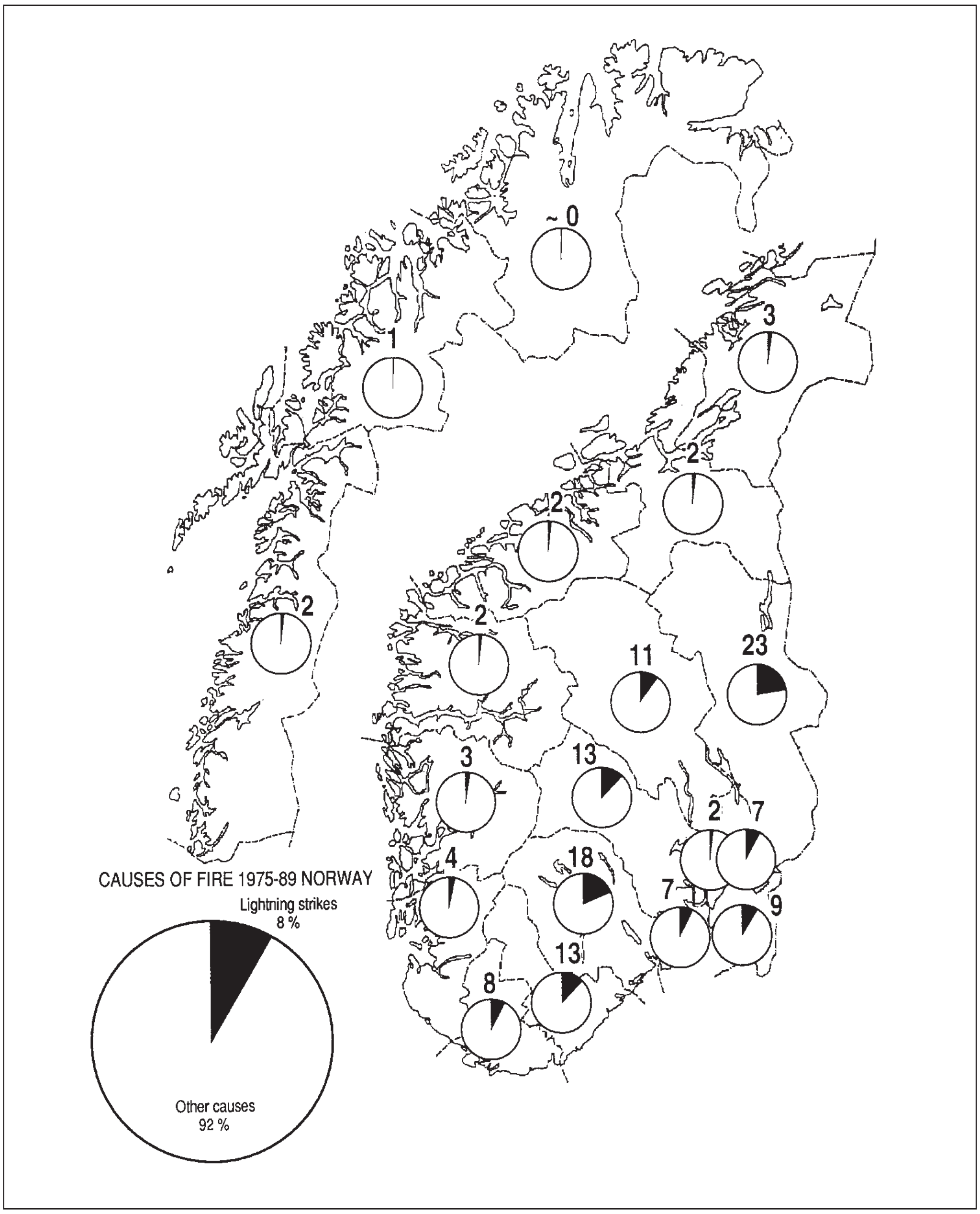


Figure 6.2. Ignition sources in the Norwegian fire regime during the period 1975–89. Percentage distribution of natural (“lightning strikes”) and human activity ignition sources (“other causes”) shown by county (the map) and for the whole country (bottom left). Values for Oslo and Akershus are shown separately (See text).
Legend map: thin line – county border.
Legend pie diagram: black sector and number – natural source of ignition (lightning strike), white sector – anthropogenic sources of ignition.

The increase in use of motorized equipment by the forest industry also contributed to an ever larger number of forest fires. Gasoline spills and sparks from power saws, exhaust systems of tractors and forestry machinery along with unwise use of chains, belts and steel wires during periods with dry weather were some of the main causes of forest fires in this connection (Strømsøe 1987).

6.2 Causes of forest fires

If we sum up the causes of fires in forests and outlying areas based on statistics from the period 1975– 89, the following spectrum emerges (Fig. 6.1). [6.1)]

Lightning strikes caused 8 % of the fires in this period (mean for the whole country). The ignition caused by human activity is thus totally dominating (92 %). Today burning off of withered grass and leaves in spring, burning of heather, grass and straw (31 %) and children’s play with fire (23 %)

are all far more important than lightning strikes in starting fires in forests and outlying areas in Norway. Self-ignition/ spontaneous ignition accounts for 2 %, but must also be counted as anthropogenic. [2.8)] The importance of lightning strikes lies approximately in the same order of magnitude as burning of camp fires, coffee cooking etc. in connection with travel/outdoor activity in outlying areas (9 %).

Figure 6.2 shows the relation between lightning strikes (8 %) and the sum of the mentioned anthropogenic ignition sources for all of Norway. The same methodical procedure has been carried out for each county. The small pie diagrams on the country map illustrate the regional variation in the relation between natural and anthropogenic ignition sources.

Hedmark is clearly distinguished with the highest percentage (23 %) of fires ignited by lightning (Fig. 6.2). Even in this continental county with large areas of forest, the anthropogenic ignition sources were responsible for as much as 77 % of the fires during this period. The percentage of fires produced by lightning is relatively high in the most subalpine counties. Oppland-Buskerud-Telemark-Aust-Agder ranges from 11–18 %, while Vest-Agder is down at the mean for Norway (8 %). In the counties around the Oslo Fiord the percentage also lies around the mean for Norway except for Oslo (2 %). This condition is due to the large population concentration in the Oslo region (see ch. 5). Also in the four counties in the western part of Norway, human activity ignition sources dominate totally (96–98 %). The same is true for the whole of North Norway. In Finnmark the importance of lightning produced fires during this long period has been close to zero (Fig. 6.2).

We are now going to look more closely at the period of time just after the turn of the century.

6.3 Forest fires in the period 1913–59

Forest fires in the first part of this century, i.e. from the collection of yearly statistics were commenced in 1913 and until 1959 is already treated by Strømsøe (1961). Large fire years were 1933, 1941, 1947, 1955 and 1959. Known fires in 1959 were the ones at Tingstadlia in Rendalen, Hedmark June 12. and at Deset in Åmot June 25. (Strømsøe 1987). Statistics Norway's numbers material from this period shows a considerable increase in number of annual forest fires (Fig. 6.3), for example from ca. 100 annually in 1920 to ca. 600 in 1950 (Strømsøe 1961). While the number of fires ignited by lightning mainly varies around the same level throughout the whole period, fires caused by anthropogenic ignition show a marked increase (Fig. 6.4).

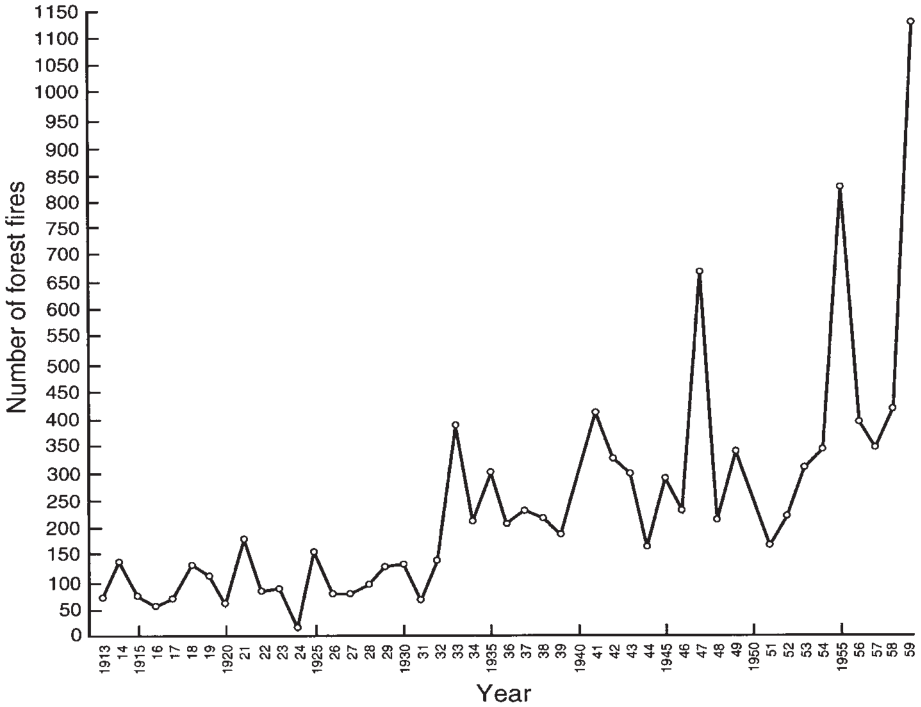


Figure 6.3. Annual number of forest fires in Norway during the period 1913–59 (Statistics Norway data, after Strømsøe 1961).

The large forest fires from the time before and around the turn of the 20th century (see Section 5.5) in many places resulted in large areas with continuous and dense regenerations. This supported forestry with large treatment units of stands with more even density and age class distribution. This was carried on and extended through the introduction of even-aged management (stand-focused forestry) where ever larger continuous areas with even-aged regeneration forest were created (see ch. 4), where the risk of forest fire is far larger than in the earlier small and uneven-aged stands (Strømsøe 1987).

6.4 Modern forestry alters conditions

The introduction of even-aged management after the Second World War led to a forced construction of a network of forestry roads. As mentioned, this increased the general travel and traffic in outlying areas, resulting in more fires. On the other hand, the increased traffic in the forests also usually resulted in quicker discoveries of the fires. In addition, the improved communications made possible a far quicker transport of fire fighters and equipment, so that the efficiency of extinguishing efforts steadily improved (Strømsøe 1987). In addition, the roads themselves constituted favorable "fire barriers" which increased the efficiency of forest fire suppression (Strømsøe 1987).

Therefore, even though the small initial fires generally increased in number, they were also discovered more quickly and suppressed ever more efficiently. The risk for *larger* forest fires was therefore less than before. During the ten-year period 1947–56 there were in average 378 forest fires annually in Norway, and the burned areas of productive forest encompassed 5 250 decares annually, i.e. 14 decares per fire (see Section 6.5.4).

Also in Sweden small fires totally dominate in numbers in statistics from more recent years. Fires smaller than 0.1 hectare constituted in average slightly above 70 % of the total number of fires during the period 1958–67 (Tenow 1974).

A comparison of burned areas between Sweden and Norway in the years 1947–56 showed a burning rate of 62 m^2 per km^2 productive forest in Sweden, while the corresponding number for Norway was 73 m^2. Thus the burned areas were relatively speaking essentially larger in Norway even though the cooler and less continental fire regime of Norway should indicate fewer fires. This may be due to the large increase in anthropogenic ignition sources in Norway at the same time as the forest fire prevention in an earlier period was far less developed and organized here than in Sweden (Strømsøe 1961). Little by little, however, the fire watch system in Norway was steadily improved and the organization of the extinguishing effort direction itself improved (Strømsøe 1961, 1987). During 1966 the first attempts with watch monitoring by airplanes were carried out in Norway, and little by little we got extended use of airplanes and helicopters in forest fire suppression (see ch. 11).

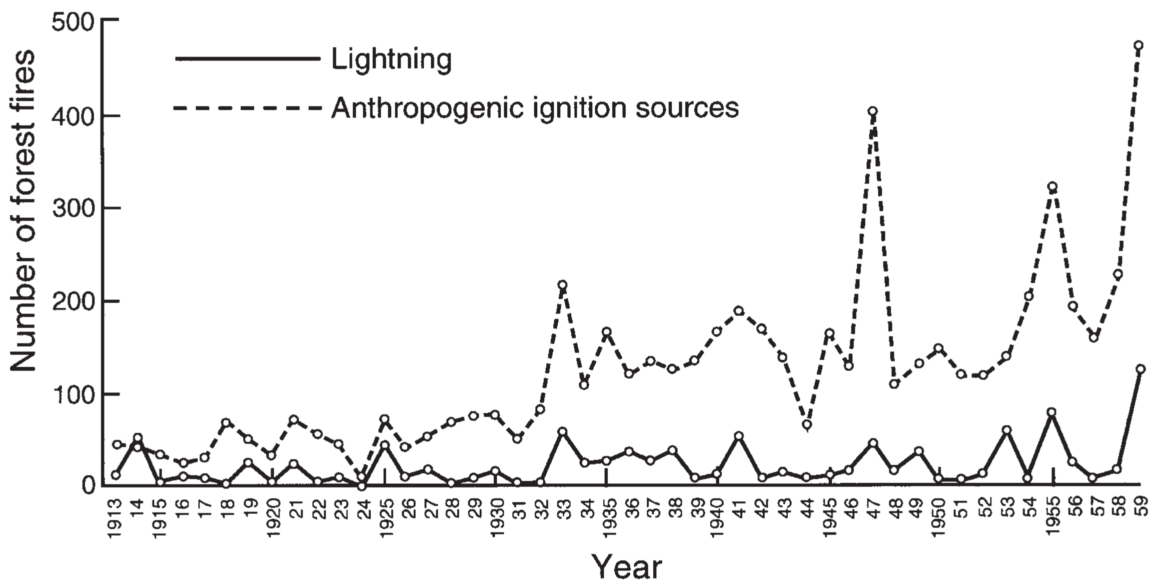


Figure 6.4. Number of forest fires caused by lightning strikes and human activity, respectively, during the period 1913–59 (Statistics Norway data, after Strømsøe 1961).

6.5 Forest fires in the period 1966–89

"Current fire regime" in Norway may be described and illustrated on the basis of Statistics Norway's data for the 24-year period 1966–89, from the year the first monitoring by airplanes started.

6.5.1 Number of forest fires in time and space

The annual number of fires varies a lot (Fig. 6.5).

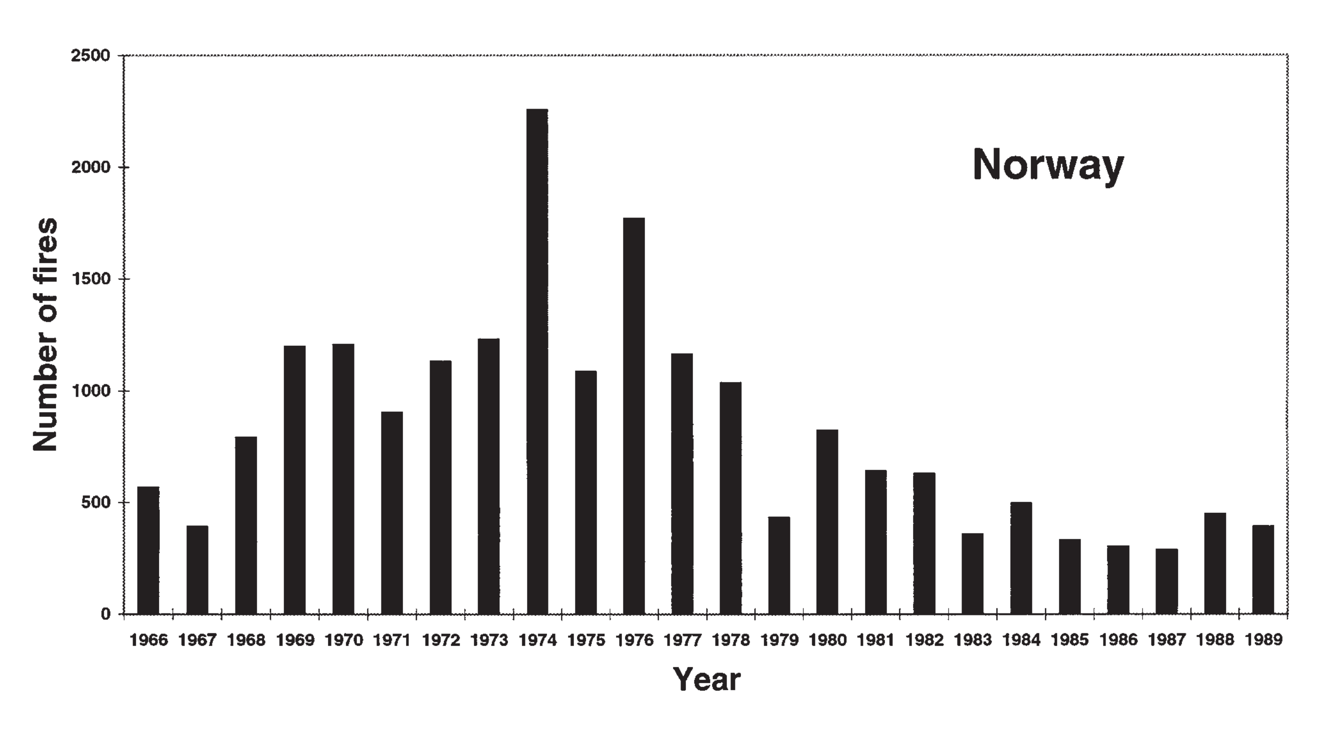


Figure 6.5. Number of fires in forest and outlying areas in Norway 1966–89 (After Statistics Norway).

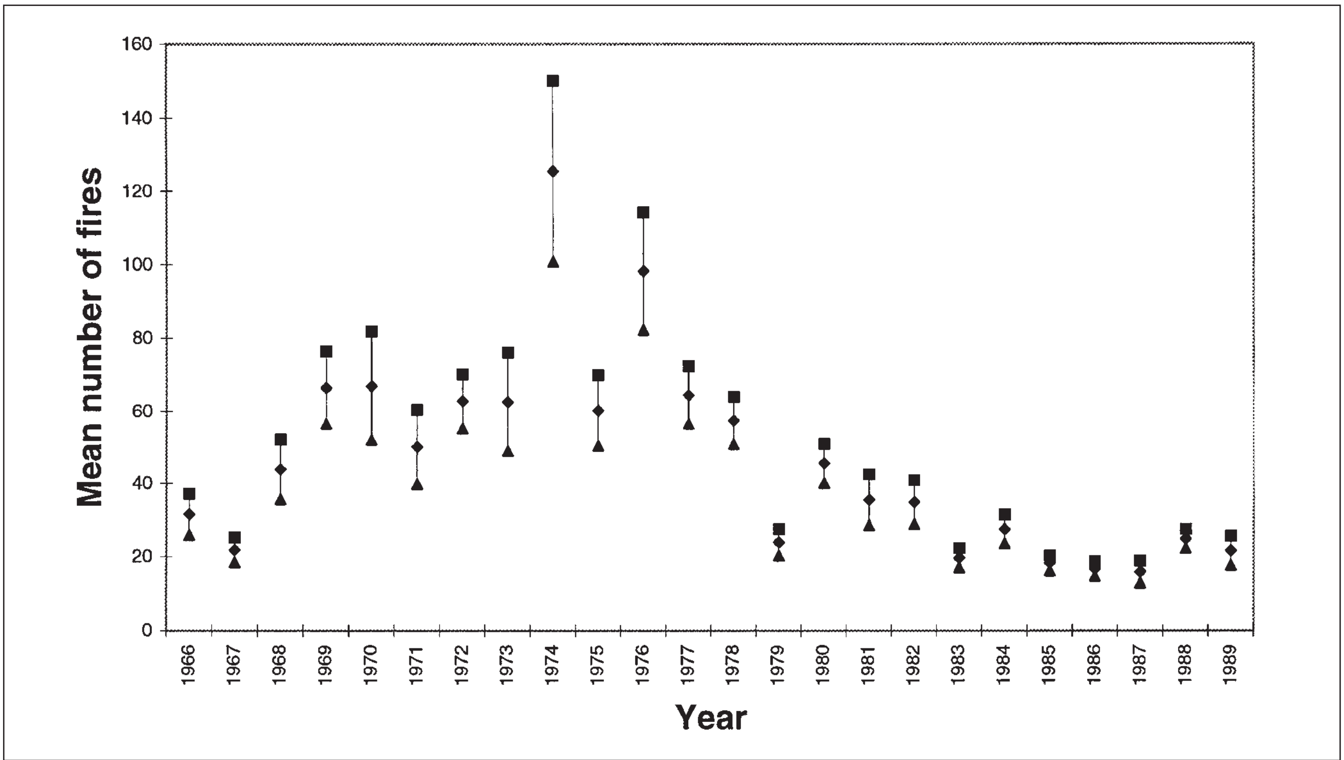


Figure 6.6. Mean annual number of fires ($\bar{x}\pm$ s.d.) per county for the period 1966–89 (After Statistics Norway).

Table 6.1. Annual number of fires (see fig. 6.5), area with productive forest and total area burned, and number of fires ignited by lightning and by unknown causes (See text).

Year	Number of fires	Forest area burned		Fires ignited by ligthning	Unknown causes
		Productive	Total		
1966	597	1216	4817	13	103
1967	391	2565	3719	7	103
1968	789	1075	7779	57	174
1969	1196	3805	23203	38	242
1970	1205	7751	17914	54	310
1971	902	1372	4898	8	238
1972	1130	7837	86053	44	172
1973	1228	3120	10109	48	332
1974	2257	5389	46296	84	784
1975	1085	3244	19563	59	316
1976	1769	16648	29832	168	484
1977	1162	970	6378	30	316
1978	1035	1408	16598	22	280
1979	430	296	5298	18	83
1980	821	1047	12403	38	189
1981	639	784	10361	11	188
1982	628	1398	7989	110	148
1983	354	548	1625	22	94
1984	495	1260	28456	16	37
1985	329	307	2435	6	72
1986	301	631	5950	12	74
1987	286	354	3384	2	56
1988	448	2085	12148	94	104
1989	390	1696	9921	37	77
Sum	19837	66806	377129	998	4976

Distribution in time

The mean number of annual fires for the decade 1970–79 was 1 220, while it was 469 for the decade 1980–89, the difference is statistically significant (t-test, n=20, T=4.557, p<0.001) (Tab. 6.1). The largest number of fires (2 257) was reported in 1974, which evidently was considered to be a “fire year” over large parts of the country. Thereafter followed 1976 with 1 769 fires, 1970 with 1 205 and 1969 with 1 196 fires. The lowest annual number for the period was reported in 1987 with 286 forest fires (Tab. 6.1). Among thoroughly described and known forest fires from this period, are “the Kongsvinger fire” in 1975 (3 450 decares) and large fires in Heddalen (3 400 decares) and at Elverum in 1976 (9 200 decares) (see Strømsøe 1984, 1987).

The main trend in the material beyond the large local variations is the far more numerous fires during the period 1968–78 than in 1979–89. It is also shown through calculation of mean and variance county by county for the same period, and emerges as a “heavy trend” (Fig. 6.6). A corresponding tendency is also described from Finland (see Parviainen 1996). Such a decline in number of fires in Norway is probably not due to climatic fluctuations since it has become warmer during the most recent period (Fig. 3.2). On the contrary, based on climatic conditions, one should have expected more fires. Also, one should not expect large changes in variables like topography, distribution of fuel, types of ignition sources etc. during this short time series. A plausible hypothesis is that the increased fire suppression activities throughout this century, have gradually become more efficient and are now clearly reflected in the statistics by ever more small fires being rapidly extinguished.

Regional distribution

Oslo and Akershus had most fires during the period (2 285), followed by Vest-Agder (2 095) and Rogaland (1 597). Sogn og Fjordane (418) and Troms (388) had

Table 6.2. Countywise number of fires in forest and outlying areas, productive forest area burned and number of fires ignited by lightning [1] during the period 1966–89 (After Statistics Norway).

County	Number of fires			Productive forest		Fires ignited by lightning	
	Total	Average	SD	Average (decare)	SD	Average	SD
Østfold	1350	56.3	46.4	103.4	161.4	3.2	4.4
Akershus/Oslo	2285	95.2	83.0	164.5	182.5	2.1	2.8
Hedmark	1225	51.0	29.1	714.7	1916.5	9.3	10.8
Oppland	978	40.8	20.9	61.3	50.5	3.5	3.9
Buskerud	1209	50.4	42.6	59.3	101.3	3.7	6.5
Vestfold	1173	48.9	46.1	37.8	61.2	1.6	2.8
Telemark	967	40.3	33.3	316.5	837.3	5.5	6.8
Aust-Agder	1195	49.8	42.0	204.3	258.8	3.7	5.8
Vest-Agder	2095	87.3	78.9	161.3	274.2	2.7	4.2
Rogaland	1597	66.5	60.2	345.7	1147	1.5	2.4
Hordaland	1309	54.5	36.4	171.8	280.9	1.2	1.5
Sogn og Fj.	418	17.4	12.3	37.4	80	0.3	0.8
Møre og R.	990	41.3	42.3	46.4	127.7	0.4	0.8
Sør-Trøndelag	669	29.1	16.9	17.8	22.6	0.6	0.7
Nord-Trøndelag	560	23.3	20.8	51.5	112.2	0.8	1.2
Nordland	759	31.6	27.1	26.7	41.6	0.8	2
Troms	388	16.2	12.2	9.8	12.3	0.0	0.2
Finnmark	539	22.5	17.1	254.0	1073.2	0.7	2.9
Norway	19837	826.5	496.5	2783.6	3635.4	41.6	39.5

1. The numbers denote number of fires ignited by lightning in all types of forest and outlying areas and not only those that are ignited in productive forest.

fewest fires (Tab. 6.2). The extreme variability of the Norwegian landscape, climate and fuel together with the stochastic variation in the local ignition sources, is reflected in extensive differences in fire frequencies over time in various parts of Norway. These differences emerge markedly when the series from the whole country (Fig. 6.5) is broken down to county level (Fig. 6.7).

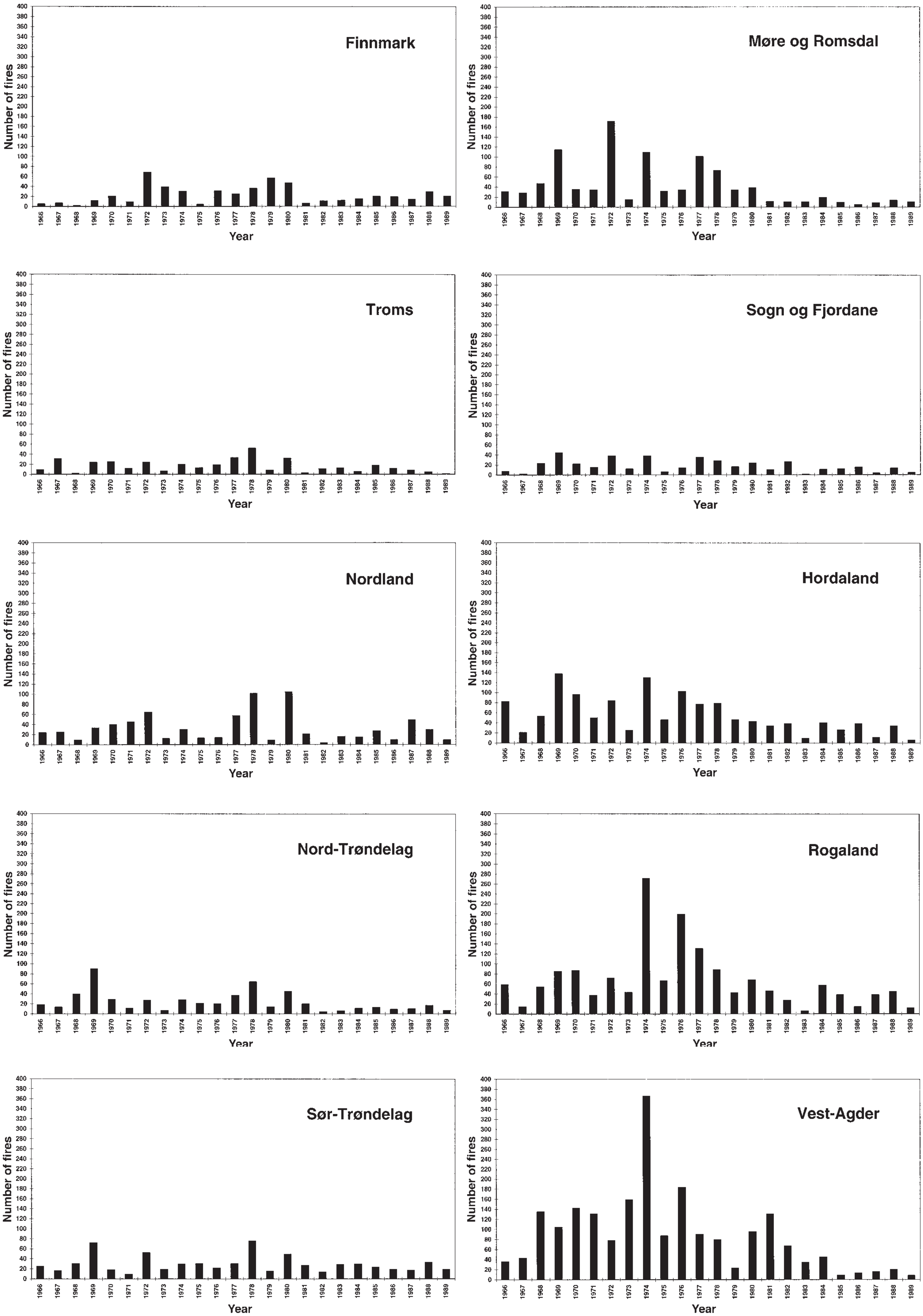
Some counties have a series where it is hardly possible to talk about tendencies at all – it seems to burn randomly and little all the time. We can for example see this in Sogn og Fjordane and Troms (Fig. 6.7). Clear tendencies of having fire numbers above the country mean emerge in Vest-Agder, Rogaland and Akershus/Oslo. During some years there are very dry conditions over large parts of the country, and this manifests itself as “fire years”. One can see several such years in the middle of the 1970s, for example 1974 when it burned a lot in Rogaland, Vest-Agder, Aust-Agder, Telemark, Akershus/Oslo and Østfold at the same time.

Seen together there seems to be a gradually decreasing number of fires as one proceeds from east to west and from south to north. More thorough statistical analyses are, however, necessary to confirm these tendencies.

A coarse regional variation of fires also emerges by presenting the numbers by county on a map (Fig. 6.8).

Hedmark county has had 1 225 fires in forest and outlying areas during the period, i.e. a lower number than for example both the counties Oslo/Akershus and Vest-Agder. In the western part of the country Rogaland county comes highest with 1 597 fires during the period. From the countywise overview (Tab. 6.2) it is seen that the largest number of fires were ignited in Oslo and Akershus, Vest-Agder and Rogaland. The variations were, however, large from year to year. The three counties with highest number of fires were among those that also have highest frequency of fires ignited by lightning (Fig. 6.2), but the anthropogenic ignition sources dominate everywhere as we have seen previously (Fig. 6.2).

Concerning countywise distribution of mean annual area (decares) burned forest (Tab. 6.2), Hedmark county was clearly different with the largest area, followed by Rogaland, Telemark, Finnmark and Aust-Agder. In the other counties, on average less than 200 decares burned



Finnmark
Møre og Romsdal
Troms
Sogn og Fjordane
Nordland
Hordaland
Nord-Trøndelag
Rogaland
Sør-Trøndelag
Vest-Agder
Number of fires
Year

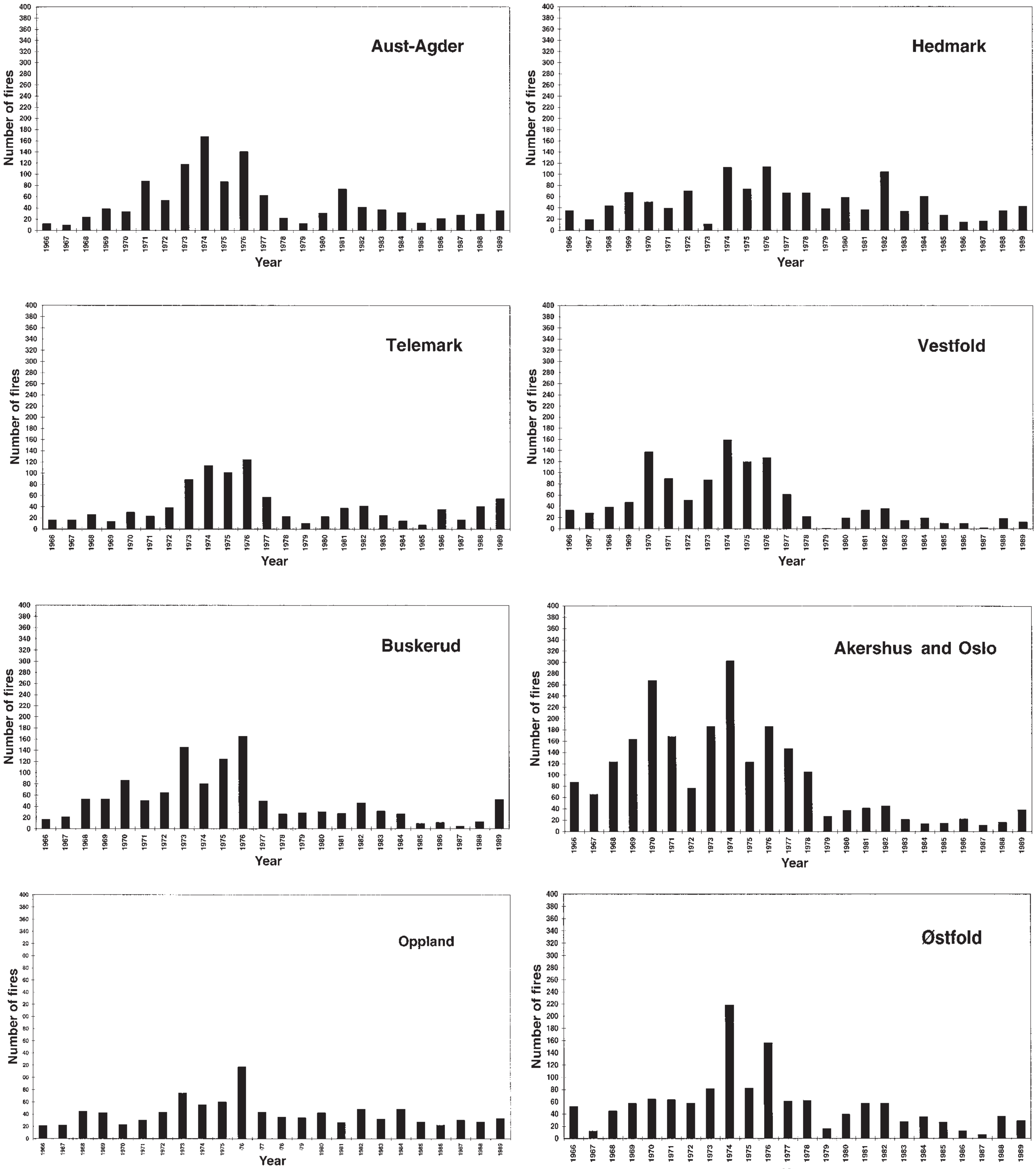


Figure 6.7. Countywise distribution of annual number of forest fires and fires in outlying areas during 1966–89 based on material from Statistics Norway.

annually. The variance, however, is considerable i.e. there are large variations from year to year (Tab. 6.2).

In addition to the climatic variables mentioned previously (ch. 3), the forest fire risk is also closely linked to geological formations and substrate. Areas rich in calcium promote more luxuriant vegetation and a higher element of deciduous trees that in itself decreases the risk of fire. Nutrient poor rocks on the other hand produce a low quality soil and a far drier and more easily ignited vegetation. Stands on shallow forest soils may become inflammable even after short dry periods (Strømsøe 1961). Considering that Hedmark county in addition to being one of Norway's most "continental" counties, also has large stretches of forest on nutrient depleted and shallow soil, this is probably a plausible explanation for why our largest forest county peaks this statistics.

From a climatic consideration one would expect most fires in the areas of the country that have dry seasons early during spring and/or marked inland climate with long dry periods during the summer. Strong winds may, however, contribute to increase the local forest fire hazard, something which may lead to extensive heather and forest fires in the coastal areas during dry windy periods also in winter time (Strømsøe 1961). One may suppose that a regional fire pattern based on climatic conditions gets considerably changed when one adds the demographic differences. In addition, the traffic around the large urban population concentrations must be supposed to result in increased frequencies of ignition in the adjacent areas.

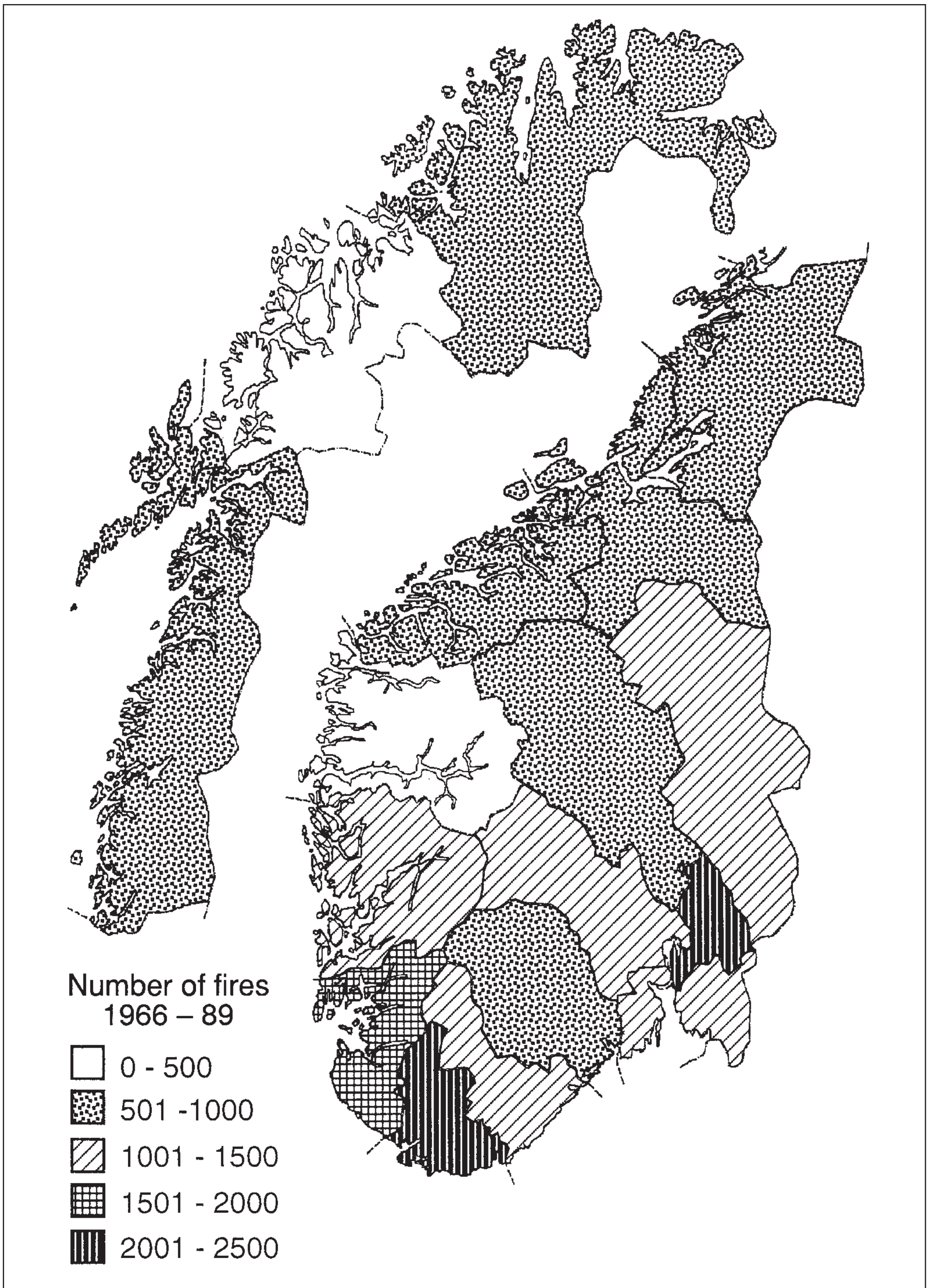


Figure 6.8. Countywise distribution of number of fires during 1966–89 (After Statistics Norway).

6.5.2 Seasonality

Number of fires in forest and outlying areas in the period was highest during April-May-June, with a marked peak in May (Fig. 6.9). Most of the fires were thus ignited in the period after the snow had melted and before the vegetation (the fuel) had

greened and thus gotten a higher moisture content. We must expect this tendency to start first in the southeastern part of the country where the snow cover is thin and melts first, and then to follow the phenological development northwards. As mentioned, strong wind may contribute significantly to increase the fire hazard during this period, which extends more or less continuously into the summer period and its more random fluctuations in dry and humid periods (see above).

6.5.3 Size of burned areas

The forest fires of Norway during this period were most often small in extent. The large majority of fires encompassed areas of less than five decares and were only as an exception larger than 1 000 decares (Fig. 6.10).

Total burned area was largest in 1972 (Tab. 6.1) with 86 053 decares, while it was 46 296 and 29 832 decares during 1974 and 1976, respectively. A relatively considerable area also burned in 1984 (Tab. 6.1).

Extent and variation in size of burned areas during the period 1962–89 emerges by comparing the burned area in this period (Fig. 6.10) with the number of annual fires (Fig. 6.5). The largest area burned in 1972, which was a year with an average number of fires. On the other hand, 1974 peaks the statistics concerning number of fires (Fig. 6.10), but during this year still only half as large area burned as in 1972. During some years, for example in 1983 where the number of fires was small, the size of the burned areas was also insignificant.

6.5.4 Productive and unproductive burned forest

The majority of the forested area, which burned during this period, was unproductive forest (impediment) (Fig. 6.11).

Number of fires and productive and unproductive area [6.2] which burned each year is shown in Table 6.1. The largest area productive forest burned in 1976, 16 648 decares, thereafter followed 1972 with 7 837 decares and 1970 with 7 751 decares. Also in the large “fire year” 1974 (see above) an extensive area of productive

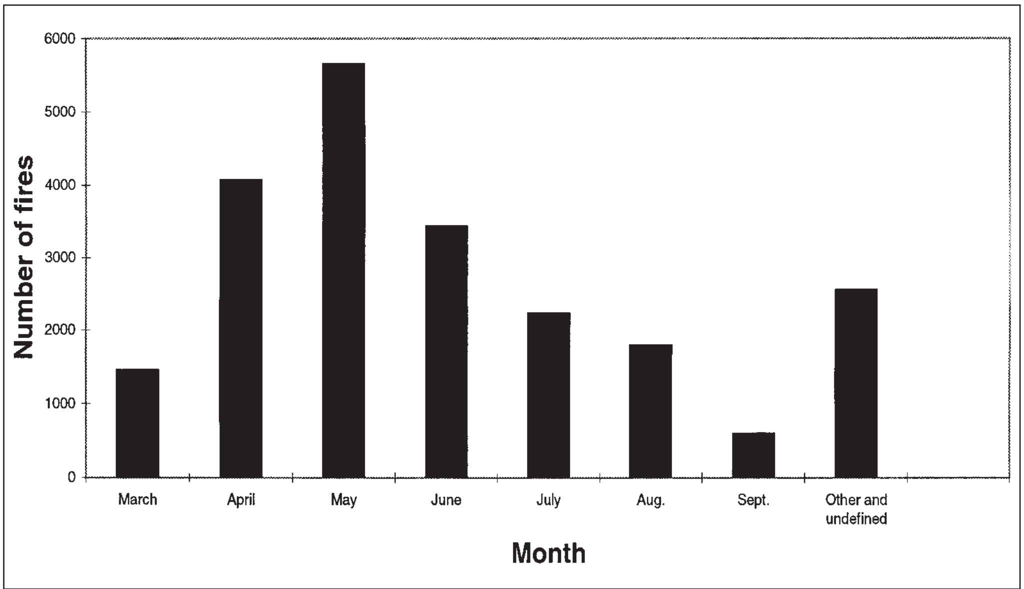


Figure 6.9. Total number of forest fires and fires in outlying areas in Norway 1962–89 distributed on the months March-September (After Statistics Norway).

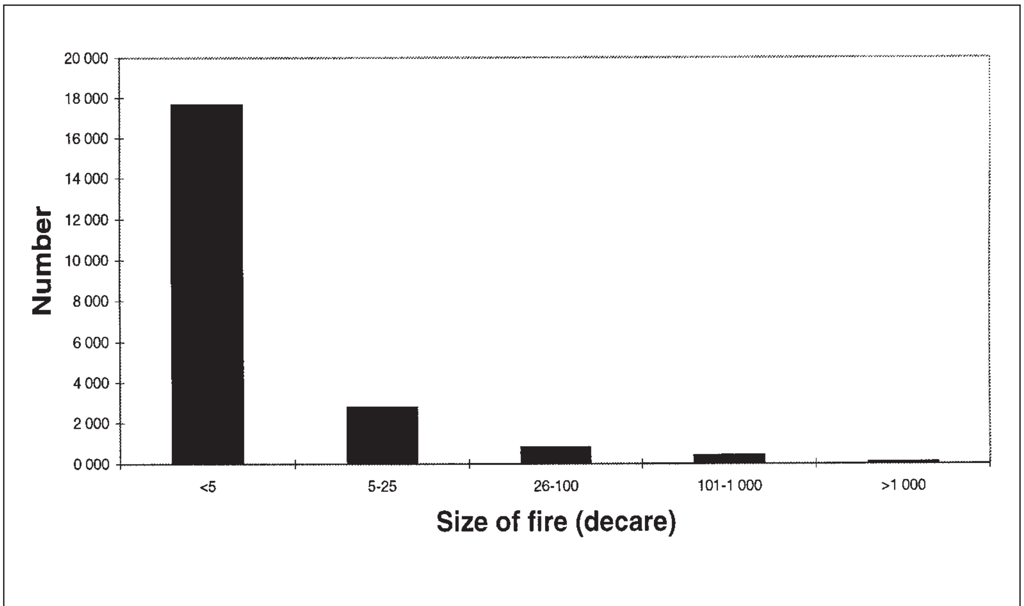


Figure 6.10. The size of burned area (decares) in forest fires and fires in outlying areas in Norway 1962–89 (Statistics Norway).

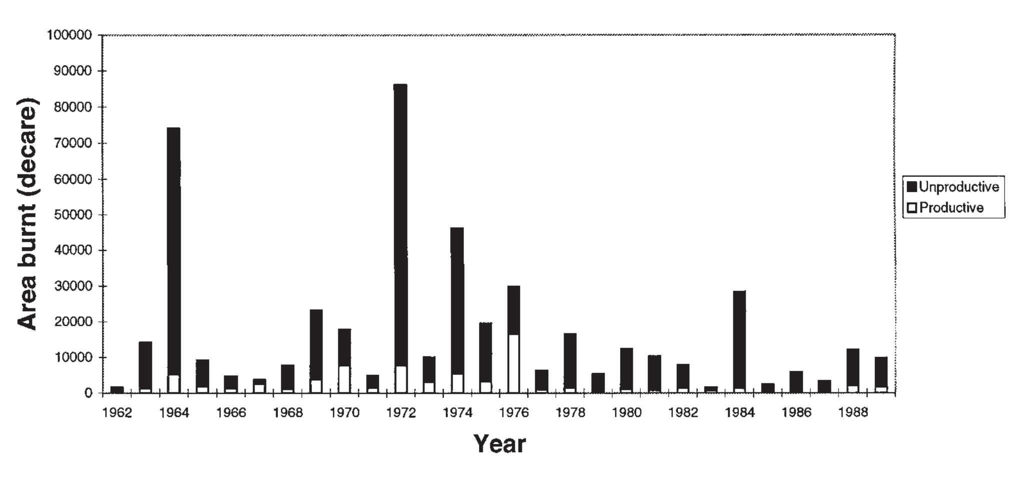


Figure 6.11. The areas (decares) of productive and unproductive forest which burned in Norway 1962–89. A countywise percentage overview is presented in figure 6.13.

forest burned (Tab. 6.1). Hedmark was the county in which the annually area of productive forest was on average affected (Fig. 6.12)

The percent share of fires on productive forest area was largest in Hedmark (65 %) and the counties in the south-eastern part of the country, among others Telemark (76 %). The country mean was 18 % (Fig. 6.13). In spite of the existence of large areas with productive forest both in Mid-Norway and northwards, the burned share was far less.

6.6 Lightning as source of ignition

There is no available material indicating that the areas of single fires ignited by lightning are larger or smaller than the ones caused by human activity. During the surveyed period the number of fires ignited by lightning was highest in the "fire year" 1976 (Tab. 6.1). High frequencies of fires ignited by lightning were also registered both in 1982 and 1988 without this being reflected in a correspondingly increased size of burned area. To accomplish a more secure evaluation of the quantitative importance of fire impacts from lightning strikes in Norway, it would be necessary to analyze statistical data, which in detail denotes the source of ignition linked to single fires. (This is possible from data collected by Skogbrand Insurance Company. It will, however, not be more closely evaluated in this technical report.)

Table 6.3. Fire statistics for Norway, Sweden and Finland 1986–95 (See text). n – number of fires, area – burned area in hectares (ha) and $\bar{x}$ – mean size of fires.

Year	Norway			Sweden			Finland		
	n [1,2]	Area (ha) [1,2]	$\bar{x}$	n	Area (ha) [3]	$\bar{x}$	n	Area (ha) [4]	$\bar{x}$
1986	301	595.0	1.98	-	-	-	717	367	0.51
1987	286	338.4	1.18	-	-	-	285	153	0.54
1988	448	1 214.8	2.71	-	-	-	621	289	0.47
1989	390	992.1	2.54	-	-	-	617	518	0.84
1990	578	86.8	0.15	-	-	-	559	434	0.78
1991	972	529.8	0.55	-	-	-	287	226	0.79
1992	892	1 370.1	1.54	-	-	-	852	1 081	1.27
1993	253	223.8	0.88	-	-	-	-	-	-
1994	471	231.7	0.49	2 500	3 100	1.24	1 173	1 659	1.41
1995	181	113.1	0.62	1 100	400	0.36	974	637	0.65
1996	246	513.5	2.09	5 700 [5]	2 100 [5]	0.37	-	-	-
Sum	7 020								

1) 1986–89 data from Statistics Norway, 1990–96 data from Directorate for Fire & Explosion Prevention, improved routines introduced from 1993.
2) Forest and range fires.
3) Proper forest fires (restrictively interpreted) 1994–95, from 1996 forest and range fires.
4) Due to methodological problems, the use of Finnish data is problematic.
5) Preliminary data, Swedish statistics not finally adjusted.

A core question was whether the category "unknown cause" in the Statistics Norway's data may hide an unproportionally large number of fires ignited by lightning. A correlation analysis of number of fires ignited by lightning and number of fires with unknown cause for the years 1966–89 (Tab. 6.1) gave the relatively low coefficient 0.539, i.e. no clear indication that this is the case.

Nor is it possible from the Statistics Norway data to decide exactly how many fires are ignited by lightning in proper *forest areas*. The frequency of fires ignited by lightning applies to fires on all outlying areas, i.e. both productive forests, forested impediments and heath- and grasslands. It is, however, possible to say something about county-wise differences. The highest annual frequency of fires ignited by lightning during 1966–89 emerged in Hedmark (9.3). Thereafter followed Telemark (5.5), Buskerud (3.7) and Aust-Agder (3.7) (Tab. 6.2). Lightning as source of ignition reflects the pattern in the climatic and nature geographical conditions, which is discussed previously in this technical report (ch. 2, section 3.2).

6.7 Norwegian fire regime vs. Swedish and Finnish

Throughout this technical report we have tried to emphasize and comment on Norwegian conditions and the fire regime in Norway compared with the other Nordic countries. Considerable interest in research and management is linked to a more thorough analysis of prospective similarities and differences between the Norwegian fire regime and the Swedish and Finnish ones. To compare the forest fire statistics for Norway, Sweden and Finland for the most recent years therefore was one of the main objectives when this technical report was planned. It turned out, however, not to be feasible, as the statistics are partly both insufficient and not directly comparable. This is also true for such basic parameters as number of fires, size of burned area and mean size of fires (Tab. 6.3). We are still going to refer a few numbers. For Norway we

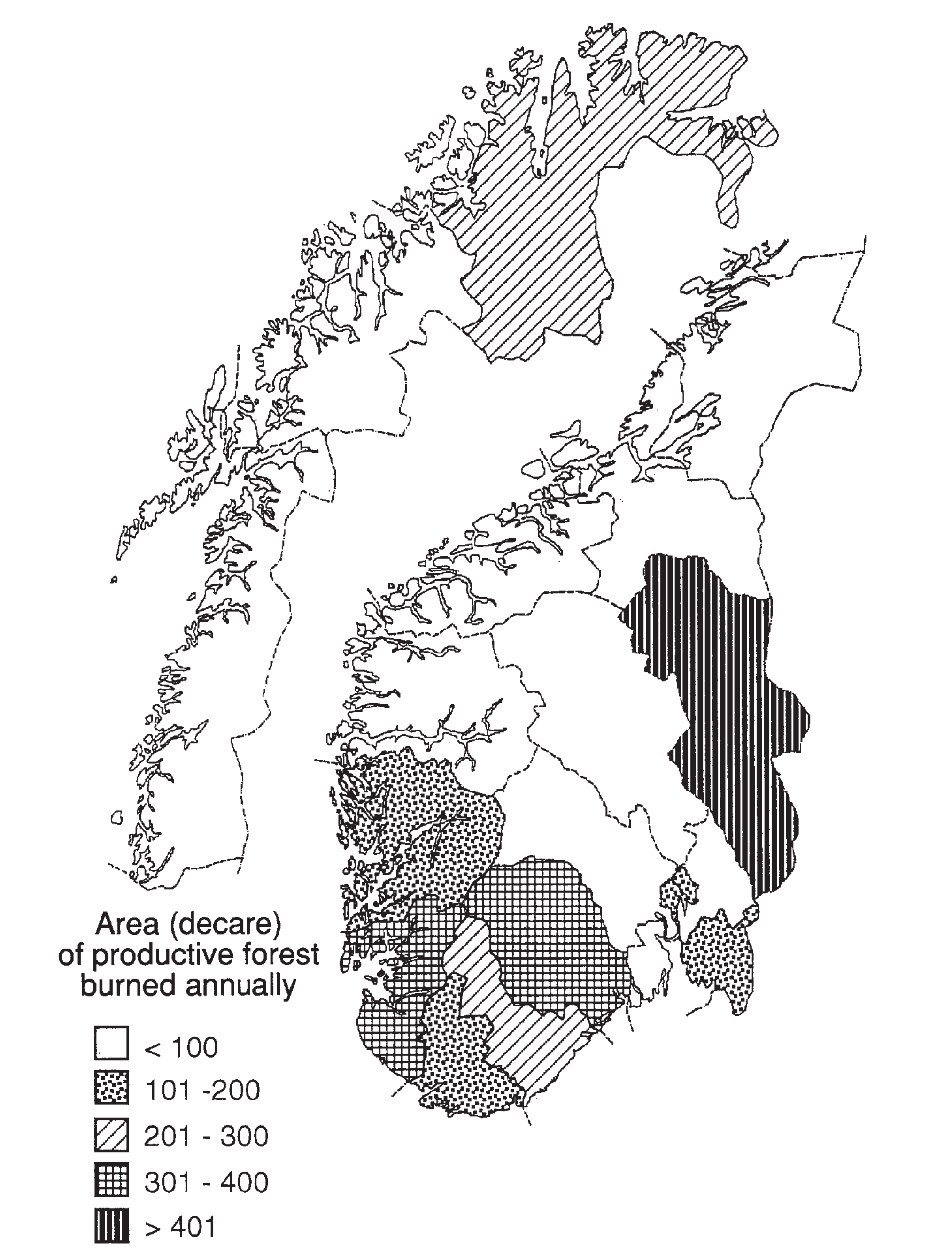


Figure 6.12. Countywise distribution of mean area productive forest (decares) which burned during the period 1966–89 (See text).

have for 1986–89 used data from Statistics Norway and from 1990–96 data from Directorate for Fire & Explosion Prevention. When this technical report was sent to print, we still lacked Finnish data from 1993 and 1996 and Swedish data for the whole period 1986–93

Even though the data are far too insufficient to undertake any statistical comparison of the countries, one trait may be commented upon. The modern "fire picture" seems to be far more similar between the countries than one would expect. Based on natural conditions, size of the forested area and population (see ch. 3) one should among other things have expected a far larger burned area in Finland than in Norway. A possible explanation of not finding this may be that the majority of fires in Finland occur in the southernmost parts of the country where the population density is high. Here the fires are quickly discovered and warned and effectively suppressed at or near the hearth before they have time to spread over larger areas.

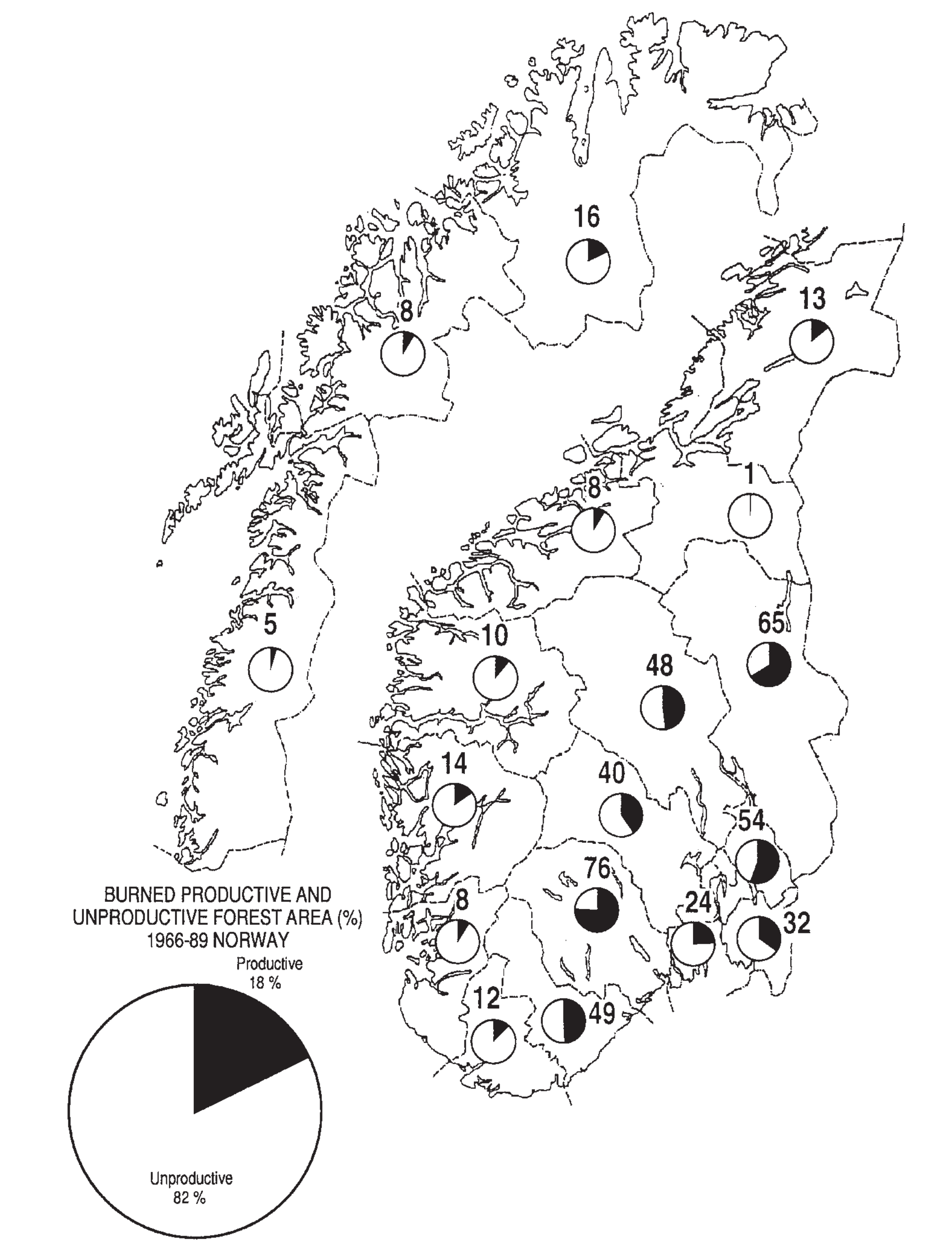


Figure 6.13. Countywise percent share of productive and unproductive forest area (%) which burned during the period 1966–89 (Statistics Norway).
Legend map: thin line – county border.
Legend pie diagram: black sector and number – productive forest area (%), white sector – unproductive forest area (%).

We also raise the question of whether the fire regimes of these three countries, Sweden possibly excepted (data lacking), today are dominated by anthropogenic ignition sources combined with management based on efficient suppression to a degree that any difference between the countries' natural fire regimes are on the verge of being obliterated. To answer this a far more thorough research-based analysis of the existing statistical data should now be initiated. The comments that are presented in the following are only based on a few spot tests.

6.7.1 The causal conditions

The material concerning causal connections of forest fires in the Nordic countries commented upon here, is also highly insufficient. A rough comparison between Norway and Sweden is based on data from the years 1994–95 and for Finland 1991–92 (Fig. 6.14). The percent importance of lightning as source of

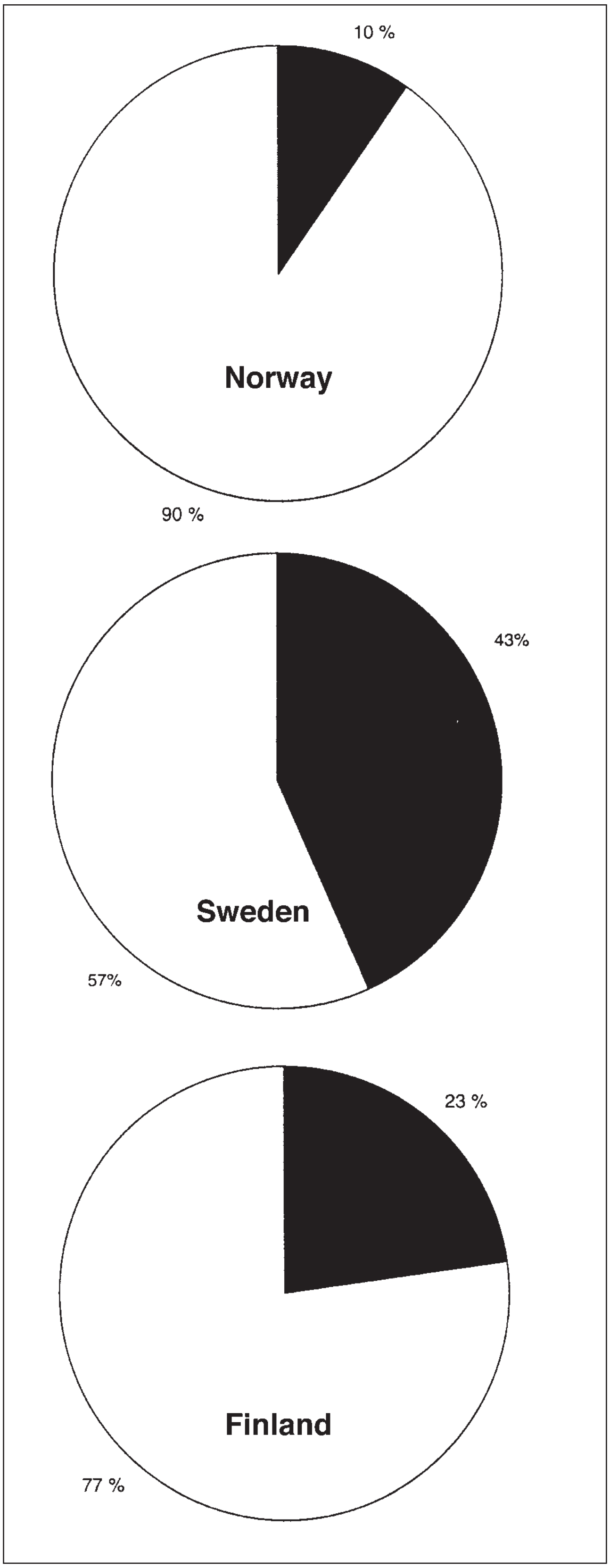


Figure 6.14. Percent distribution of lightning and human activity ignition sources as causes of forest fire in Norway, Sweden (the years 1994–95) and Finland (1991–92). Legend: black sector and number – lightning fires, white sector and number – fires from human activity ignition sources.

ignition seems to be considerably larger in Sweden and Finland than in Norway in accordance with what can be expected from nature geographical and climatic conditions (see ch. 3). The comparison is, however, as mentioned done on very incomplete statistical grounds. For Norway, where a part of the material about the country's fire regime today is presented elsewhere in this report (ch. 4), the sources from human activities totally dominate, something that also emerges in this spot test. The large importance of anthropogenic ignition sources also emerges in Sweden and Finland, but the relative dominance is less in these countries.

6.7.2 Nordic standardization of data

To be able to undertake a better comparison of the countries and get a description of single fires in an ecological and cultural perspective, the data collection should now be standardized in the three countries.

We suggest that the following parameters should always be collected for every single fire: size, time (date and time), UTM coordinates (middle point of burned area), forest type, soil quality class, cutting class/age class, exposition and slope (coarse scale). One should also try harder to improve in exposing the direct and indirect causes, in addition to the fire type (low stratum running fire, crown/top fire, ground fire/peat fire etc.). This will make possible analyses of fire pattern in relation to lightning frequency, climatic data and human activities and demographic patterns. Only in this way will it be possible to judge the relative importance of the natural and the anthropogenic fire regime in a holistic Nordic picture. The standardization should also encompass a closer examination of the basis of evaluation of the concepts "forest and outlying fire", so that one can get more homogeneous definitions. This revised survey should also be arranged so that the data may become part of the international data collection which is now in the process of getting organized both in regional and global context (Goldammer & Furyaev 1996).

A better scaling program and an extended data collection will also be decisive for getting a more problem based and hypothesis oriented forest fire research, something which must constitute the scientific basis in future management.

As prescribed fires and other tentative test burnings gradually get more common, data collection from these should also be coordinated. It is urgent to get this done because the interest in burning for conservation purposes seems to increase rapidly.

6.8 Summary

It was only after modern forest fire statistics were commenced in 1913 that we could obtain a reliable picture of the significance of lightning strikes compared with human activity in the Norwegian fire regime. Lightning strikes as an ignition source manifest themselves to a certain degree east of the divide, mostly in continental Hedmark. In our century, we have experienced a number of new types of ignition sources linked to the increase in traffic, industrialization, development of communications and transmission lines, mechanizing of forestry, etc. While the number of fires ignited by lightning fluctuates from year to year around the same level, the anthropogenic ignition sources have exhibited a marked increase, and have become totally dominating today. Increased traffic means that fires are more easily discovered, and improved communications and new methods of putting out fires have made extinguishing forest fires increasingly efficient. Even though the number of fires during a period continued to increase, the fires were extinguished more rapidly, and the burned area per fire decreased.

Material obtained from Statistics Norway's forest fire statistics was used to describe the fire regime during the period 1966–1989. The number of fires, causal relationships, seasonal factors, and the size and type of areas to burn varies considerably from county to county. During certain dry years, there are many fires in many counties. In general, we can say that the significance of fires ignited by lightning is modest, with the exception of Hedmark and certain other southeastern forest counties. A clear trend is that there were more fires during the period 1970–1979 than in the period 1980–1989. In other words, this would indicate that the number of fires has recently declined.

We have also commented on the Norwegian fire regime versus the Swedish and Finnish regimes. A comparison of statistical materials from the past ten years is not easy, as the statistics are both insufficient and not very comparable. We have therefore recommended that Nordic data collection regarding forest fires be standardized now, and that work with prescribed fires and test burning also be coordinated in a better way on a Nordic level.

7 FIRE REGIONS IN NORWAY

By Ivar Mysterud and Iver Mysterud

If, in the future, one shall perform a more systematic research and management of fires, it might be convenient to define, describe and name *fire regions* in Norway. An objective with this report was to identify various fire regions that reflect the large countrywide variation existing in Norway. A preliminary classification in six fire regions is suggested identifying various elements of the Norwegian fire regime, and at the same time is practically applicable. The classification is based on the preceding review of the number of fires and fire patterns in the counties during the period 1966–89 (ch. 6) combined with approximate evaluations of differences in the climatic and nature geographical conditions (ch. 3). Among these conditions, the fire intensity, vegetation (the fuel), topography, climate, sources of ignition and fire frequency are most important (ch. 2).

All fire statistics in Norway are distributed according to administrative units, i.e. based on classifications of counties. As the administrative units of nature management in Norway also work by county (County Governor), the basic units in the fire regions should also be the counties. Identification and description of fire regions will therefore require deciding which counties naturally go together such that the diversity of the fire regime is considered. Thus, the classification is a tentative compromise based on administrative and nature geographical landscape criteria.

7.1 Methods

As a point of departure for these evaluations, a pair-wise correlation analysis was first conducted where number of fires for the period 1966–89 for each county was correlated with all the other counties.

To ease the visual comparison between the counties, data (Fig. 7.1, upper) were first transformed by means of natural logarithms (Fig. 7.1, middle). The transformed curve was then adjusted by subtracting the average for the single county so that they got the same origo, and thus, merging axes (Fig. 7.1, lower). The data from Statistics Norway for number of fires in Norway was then tested for autocorrelation. [7.1] For the entire country combined and for the counties Østfold, Hedmark, Oppland, Vest-Agder, Rogaland, Hordaland, Sogn og Fjordane, Møre og Romsdal, Sør-Trøndelag, Nord-Trøndelag, Nordland, Troms and Finnmark, no autocorrelation was found. However, the counties Akershus and Oslo, Buskerud, Vestfold, Telemark and Aust-Agder showed autocorrelation for lag=1. This indicates that in these counties there could be a connection between number of fires one year and the next.

A benefit with the ln-transformation is that it provides curves with the same percentages change (in number of units) on the y-axis, irrespective of the mean on the y-axis. This is demonstrated by comparing Aust-Agder

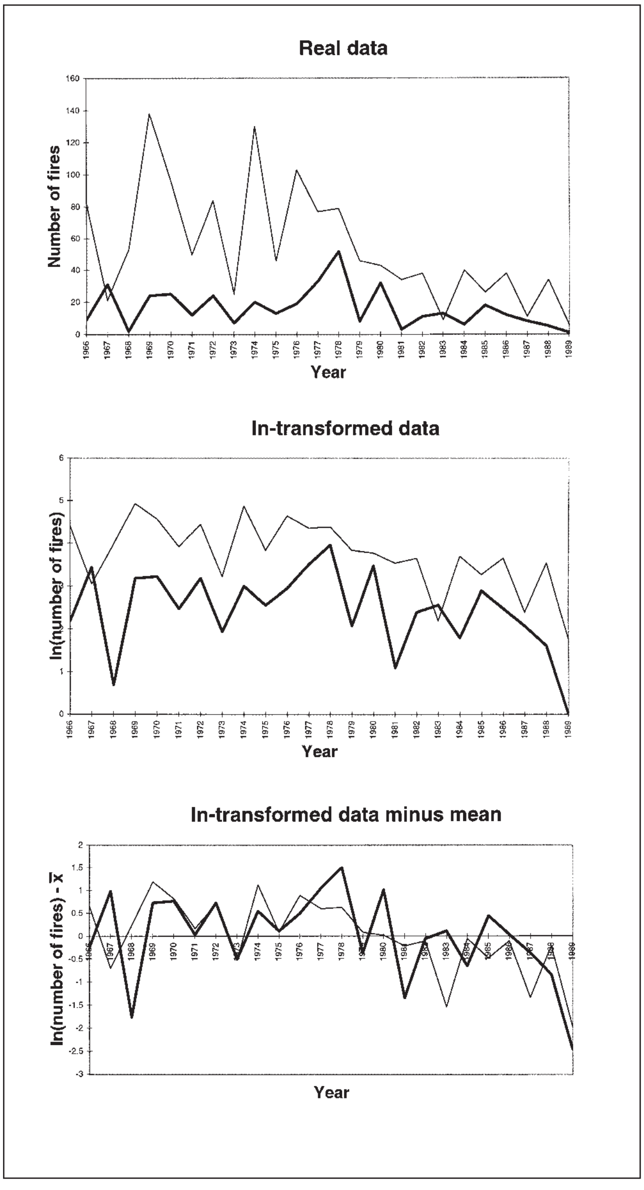


Figure 7.1. Comparison of the variation of number of fires in Troms (thick line) and Hordaland (thin line) counties, respectively, 1966–89, represented by real data (upper), ln-transformed data (middle), and ln-transformed data minus the mean (lower) (See text).

and Sør-Trøndelag (low correlation) and Østfold and Vestfold (high correlation), respectively (Fig. 7.2). Such correlations between paris of counties might also be visualized statistically in so-called scatter plots (Fig. 7.3). If the county pair shows high correlation when fire statistics are being compared, the single points will appear with short distances to the line (Fig. 7.3, lower). In the opposite case, the points will show a scattered distribution, with poor assembly along the line (Fig. 7.3, upper).

The correlation analyses for each county with all the other counties were then estimated as values in an 18x18 row matrix. The correlation coefficients for neighboring counties are denoted along the borders on a county map of Norway as basis for a first grouping (Fig. 7.4).

7.2 Six fire regions

A division of Norway in fire regions is important for systematizing research and management. The variation of the Norwegian landscapes is considerable. We therefore suggest six various fire regions (Fig. 7.5):

1. Hedmark Fire Region,
2. Southeast Norwegian Fire Region, [7.2)]
3. West Norwegian Fire Region,
4. Middle Norwegian Fire Region,
5. North Norwegian Fire Region and
6. Finnmark Fire Region (Table 7.1).

7.2.1 Hedmark Fire Region (HMR)

The Hedmark Fire Region (HMR) is delimited to Hedmark County. The basis for the delimitation is the relatively low and medium correlation coefficients for Hedmark and Oppland (0.49), Hedmark and Sør-Trøndelag (0.36) and Hedmark and Akershus/Oslo (0.40). [7.3)]

HMR is characterized by a large and homogenous distribution of fuel in expansive boreal coniferous forests with high resin content and relatively leveled topography (Fig. 3.12). There are also fewer natural fire barriers that characterize several of the other regions. It has the most continental climate in Norway (Fig. 3.5), with pronounced dry periods and relatively high frequency of lightning strikes (Fig. 2.2). Thus, the natural component of the fire regime is most prevalent in HMR, with relatively high ignition frequency by lightning (Fig. 6.2). This does not mean that anthropogenic sources of ignition have not also been historically important in this region. In Hedmark, high quality class forest was systematically burned by immigrants from Finland using swidden agriculture (ch. 4).

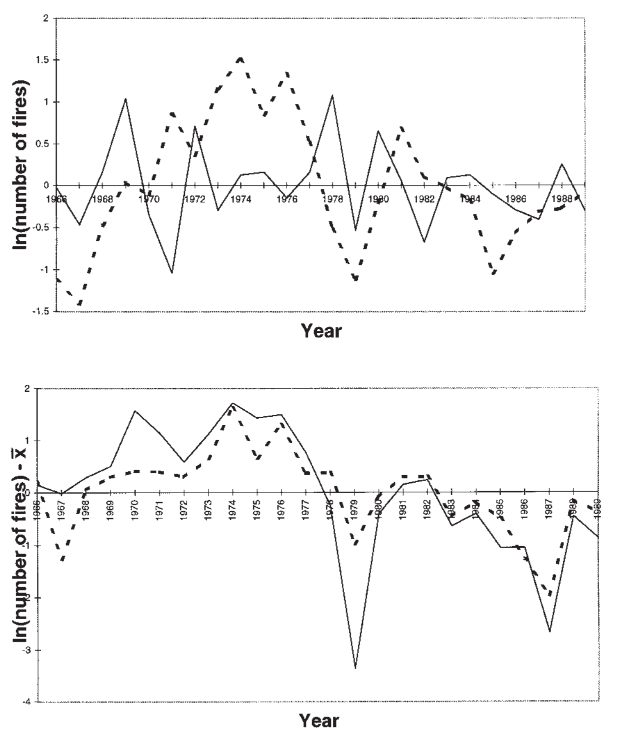


Figure 7.2. The counties are compared pairwise by examining the statistical correlation between the variation in number of fires during the period 1966–89. The examples show Aust-Agder county (dashed) and Sør-Trøndelag county (full line) with low correlation (0.01) (upper) and Østfold county (dashed) and Vestfold county (full line) with high correlation (0.84) (lower), respectively (See text).

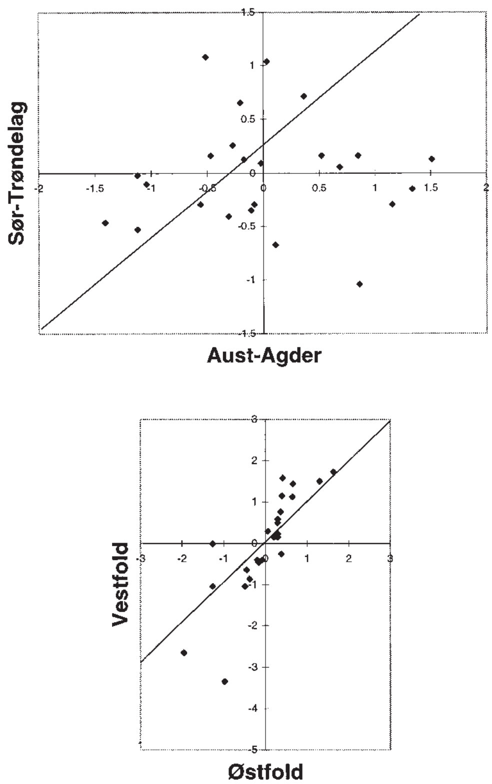


Figure 7.3. Scatter plot of correlation analyses comparing Sør-Trøndelag and Aust-Agder counties with low correlation (0.01) (upper) and Vestfold and Østfold counties with high correlation (0.84) (lower), respectively. The actual course of the curves are shown in figure 7.2 (See text).

Table 7.1. Suggested division of Norway into Fire regions (See text).

No.	Fire region	Abbre--viation	Counties	Lightning frequency 1)	Cause of fire (%) 2)		Characteristics
					Natural sources of ignition (lightning)	Anthropogenic sources of ignition	
1	Hedmark	HMR	Hedmark	10-80	23	77	Relatively many fires Continental climate, little precipitation Relatively leveled topography, boreal forests
2	Southeast Norwegian	SNR	Østfold Akershus og Oslo Oppland Buskerud Vestfold Telemark Aust-Agder Vest-Agder	10-360	2-18	82-98	Relatively frequent fires, but the amount varies regionally Varying climate and precipitation conditions Varied topography, characterized by forests, but large timberline areas and many mountains in western parts
3	West Norwegian	VNR	Rogaland Hordaland Sogn og Fjordane Møre og Romsdal	5-40	2-4	96-98	Relatively few fires, most in southern parts Oceanic climate with high precipitation; humid Topographically very varied, very steep relief Long coast line
4	Middle Norwegian	MNR	Sør-Trøndelag Nord-Trøndelag	5-80	2-3	97-98	Relatively few fires Climate characterized by high precipitation; humid Varied topography, medium altitudinal variation Coastal and boreal coniferous forests
5	North Norwegian	NNR	Nordland Troms	-	1-2	98-99	Relatively few fires Oceanic climate, high precipitation; humid Mountainous with coast line Clumped and dispersed distribution of forest
6	Finnmark	FMR	Finnmark	-	approximately 0	approximately 100	Relatively few fires Varying climate and precipitation conditions Leveled relief Alpine coastal areas, boreal forests in inner parts

1) Number of lightning strikes per 10 km^2 during the ten year-period 1982–92 (See Fig. 2.2).
2) Fire causes (in percent) for the period 1975–89 (See Fig. 6.1).

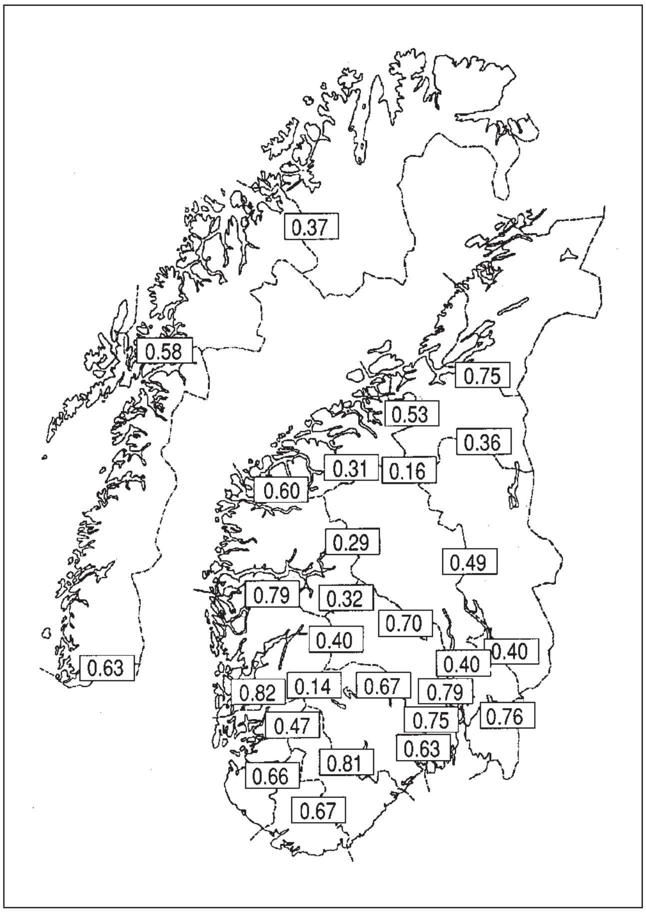


Figure 7.4. Correlation coefficients for neighboring counties denoted along the borders between them. The coefficients were used for a coarse grouping of counties according to the merging of fire patterns (See text).

7.2.2 Southeast Norwegian Fire Region (SNR)

The Southeast Norwegian Fire Region (SNR) consists of the eight counties Oppland, Buskerud, Telemark, Aust-Agder and Vest-Agder in addition to Østfold, Akershus, Oslo and Vestfold. The first five represent the closest counties to the Scandinavian mountain range, and the latter three a large landscape section around the Oslo Fiord. The basis for uniting these counties is the relatively high correlation coefficients through the county group Oppland-Buskerud-Telemark-Aust-Agder. [7.4)]

SNR is Norway's largest fire region, maintaining large variations in landscape types, topography, climate and vegetation conditions. Furthest towards the coastal area, the Nemoral zone is found (Fig. 3.12), with a broader Boreonemoral zone in the areas farther from the coast. Within this, we find another zone of northern boreal coniferous forest running continuously from the border towards Hedmark and southwestwards to Aust-Agder. In the collection of counties lying towards the mountains, the Alpine zone is represented farthest to the west. The occurrence of various qualities of fuel therefore varies greatly in both north-south and east-west gradients. Fires will seldom become comprehensive in area due to the torn up landscape of the region, with a high density of natural fire barriers. Some of the coastal and southernmost areas have relatively high precipitation and much wind, which, however, declines towards the north and east. Some very dry periods may also occur, especially when the snow has melted in the spring and before the vegetation turns green. The conditions are then often appropriate for ignition, and fires occur often in SNR (Fig. 6.8).

The thunderstorm frequency varies regionally, but some local areas, both close to the coast and around and north of the Oslo Fiord, show maximum numbers of lightning strikes per 100 km^2 in Norway (Fig. 2.2). Thus, SNR also has a relatively high number of fires with natural sources of ignitions, but the conditions vary much more than in HMR. Even though the thunderstorm frequency in some areas in SNR are particularly high, this is not reflected in a correspondingly larger amount of burned forest. Fires with anthropogenic sources of ignition have been important in SNR throughout history. In the districts close to the coast, fire-created heathlands have developed (See section 4.2.6). During waves of earlier colonization, the landscape within the forested areas became opened by use of fire, both in connection with cultivation and grazing. The northeastern part of SNR has also been influenced by the immigration of Finnish swidden agriculturists (Section 4.2.5). SNR is therefore very well suited for comparative research focusing on biological diversity in a large area with varying fire conditions.

7.2.3 West Norwegian Fire Region (VNR)

West Norwegian Fire Region (VNR) consists of the four counties Møre og Romsdal, Sogn og Fjordane, Hordaland and Rogaland. This comprises a well delimited and relatively homogeneous fire region with low correlation values towards their eastern adjacent counties (Fig. 7.4) (Oppland-Sogn og Fjordane (0.29), Buskerud-Hordaland (0.40) and Telemark-Hordaland (0.14)) and high correlation values between the coastal counties in the western part of Norway (Hordaland-Rogaland (0.82)).

The vegetation consists of a Boreonemoral zone close to the coast, which may abruptly change to an Alpine zone due to the steep relief at the western side of the

Scandinavian mountain range (Fig. 3.12). The protected areas near the coast inside the fiord districts contain the most fuel. The topography of VNR is varied, with a long coastline criss-crossed by fiords and valleys in all compass directions. The density of natural fire barriers is large. In addition, VNR has high precipitation, and in many areas more than 4 m may fall annually. The thunderstorm frequency shows only low to medium values, with a maximum in the wintertime. In this part of Norway, the importance of natural sources of ignition has probably been low in the coniferous forests close to the coast. However, there seems to have been a great deal of burning along the entire coast, indicating that anthropogenic sources of ignition in historic time may have been important. VNR has a long coast line, where cultural impacts from people coming in from the sea have been of significance during various times throughout large parts of the postglacial period. The consensus among researchers and historians is that the decline and/or disappearance of the forest in VNR was caused by human activity, although details about how this happened is still a matter of discussion (ch. 4).

7.2.4 Middle Norwegian Fire Region (MNR)

The Middle Norwegian Fire Region (MNR) consists of the two counties Sør-Trøndelag and Nord-Trøndelag, comprising a well-defined region. Sør-Trøndelag and Nord-Trøndelag have a relatively high internal correlation value (0.75). The differences with Møre og Romsdal (0.53) and Hedmark (0.36), respectively, are relatively marked, while the delimitation towards Nordland is less pronounced (0.63). If the delimitations of the fire regions had followed natural dividing lines, parts of Nordland would have been added here, and parts of Sør-Trøndelag would have been added to the Hedmark region (See above).

MNR is also characterized by larger boreal coniferous forests, but they are closer to the coast and more exposed to a particular climate characterized by high precipitation.

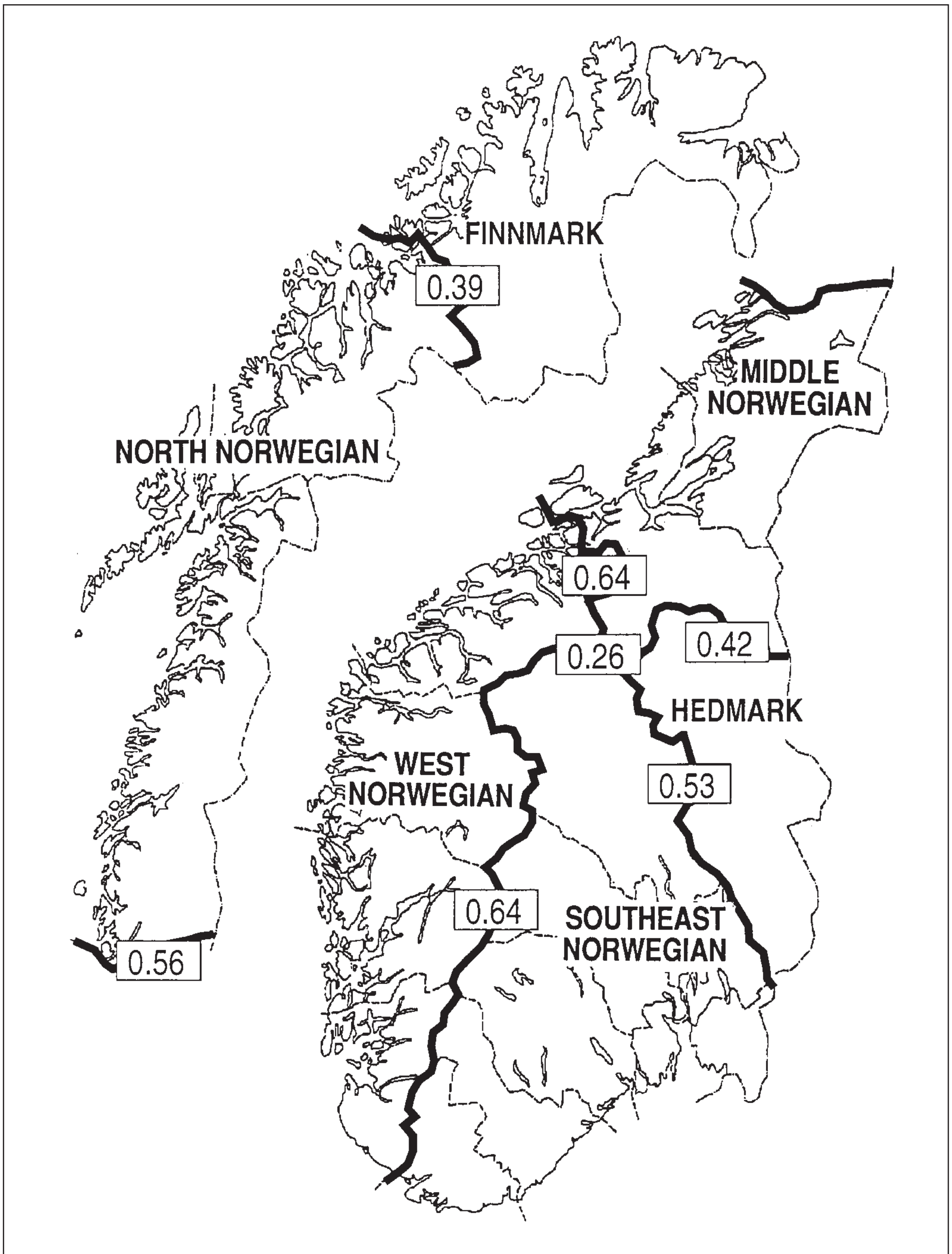


Figure 7.5. Suggested division of Norway into six fire regions (See Tab. 7.1). Numbers denote correlation coefficients for neighboring regions (See note 7.2).

The topography is varied, but within a smaller altitude variation and more moderate relief than in the fire regions both south- and northwards. The Alpine zone is most pronounced in areas towards the Swedish border (Fig. 3.12), where one also finds the most continental climate.

The thunderstorm frequency shows medium values (Fig. 2.2), but the high precipitation and humidity results in a seemingly low frequency of fires ignited by lightning. The Trondheim Fiord has been central for trade and communication along the coast through several thousand years. Therefore, historically, anthropogenic sources of ignition may have been most significant. In the coastal areas, there are *Calluna*-heathlands over extensive areas that were created by fire (See section 4.2.6).

7.2.5 North Norwegian Fire Region (NNR)

The North Norwegian Fire Region (NNR) consists of the counties Nordland and Troms. Mountain formations with large areas in the Alpine zone make the conditions regarding forest fires clearly distinct from the Swedish and Finnish areas eastwards.

This fire region has high precipitation, varied topography and torn up relief, unevenly distributed coastal forests and relatively dispersed small sections of boreal coniferous forests (Fig. 3.12). The coastline is sectioned by fiords and river systems in all directions, and includes many large and small islands. Even though both southern and northern boreal coniferous forests are represented, the landscape is seldom able to burn over large areas due to the dispersed distribution of fuel and the density of natural fire barriers.

The thunderstorm frequency varies from medium to low, and the ignition frequency seems to be relatively low. As in the regions VNR and MNR, the anthropogenic sources of ignition were most likely important. In NNR there is also a zone with coastal *Calluna*-heathlands created by fire (See section 4.2.6). Even though the forests close to the coast are more fragmented than in areas both northwards and southwards, there has been extensive forest fires in these counties.

7.2.6 Finnmark Fire Region (FMR)

Finnmark Fire Region (FMR) is delimited to Finnmark County. The reason for this is the relatively low correlation value (0.37) between Troms-Finnmark.

Finnmark has a far more leveled relief and alpine coastal areas than NNR. More continental conditions in the inner parts constitute a large region with northern boreal coniferous forests. These particular conditions merge with similar conditions along the Finnish side of the border, and concerning Pasvik, also along the Russian side of the border.

FMR may roughly be characterized in two parts, one middle zone close to the coast representing the Alpine zone, and one inner part with northern boreal coniferous forest. Sections of the coast have high amounts of precipitation, but the coast farthest to the north and the intermediary regions have less precipitation. The continental regions of the pine forests of inner Finnmark and Pasvik have the least amount of precipitation. The distribution of fuel combined with the climate reduced the likelihood of natural ignition. Some fuel exists in the inner parts, where conditions are more continental and the importance of lightning induced fires is somewhat greater.

7.3 Summary

In this report, we have proposed dividing the country into six fire regions to address the substantial variations in the fire regime in Norway. These six regions are Hedmark Fire Region (HMR), Southeast Norwegian Fire Region (SNR), West Norwegian Fire Region (VNR), Middle Norwegian Fire Region (MNR), North Norwegian Fire Region (NNR) and Finnmark Fire Region (FMR). The basis for these regions is a grouping of the counties according to similarities in fire patterns and more discretionary evaluations based on materials presented in this report. A division such as this is important in order to systematize both research into and management of forest fires in Norway.

8 EFFECTS OF FOREST FIRES

By Ivar Mysterud and Iver Mysterud

Forest fires can affect nearly every part of the ecosystems, i.e. soil, water, air, plants, animals and all types of ecological processes. It is not possible to provide a complete overview of all of the quantitative and qualitative effects within the framework of this report. General overviews covering parts of this huge topic with emphasis on the boreal areas may be found *inter alia* in Lutz (1956), Ahlgren & Ahlgren (1960, 1965), Cooper (1961), Requa (1964), Kayll (1968), Hakala et al. (1971), Slaughter et al. (1971), Ahlgren (1974), Kozlowski & Ahlgren (1974), Christensen & Muller (1975), Albini (1976), Kelsall et al. (1977), Wells et al. (1979), Bisset & Parkinson (1980), Gill et al. (1981), Gochenaur (1981), Warcup (1981), Chandler et al. (1983), Wein & MacLean (1983), Broysen & Tainton (1984), Goldammer (1990), Walstad et al. (1990), Johnson (1992), Payette (1992), Agee (1993), Rolstad (1993), Whelan (1995), Bond & van Wilgen (1996), Goldammer & Furyaev (1996), Persson (1996), Goldammer et al. (1997), Kimmins (1997) and Wikars (1997).

We can divide the effects of fires into those that have direct effect by killing organisms and disposing of biomass, and those that have more indirect and long-term effects through altering environmental conditions. The following comparison is based partly on the general effects of forest fires and partly on conditions that apply particularly to the boreal coniferous forest. Few studies have been carried out in Norway, and we must look to Sweden and Finland to find much of the literature on Nordic conditions.

The effect of fire on living organisms is often presented by spectacular examples of species that are capable of tolerating or escaping the most intense fires in ecosystems that burn often. The survival of the individual organism in a fire will be determined by its life history and anatomical, physiological and behavioral traits. The understanding of how populations and societies change as a response to a specific fire regime will largely depend on the characteristics of the individual organism and the populations it builds up.

The relationship of fire to living societies is very complex, which makes evolutionary observations of the individual traits difficult.

Most of the traits that provide improved survival in connection with fires can have several advantages, including protection against grazing, frost and organisms that cause disease (Whelan 1995, Bond & van Wilgen 1996), and they may be developed independent of fires.

Therefore, internationally recognized researchers warn against casual use of the characteristics referred to as so-called “fire-adaptive features” (Gill 1981b, Keeley 1981). The word “adaptive/adaptation” or “adjustment” may provide an incorrect impression of a nearly obligatory (unavoidable) adaptation to prevailing or future conditions. The designation “fire-adaptive” may also easily lead to fires being perceived as the only selective mechanism that has produced the particular characteristic.

An additional problem is that the responses of a species will depend on the special characteristics of the individual fire and, as we have seen, fires are highly variable phenomena. A species that is “favored” and can exhibit a strong increase in recruitment during the phase after a fire, may very well be vulnerable to a high mortality rate and deficient recruitment after the next fire, which may have other special characteristics. In other words, a trait of the species regarded as being “adaptive” in one fire, may be regarded as being “maladaptive” in the next (Whelan 1995).

Nevertheless, identification of the characteristics of an organism that allow it to survive in special fires may be important. They can indicate the potential significance various characteristics of a fire regime may have had with regard to forming organisms through evolutionary time. Such insights may also make certain predictions possible with regard to survival and reproduction of organisms in fires that have special properties. Knowledge about these things is important in management.

This report has placed considerable emphasis on the approach of Whelan (1995), which also takes into account the fundamental effects fires have on living tissue, i.e., on a scale below the organism level. This constitutes a logical basis on which to evaluate the spectrum of solutions that various organisms have developed and exhibit in various environments.

Plants, fungi and animals have developed fundamentally different solutions to such problems, linked to anatomy and morphology and the relative immobility of plants and fungi as compared with most animals. Plants, for example, are far more "elastic." They can more easily tolerate serious injury to certain of their "body parts" than animals (Whelan 1995).

In the following sections, we will look at the effects of forest fires on soil, fungi, plants and animals, and finally, we will comment on some factors that apply to the entire ecosystem.

8.1 The effect of fires on soil

Soil properties can be profoundly influenced by living vegetation and stored dead organic material, both of which can be removed by forest fires to varying degrees. Fires thus have the potential to induce great changes in the soil.

The combustion releases organic and non-organic compounds. The fire's "mineralizing" effects depend on the temperatures achieved during burning of vegetation and litter and the biomass that is converted, which in turn depends on moisture, topography, weather conditions, etc. (Section 2.2.5).

The degree to which fires change the properties of the soil depends particularly on the fire's intensity/ severity. As we have mentioned previously (ch. 2), fire severity is in turn influenced by the amount of available organic fuel, its distribution and moisture contents, and the prevailing weather conditions (Kimmins 1997).

Because fires can cause great changes in soil conditions and because fires are so common in forests and pastures, it is important to have a clear understanding of the potential effects a fire may have on the soil. These effects are discussed in a large amount of literature (U.S.D.A. 1971, 1979, Bell et al. 1974a,b, Cramer 1974, Kozlowski & Ahlgren 1974, Wells et al. 1979, Wright & Bailey 1982, Chandler et al. 1983, Whelan 1995, Kimmins 1997). Gluva (1984) did the most comprehensive Norwegian survey of the soil in a fire area. In the following description, we discuss effects associated with physical, chemical and biological factors, but it is also made clear that they are inter-related to a significant degree.

8.1.1 Physical changes

Physical changes resulting from fires are primarily the conversion of organic material (reduced humus cover) and influences on the soil structure, its porosity, moisture and temperature.

8.1.1.1 Organic material

A main ecological effect of fires is that inaccessible mineral nutrients that are bound to organic material are converted into soluble forms that can become accessible to plants.

Among other things, many of the metal nutrients that are deposited as water-soluble oxides in the ash are released (Davies 1959, Ahlgren & Ahlgren 1960, Skoklefald 1973a, Viro 1974, Raison 1980, Gluva 1984). Increases in the concentrations of sodium, potassium, calcium (Ahlgren & Ahlgren 1960, D.W. Smith 1970, Viro 1974) and magnesium (Stark 1977, Kraemer & Hermann 1979, Raison 1979) have been established in the ashes after burning.

This means that even if a fire causes a significant decline in the soil's total capital of nutrients as a consequence of the losses in gas form, fly ash and leaching, it may nevertheless improve the accessibility to nutrients for plant growth (Chandler et al. 1983). This is first apparent on the forest floor and at the top of the soil profile (with the exception of very soluble elements such as potassium), however, the concentration decreases over time due to leaching to a lower layer in the profile, absorption by plants and microbial conversion to more inaccessible forms. The increase in the level of accessible nutrients farther down in the profile can often occur after periods of several years (Kimmins 1997).

Loss of organic material is one of the most important effects fires have on the soil. Fires increase the speed of the normal mineralization process that takes place in organic material. In just a few minutes, a fire can do what would have taken several years for microorganisms to accomplish (for material such as dead leaves and fine root material), or even decades or centuries (for rough fuel such as stumps and logs). Fires are usually confined

to the surface and the upper part of the accumulated organic material. This is due to the need for oxygen to support the combustion and because the deeper layers are often too wet to burn. Glowing ground fires, however, can be ignited and move slowly through the deep layers, even in moist organic material. In these cases, the fire pre-heats the material in front of it. Organic material that is mixed with mineral soil normally remains unaffected by fires, but in extremely intensive fires, the heat effect can also penetrate the mineral soil layer and destroy colloidal organic material. Fires can also penetrate deep into the soil by burning along dead roots (Kimmins 1997).

The loss of organic surface material depends on the fire's duration, intensity, severity and the moisture of the fuel, which varies considerably according to the season (Chandler et al. 1983). A substantial reduction of organic material takes place already at surface temperatures above 200 ˚C (Gluva 1984). Viro (1974), for example, reported a 25 % reduction in the two lower organic layers of the profile, from 33 to 25 tons per hectare after fires in Finland, while the quantity of organic material in the mineral soil fell by 17 % in the upper 10 cm and 7–10 % further down in the profile. The effects of fires on the soil's overall content of organic material will also depend on how much organic material is found in the mineral soil. Where there is a lot of organic material stored in the mineral soil, the loss of organic material stored on the surface does not necessarily mean a significant impairment of the production capability, of new colonization opportunities for plants. However, this varies greatly from fire to fire (Kimmins 1997).

Loss of ash can occur due to wind and water erosion.

In an extremely hot fire with sufficient oxygen supply, all carbon compounds can be oxidized to CO or CO_2. In many fires there is insufficient heat and/or oxygen for the combustion, and many organic compounds simply evaporate. Much of the steam disappears in the smoke column, but some of it can also be driven down and into the unburned portion of the soil where it often condenses on cooler, unburned material (Kimmins 1997).

8.1.1.2 Structure and porosity

Fires that only remove the litter layer of the soil profile will generally have little effect on the soil structure. On the other hand, a fire that removes the entire organic part, exposing the mineral soil to the direct effects of precipitation and raindrops, may lead to significant loss of structure in the surface layers. The ability of the soil to allow water to penetrate (percolate) is important. This is a function of the pore volume. The infiltration rate may be reduced and surface run-off may increase, which will in turn lead to erosion.

In a hot pasture fire, colloidal organic material on the surface of the mineral soil layer may also be broken down and destroyed, followed by structural changes, including a significant reduction in porosity. One factor that can counteract the effect of this is an increase in pH and the amount of bivalent cations that can lead to an increase in the flocculation and an improvement in the structure of the surface layers of the soil which already have a fine structure.

Investigations in fire areas have shown both a decline in the macro pore volume and an increase in the micro pore volume (Tarrant 1956). In sandy clay with mull-like humus, the macro pore volume was reduced by 25 % and water penetration (the percolation rate) was reduced by 30 %. On the other hand, no effect on the total pore volume was noted. The effect of reduced water penetration is increased run-off in connection with heavy precipitation, which in turn causes erosion and reduced infiltration of water through the soil (Gluva 1984).

A subsequent penetration of heat may, in certain cases, drive the most volatile compounds deep into the soil, considerably expanding that part of the soil strata which is affected by condensates. This can contribute to the development of a well-defined layer of materials that, because of this layer of previously volatile substances, acquires properties that are water-repellant. Such water-repellant layers can reduce the degree of infiltration both in the rest of the organic material and in the underlying mineral soil (Kimmins 1997). We are familiar with these kinds of special effects resulting from fires with the formation of an impenetrable and water-repellant layer in the soil profile *inter alia* from the chaparral systems in California (DeBano et al. 1977). These very unique conditions allow organic compounds to be distilled down through the soil profile, forming such water-repellant layers not to be softened (see Wright & Bailey 1982).

The course of such water-repellant processes varies according to the type of fuel and the other properties of the soil. Sand, which has a relatively small surface area, is affected much more than soil formed from sediments and various types of clay soil (Kimmins 1997).

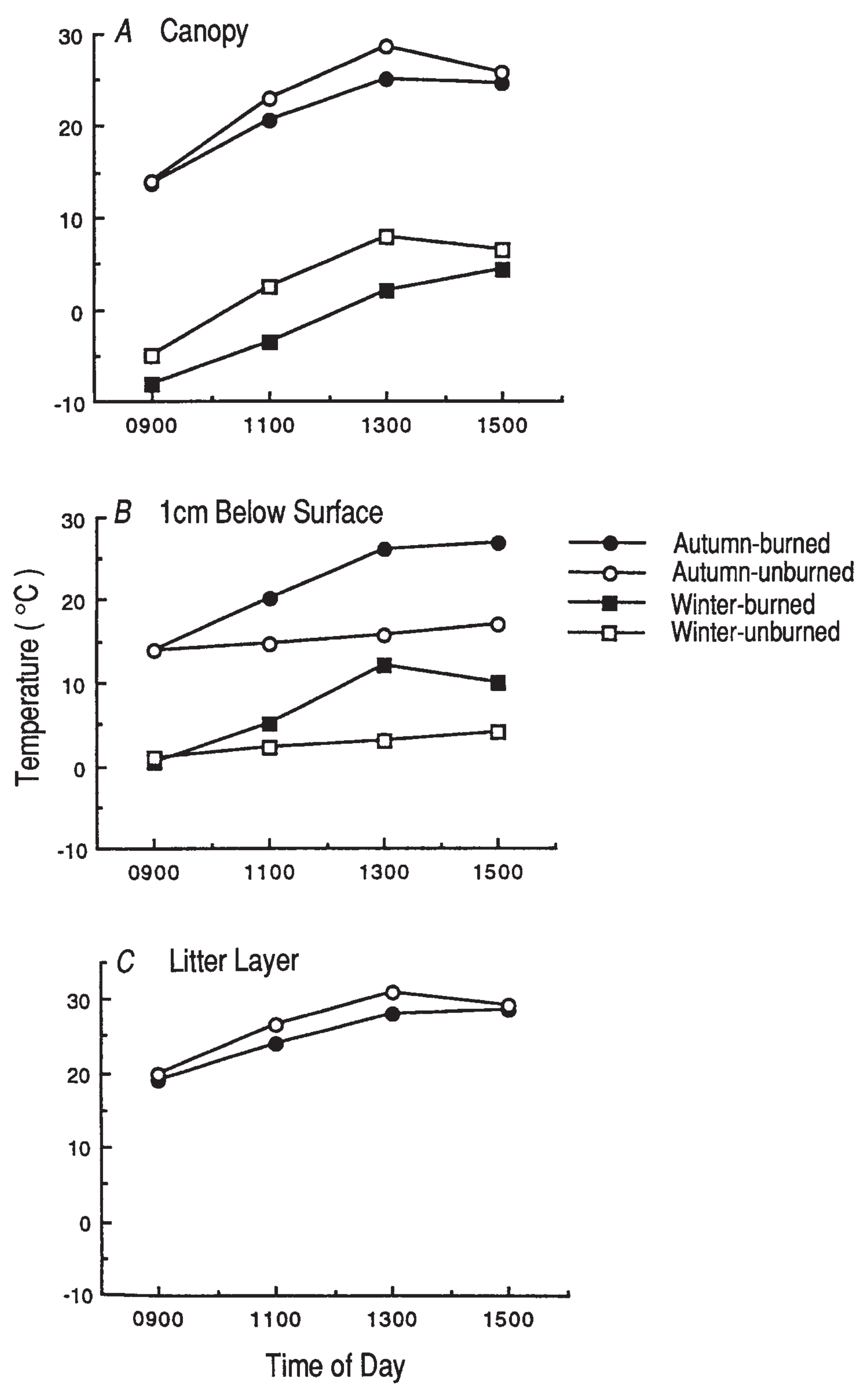


Figure 8.1. Air temperatures measured on burned (filled symbols) and unburned localities (open symbols), autumn (circles) and winter (squares) in a prairie system in North America (Ewing & Engle 1988; redrawn from Whelan 1995). Burned areas are normally cooler at the level of the plant cover (A), but warmer in the soil 1 cm under the ground surface (B), but the differences are small in the litter/grass layer (C).

However, it is not very likely that wildfires in damper and cooler northern coniferous forests will lead to significant formation of such water-repellant layers.

We have established that fire can reduce the infiltration properties of soil in several ways; through the loss of structure in mineral soil, through clogging macro pores with ash, through formation of charred, crusty layers, or through the formation of “water-repellant” layers.

The leaching of various elements from the soil must also be viewed in context with both structural changes in the soil and with the development of the subsequent vegetation. Nutrients that are released in connection with combustion may either be absorbed by unharmed vegetation or new vegetation, they may bind to soil colloids in the upper soil strata, leach down into lower sections of the soil or be lost through run-off and wash-out. These factors will vary from fire to fire, and the natural course cannot be generalized (Gluva 1984).

Run-off has also been studied in a number of areas with extremely varied results (Johnson & Needham 1966, Wright 1976, McColl & Grigal 1977).

8.1.1.3 Moisture

It must be expected that removal of biomass above and on the soil surface and increased temperatures and wind speeds will change the water resource system in burned areas (Wright & Bailey 1982). Fire reduces the content of organic substances and will thereby decrease the ability of the soil to retain moisture (Neal et al. 1965).

Changes in moisture conditions near the soil surface after fires have been documented, *inter alia* in Scottish moors (Mallik 1986). The water content in the upper 2 cm of the soil generally declined as a response to fire, particularly in the summer months. Evaporation was also lower in burned areas.

Fires reduce transpiration and interception due to the reduction of foliage. Where all vegetation is killed, the soil may be comparably wet, but this depends on the fire's total effects on the organic material and the soil structure. This applies only when the fire leaves the forest floor more or less intact. In soil with a coarse structure, much of the capacity for storing moisture is linked to the organic material. If the organic material is burned off, the soil may become much drier (Kimmins 1997).

If the fire has caused a reduction in the infiltration capacity, less water will penetrate down into the soil, and less will be stored. This will, in turn, cause desiccation. Fires can also increase loss through evaporation if the entire ground cover is removed. In warm, dry climates and soil that is of a medium-coarse structure, the loss through increased evaporation can be significant.

8.1.1.4 Temperature

The temperature conditions in the soil are normally changed after a fire (Fig. 8.1). This can affect plant productivity and soil organism activity, particularly as regards microorganisms. In arctic areas, the changes also have an impact on the depth of the permafrost (Whelan 1995).

Energy that is released during the course of a fire will create short-term effects on the soil temperature; however, due to the remarkably insulating properties of forest and soil material, heat penetration is generally very limited (see Section 2.2.2). Temperatures of 900–1000 ˚C have been measured just above the ground level under conditions that are particularly favorable for intensive fires (Ahlgren & Ahlgren 1960, 1974, D.W. Smith 1970, Uggla 1974) and 220 ˚C 7.5 cm down into the soil. Pasteurization temperatures [8.1] have been measured at depths greater than 20 cm (Raison 1979). Uggla (1957) performed tests with burning of logging waste in Sweden and noted temperatures in the range of 80–540 ˚C just at the surface. The duration of the temperature, and the maximum temperature, varied according to the amount of biomass and the local conditions. In areas with a thin cover of humus and low moisture, the burning had clear effects on temperatures all the way down to depths of 20 cm.

Fires can affect the soil temperature both in the shorter and the longer term. The long-term effects include a general increase in soil temperatures by blackening the surface of the soil, promoting absorption of solar energy and by reducing the depth of the organic material that has accumulated on the surface. This promotes the transfer of heat to the mineral soil. [8.2] By removing trees and vegetation that shade the surface, fires also increase the soil temperature.

The temperature effects are caused by a combination of several factors, including the elimination of shade from vegetation and the insulating effects of litter (Ahlgren & Ahlgren 1960, Old 1969). In addition come changes in the soil surface's albedo [8.3] (van Cleve & Viereck 1981). Many have proven higher daytime temperatures in ashes than in unburned humus (Uggla 1957, Ahlgren & Ahlgren 1960, Raison 1979).

8.1.2 Chemical changes

The most important chemical changes entailed by forest fires are changes in pH and the effect on nutrient capital and availability of nutrients in the burned areas (MacLean et al. 1983). This in turn determines the biological development that follows during the period after the fire.

8.1.2.1 pH

When fires oxidize organic compounds, elements that form anions; nitrogen, phosphorous and chlorine, are lost in far greater amounts than cation-forming elements such as calcium, potassium and magnesium. The ash that is left behind by fires is most often composed of soluble oxides of these earth alkaline substances. These oxides are rapidly converted into carbonates, however, which have alkaline reactions and therefore a tendency to neutralize acidic components in the soil. Because of this, the pH of the soil generally increases after fires (Fig. 8.2).

This increase of pH in the humus immediately after fires

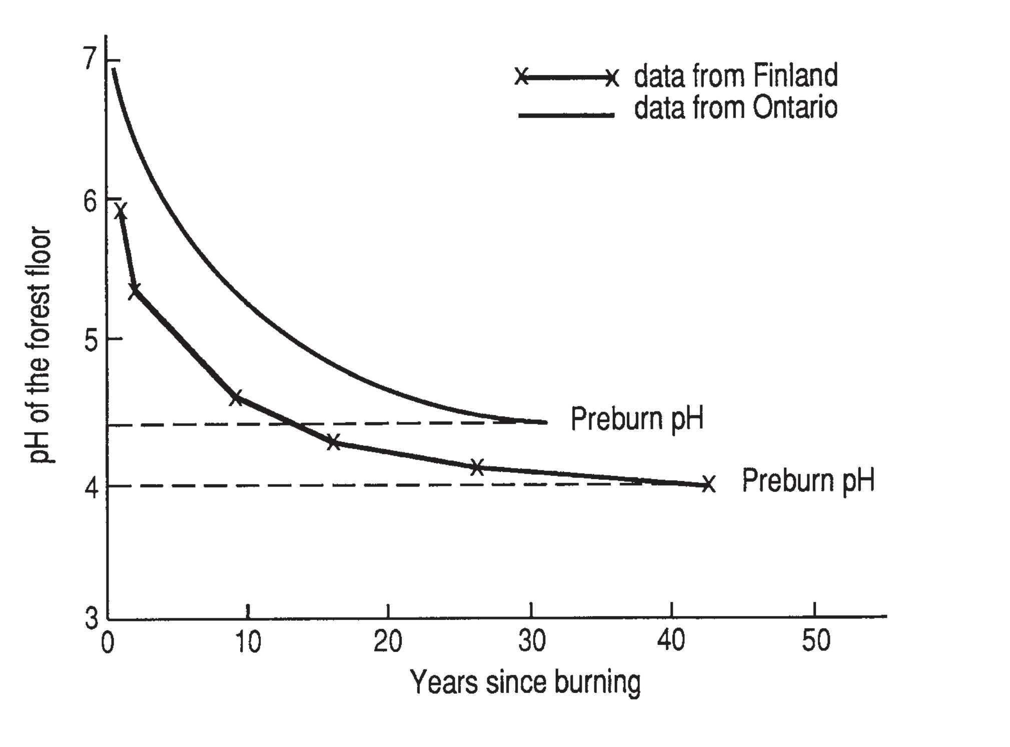


Figure 8.2. Effect of fires on pH in litter and humus and the length of time it takes for the pH to return to the initial value (Redrawn from Kimmins 1997).

development and growth of herbs and shrubs which often follow rapidly after fires, helps to delay the change back to the original acidity level in that the plants reduce the leakage of cations and start an active circulation of nutrients (Kimmins 1997).

pH changes that follow fires and burning may be one of the main advantages of swidden cultivation in tropical areas (Section 4.2.5). Tropical soil often leaks easily, particularly if it has evolved from poor source materials. This soil often has such a low pH (in the 3–4 level) that food plants cannot grow satisfactorily until the pH is increased through the effects of ash after the vegetation is burned.

has been documented by a number of studies (Ahlgren & Ahlgren 1960, D.W. Smith 1970, Skoklefald 1973a, Viro 1974, Raison 1979, Gluva 1984). The increase varied from approx. 0.5–5 pH units.

In some studies, the increase has been explained on the basis of large amounts of released calcium (Uggla 1957). However, the pH increase must be viewed in connection with the total reduction of organic material in the surface layer, as well as the more general release of alkali and earth alkaline metals (Viro 1974, Raison 1979). The degree and duration of the increase will depend on the intensity of the fire, the amount of organic material that is disposed of and the buffer capacity of the soil (see Gluva 1984).

Viro (1974) has reported an increase of 2–3 pH units in the ground layer after fires in Finland. It took 50 years for these changes to return to the original value. The underlying mineral soil was affected to a lesser degree; however, an increase of 0.4 pH units was registered for 20 years, and even after 50 years a difference of 0.2 pH units still existed.

The degree of the change in pH is related to the exchange capacity in the soil. This also applies to the speed at which the pH returns to its original level. The

A higher pH provides more favorable living conditions for microorganisms, and increased microbial activity will lead to increased degradation of organic compounds (Viro 1974).

8.1.2.2 Nutrient capital

As previously mentioned, fires can induce a substantial number of chemical changes in the soil's nutrient capital. When organic material is burned, carbon is released as oxides in gaseous form, and nitrogen is lost in increasing amounts as the temperature increases to more than 300 ˚C (Kimmins 1997). Sulfur and phosphorous are also vulnerable to being lost in gaseous form, and some potassium may also be lost when temperatures rise above 500 ˚C. Similarly, boron can also be lost in fires (Kimmins 1997).

The ability of the substances to take gaseous form also varies substantially. For calcium, magnesium, potassium and sodium, these temperatures are so high that small losses must be expected in most fires (White et al. 1973).

The chemical nutrient content of the ash depends on the source material. The ash in fire fields thus contains

mainly carbonates and oxides of alkali and earth alkaline metals, together with substances such as silicates and heavy metals (Gluva 1984). As the source material varies greatly with regard to nutrient content, no generalizations can be made regarding the nutrient quality of ash (Raison 1979). If all organic material is completely combusted, the ash is white (Gluva 1984). Few natural fires are so intense. Therefore, a varying amount of incompletely combusted remnants are formed in the ash.

Many nutrient substances are removed from burned sites in the form of fly ash that is lifted with the smoke. In very hot fires with high fire-induced winds and strong convection columns, most of the ash and the nutrients it contains will be removed from the site. In cooler fires, on the other hand, most of the chemical elements that are found in the burned material will remain at the site.

In connection with burning of vegetation and litter from pine forests of the *Pinus ponderosa* species, significant losses of potassium (46 %), calcium (16 %) and magnesium (14 %) have been registered through release of gas and ash convection (Boerner 1982).

Because of such effects, the total amount of chemicals such as calcium and magnesium in the forest floor can be significantly increased through fires of low to moderate intensity. This occurs through the addition of ash from combusted small bits of vegetation and from the tree crowns. However, this increase does not generally have to last very long. Some of the chemicals in the ash will gradually be washed down into the mineral soil, and the vegetation will absorb some.

Of all of the macronutrients that are lost in fires (see Section 8.1.2.1), nitrogen is the most vulnerable, and the soil's content of total nitrogen may be significantly reduced. However, the variation from fire to fire is great.

The availability of nitrogen can also increase after fires because they only burn off the upper and adjacent part of the middle strata of the soil, so that the availability of nitrogen increases due to the increase in pH (Section 8.1.2.1) and the increased temperature-induced mineralization that takes place in what is left of the organic material in the middle and lower strata (Kimmins 1997).

The chemical changes are closely connected with biological factors. In many cases where fires burn off the entire organic layer, the availability of nitrogen will be drastically reduced unless this is followed by an invasion of plant species that either independently or with symbionts can contribute to a new fixing of nitrogen at the site.

With regard to sulfur and sulfates, high losses have been proven in some fires. Losses of as much as 36 % of sulfur that is incorporated in the organic material have been proven during controlled burning of heather under laboratory conditions (Evans & Allen 1971). It has been indicated that a high loss of sulfur can be expected in connection with complete combustion. According to Norwegian studies, up to 96 % of the total sulfur is bound to organic material in the uppermost strata of the soil (Bergseth 1978).

Washout and erosion processes may also cause significant changes. Rain falling directly on mineral soil after a fire (see e.g. Boyer & Dell 1980) and the absence of litter and surface vegetation can increase the amount and speed of run-off.

So far, only sporadic studies have been made in Norway of the chemical content of run-off water from fire fields (Ogner 1977, Hegna 1986, Holm Nygaard 1997).

An elevated content of sulfates has been registered in the run-off from burned areas in Telemark (Ogner 1977); however, large variations have been noted in the studies from different areas (Gluva 1984). The increase of temperature in this county was regarded as being an important factor in the release of sulfate for washout.

Studies of run-off from a fire surface are underway in Lisleherad north of Notodden in Telemark after a fire in 1992 (Holm Nygaard 1997). Preliminary results show an increase in the run-off of calcium, magnesium, sodium, potassium, ammonium, sulfate, nitrate, chloride and bicarbonates. As regards ammonium, a high pulsation out of the system was noted in connection with the first period of precipitation after the fire. For the other compounds, the increase in the run-off was measurable until 700 days after the fire (Holm Nygaard 1997).

8.2 Biological effects

All organisms can be divided into groups according to the effects that fires have on their life history. Species that not only increase their numbers in burned areas (Chandler et al. 1983, Ehnström 1991, Wikars 1992, 1997, Muona & Rutanen 1994), but which are more or less dependent on fires, or react very positively to fires,

are often called pyrophilic species or fire specialists. The pyrophilic species (the specialists) have developed life history traits that make them particularly well adapted to, and often completely dependent upon, fires and fire areas, e.g. to reproduce. Some specialists are adapted to exploit special resources that are created in burned areas. Examples of such species may be found among fungi, mosses, lichen, higher plants and animals, and are most numerous in areas that burn often.

A number of species may benefit or profit from burning, without being totally dependent on fires. We can call these fire profiteers or fire winners. The other extreme is species that avoid or make way for fires, the so-called fire refugees or fire losers. The majority of organisms fall somewhere between these extremes. The individual numbers and population density of some species is significantly reduced in fires, and it takes a long time to "restore" their populations in the burned area. Use of these terms is often imprecise, *inter alia* because we often do not have adequate knowledge concerning the life history of the species.

8.2.1 Bacteria and microorganisms

Fires may have important effect on microflora and microfauna in the soil (Ahlgren & Ahlgren 1965, Viro 1974, Ahlgren 1974, Riess 1976, Warcup 1981). The soil's microflora includes various groups of bacteria, fungi and algae. The effects of fire on the microflora are extremely variable due to the great variations fires have on factors such as soil temperature, moisture and pH (Ahlgren 1974). Because of the dispersion capacity of spores and other reproductive mechanisms, bacteria and fungi are usually rapidly able to re-invade and colonize burned areas. Therefore, changes in the microflora tend to be of lesser duration than other fire-related change effects (Kimmins 1997).

It is typical that fires that induce an immediate reduction in the population of organisms in the microflora are often followed by an increase that occurs in connection with the first rain after fires (Ahlgren & Ahlgren 1965). Moreover, individual numbers and densities (abundance) of such populations may exceed the pre-fire levels due to increased pH, reduced microbial competition and improved availability of nutrients (see above).

Sometimes fires can sterilize an area and lead to a more or less complete replacement of the original microorganisms with other species. An example is the loss of fungi that can form mykorrhiza (Dix & Webster 1995). In some burned areas when such replacements of the microflora take place, plants may lose the ability to reproduce, and/or seed plants show poor growth. The duration of the changes in the microflora will depend on the duration of the critical conditions that may have arisen in the soil (Kimmins 1997).

The effect of fires on various groups of bacteria is not fully known. It has been claimed that the instant improvement in nitrogen fixation by plants that follows moderate fires may reflect fixation of atmospheric nitrogen from free-living bacteria (Kimmins 1997).

Direct documentation for such a bacterial and fire-induced fixation is lacking, but it may be a result of the increase in pH (Armson 1977). Burning has been reported to increase the individual numbers and densities of nitrogen fixing *Azotobacter* and *Clostridium* species (Kimmins 1997). Fires can increase the mineralization of nitrogen for periods of up to 12 years (Ahlgren 1974). However, the opposite effect has been documented after fires on dry soil types (Meiklejohn 1953).

Some of the same variations we see in the microflora also apply to the microfauna in burned areas. The microfauna consists of a great number of animal species such as protozoans, mites and nematodes whose bodies are smaller than 0.2 mm. With regard to the microfauna, however, it is common to discuss this together with both the mesofauna and the macrofauna in the soil. We will comment on this in section 8.4.5.

8.3 The effects of fires on fungi

As quickly as the first weeks or months after fires, slime molds (Myxomycetes), mould fungi (Zygomycetes) and ascomycetes fungi (Ascomycetes) may become numerous on burned ground (Butin & Kappich 1980, Dix & Webster 1995).

Many species and several large and important groups of fungi (mostly Ascomycetes) and capped fungi (Agaricales *sensu lato*) fructify in burned areas. The designation "Phoenicoid fungi" (Carpenter & Trappe 1985), in the context that they spring from the ashes like the Phoenix, has been proposed as a name for such fire-related fungi. They are, however, also often called "pyrophilic" or are discussed under different names. Such fungi occur in all types of burned areas, and the effect of fires and burning on these species has been

studied *inter alia* in boreal coniferous forests in Canada (Egger 1985, 1986, Egger & Paden 1986a,b), prairies in the USA (Wicklow 1973, 1975, Zak & Wicklow 1978a,b), areas in Greenland (Petersen 1975) and in areas after volcanic eruptions (Carpenter et al. 1981, 1987). Fire-related fungi have been examined in a number of European countries, including Germany/Austria (Moser 1949, Benkert 1981), England (El-Abyad & Webster 1968a,b) and Poland (Turnau 1984a,b). In the Nordic countries, comprehensive studies have been conducted in Denmark (Petersen 1970, 1971) and recently also in Norway (Holm 1995, Vrålstad 1996, Egil Bendiksen, in prep.). Studies in Finland have included the effects of burning logging waste on mycorrhiza (Mikola et al. 1964) and effects of burning on rot fungi (soft rot and dry rot) (Penttila & Kotiranta 1996). Otherwise, there appear to be no published studies of fungi colonization on burned surfaces from Sweden and Finland (Christian Holm, pers. comm.).

Gradually, an increasing amount of international literature has become available. It describes comprehensive experiments with fire-related fungi to see whether they react to the availability of nutrients, whether the heating effects of the fire stimulate germination, or whether there is reduced competition, chemical changes or other factors that are important.

When a fire moves on, some areas will experience persistent high temperatures that may kill fungi, bacteria and other microorganisms. In the perimeter zone of such highly heated areas, however, there is evidence of many more varied effects. Once again, we see that the severity of the fire is crucial for the formation of the abiotic and biotic environment for fungi. Please refer to Petersen (1970) and Dix & Webster (1995) for an overview.

8.3.1 Effects on dispersal and fruit setting

As previously mentioned, Phoenicoid fungi that appear in burned areas have various foundations for doing this (Dix & Webster 1995, Holm 1995). The first to appear are usually species that are sensitive to competition (weak competitors), and that react spontaneously to disturbances and removal or weakening of other vegetation, or species that are adapted to environments defined by special ash layers left behind by the fire. Three such species are thought to fructify on the basis of the chemical quality of such ash as well as an increase in pH (Dix & Webster 1995).

Many fire-related fungi are favored by high pH (Section 8.1.2.1). Over the course of time, the pH will again decline with the effects of weather and leaching, and the conditions for these fungi species will gradually deteriorate (Holm 1995). As we have seen (Section 8.1.2), fires can lead to comprehensive changes in soil chemistry that may persist for many years after burning. Other species are stimulated to fructify by the actual heat effect of the fire, the general temperature increase in many burned areas or the effect of the heating on competing microorganisms. Among the Ascomycetes, temperatures of 55–70 ˚C promote the germination of spores (ascospores), while at the same time, there is a significant reduction in the biomass of competing microorganisms. This lack of competition stimulates many Ascomycetes to fructify (Zak & Wicklow 1980). The organization and structure of many Ascomycetes communities in burned areas appear to be determined partly by abiotic factors such as heating, increased temperatures and depositing of ash layers; partly by biotic factors and ecological processes in the underlying layers of soil that have been affected, but not burned (Dix & Webster 1995).

8.3.1.1 Strategies for use of spores

The fact that the uppermost layer of soil is more or less sterilized (dead) after burning (Ahlgren 1974), indicates strategies for rapid growth of incoming spores or various forms of “resting spores” which lie deep in the earth, just waiting for nutrients and moisture to germinate (Warcup & Baker 1963, Warcup 1990). Fruit bodies from species in the Ascomycetes family Discomycetidae are usually the first conspicuous fungi that are observed above the ground. This family contains several species that grow only on burned ground. Somewhat later, various Basidiomycetes appear (Petersen 1970, Ahlgren 1974, Butin & Kappich 1980).

8.3.1.2 Use of resting spores

It is very likely that the use of long-term resting spores is an important strategy for some species of fungi. One example is the Ascomycete *Rhizina undulata* (Discomycetidae), which occurs in burned forest areas all over the world, and which lives on the ruined roots of coniferous trees (Lundquist 1984). The germination of this species’ spores is induced by heat (Jalaluddin 1967a).

The results from studies conducted in the State of Washington, USA after major forest fires triggered by the volcanic eruption of Mt. St. Helens (Carpenter et al. 1981, 1987) support the hypothesis that fire-related

fungi may use resting spores. Dishes of agar were placed on forest fire surfaces to study spore dispersal. In spite of the fact that no spores were discovered in the dishes, the species germinated on the surfaces.

8.3.1.3 Dispersal of spores

Short development periods can allow for rapid population build-up for some fungus species. This is characteristic of, for example, the cup fungi *Anthracobia melaloma* and *A. macrocystis* (Discomycetidae), which are both typical of newly burned fields. It takes just eight days from when the spores germinate until new sporulating fruit bodies are produced (Butin & Kappich 1980). These spores are spread to burned areas as airborne spores.

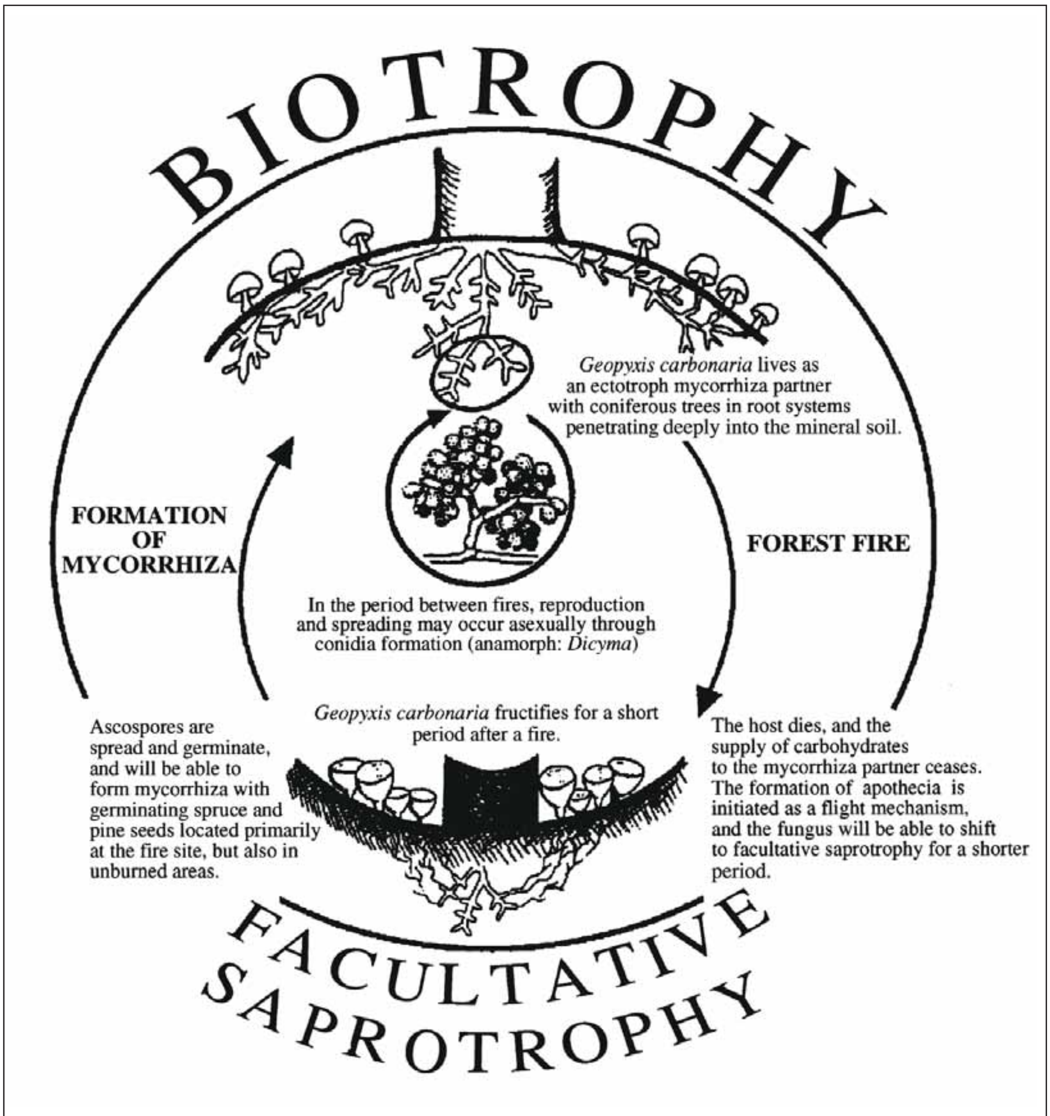


Figure 8.3. Hypothetical life cycle of the fungus *Geopyxis carbonaria* that develops ectotrophic mycorrhiza with the deepest root systems of the spruce in the mineral soil. The species does not fructify as established mycorrhiza, but dispersal and survival is sustained by growth of the mycelium and through formation of conidia. During a forest fire the deepest root systems of the host tree are not injured, but the death of the host leads to stagnation in the supply of carbohydrates to the mycorrhiza partner/symbiont. As a response to the unfavourable nutritional conditions a formation of fruit bodies (ascospores) is initiated, involving a spread of spores as a “flight mechanism”. The formation of apothecia allows *inter alia* because the heating of that substratum has killed competing species that were present in the upper soil layers. The fungus will be able to survive for a shorter period as a facultative saprotroph until new mycorrhiza associations are re-established (After Vrålstad 1996).

The spore dispersal strategies of many species of fungi are not yet completely understood (Wikars 1994), and certain phenomena appear to refute the hypothesis regarding the extensive spread of propagules (see e.g. Ingold 1971).

In particularly large fire areas, the appearance of fungi seems to be limited by inadequate dispersal. In the beginning, only those species that normally colonize fastest and disappear after a short period appear in the center (ruderal species), while other species colonize the perimeters first (Jalaluddin 1969, Petersen 1970). It is also possible that insects can act as vectors, and make a significant contribution to the spread of fungi to burned areas (Wikars 1992, Muona & Rutanen 1994). Beetle taxa associated with fungi that occur on burned ground and in trees killed by fire, i.e. species in the families Cryptophagidae, Latridiidae and Cucujidae (Palm 1951,

Lundberg 1984), include species with special “pouches” (mycangia) on the body for storage of fungal material (Crowson 1981). Therefore, it is likely that many fungi can profit from or depend on dispersal by insects (Wikars 1994).

Different life cycles

Many species have a life cycle that exhibits “sophisticated” specialization in relation to fires. This applies *inter alia* to several species connected with coniferous forests, where the fruit bodies appear in holes in the soil surrounding the trunks of damaged and dead spruce trees (*Picea*). The fungi’s mycel often follow the horizontal spread of the spruce roots found in the transition between the raw humus layer and the mineral soil. Several species exhibit the same distribution pattern, and it is assumed that all of these fungi feed on dead material (saprotrophs), i.e. participate in the decay of roots (Dix & Webster 1995). It has also been reported that *Geopyxis carbonaria* appear in connection with charred spruce needles (*Picea*) (Moser 1949). This species lives in symbiosis with spruce all over Norway. When the host tree burns and dies, the fungus changes strategy. It “goes down” into the soil and survives saprotrophically on the deepest part of the root system that decays (Figure 8.3), while it simultaneously fructifies intensely and spreads its spores away from the surface (Vrålstad 1996). The life cycle is not known in detail, and there is a great deal of interest in research to clarify how such fire-related fungi survive in periods between fires.

Other species may be associated with the root systems of living species. A good example is *Rhizina undulata*, which is particularly common in regenerated pine (*Pinus*) in acidic soil in burned areas. The characteristic yellow mycel can be found throughout the raw humus layer, but it can also spread to the roots of living conifers where it can grow parasitically and spread to other trees, thereby causing groups of trees to die (Jalaluddin 1967a,b, Ginns 1968, 1974, Gremmen 1971). This is also a problem in Norway as regards regeneration of burned forests (Section 4.2.8), where the *Rhizina undulata* can rapidly colonize burned surfaces and attack the roots of sprouting pine plants (Solbraa 1992, 1997b).

Many fire-related fungi compete with other microorganisms that can be diminished or eliminated in fires. However, the various fungi that colonize such areas also compete. It is unknown whether fungal species have developed the use of restrictive and germination-impairing chemicals, so-called allelopathic substances (Dix & Webster 1995) (see Section 8.3.4).

8.3.2 Classification system for fire-related fungi

Many systems have been proposed for classification of fire-related fungi into various groups according to their relationship to fire (Moser 1949, Petersen 1970). For example, there is a proposal to classify in relation to when the fungi fructify after fires (see Dix & Webster 1995). This report, however, will propose use of Petersen’s system of classification into four groups (A-D) according to dependency on burned areas. *Group A* is species that occur only on burned ground. *Group B* is species that occur exclusively on burned ground during natural conditions, but which may also occur on unburned ground that has been subjected to disturbance. *Group C* is species that are common on burned ground under natural conditions, but which may also occur on unburned ground under certain conditions. *Group D* is species that occasionally occur on burned ground, but which are more common on unburned ground.

When Petersen’s classification is not utilized consistently for the Norwegian material in this report, this is due to the fact that sufficient information does not exist regarding all of the species that occur on the burned surfaces. Some species appear to react to disturbance regimes in general, not just to fires.

8.3.3 Fungal succession in a Norwegian forest

So far, the most representative studies in Fennoscandia have been conducted in Maridalen north of Oslo in 1992–1995, where colonization and succession of fire-related fungi are being studied on a fire field in the southern boreal coniferous forest (Tab. 8.1). Several important traits of life histories of fire-related fungi have already been clarified (Holm 1995, Bendiksen 1996, 1997, Vrålstad 1996, Vrålstad & Schumacher 1997).

The area burned on 26 June 1992. Some fungal species appeared on the field immediately after the fire. These are assumed to be species that have had spores lying ready in the soil. However, the rapid appearance may also be based on other adaptations (Vrålstad 1996). Among the 15 species of Ascomycetes that were observed on the surface after the fire, there were eight fire specialists. The seven remaining species included three that typically appear on fire surfaces, but which may also occur in other substrata, and four typical pio-

Table 8.1. Preliminary list of species of fungi which produced fruit bodies on a fire field in a southern boreal coniferous forest in Maridalen, Oslo during the summers 1992 – 95 (After Holm 1995, Trude Vrålstad unpubl., Egil Bendiksen, unpubl.). Characterisation of species: A: Occurs only on burned areas (fire specialists); B: Occurs under natural conditions exclusively on burned areas, but may also be found on disturbed unburned areas; C: Occurs as common on burned areas, but may also be found on unburned areas; D: Occurs as a vagrant on burned areas, but is more common on unburned areas (common "forest fungi").

Class Ascomycetes Order Pezisales	1992 [1)]	1993 [1)]	1994 [1)]	1995 [1)]	Characteristics
Anthracobia melanoma	□	■		●	A
Geopyxis carbonaria	□	■	■	●	A
Gyromitra esculenta			■		B
Gyromitra intula		■	■		B
Morchella elata		■		●	B
Peziza badia			□		B
Peziza echinospora		■	■	●	A
Peziza tenacella					
(=*praetervisa*)	○	■	■	●	A
Peziza lobulata					
(=*violacea*)	○	■	■	● [2)]	A
Plicaria endocarpoides		■		●	A
Plicaria anthracina					
(=*carbonaria*)		■			A
Pyronema domesticum	○	■	■	●	B
Rhizina undulata		■	■	●	B
Rhodotarzetta rosea			■	●	A
Tricharina ochroleuca		○			B
Tricharina gilva				●	A-B
Octospora humosa				●	C
Basidiomycetes					
Amanita muscaria			□		D
Baeospora myosura			□	●	?
Calocera viscosa				●	D
Clitocybe candicans		○		●	D
Clitocybe sinopica				●	D
Clitopilus hobsonii				●	D
Collybia cirrata			■	●	D
Collybia cookei				●	D
Coprinus angulatus	○	○	■	●	B
Coprinus lagopides			□		?
Cotylidia undulata		○		●	C
Entoloma spp.			□		D
Fayodia maura	○	■	■	●	A-B
Gymnopilus penetrans			■	●	D
Hebeloma helodes				●	D
Hebeloma spp.			□		D
Hypholoma capnoides	○	○		●	D
Inocybe lacera			■	●	D
Inocybe spp.			□		D
Laccaria laccata		■	■	●	D
Marasmius androsaccus				●	D

	1992 [1)]	1993 [1)]	1994 [1)]	1995 [1)]	Characteristics
Mycena amicta			□	●	D
Mycena galopus		■	■	●	C
Mycena leucogala [3)]		○	■	●	A-B
Mycena cineroides				●	D
Mycena epipterygia				●	D
Mycena sanguinolenta				●	D
Mycena septentrionalis				●	D
Mycena vulgaris				●	D
Mycena stipata				●	D
Hygrophoropsis aurantiaca			□	●	D
Omphalina ericetorum			□		D
Omphalina pyxidata			□	●	D
Omphalina rickenii			□		D
Pholiota highlandensis	○	■	■	●	A-B
Psathyrella candolieana			■		?
Psathyrella pennata		○		●	A-B
Psathyrella velutina			■		?
Psathyrella spp.		■			D
Psilocybe montana			□	●	D
Thelephora terrestris		■			D
Tephrocybe anthracophila		○		●	A-B
Xeromphalina campanella			■		D
Entoloma conferendum				●	D
Galerina allospora				●	D
Galerina atkinsoniana				●	D
Galerina hypnorum				●	D
Galerina marginata				●	D
Galerina mniophila				●	D
Galerina pumila				●	D
Galerina spp.				●	D
Paxillus involutus			□	●	D
Pluteus atromarginatus				●	D
Rickenella fibula				●	D
Strobilurus esculentus				●	D
Thelephora terrestris				●	D
Leccinum scabrum			□		D
	9	23	36	ca. 56 [4)]	

1) ■ Indicate species found by Holm (1995) in particular sampling areas, □ indicates species sampled by Christian Holm and Trude Vrålstad outside the proper sampling areas, ○ indicates species found by Egil Bendiksen outside the sampling areas, ● indicates species found by Egil Bendiksen during surveys in the area in 1995. The surveys are still ongoing (Egil Bendiksen, pers. comm).
2) *Peziza praetervisa* or *P. lobulata*, not finally classified (Egil Bendixen).
3) *Mycena leucogala* possibly occurs on burned areas only (Taxonomical position towards closely related species not determined) (Egil Bendiksen, pers. comm.).
4) Preliminary numbers, adjustments must be expected after final control of taxonomic determinations (Egil Bendiksen, pers. comm.).

neer species (Tab. 8.1, Groups A, B) (Trude Vrålstad, pers. comm.). Among the Basidiomycetes, a steadily increasing number of species were discovered during the four years the fire surface was followed. In 1995 (the fourth year), the species inventory was dominated by normal forest fungi (Tab. 8.1). For a number of species that have gradually established themselves on the surface in Maridalen, the status in relation to this type of living area remains unclarified (Christian Holm, pers. comm.). Studies of fungal succession on this fire surface will continue. It is emphasized that the overview presented in Table 8.1 is only a preliminary list, and that the checking of the determination of species and revisions are still ongoing (Egil Bendiksen, pers. comm.).

The study in Maridalen has generally established a lower diversity in this area as compared for example with similar studies from Denmark (Petersen 1970, 1971). Many of the species that have been established in the fire areas in Norway have also been established in connection with studies conducted in both North America and Europe (circumpolar distribution).

Based on more recent Norwegian studies, it has been argued that abiotic explanatory models have not provided satisfactory causal explanations of the occurrence and behavior of Phoenicoid fungi. A hypothesis regarding heat-induced spores in a resting stage in the soil cannot automatically be applied to cold and moist climates with low selection pressure for drought and fire adaptations (Vrålstad 1996).

8.4 The effect of fires on plants

The effect of fires on higher plants and plant societies can be asserted on the basis of *inter alia* changes in soil temperature, soil moisture, water resource system, soil chemistry (including availability of nutrients), sun radiation and competition conditions. In addition, a reduction in the animal population can lead to less intensity in grazing and seed predation. Plant individuals that survive fires can be exposed to severely altered living conditions, or its offspring may have to start their life histories under completely new conditions (Chandler et al. 1983, Whelan 1995, Bond & van Wilgen 1996,

Table 8.2. Responses to, and effects of burning, in several plant species, and their possible causal explanations (Modified from Whelan 1995).

Observation	Possible explanations
Increased productivity	Increased nutrient availability Removal of suppressive dead leaves Increased average soil temperature Extended period of high temperatures Earlier start to growing season Removal of competing vegetation
Increased flowering	Increased nutrient availability Increase in numbers of shoots sprouting Removal of competing vegetation
Increased seed-dispersal distances	Removal of canopy from around fruits improves wind-flow Removal of ground vegetation and litter Greater foraging distances by seed-dispersal agents
Synchronous release of canopy-stored seeds	Heat treatment of sealed follicles or scales
Synchronous germination of soil-stored seeds	Heat treatment of impermeable seeds coats Charcoal residues break dormancy
Alteration of surface light and/or temperature regime	Removal of vegetation
Improved establishment of seedlings	Increased nutrient availability Decreased herbivore activity Satiation of populations of seed predators Removal of competing vegetation Degradation of allelopathic chemicals

Kimmins 1997). The variations are quite substantial. The environment in burned areas can become cooler and wetter, the soil may acquire a more fine-grained structure and a high organic matter content. However, burnt areas can also become warmer and drier, more coarse-grained or water-repellant with a lower organic content (Section 8.1). The new conditions may lead to radical changes in the primary production of the ecosystem through influences on the plants. Fires can affect each *stage* in a plant's development, whether it be the vegetative stage, the flowering, the fruit setting, or the resting stage. This is reflected in a corresponding variation in so-called adaptive traits in plants (see Johnson 1992, Bond & van Wilgen 1996).

8.4.1 Terminology for responses and effects

We have gradually seen a great number of descriptions of the responses of plants to the changes and effects that accompany fires. A selection of these is presented in Table 8.2 and includes *inter alia* factors such as increased productivity, increased flowering and improved establishment of seed plants.

For example, a mass flowering after a fire of a plant that reproduces through sprouts may be due to a proximate reaction to damage, increased availability of nutrients or favorable soil temperatures. Alternatively, it may be an evolutionary trait where the proximate factors are only used as "keys" to maximize survival (fitness) through increased pollination and/or mass production (saturation) of seeds so that seed predators do not take everything.

As previously mentioned, an important factor is that there is great variation in the effect of forest fires. Therefore, there is no common and uniform terminology or classification in the literature to describe the response of plants to fire, or of the effects that fires have on higher plant species (Ahlgren & Ahlgren 1960, Bell et al. 1984, Gill & Bradstock 1992, Whelan 1995). Classifications have, for example, been made with reference to the *mechanisms* that enable individual plants to tolerate fire (e.g. "thin" and "thick bark"), to the *consequences* it has for changes in the plant society or to the *strategies* that can be identified with background in the plants' various living conditions.

Different terms have been used to describe the same biological response of a plant species because some are based on the pattern of *re-establishment* after the fire, for example to describe a changed community structure; while others have been based on the pattern in the individual species' *survival* and *mortality*. With regard to "strategies", i.e. descriptions of plant behavior seen as evolutionary consequences of prolonged exposure to fires, there are also various systems. For example, Swedish researchers have proposed a frequently used form with classification into three different strategies for re-colonization of burned areas (Schimmel & Granström 1991), a classification which has also been passed on to Norwegian conditions (Midtgaard 1996). These are:

1. Re-growth from surviving roots, rhizomes or other tissue lying buried in the soil.

2. Establishment from a supply of resting seeds and spores in the soil.

3. Dispersal of seeds or spores into the burned surfaces after the fire.

Klingsheim (1996) has added two additional strategies to make the overview more complete, namely:

4. Dispersal from seeds and spores produced by re-established vegetation.

5. Vegetative dispersal from re-established vegetation.

8.4.2 Fire tolerance

The temperature to which plant cells are exposed is the real cause of tissue damage and death in fires. Studies of physiological responses by plants to heat have most often been carried out by exposing them to continuous heat in their surroundings (Alexandrov 1964, Levitt 1972). These are conditions that differ from the sudden and intense pulse of heat the plants are exposed to during fires. [8.4)] At one end of the scale we find complete combustion, which causes total mortality for both cells and tissue. Such destruction through high temperature can occur through denaturation of proteins, changed motility of fats, or chemical decomposition. The effects can be extremely varied. At the other end of the scale, short and minor increases of the temperature may indirectly cause metabolic changes, i.e. more or less permanent breakdown in certain biochemical factors in the plant's metabolism (Fig. 8.4).

Mortality of plant tissue varies with the length of the exposure time for a given temperature and the condition of the cells, and it increases if the cells are filled with water and/or are metabolically active. Dehydrated plant tissue in a state of rest can tolerate far more serious heat

effects. This has *inter alia* been proven in experiments with seeds (Levitt 1972), and the same seems to apply to other plant tissue as well (Whelan 1995).

The likelihood of an entire plant dying will depend on the degree of damage to various parts and what types of tissue are affected by the heating. The survival of certain parts is more important than others with regard to a plant's ability to continue to function after fire. Cambium is a critical tissue for the survival of the crown layer due to its significance as conducting tissue (Kolström & Kellomäki 1994). A high correlation has been proven between gradual dying-out in the crown layer and burns (scars) on the lower part of the trunk, e.g. in sequoia trees (Rundel 1973).

Meristem, i.e. tissue that differentiates for new growth and contains cells that actively divide and grow, is particularly important for the plants. Such tissue may be found, for example, at the tips of young stems, leaves and roots. Production of new leaves and flowers after fire damage depends on the survival of these buds. Seeds are also critical.

There are two basic ways in which plants can tolerate exposure to fire. One is that cells that build up important tissue types are better able to resist degradation by heat, i.e. to develop a tolerance for a higher fatal temperature. Generally, the fatal thermal point for cells in typical mesophytic plants is considered to be 50–55 ˚C (Hare 1961). The other explanation for the significant adaptations of certain plant species to avoid exposure to intensive fire is their ability to protect critical tissue (Whelan 1995). They prevent important types of tissue from being heated up to fatal temperatures. The water content in critical tissue and the degree of metabolic activity during the time leading up to a fire will thus determine survival.

8.4.3 Adaptations in the vegetative stage

Plants can be classified in several categories based on traits in their vegetative stage that determine their reaction to fires.

There are several ways of protecting important types of tissue against fatal temperatures as the fire front passes. Examples of this are that the cambium and meristem

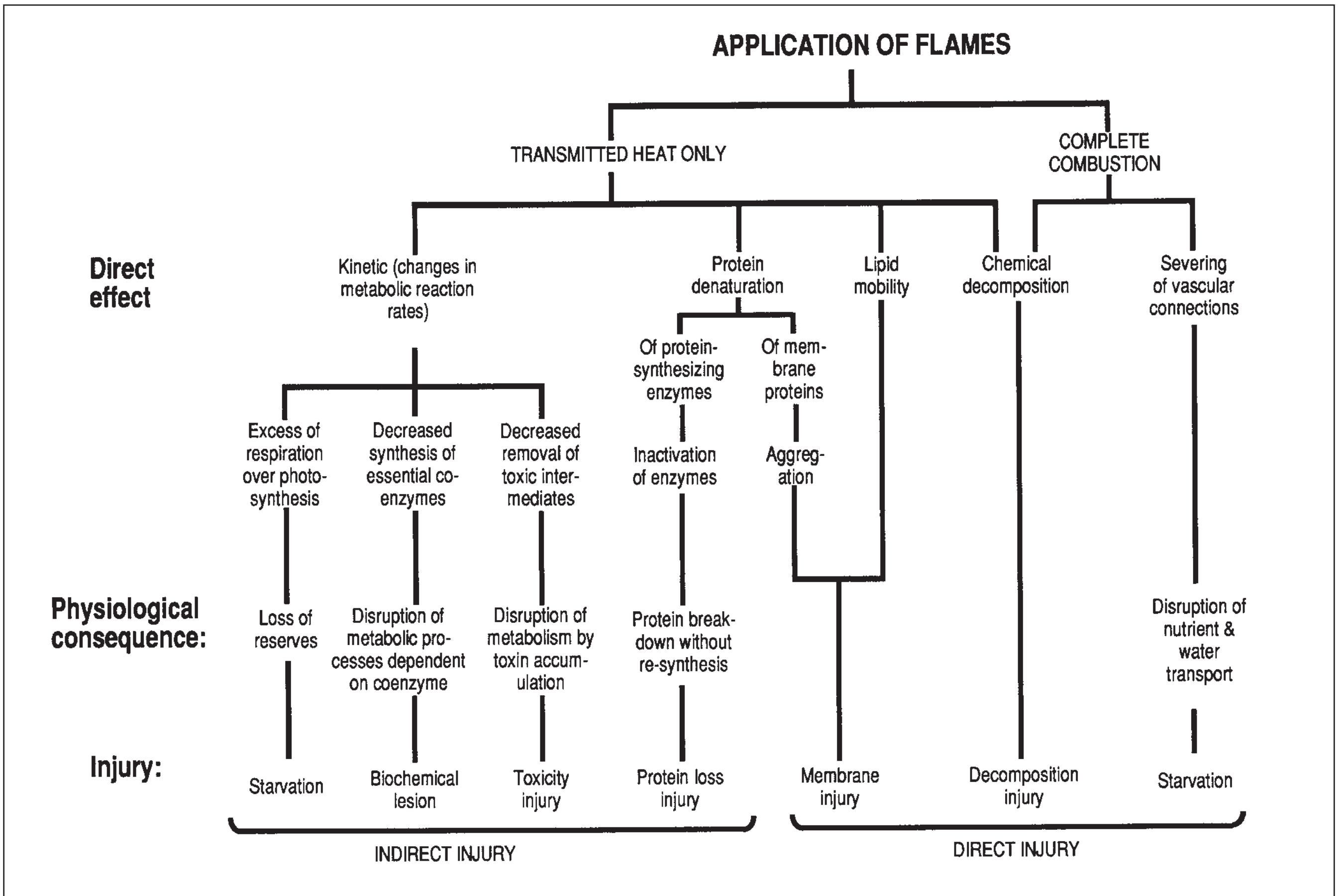


Figure 8.4. Heat may cause direct and indirect destructive effects on plants (After Levitt 1972, redrawn from Whelan 1995).

cells can be protected against radiated heat by insulating bark, or by overlying soil. Sensitive tissue can also be borne at such a height that the likelihood of it being exposed to intense heat decreases. For example, seeds can be protected by insulating fruits through burial in the soil profile, or location high in the crown layer.

As evolutionary arguments have been brought into fire ecology, an important discussion has developed concerning whether some plant species also develop increased combustibility (Section 8.4.3.3).

8.4.3.1 Bark as insulator

Fire resistant bark is one of the most common adaptations to surface fires or running fires (Kimmins 1997). Some trees develop a very thick layer of dead bark as they reach the adult stage. Comprehensive studies have been conducted of the insulating properties of bark (Spalt & Reifsnyder 1962), and some researchers claim to have demonstrated major differences between species with regard to heat penetration (Gill 1975). The time it takes for the cells in the cambium to reach fatal temperatures when a tree trunk is exposed to heat is a function both of the thickness of the bark and its heat-related properties (reflection, conductivity, etc.). These factors vary according to species and plant size (Whelan 1995). Small trees of one species are more vulnerable than larger trees, due to the different relationship between bark thickness and trunk diameter. The amount of reflected energy from the surface of the bark also varies between the species. The Scandinavian forest trees have significant differences in such properties (Section 8.4.7).

8.4.3.2 Other vegetative protection mechanisms

Reduced tissue flammability will reduce the spread and intensity of a fire and thereby the risk of damage. Species with high moisture content in their foliage and a low content of resin and oils will generally be more fire resistant than coniferous trees rich in resin and oils. Individuals in mixed stands of deciduous and coniferous trees, or in pure deciduous stands, will be more resistant to fires because there is an interruption in the continuity of fuel in the crown layer.

Protective buds ensure the plants' ability to continue to grow and to recuperate after temporary loss of branches, foliage or even whole sprouts.

Some types of coniferous trees have developed the ability to replace foliage and branches that are lost in a crown fire with the aid of new lateral shoots (adventitious buds) or latent auxiliary buds (Kimmins 1997). When the free buds of American aspen (*Populus tremuloides*) are killed by fire, root shoots are developed from adventitious buds on lateral roots that are found in the surface layers of the soil (Kimmins 1997).

Grass species carry their meristem at the base of the leaves, while in dicotyledon plants the meristem is exposed and is lifted as the plants grow. This property of grass protects many of the species during fires, particularly those that grow in compact tussocks. Much of the heat in the fires is carried upwards, and the stems and leaves in a tussock insulate the meristems that are well protected on the inside.

Some researchers have emphasized that the entire crown layer of some plant species is formed so that it increases the tolerance for fire by leading heat away from end buds (Kruger & Bigalke 1984).

Many species are able to replace entire plants in the bush and tree layer by developing new shoots from underground buds that survive the fire. Many angiosperm trees, scrub forms, herbs and even coniferous trees have this ability.

Many plants, particularly bush species, can "sacrifice" meristem tissue in the crown layer. They are adapted to fires by sprouting from suppressed underground buds, either in buried stems or roots.

8.4.3.3 Increased combustibility

While many species have developed a resistance to fires and effective mechanisms for protecting themselves, some researchers believe that other fire-adapted plant species have developed increased combustibility in the vegetative stage combined with efficient seed adaptations (Mutch 1970, Kimmins 1997). For example, the pine species *Pinus banksiana* develops very rapidly to the flowering stage and has protected seeds and forms stands that, under natural conditions, burn with nearly monotonous regularity. The fire eliminates stands of the light-craving pine species, but it also kills competitive tree species that would have replaced this species in the absence of fire. Thereby, it appears that this pine species is ensured permanent occupation through its prompt strewing of the burned areas with seeds from its resin-sealed cones.

A similar example from Nordic flora may be taken from fireweed and bracken, which produce flammable litter that is extremely combustible and which accumulates due to slow decomposition. This increases the likelihood

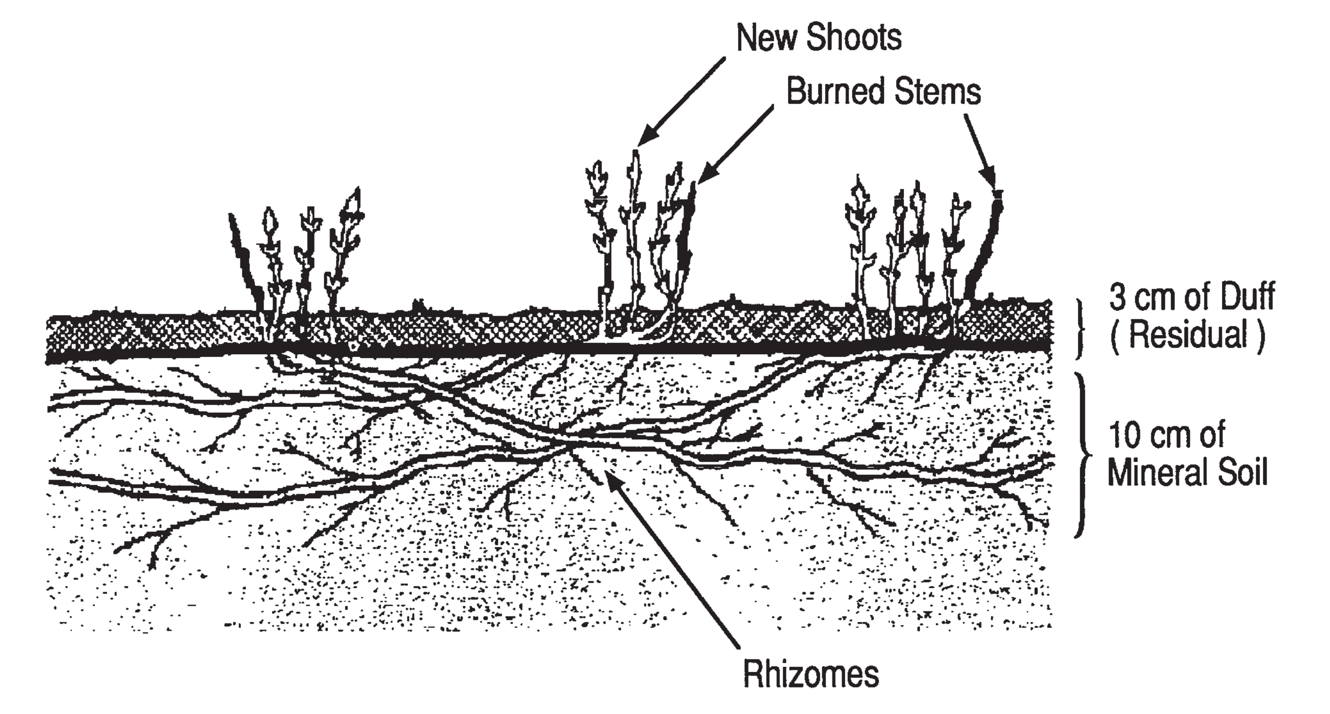


Figure 8.5. Section through a soil profile with heather vegetation (*Vaccinium globulare*) to show the specialization with rhizomes (After Wright & Bailey 1982).

of fire. Fire benefits species that have rhizomes, while eliminating woody species that may throw them into shadow (Kimmins 1997).

Such hypotheses that favor "species" are not compatible with current knowledge in modern evolutionary theory. Reference is made to Bond & van Wilgen (1996) for a broader discussion of this.

8.4.3.4 Utilization of insulating soil

Soil is a good insulator, and tissue that lies deeper than 5 cm is often not exposed to any significant increase in temperature (Priestley 1959). However, this can vary substantially.

Soil as a refuge for seeds and spores has been documented in burned areas all over the world. There is also a description of plant species that produce their seeds under the soil surface, well below the depth where the soil temperature may become fatal when fires rage (Whelan 1995).

Plants that have rhizomes (horizontal, underground stems) are also able to sprout immediately after a fire (Fig. 8.5). The rhizomes are adaptations that make these species resistant to fires. The success often enjoyed by species such as fireweed (*Epilobium angustifolium*) and bracken (*Pteridium aquilinum*) in burned areas is often due to this trait (Whelan 1995, Kimmins 1997).

The ability of the various species of higher plants to send roots deep into the humus layer will therefore often determine their survival after the fire. In a light fire where only the upper part of the moss is dried out and consumed by the flames, the old field layer vegetation quickly returns by shooting sprouts from the rhizomes (Schimmel & Granström 1991). The three most common rhizome colonizers in this group are bilberry, red whortleberry and wavy hair-grass, all of which have the main parts of their underground stems in the organic layer of the ground level; wavy hair-grass in the upper part of the humus and bilberry and red whortleberry somewhat deeper. Wavy hair-grass reacts particularly fast to the increased supply of light and nutrients and will, during the first years after fires, increase its dispersal spread considerably. It will normally flower intensely starting from the second year after the fire.

In some sections that have burned harder, the shallow rhizomes of wavy hair-grass may be destroyed, with the result that bilberry and red whortleberry will dominate the field layer. Medium-hard fires benefit species that have seed banks, while both the heather's rhizomes and a great portion of the seed bank may be eliminated in that patches that have burned hardest (Schimmel & Granström 1991).

Which soil recolonization strategy in burned areas gener-

ally proves to be the most beneficial for various species based on rhizomes, seed banks or external wind dispersal in a given instance depends on how deep the fire has gone, and how far fatal temperatures have penetrated in the ground level. An exponential relationship exists between the depth under the burned surface and the highest temperatures that occur at this depth (Schimmel & Granström 1991, 1996, Granström & Schimmel 1993). For example, fatal temperatures of 60–70 ˚C in humus do not normally go deeper than 2–3 cm during a potential glowing fire. An increased severity or an increased desiccation of the humus, on the other hand, means that the glowing fire can penetrate deeper, and a greater part of the humus will be consumed. In mineral soil there is a more flattened connection between burn depth and the temperatures that develop. The reason that different burn depths result in differences in the development of future vegetation is that the rhizomes and buried seeds of the various species are found at various depths in the soil.

Many plant species in areas that burn often, such as in Australia, have also developed special outgrowths on the roots, so-called lignotubers. This involves a significant swelling of the plant's principal axis, which is formed in the transition between stem and root, and which is mostly located in the soil. The lignotuber is full of nutrient resources, and is an important source of new shoots if the free buds are killed in a fire. It is this type of adaptation that enables certain eucalyptus species to re-colonize rapidly after a fire (see Gill 1975).

8.4.3.5 Height as protection

The temperature of a fire decreases with height (Section 2.2.2) so that seeds and buds can be protected from destruction by heat through location at increased heights above the flames. The structure in older pine forests of uniform age and layers is a good example of this. The rapid growth in height exhibited by some pine species (*Pinus* spp.) has been interpreted as a response to fire, as they raise the end growth zone out of the fire's "danger zone" through rapid growth. Adult trees, however, may be exposed to considerable crown damage if there is an intermediate layer of fuel that "lifts" a ground fire up to the crown layer.

8.4.4 Effects on the reproductive phase

Plant species that are exposed to frequent fires appear to have developed a number of reproductive traits that increase survival and reproduction. Rapid growth/maturation and early flowering reduces the time from germination to seed production in perennial plants. Species, such as the contorta pine (*Pinus contorta*), can produce seeds in as little as five years (Fowells 1965) which will normally be before the next fire occurs. Pine (*Pinus silvestris*) can also produce seeds of various color varieties, of which dark seeds do best against seed predators on fire surfaces (Nystrand & Granström 1997). Frequent fires can eliminate species that flower rarely or only after a long juvenile phase unless there are special adaptations.

8.4.4.1 Flowering

In monocotyledon plants, it has often been reported that flowering is stimulated by fires (Gill 1981b, Kruger & Bigalke 1984, LeMaitre & Brown 1992, Lamont & Runcican 1993). This may be closely linked to the increased productivity after fires (see Section 8.1). More vigorous plants are better at promoting greater flowering (Daubenmire 1968, Rundel 1982). As previously mentioned, important factors are also linked to when the fire occurs in the plants' cycles (see above).

An example of plants that increase their reproductive efforts after fires is a number of Australian bush/ shrub species of the *Xanthorrhoea* genus, even though some flowering does take place between fires (Specht et al. 1958, Kimmins 1997). The increase may be due to a pure temperature response or reduced competition for light, moisture and nutrients. It may also be an effect of smoke. Ethylene, which is one component of the smoke from forest fires, can stimulate flowering (Komarek 1971a). Pineapple growers in Puerto Rico, who blanket their crop areas with smoke to induce flowering, have *inter alia* utilized this.

The relationship between the timing of the fire and flowering of the plants is important. A fire that comes too early can kill flower buds or developing flowers and thus knock out an entire year's worth of potential seed production. Germinating plants that are affected by fires may spend several years in recuperating enough to flower again. Thus, there are dynamics between seed storage, flowering processes and fire seasons as regards many plants' reproduction (Whelan 1995).

8.4.4.2 Seeds

Seeds contain cells that are resting and often in a dehydrated condition. This is an advantage with regard to tolerating high temperatures. The seeds of many species lie at rest in the soil until the area is burned. A great number of plant species produce substantial amounts of seeds with hard shells that only germinate after they have been heated.

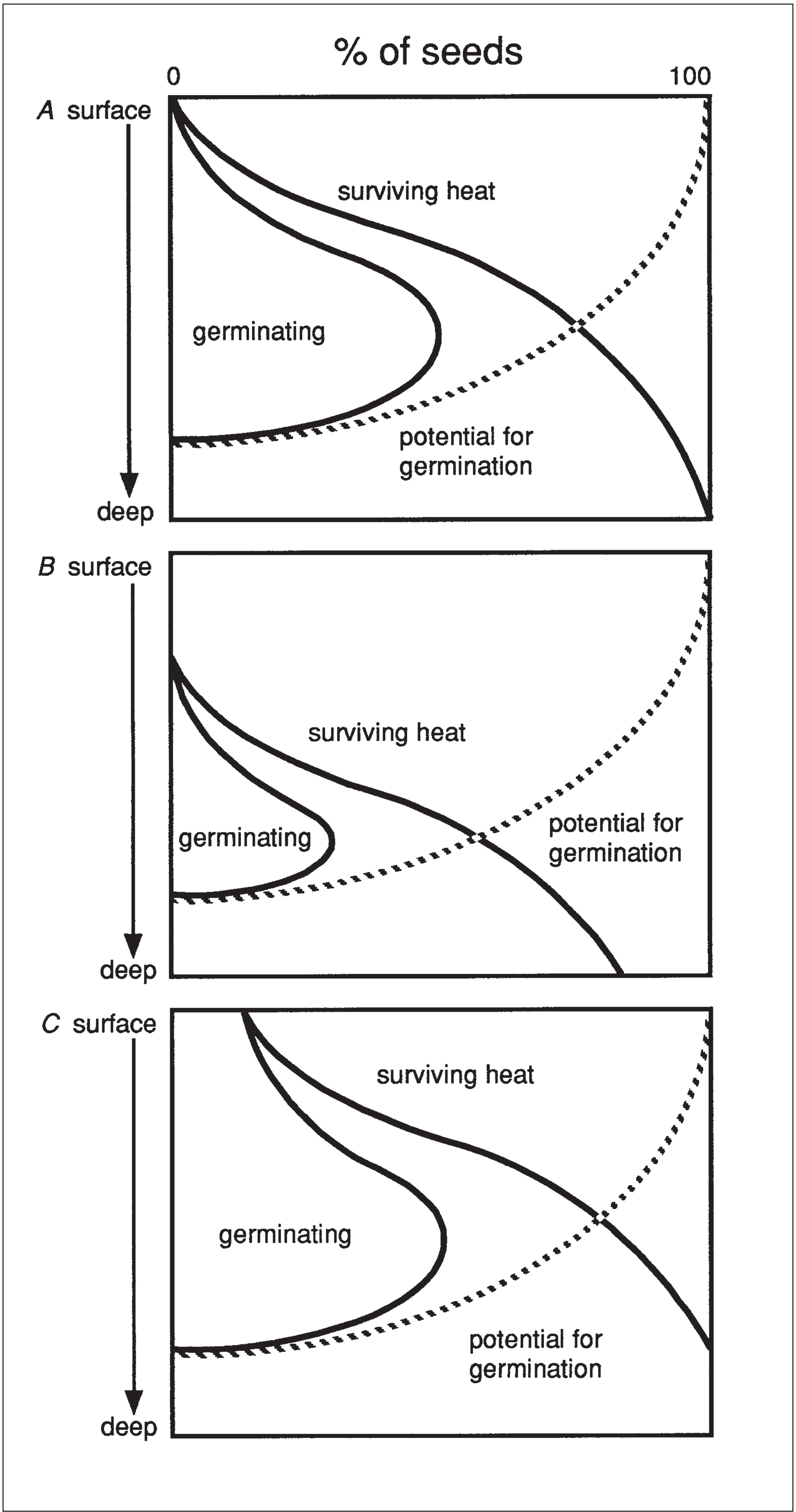


Figure 8.6. Schematic model of fire intensity and survival and germination of seeds with hard seed shells in relation to in which depth of the soil profile the seeds lie buried (Modified from Martin & Cuswa 1966, redrawn from Whelan 1975).

A. Seeds near the soil surface will be killed by the heat from the fire (survival curve – solid curve), while seeds buried too deep will stay in a resting stage (resting stage curve – dotted curve). The germination success is related to the balance between the two opposite effects from heat and depth.

B. With increasing fire intensity the mortality curve for seeds will move downwards, and press the zone of mortality success towards the resting stage curve.

C. With decreasing intensity the zone of germination success will be pushed upwards with the mortality curve for the seeds.

A great deal of research has been conducted in order to measure the heat tolerance of seeds (Ashton 1986, see Whelan 1995). Some species in ecosystems that burn often have developed seeds that are extremely resistant. The seeds of the pine species *Pinus banksiana* can be heated up to 370 ˚C for 5–20 seconds or 430 ˚C for 5–10 seconds without showing any signs of reduced vitality (Beaufait 1960). This species belongs to the so-called "fire pines" that depend on fires to drop seeds. They have resin-sealed cones that melt at temperatures above 60 ˚C, and allow a nearly spontaneous establishment of a post-fire generation in burned areas (Whelan 1995, Kimmins 1997). We also find plants in several Australian plant genera that are dependent on heat for seed dispersal, and a number of various mechanisms have been described (Gill 1975, Kimmins 1997). Temperatures that seeds are exposed to in fires normally exceed 110 ˚C. Individual seeds are most often small and are therefore rapidly heated to the temperature of their surroundings. Seeds that lie in the upper part of the litter will therefore almost always be killed. They must be protected against direct heat in order to survive. As mentioned, they can avoid this either by lying buried in humus and soil, or by being protected by fruits high up in the crown layer.

The complex relationship between seed survival and germination, the depth at which the seeds are buried, the intensity of the fire and soil moisture (Gill 1981b), are shown here in a simplified and schematic model (Fig. 8.6).

Qualitative models of this type can predict the effect of increasing intensity and severity in fires and increasing duration of heating at the soil surface. However, few studies have been conducted to make quantitative models (Whelan 1995). Surveys have, however, proven that there are substantial differences between species (Floyd 1966), i.e. that hereditary factors exist that are linked to resting stages.

8.4.4.3 Seed dispersal

Generally, there have been few studies of seed dispersal in burned areas (Whelan 1986, 1995). It seems likely that, for some species, dispersal may be intensified after fire. Surface winds and water currents increase, and both of these factors can contribute to moving seeds.

There are plant communities in certain ecosystems where there appears to be a complete absence of seed banks stored in the soil. There are also individual species in many plant communities that have not developed a store of resting seeds. A group of plant species has developed seeds with great dispersal abilities as a compensation for the effect of local death in fires. Fireweed (*Epilobium angustifolium*) is a good example of this form of seed survival. This species flares up after fires in coniferous forests and mixed forests in northern areas, and the species is an important component in the early succession stages in fire areas. The seeds can retain their vitality only for short periods of up to 18 months (Granström 1987). The mass appearance of fireweed in fire areas must therefore be due to dispersal from plants outside of the burned areas. However, it is questionable whether this trait of the species' life history should be viewed as a unilateral adaptation to fires (Whelan 1986, 1995, Trabaud 1987b). It seems to invoke a *generalist strategy* that enables colonization of areas that have been exposed to one or more of a long line of various disturbances.

Plant species in environments that burn often must thus solve the problem of local seed dispersal. This particularly applies to woody, perennial species that are obligatory seed setters, and which also have a seed bank stored in the crown layer, and with delayed dispersal ("bradyspori"). Mature and established individuals of these species are sensitive to fire, so stored seeds become important with regard to maintaining the population. A single fire that may kill all of the established plants in a stand, simultaneously releases seeds from the seed bank. If we assume a high germination success rate and adequate establishment of seedlings, the timing of the next fire will be critical for such species. If it occurs so rapidly after the first fire that the seedlings have not yet developed, then fires can lead to local extermination of the species (see Section 8.4.4.3). Fires that occur frequently will, however, quite likely result in an increasing number of unburned patches (islands) due to the uneven occurrence of combustible material. Seedlings of such species therefore have a good opportunity to survive in unburned "islands".

In the same manner, the dynamic of frequency and the pattern of the fires may be important for obligatory seed setters with a seed bank stored in the soil.

8.4.5 Effects on germination and productivity

Fires often lead to apparent increased vigor and growth rate for plants that germinate. This is described both from grass species (Daubenmire 1968, Singh 1993), forest trees (Wallace 1966, Kimber 1978, Engelmark 1993) and herbs (Whelan 1995). The phenomenon may be the result of one or more integrated causes (Tab. 8.2). In for-

est trees, the increased productivity may be exhibited through broader growth rings over a period of several years. When forest production is the issue, it is important to confirm whether such effects are just a brief acceleration of the growth, which may later lead to reduced growth. For example, growth (measured as an increase in trunk diameter) after annual burning in a forest in Australia was followed by a period when the trees affected by fire grew less than those on an unburned control surface (Henry 1961).

This is also an important issue with regard to regeneration of spruce and pine in Scandinavia, for which we have experience after many years of clear-cut burning (Hallsby 1995). If too little of the soil's organic material burns, competing vegetation (primarily grass) benefits, the water supply on the surface becomes uncertain and the release of nutrients is insignificant. The positive effects of clear-cut burning on seed germination, establishment of seedlings and new growth will then fail to appear. If too much of the soil's organic material is burned, the nutrient capital of the grow site may be lost through combustion and/or the subsequent washout. The vegetative augmentation of deciduous trees is impaired, and the water capacity of the ground is decreased. In the worst case, the productivity class falls (Section 4.2.5). The appropriate fire severity is determined by the thickness of the litter and humus cover. In areas with the thinnest organic layers, it is probably difficult to achieve such a minor fire severity that the negative consequences will totally fail to appear. Fire severity is probably the most important factor to control in connection with clear-cut burning under Scandinavian conditions (Hallsby 1995).

With regard to the effect of fires, increased growth even after fires of high intensity is in no way universal (Hare 1961, Abbott & Loneragen 1983). This is particularly important for Norwegian conditions where fires in steep terrain, such as along the coast, may achieve high intensity and severity in dry periods and consume a lot of organic material. Precipitation in the period after the fire can lead to rapid and extensive loss of nutrients with reduced growth conditions as a consequence.

8.4.5.1 Allelopathy and chemical factors

Studies of growth conditions in fire areas compared with "control areas" have shown that, in many places, there is a gradual suppression of the productivity in certain plant societies in the absence of fire. This may be due to an accumulation of litter and coarse debris on the forest floor, but it may also be linked to changes in soil chemistry. Many plants germinate better in mineral soil than in an accumulation of loose organic material on the surface. This can be explained both in the form of improved moisture content and temperature conditions in the mineral soil and/or removal of chemicals that can serve to prevent germination (allelopathy).

"Chemical warfare", so-called "allelopathy", can be employed by plants in competition with other species. Toxic substances that leak from leaves, are produced by roots or are of microbial origin, and can accumulate in the soil may prevent germination and growth on the part of competing species (Muller et al. 1964, C.H. Muller 1965, W.H. Muller 1965, McPherson & Muller 1969). These substances may be various terpenes, phenols, alcaloids and other organic chemicals (Kimmins 1997). [8.5)]

Also plant species in boreal coniferous forests in Scandinavia have developed allelopathic strategies. Crowberry emits a toxic substance that *inter alia* reduces the ability of pine seeds to germinate. It is also possible that the substance may have a negative effect on mykorrhiza (Zackrisson & Nilsson 1989). If active carbon is added to crowberry litter, the negative effects cease completely. This can indicate that the carbon effectively binds the allelopathic substances. With its shallow ground stems, crowberry is sensitive to fire and dies even after lighter surface fires. Areas dominated by crowberry are combustible and no common heather species burn as well as this one (Hörnsten et al. 1995). Forest fires should thereby have a "double effect" on crowberry, partly through killing the heather, partly through the fact that the carbon that is formed binds the toxic substances that may remain in the burned litter so that new species can invade. [8.6)]

Chemicals that are leached out from charcoal (Keeley et al. 1985, Keeley 1986) can also affect germination. Fires change the environmental chemistry, and these chemical changes can trigger fire-stimulated germination. Wicklow (1977) was the first to discover that seeds were stimulated to germinate in the proximity of charcoal. This has subsequently been established for many plant species (Keeley & Pizzorno 1986). The substance in extracts of charcoal which causes this is assumed to be an oligosaccharide derived from hemicellulose compounds, but the charcoal stimulant's character and mode of operation are still unknown (Bond & van Wilgen 1996). Recently, however, it has been proven that the ability of charcoal to absorb substances toxic to plants

may also be important, and that the proximity of charcoal stimulates microbial activity in the soil (Zackrisson et al. 1996).

Recent studies have also shown that seed maturation in some species may be stimulated directly by smoke. This mechanism is also unknown (Bond & van Wilgen 1996).

8.4.5.2 Seed plants

As previously mentioned, fires can be a “two-edged sword” for seeds that are already dispersed and lying in the soil/humus layer (Section 8.4.6), as seeds near the surface may be completely combusted or at least killed by the sudden, intense heat wave. In most plant communities, however, there is a large “resting” seed bank in the soil, where fires can stimulate germination, thereby forming new seed banks from this seed bank. [8.7)]

Delayed seed dispersal from a seed bank in the crown layer is a mechanism that can produce a flare-up of seeds and thereby seedlings. This mechanism is found, as previously mentioned, in various plant genera in many regions, including among others coniferous trees in North America (Section 8.4.4). Parts of such a seed bank may be released each year, due to the spontaneous opening of a few fruits, or through the death of individual branches from breakage or attack by insects. The majority of the seeds may, however, remain resting until the next fire causes mass dispersal.

Increased establishment of seedlings and improved growth may therefore be related to increased availability of nutrients and reduced competition (Section 8.1). The conditions after a fire may, however, also have a destructive effect on the establishment, growth and survival of seedlings, with development of excessive temperatures and thereby changed physical and chemical conditions, such as reduced availability of water. Such changes may cause significant mortality (Fig. 8.7).

There are reports from certain ecosystems of quite unique effects. Heating of damp soil may, as noted, lead to special chemicals being driven down into the soil profile where they can produce an impenetrable layer (Section 8.1.1.2). The layer reinforces run-off and prevents precipitation from sinking down, so that the water resource system is changed (Scott & van Wyk 1992).

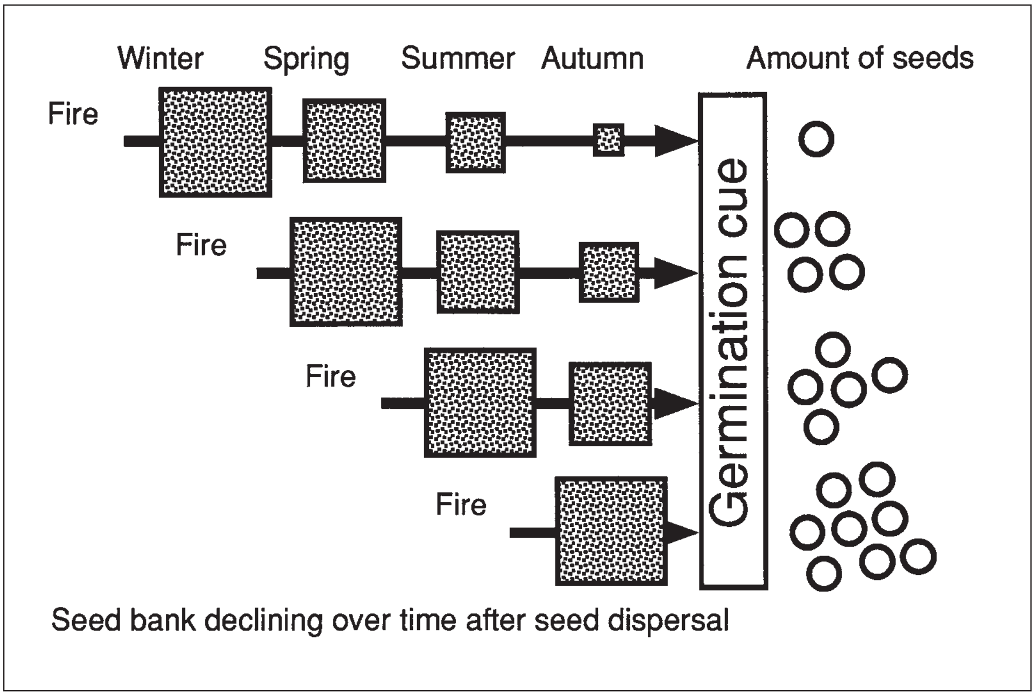


Figure 8.7. The actual point of time when a fire occurs may influence the success of the seedlings to establish themselves in different ways. The diagram shows a possible influence from seed predators that show up after fires. The hatched boxes on each arrow represent the change in the seed bank after fires in an individual season, and the size of the box represents the amount of sustaining vital seeds. The seed depot late in autumn represents the key to the next spring; hence the earlier in the season the fire occurs, the larger the release of seeds (Modified after Bond 1984, Whelan 1995).

In areas of high fire intensity, the soil may become mineralized, so that little other than lichen and moss colonizes the soil surface after fires. Such an effect may last for several decades (Whelan 1995).

In soil with poor nutrient status, formation of mykorrhiza may be of critical importance for the plants’ roots. Mycorrhiza reinforces absorption of water and nutrients both for seedlings and more established individuals (Harley & Smith 1983). Heat from fires can reduce the populations of mycorrhiza (Klopatek et al. 1988, Wicklow-Howard 1989). However, the variation appears to be great, and the relationship between

Table 8.3. Five categories used to group plants according to their reactions and functional adaptations to fire (Ahlgren & Ahlgren 1960, Rowe 1983, Øyen 1996a).

"Invader"	Characterized as wind dispersers of seed and spores. Often light demanding species with rapid dispersal into burned areas. Some might have asexual reproduction that in addition might add to the colonization.
"Evader"	Constitutes a specific group of species that have profound adaptations to forest fires. Seeds from such species might need heat treatment to germinate.
"Avoider"	Constitutes a group of species on areas that do not burn, so-called fire refuges.
"Resister"	Constitutes a group of species that has the ability to resist forest fires.
"Endurer"	Constitutes a large number of heather plants that have the ability to let roots penetrate deep into the humus layer. This might mean survival after forest fires.

mycorrhiza and fires is not yet completely understood (see Vrålstad 1996).

8.4.6 Classification system based on functional adaptations

Since the fire ecology is, as mentioned, a part of the general coniferous forest ecology, a classification system should be able to capture and characterize the entire flora, including the species that "flee" from fire. In this report, we will propose the classic system of classifying plants according to functional adaptations (see Lutz 1956, Ahlgren & Ahlgren 1960, Ahlgren 1974, Rowe 1983), [8.8] and which Øyen (1996a) has prepared for Norwegian conditions (Tab. 8.3). The problems associated with this classification are thoroughly discussed by Rowe (1983).

As mentioned previously, some species tolerate or profit from fires and spread in fire areas ("fire profiteers"), while others are more sensitive to fire and disappear ("fire refugees"), (Section 8.1.3). A few are specialists that actually require fire in order to complete their life cycles. On the basis of changes in cover after forest fires/controlled clear-cut fires, Øyen (1996a) has listed some representative examples of such species in Norwegian and Nordic flora (Tab. 8.4).

8.4.6.1 "Invaders"

"Invaders" among the plant species are often characterized by wind dispersal of seeds or spores. The species often require light and can spread rapidly. In addition to seed dispersal, some species may have vegetative reproduction that contributes to colonization. Among the invaders we find the birch species and several light-craving grass species such as wavy hair-grass and the grass *Calamagrostis arundinacea* (Tab. 8.4).

Small, wind-dispersed seeds from species such as fireweed and birch may, however, have difficulty in establishing themselves after fires that are so light that the humus remains relatively thick (Schimmel & Granström 1991).

Deciduous trees have a far higher mineral content than coniferous trees, and therefore do not burn as well (Section 2.2). It is far easier for them to survive fires than coniferous trees even with damage to the crown layer. Regeneration of, e.g. birch often takes place vegetatively, but the regeneration depends on the temperature conditions during the fire. Even if the temperature has been too high so that the adventitious buds are destroyed, the birch is nevertheless a strongly competitive invader (Tab. 8.4) because the birch fruits are easily dispersed.

8.4.6.2 "Endurers"

The "endurer group" comprises plant species that constitute a large share of the flora in boreal forests (Tab. 8.4). Short plants such as moss, heather and lichen cannot save their aboveground parts when the fire front passes. The majority of such plants, however, have protected parts that survive the fire down in the soil so that they can once again spread over the area (Section 8.4.3.2). Several species of moss are known to colonize fire surfaces at an early stage. This is probably due to the fact that they are weak competitors, as the same species are often also found on other patches of exposed mineral soil, on roadsides or in greenhouses (Schimmel & Granström 1991).

Species in the "invader" and "endurer" groups consistently exhibit an increase a short time (1–10 years) after a fire. The increase in degree of cover, frequency or appearance occurs at various times after the fire, and may have shorter or longer duration depending on the growth requirements needed by the species. Competition

Table 8.4. Categorisation (see Tab. 8.3) of some selected plant species in the Nordic flora, sorted according to their reactions and functional adaptations to forest fires ("(?)" indicates that the classification varies between different authors (After Øyen 1996a) (See text).

Group				
Invader	Evaders	Avoiders	Resisters	Endurers
Birch (*Betula pubescens*) Silver birch (*Betula pendula*) Smallreed (*Calmagrostis arundinacea*) The moss *Ceratodon purpureus* Creeping thistle (*Cirsium arvense*) Wavy hair-grass (*Deshampsia flexuosa*) Fireweed (*Epilobium angustifolium*) The mosses *Funaria hygrometrica* *Marchantia polymorpha* Scots pine (*Pinus sylvestris*) The mosses *Polytrichum* spp. Aspen (*Populus tremula*) Raspberry (*Rubus idaeus*) Goat willow (*Salix caprea*) Ragwort (*Senecio* spp.)	Pill-headed sedge (*Carex pilulifera*) Cranesbill (*Geranium bohemicum*)	Crowberry (*Empetrum* spp.) (?) Creeping lady's tresses (*Goodyera repens*) The moss *Hylocomium splendens* Linnaea (*Linnaea borealis*) Yellow bird's-nest (*Monotropa hypopitys*) [1] The lichen *Peltigera aphthosa* Norway spruce (*Picea abies*)	Cotton-grass (*Eriophorum vaginatum*) Scots pine (*Pinus sylvestris*) (?) The mosses *Sphagnum* spp. (?)	Bearberry (*Arctostaphylos uva-ursi*) Birch (*Betula* spp.) Heather (*Calluna vulgaris*) Dwarf cornel (*Cornus suecia*) Crowberry (*Empetrum nigrum*) Bell-heather (*Erica cinerea*) Wood horsetail (*Equisetum sylvaticum*) Alpine clubmoss (*Lycopodium complanatum*) May lily (*Maianthemum bifolium*) Aspen (*Populus tremula*) Bracken (*Pteridium aquilinium*) Bilberry (*Vaccinium myrtillus*) Bog whortleberry (*Vaccinium uliginosum*) Cowberry (*Vaccinium vitis-idaea*)

1. In Øyen (1996a) denoted as *Monotropa uniflora*. This is a North-American species and is probably a slip of the pen for *Monotropa hypopitys*.

conditions determine how long they will dominate the fire field (Øyen 1996a).

If the entire humus layer is consumed, or if less than the uppermost 2–3 cm of the humus layer remains, a large part of the ground layer's potential for regrowth of "vegetative" species will be knocked out. Thus, in such places, the colonization will depend on invaders, i.e. species that spread their seeds into the burned surface from outside.

8.4.6.3 "Resisters"

The "resister group" (Tab. 8.4) comprises species that have the ability to resist fires. Pine can tolerate minor

fires at a mature age (Tab. 8.4) and it is perceived by most as a typical “resister”. Of all the forest trees, it is the best adapted to forest fires, it requires lots of light and exhibits rapid juvenile growth. Pine possesses fire adaptations in the form of a thick, heat-protective bark, special repair mechanisms for rebuilding cambium and generally deep-running root systems that are rarely destroyed by fire, as well as crowns on older trees that are developed high up (Zackrisson 1977a, Schimmel & Granström 1991). If there is pine in the climax stand that survives the fire, they will drop seeds on the fire surfaces relatively quickly after the fire has passed. If the flames do not reach the crown layer, particularly older trees, many survive even relatively severe fires. [8.9)]

Often, the cambium layer on thick-barked pines is not damaged so badly that the transportation system for assimilants stops functioning.

Thick tussocks of cotton-grass (*Eriophorum*) can also resist fire (Wein & Bliss 1973).

8.4.6.4 “Avoiders”

The “avoider group” (Tab. 8.4) includes species that are particularly found in areas that do not burn, so-called fire refuges. As members of the climax society, they prefer old, shady forest with thick humus layers (Øyen 1996a). Spruce is a typical representative for this group (Tab. 8.4). Due to its thinner bark and shallower root system, it is far more vulnerable to forest fires than pine. After a forest fire, the spruce in the stand often more or less dies out. Spruce is a species of tree that more easily tolerates shade, as its juvenile growth is slower than both birch and pine. It is also particularly vulnerable to the invasion of rot fungi (soft rot and dry rot) in burns. However, spruce enters into many fire successions in the secondary phases, and dominates most often in climax phases in good productivity classes. [8.10)]

Crowberry (*Empetrum* spp.) has recently increased in coverage and frequency in northern Sweden. This is assumed to be a consequence of effective forest fire fighting during recent decades (Zackrisson et al. 1995). The species in the “avoider group” will have a stronger or weaker reaction to fire over the short term. Species connected with peat soil forest can also be included on this list (Hörnberg et al. 1992).

8.4.6.5 “Followers”

The “follower group” (Tab. 8.4), or “fire specialists”, constitutes a distinctive type of species that have physiological adaptations to forest fire. Seeds from these species ought to be treated with heat in order to germinate (Granström 1991a), i.e. they are dependent on fires to complete their life cycle. Among such species in this country, we would particularly emphasize common cranesbill (*Geranium bohemicum*) and in Sweden also the even more fire adapted *Geranium lanuginosum* (Granström 1991a) (Fig. 8.8). These are seed bank species that have developed seeds that can be stored over longer periods of time. These species depend on repeated fire disturbances in the same area at certain

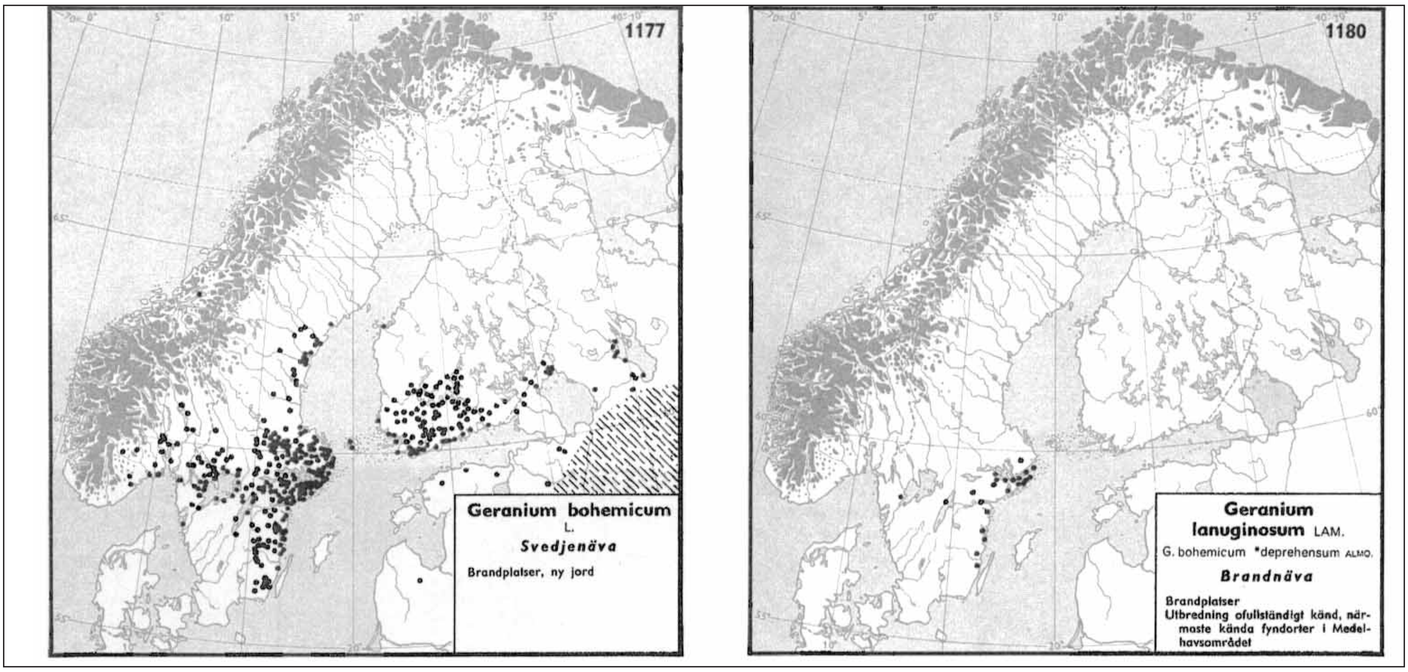


Figure 8.8. Distribution of common cranesbill (*Geranium bohemicum*) (1177) and the even more fireprone cranesbill 1180 (*Geranium lanuginosum*) in Fennoscandia (After Hultén 1971).

intervals in order to renew their seed banks. Another fire specialist in this group is pill-headed sedge (*Carex pilulifera*). Most of the seed bank species, particularly species that benefit from disturbances, such as pill-headed sedge and hairy woodrush, have their seeds in the interface between humus and mineral soil. Light fires always activate seeds that are buried in seed banks as they still lie too deeply under the surface. The number of followers or fire specialists in Norway appears to be low, which must be assumed to be a consequence of the country's cool fire regime.

Together with factors specific to the growing site, such as climate and production ability and a number of more random factors, the severity of the fire determines the development of vegetation to a great degree and for a long time after a fire (Fig. 8.9).

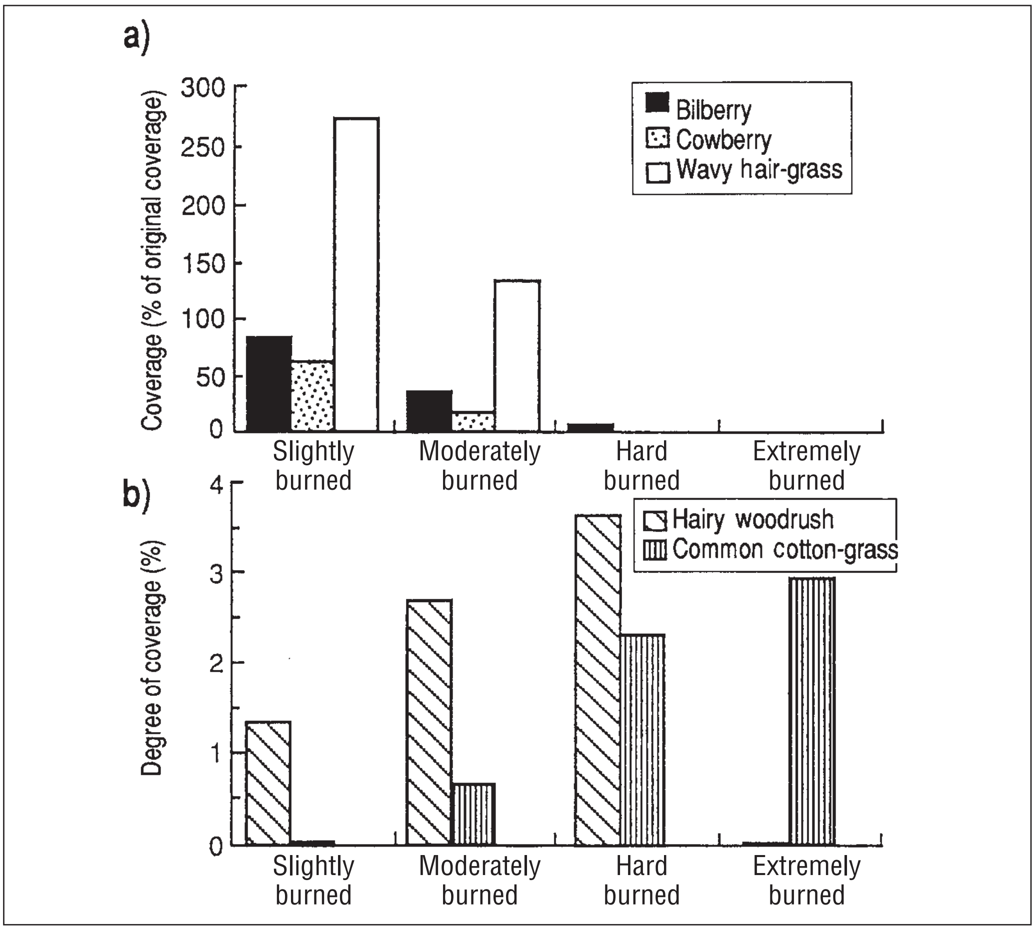


Figure 8.9. The severity of a fire, i.e. the depth of burning, decides which colonization strategy is the most beneficial one. The degree of cover of various species 2 years after a fire on test areas has been manipulated experimentally through addition of fuel. a) Cover in percentage of the cover of the species prior to fire for the species bilberry, red whortle-berry and wavy hair-grass (the "vegetative group", colonizers through rhizomes). b) Cover in percentage for hairy woodrush (seed bank species) and fireweed (the "pioneer group", seeds dispersed by wind) (After Schimmel & Granstrøm 1991).

8.4.7 Successions in Norwegian forest types

The many effects of forest fires lead to extremely different courses of succession in the plant community in various Norwegian forest types (Heiberg 1938, Skoklefald 1973b, Sunding 1981, Moe 1994, 1995, 1997, Klingsheim 1995, 1996, Øyen 1996a, Skre & Wielgolaski 1996, 1997, Klingsheim & Wielgolaski 1997, Skre et al. 1998). After forest fires and clear-cut burning on good and medum soils, *Oxalis-Myrtillus* type, *Dryopteris* type, *Myrtillus* type and *Vaccinium* type, the soil often undergoes a strong reaction. Grass species, particularly wavy hair-grass, start to spread together with nitrophilic species such as fireweed and raspberry. Of the moss species, *Ceratodon purpureus*, *Funaria hygrometrica* and hair-cap moss (*Polytrichum* spp.) are among the first to establish themselves. During the course of 3–8 years, invaders cover large parts of the fire field. As mentioned in several places in this report, the soil improvement may last for decades. If good seed years occur during the first years after the fire, the burned area may be suitably regenerated with pine (Heiberg 1938, Skoklefald 1973b, Øyen 1996a).

In poorer forest types, such as in heather / bog-whortleberry and lichen pine forests, a similar reaction occurs, although it is weaker.

Moreover, "the fertilizer effect" from the ash is often more short-lived. Particularly heather, but also lichen species as *Cetraria islandica*, *Cladonia stellaris* and "reindeer lichen" (*Cladonia* spp.) can spread rapidly. During the course of 5–10 years, the vegetation is not very different from what it was before the fire (Heiberg

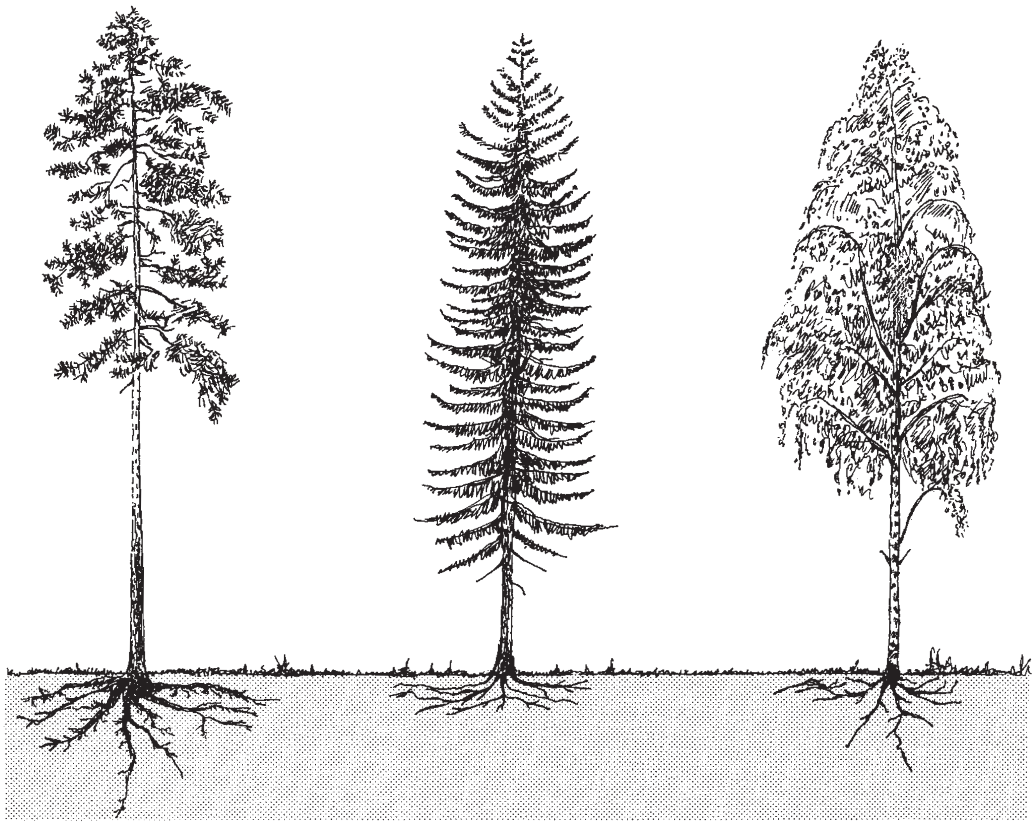


Figure 8.10. In accordance with their functional adaptations the three dominant trees in Norwegian forests may be characterised as one "resister" (pine, left), one "avoider" (spruce, center) and one "invader" (birch, right). The two conifers contain large amounts of very combustible chemicals and are therefore important suppliers of fuel in Norwegian ecosystems, also in the litter they produce. Birch has a high content of minerals and therefore burns less intensively.

1938, Øyen 1996a). In the event of strong, often repeated fires on nutrient-poor soils, and if there is no sowing of woody plants, the fire area may gradually take on a heath-like character (see Section 8.6.1). The decomposition of humus stops because of dryness and lack of new litter (Eneroth 1928, Heiberg 1938, Øyen 1996a). The effects of forest fire on vegetation, humus and the long-term productive capability of the soil is addressed *inter alia* by Uggla (1958), Huss & Sinko (1969), Viro (1974) and Tamm (1990). It is pointed out in that context that the most important question is not how often it has burned, but the effect the individual fire has had (Schimmel 1993, Granström 1994). The long-term effects of the burning appear to be particularly linked to intensity (highest temperature), fire severity (amount of organic material combusted) and original humus thickness (cf. Ahlgren & Ahlgren 1960, Schimmel 1993).

Whether the burned areas will be colonized by pine or not depends on a combination of seed year with subsequent wet spring and good germination conditions, while the favorable effect of ash supply endures. The conditions for establishing regeneration are thus best 3–5 years after fire (Yli-Vakkuri 1961). Assuming that several seed years have effect, the field can gradually regenerate. Birch and aspen generally come up quickly and constitute a large part of the early succession stages on the fire surfaces (cf. Kielland-Lund 1970, Skoklefald 1973b, Sunding 1981, Granström 1991b, Klingsheim 1995), and form what in everyday terms is called "deciduous burns" (Norw. "løvbrenner").

Important fire ecological precedent is linked to the three dominant tree species in Norwegian forests: spruce, pine and birch (Fig. 8.10). Spruce and pine contain large amounts of very flammable chemicals, while birch has a higher mineral content and therefore does not burn so well. The composition of the types of trees determines important aspects of the composition of fuel. The more birch and other deciduous trees, the lower the com-

bustibility. Therefore, the spread of these important species has a great impact on the regional quality of fuel, including that which is formed in the litter.

Thus, in deciduous forests, the frequency of forest fires is far lower than in coniferous forests. An exception is beech forests, which with their ground cover of dry leaves, or in more sparse form with good coverage by heather species, can support surface fires that can achieve great speed (see also section 8.6.1).

8.5 The effect of fires on animals

Fires have a number of direct effects on animals. The changes that fires cause in the soil, fungus and plant communities also lead indirectly to radical and long-lasting influences on the animal community in burned areas (Chandler et al. 1983). Through disturbances, fires create successions of new plant communities that also form the basis for succession in the fauna (Ahlgren & Ahlgren 1960, Ahlén 1966, Lyon et al. 1978). The effects are of a different type and are more complex than for plants due to great capacity in animals for dispersal. A unique resource in fire areas is large amounts of partially burned, partly charred and dead wood created by incomplete fire and combustion processes. This is exploited by a number of specialists in the fauna. Insects connected with wood constitute the majority of insects that exhibit adaptations to fire (Wikars 1994, 1997).

The animals are roughly classified into invertebrates and vertebrates. The effects of fire on invertebrates can vary within wide limits according to fire type, which plant communities are affected, and regional environmental conditions (Chandler et al. 1983). In regions where fires are not particularly intensive, the direct effects of heat appear to be less important than the subsequent environmental changes. Living organisms have been observed in forests under charred windfall trees on the ground immediately after fires (Rice 1932).

Combustion of biomass does not only produce light (flames), but also a number of other rays with various wavelengths (heat). Some of these wavelengths have been shown to be important for certain animal species. Smoke from fire areas also spreads chemicals that can be perceived over great distances. Buprestid beetles of the genus *Melanophila* have infrared sense organs on their hind legs (Palm 1949, Evans 1966a,b, 1971, Schmitz et al. 1997, Wikars 1997). The most extreme of the pyrophilic species can mate on glowing wood, and some have mechanisms to pick up the smell of soot and smoke more than 50 km away (Schmitz et al. 1997). The larva of the buprestid beetle *Melanophila acuminata* can only develop in recently burned wood (Schmitz et al. 1997). Such beetles can be found in Europe, Asia, the USA, Canada, Mexico, as well as one species in Central America. The group is also represented in Norwegian fauna. In conservation work, many pyrophilic species are almost always characterized as rare or in need of specific management considerations (Thunes 1993).

With regard to the vertebrates, on the other hand, which are larger species with much better dispersal capabilities, we have already noted that they are more rarely exposed to direct mortality. Some species are fire profiteers that react in a positive way to the ecological changes created by fires, while others can decline in individual numbers after fires.[8.11)]

In the following we will first examine animals' general tolerance of fires on the basis of anatomical and physiological factors. We will then provide an overview of some of the available information regarding the effects of fires on the various groups. The overview is not complete, and there are major, general defects in our knowledge in this field. For the sake of good order, the groups are organized systematically according to where they belong in the taxonomic system.

8.5.1 General tolerance of fire

Animal cells are destroyed at high temperatures, and animals that cannot escape a fire front may in extreme cases be directly burned. There are many anecdotal accounts of charred cadavers found after wildfires (Chew et al. 1958, Ahlgren & Ahlgren 1960, Bendell 1974, Newsome et al. 1975).

Body tissue in animals that has been heated as a response to high temperatures has traditionally been discussed in a physiological context (see Schmidt-Nielsen 1979). Several factors have been pointed out that may contribute to death caused by heat (Tab. 8.5). The mechanism that is the cause of potential death by heat is still poorly understood (Whelan 1995), but it appears to be a connection of several relevant individual factors. The highest body temperature where animal survival may be considered possible is about 50 ˚C.

The situations an animal faces in a forest fire are, however, different from those faced by an animal that lives in an environment where high temperatures remain con-

Table 8.5. Significant factors for death caused by heat in animals (from Whelan 1995).

1. Denaturation of proteins
2. Heat inactivation of enzymes faster than they are formed
3. Insufficient supply of oxygen
4. Different types of temperature effects on mutually dependent metabolic reactions
5. Temperature effects on membrane structures

stant over time. They can be exposed to much higher temperatures in fires, but only for brief periods.

Even though few experiments have been done that have directly examined the effects of this type of exposure, it is possible to make some reasonable predictions by looking at which critical tissue types are protected from high temperatures. Animals differ from plants in their basic biological structure in that serious injury to one body part means death for the entire organism, even though they have avoided direct thermal stress and have managed to survive the passage of the fire front (Whelan 1995).

8.5.1.1 Resistance against heating

In animals, the outer layer of cells is called the ectoderm. It constitutes the outermost barrier and prevents radiant heat from reaching underlying tissue. Three factors determine the protection of critical body tissue from fatal temperatures. These are the insulating capacity of the ectoderm, the size of the organism and the duration of the heat exposure (Whelan 1995).

Studies of the insulation value of fur in various types of animals have mostly revolved around measuring tolerance for low temperatures. The thermodynamic principles, however, are the same regardless of whether the heat through the fur is going into or out of the animal. Thermal conductivity (k) is measured in units for heat transfer per unit of time, per unit of surface area and per unit of temperature difference. Measurements of thermal conductivity in a selection of materials shows that animal fur has lower conductivity (i.e., it is a better insulator) than tissue (Schmidt-Nielsen 1979).

For example, for a specific temperature range where animals with similar surface area are exposed to heat, mammals will heat up more slowly than a reptile, which lacks fur. The insulating capacity of fur is determined by the thickness and the amount of air within it. There is also a correlation between mammal size and fur thickness. Small mammals will thus have poorer insulation simply because they have shorter fur than larger mammals. Small body size is also a disadvantage because a smaller object has a much greater surface area relative to its volume than a larger object. This will lead to much faster heating (Whelan 1995).

It is possible that if a fire front passes very rapidly, the insulating capacity of the fur and the “thermal inertia” entailed by large body size as regards slower heating may be sufficient protection (Whelan 1995). Many observations exist that large mammals, such as deer, can get through the fire front. Animals that choose to avoid extreme temperatures by seeking refuge in lairs and tunnels or cavities in trees may, however, be exposed to high temperatures for somewhat longer periods.

Measurements of temperatures in various locations in a fire in a chaparral society in California showed that even if the fire’s peak temperature went above 300 ˚C, the peak temperature 15 cm down in a straight tunnel that could accommodate animals was only 72 ˚C (Lawrence 1966). However, the temperature at this depth remained above 50 ˚C for about 20 minutes (Whelan 1995).

8.5.1.2 Thermal regulation

Thermal regulation can be achieved either through behavior, for example by seeking out appropriate micro-locations, by assuming suitable body positions (“postures”), or through physiological mechanisms, such as cool-down through evaporation (Schmidt-Nielsen 1979). Seeking shelter in an immobile posture while the temperature of the surroundings increases and remains high places a clear limit on the behavioral mechanisms that can be utilized for thermal regulation. Cool-down through evaporation seems to be the only potential way to survive when the temperature of the surroundings exceeds the fatal temperature for a somewhat extended period of time. This can happen in several ways, *inter alia* through panting and sweating. The effectiveness of thermal regulation through evaporation cooling depends on the relative humidity. The vapor pressure is therefore an important expression of an organism’s capability with regard to cooling through evaporation (Lawrence 1966), however, this relationship between temperature, humidity and survival has not been sufficiently studied.

The survival of caged animals placed in various locations in grassy fields/brush areas and in a chaparral society was studied in an experimental fire (Howard et al.

1959, Lawrence 1966). These studies resulted in a simple survival model (Fig. 8.11).

The water vapor pressure increased much faster with increasing temperatures in connection with high humidity as compared with low humidity. The limited amount of data gathered in this “survival experiment” indicated that the fatal temperature limit would be approximately 60 ˚C at 22 % relative humidity, but only about 45 ˚C at 82 % relative humidity (Fig. 8.11).

If mammals (warm-blooded) in their refuges manage to survive a period of raised temperatures, their continued survival may depend on their ability to restore the water loss. In other words, they must have access to a water source after the fire. Free water will probably often be a limited resource when the fire occurs in arid and semi-arid environments or in dry seasons.

The question is whether cold-blooded animals will have the same problems. Significant differences must be anticipated here because the lack of hair as an insulating agent will mean that they heat up more rapidly. On the positive side, the fact that they may have a lower metabolism than mammals (of comparable size) may limit the “urgency” with regard to restoring a potential deficit of water after passage of the fire front. Few field experiments have been carried out that can clarify this (Friend 1993).

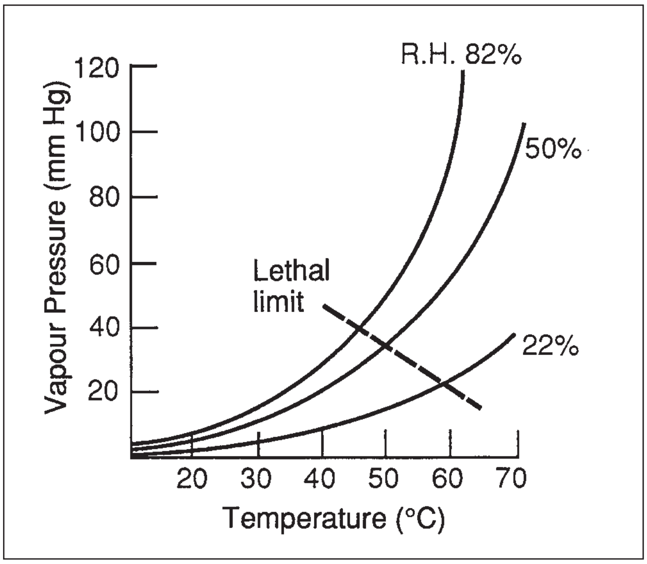


Figure 8.11. The relation between water vapour pressure and ambient temperatures at different degrees of humidity (82 %, 50 %, 22 %) in a survival experiment carried out on small mammals in a chaparall system in California. Low humidity allows animals to tolerate far higher temperatures than if the humidity is high (After Lawrence 1966, redrawn from Whelan 1995).

8.5.1.3 Effects of smoke and lack of oxygen

Even if the surrounding air temperature in fires does not reach fatal levels, inhalation of smoke can be harmful (Bendell 1974). Examples of this are documented in many reports regarding injuries to firefighters both under wildfires in the field and otherwise. Medical treatment after smoke inhalation is far more common than treatment of burn injuries. Material presented shows that 76 % of the fatalities after fires in New York are due to some form of respiratory failure, such as carbon monoxide poisoning, lack of oxygen or inhalation of toxic chemicals in the smoke (Zikria et al. 1972). The cause of death of a medium-sized marsupial that crawled into a hollow trunk during an experimental fire proved to be suffocation (Christensen 1980). Small rodents of the genus *Peromyscus* survived the passage of a fire front if the tunnels they hid in had two openings that allowed for ventilation. In the opposite case, they died of suffocation (Lawrence 1966).

The pyrolysis reaction consumes oxygen and can therefore be assumed to reduce the surrounding oxygen level long enough for certain groups of animals to suffer death by suffocation in strong fires. Once again, differences may be expected between warm-blooded and cold-blooded animals because differences in metabolism may allow the cold-blooded animals to tolerate oxygen-poor environmental conditions for longer periods of time.

8.5.2 Life history as defence

In terms of physiology, any resting stage in an organism’s life cycle is probably particularly tolerant of heat (Schmidt-Nielsen 1979), especially if they are simultaneously dehydrated. In climate types where it is probable that the wildfire season corresponds with hot and dry periods, many species of animals can survive because they develop an “aestivating” stage with special adaptations. Some species may also bury themselves, thereby achieving double protection. Species can also survive fires that occur during periods when they are active, for example birds and insects that can fly away from fires.

From other parts of the world, we know that vertebrate animals can have extensive “fire adaptive” traits in their life histories. A species of turtle in South Africa buries its eggs 10 cm into the soil, and the period for laying eggs and hatching is adapted to the period when there is the least chance of fires occurring.

8.5.3 Behavior in relation to fire

The highest temperatures reached on the surface of the soil in many types of fires are normally well over 50 ˚C, which constitutes a fatal temperature limit for animals (Whelan 1995). Nevertheless, many animals escape burning and death through heat stress, burn injuries and suffocation. Therefore, it seems that behavior aimed at avoiding high temperatures is widespread and can explain animals' tolerance to fires. Animals can also relate to fires through choice of habitat. They can, for example, spend the most time in the type of vegetation that is least likely to ignite and burn. Through their choice of habitat, they can prefer productive, open and recently burned areas (Kruger & Bigalke 1984).

Earlier, there was a common belief and somewhat of a myth that animals were gripped by the same panic in fires as many humans exhibit. Observations made in many different ecosystems on several continents in and close to fires have shown a completely different picture (Komarek 1969a, Vogl 1973, Bendell 1974, Main 1981). Large, mobile mammals seem to be able to move rapidly to unburned parts of their living areas, or move through breaks in the flame front.

The behavior of a small, kangaroo-like marsupial (*Bettongia penicillata*) was studied in a fire of moderate to high intensity in eucalyptus forests in southwestern Australia. The living areas of 19 animals were mapped in advance using radiotelemetry. After the fire, all of the animals remained within their living areas, where they stayed close to their homes. Nine of the tagged animals made their way safely back through the flames, six animals were found in unburned refuges, while four animals sought refuge in hollow trunks (Recher & Christensen 1981).

Not all species with a great capacity for dispersal exhibit such a bond to the living area. During fires they may actually move ahead of the fire front until they end up on a patch of vegetation that remains unburned. Attempts have been made to document such effects in two ways. The most common is observations of live animals immediately after fires in locations that are regarded as being refuges. Studies of populations of small mammals have on several occasions established surviving animals on unburned patches of vegetation such as wet areas near watercourses (Newsome et al. 1975) or protruding cliff projections (Lawrence 1966). There are also reports of vertebrate species that make their way out, and are found alive in tunnels and cavities, such as small reptiles and frogs (Main 1981). Such observations can thus indicate that vertebrates are able to seek out unburned refuges. However, the same observations may alternatively be interpreted such that all of the animals in a population are killed, except for those in the refuges. There are surprisingly few studies that have attempted to test such hypotheses (Whelan 1995).

Small rodents of the genus *Peromyscus* were tagged in Douglas fir forests in North America before a fire where the purpose was to remove logging waste. Marked animals were found on unburned patches and in the surrounding unburned forest (Tevis 1956).

Similar studies have been made of invertebrates. The density of grasshoppers on the African savanna was tested using sampling on burned and unburned areas before and after a fire. The total biomass of grasshoppers on the unburned patches increased immediately after the fire to three times the biomass that was found there before the fire, while the biomass in the burned areas sank dramatically. In other words, the results clearly indicated that many individuals moved to the unburned areas.

Unburned patches are not the only potential refuges for animals in fire areas. In Australian eucalyptus forests, mass migrations of arthropods that normally live in the litter were reported. Some of these animals were observed as they dug themselves in high up in the dense crown layer of certain plant species (Main 1981). The fauna of invertebrate animals in such dense crown layers has been compared with similar crown layers in unburned control areas immediately after a wildfire. The results indicate that the animals actively sought out the crown layer of these plants and used them as refuges (Whelan et al. 1980, Whelan 1995). Similar observations have been made on African savannas (Gandar 1982).

A high density of herbivores within unburned patches of vegetation can clearly lead to significant local grazing pressure, also overgrazing. This is also a question of whether such patches constitute a reservoir for plant-eating species of animals that are able to start grazing on the burned areas immediately after regeneration has commenced, or whether colonists must be produced through reproduction (Whelan 1995).

Important questions linked with the ability of animals to escape fires are still without clear answers, and caution

should be taken in drawing general conclusions regarding the effect of fire on animals (Chandler et al. 1983). A hypothesis stating that wildfires do not generally constitute a major cause of death in populations of vertebrates may be incorrect, but it is often presented by researchers who possess experience from studies in areas with cool fire regimes. Therefore, it is important that this is addressed in future investigations. Studies should be performed on individual marked vertebrates before and after experimental fires of high intensity and covering a larger area (Whelan 1995). In Norway, tests using radio-tagged animals before and after prescribed fires should be well suited to clarify such questions.

8.5.4 Effects of the conditions after fires

Animal populations that survive the passage of the fire front must deal with a radically changed environment. It is often observed that animal species that are present prior to a fire may be observed in the area just after the fire, but that they then disappear (Whelan 1995). The effect of the significant environmental changes created by fires is complex. Most important is that the vegetation that previously offered food and shelter is radically changed or removed. The vegetation affects nearly all of the habitat requirements of vertebrate animals; physical conditions in connection with temperature and wind, concealment from predators, nest and lair locations and food (Winter 1980a). When one knows the habitat requirements of a particular animal species, and also how the vegetation will change after the fire, many of the vertebrates' responses can be predicted.

The way in which fires indirectly affect species has been studied in North America (Spires & Bendell 1983), Africa (Kruger & Bigalke 1984) and Australia (Christensen 1980). The responses to the fire effects show extreme variation. With regard to rodents and their colonization of fire areas, it is for example important that the litter layer and the associated fauna of invertebrate animals are re-established (Fox & Fox 1987). Many species can be so flexible in their choice of nutrients that they switch after fires.[8.12)]

Fires often seem to improve the quality and the quantity of the nutrients that are available for plant-eating animals. The physical and chemical changes that are caused by fires, particularly redistribution and increase in the availability of plant nutrients, must in many cases be expected to improve the quality of the regrowth, and thereby the suitability of the plant cover as food. This has been a well-known fact for domestic animals in the early farming cultures on several continents. Early colonization in Australia included cattle husbandry, which was almost always associated with grazing in areas that were burned (Section 4.2.6). Grassy forest fields in the surrounding landscape were burned to obtain pasturage for flocks of domestic animals (Pyne 1991).

The fact that burned areas are extensively used by grazing animals is in turn exploited by predators. It is easier to discover the prey in the open vegetation after a fire. Hypotheses have also been presented stating that individual species of animals may benefit from fires due to the reduced pressure from parasites. In the American blue grouse (*Dendragapus obscurus*), the appearance of a blood parasite in the population was examined at 5 and 12 years after a fire. As much as 17 % of the individuals were free of blood parasites 5 years after the fire, while all were infected 12 years after. The frequency of infection with special blood, intestinal and external parasites measured 12 years after the fire was more than 8 times as high as the rates of infection after 4 years (Bendell 1974).

As we can see, the effects of fires on the thousands of animal species found in various ecosystems that burn are nearly endless. In the following sections, we will refer to some relevant work that is being done with regard to various animal species. For the sake of good order, the work is organized in systematic groups.

8.5.5 Invertebrates

The effect of fires on invertebrates varies greatly according to the type of fire, which vegetation communities are affected and the region in which the fire occurs (Winter et al. 1976, Winter 1978, Chandler et al. 1983, Wikars 1997).

8.5.5.1 Effects on soil fauna

"Soil fauna" means all important groups of animals which, together with bacteria, fungi and other microorganisms (see Section 8.2.1), break down organic material in the litter and humus, or take part in the degradation in other ways (Tab. 8.6).

The soil fauna can be classified in various ways. A common classification is according to size into *microfauna* (body size < 0.2 mm), *mesofauna* (0.2 mm – 1 cm) and *macrofauna* (> 1 cm) (Kimmins 1997). The microfauna includes groups of protozoans, mites and nematodes; the mesofauna includes mites, springtails, enchytraeidae and larger nematodes; and the macrofauna is composed of

Table 8.6 The most common groups of animals that live in the soil, and that participate in the degradation of organic remnants in forest soil (from Lundmark 1988).

- Earthworms (Lumbricidae, Annelida)
- Roundworms (Nematodae, Nemata)
- Enchytraeids (Enchytraeidae, Nemata)
- Mites (Acarina, Arachnida)
- Springtails (Collembola, Entognatha)
- Beetles (Coleoptera, Insecta)
- Spiders (Aranea, Arachnida)
- Millipedes (Diplopoda)
- Isopods (Isopoda, Crustacea)
- Protozoans (Protozoa)

larger arthropods, molluscs, earthworms and certain species of vertebrates.

With what we now know about variations in fires, major differences must be expected from fire to fire with regard to the impact on the soil fauna. Even in fires where the temperature is not high enough to ignite the organic soil itself, it may be high enough to affect the soil fauna. The meso- and microfauna in the upper organic layers have limited mobility, and are therefore normally killed in fires. Surviving individuals in the lowermost organic layer or on unburned islands form the basis for re-colonization.

It is important to measure how long it takes for the soil fauna to re-colonize fire surfaces. In order to interpret the re-colonization data correctly, we must take into consideration the time it takes to physically colonize a fire surface once again, i.e. the ability of the individual species to disperse. Many species disperse slowly. In the southeastern United States, it has been established that the fauna in the soil of a forest returned during the course of a period of 43 months (Metz & Farrier 1971).

The populations normally return to the same levels during the course of a few years. The effects are therefore related to the fire frequency, which has been documented in several studies (Kimmins 1997). After fires in pine areas in New Jersey, USA, a decline in the soil fauna was observed which was attributed to the loss of organic material and the reduction in nutrients this represented. Therefore, the conditions for predatory forms were also affected indirectly. The population of arthropods sank by 50 %, with an associated 80 % reduction in the number of systematic groups (Buffington 1967).

In a pine forest (*Pinus taeda*) in South Carolina, USA, the soil fauna was reduced by one-third after fire (Pearse 1943). The representation of all species remained identical on burned and unburned areas, with the exception of earthworms where the population declined dramatically, and ants, whose numbers increased in the burned areas. In forests with the pine species *Pinus palustris*, Heyward & Tissot (1936) observed five times more ground organisms in the upper leached horizon in burned patches, and 11 times more organisms in the upper 5 cm of unburned mineral soil than in the previous study (Chandler et al. 1983).

Annual burning of test fields reduced individual numbers and densities of mites and springtails, while burning every 5 years did not produce long-term changes in numbers (Metz & Farrier 1971).

There are great differences in a fire's severity on a very small scale when the fire moves through forests. For example, springtail populations survive best in the areas that are least affected (Dyrness et al. 1986). Unburned patches function as island refuges, and these are important for soil arthropods, particularly for species such as springtails and mites (Macfayden 1952, Tamm 1986, Athias-Binche 1987, Bellido 1987).

In cases where severe fires remove all organic material that has accumulated on the surface, all meso- and microfauna may be eliminated for periods of many years. However, such fires are most often limited to the summer season when the organic surface material is dried out and high temperatures have already driven these animals down into damper and cooler mineral soil where they will survive fires (Kimmins 1997).

There are no systematic studies of the effects of forest fires on the soil fauna in Norway, but some work has been done in Finland (Baath et al. 1995, Koponen 1995). Therefore, it is necessary to chart the changes that fires of varying intensity and severity cause under conditions in Norway for this important part of the fauna.

8.5.5.2 Phylum Molluscs (Mollusca) – Class Slugs (Gastropoda)

A reduction in slug populations after fires has been documented in the southern USA (Heyward & Tissot 1936). Ahlgren (1974) mentions that the slugs disappeared for at least three years after fires in pine forests (*Pinus banksiana*) in northern Minnesota, USA. Several other studies have proven a reduction in the number and

species of slugs after fires (Phillips 1965, Brabetz 1978). This group does not appear to have been studied in detail in Norway.

8.5.5.3 Phylum Annelid Worms (Annelida) – Class Oligochaetes (Oligochaeta) – Earthworms (Lumbricidae)

It has been reported that populations of earthworms can be significantly reduced in forest fires. Pearse (1943) established a 50 % decline after fire in litter of the pine species *Pinus taeda*. In forest stands of a different pine species (*P. palustris*), it was established that the earthworm populations were four times larger in the first 0–5 centimeters of an unburned mineral soil than in corresponding burned areas where the population of earthworms had been especially large in the uppermost leached horizon of the soil. Earthworms live largely in humus and in the upper part of the mineral soil. They are presumed to be more sensitive to reduced moisture content in the soil than to the actual heat from the fire (Heyward & Tissot 1936).

8.5.5.4 Phylum Arthropods (Arthropoda)

A number of studies exist concerning the composition of the arthropod fauna and the changes in the first years after a fire in the boreal coniferous forest, particularly of insects from Europe and North America (Tab. 8.7). Comprehensive studies have been conducted *inter alia* in Sweden, Finland, Germany, Canada and the USA (Riess 1978, Hoffmann 1980, Chandler et al. 1983, Wikars 1996, 1997).

Table 8.7. Preliminary overview of effects of fires on individual numbers, density and diversity (D) in arthropods. A question mark after the plus symbol indicates that an increase in the number after fires may be due to use of more effective traps (e.g. fall traps) after the fire. Both plus and minus in the same studies indicates that different sub-groups within the relevant unit have exhibited different responses. 0 means no observable effect (from Wikars 1996). *)

Taxa	Subtaxa	1-4 weeks	1-3 months	3-6 months	0.5-1 year	> 1 year
ARTHROPODA						-(D-)[27]
Acari		0[5,6], -[6,16]			-(D-)[5] +,-[20]	-[16, 23]
Aranea		-[7, 15]	-[7, 15]	-[15]	-[13, 15] -(D-)[24] +?[20]	-[13] -(D-)[15]
-"-	Linyphiidae					-[15]
-"-	Lycosidae					+[15, 24]
Thysanura						-[1, 22]
Pauropoda						-[23]
Diplopoda						+[1, 27] -[20, 23, 27]
Chilopoda						-[1, 23]
Collembola		0[6],-[6]	-[7]	-[28]	-(D+)[9] +[15, 28, 30] +?[20]	-(D+)[9] +[28]
INSECTA		-(D-)[20]			+(D+)[11]	
Blattodea						-[1]
Orthoptera				+[19]	+[19]	-,+[10] (D+)[10]
Homoptera		-[7]	-[7],+[8]	+[19]	+[4, 19]	+[4]
Hemiptera		-[7, 12]	-[7],+[8]		-(D+)[12]	
Thysanoptera					-[20]	
Coleoptera		-[7]	-(D-)[7]		+[18]	+?[22]
-"-	Carabidae				-[30] +?[18]	-[14],+?[18] (D+)[17] +(D-)[29]
-"-	Staphylinidae	-[26]			-[18]	-[18]
-"-	Latridiidae				+[18, 25]	+[18, 25]
Hymenoptera		-[7]	-[7]			
-"-	Formicidae	+?[2, 20] +[26] -(D+)[3]		+[4, 17]	+[19] +?[20]	+[20]
-"-	Parasitica				+[20]	-[11]
Diptera		-[7]	-[7]			
-"-	Chironomidae				+[21, 30]	+[30]
-"-	Ephydridae				+[30]	

* This is a preliminary overview that is primarily based on European and North American literature. The work to complete the list is ongoing (Lars-Ove Wikars, pers. comm.).

1. Abbot 1984; 2. Andersen 1988; 3. Andersen & Yen 1985; 4. Anderson et al. 1989; 5. Athias-Binche 1987; 6. Bellido 1987; 7. Bulan & Barret 1971; 8. Cancelado & Yonke 1970; 9. Dindal & Metz 1977#; 10. Evans 1984, 1988; 11. Force 1981; 12. Gillon 1985; 13. Hauge & Kvamme 1983#; 14. Holliday 1991#, 1992#; 15. Huhta 1971#; 16. Karppinen 1957#; 17. McCoy 1987; 18. Muona & Rutanen 1994#; 19. Nagel 1973; 20. Neumann 1991#; 21. Nicolai 1991; 22. Pantis et al. 1988; 23. Prodon et al. 1987; 24. Schaefer 1980#; 25. Schauermann 1980#; 26. Spires & Bendell 1983#; 27. Springett 1979; 28. Tamm 1986#; 29. Winter 1980b#; 30. Winter et al. 1980#

= studies conducted in boreal or temperate forests.

Class Arachnids (Arachnida)
Order Spiders (Aranea)

Spiders, particularly those that live on the ground, can be severely affected by fires. Declines in population of from 9 to 31 % in burned environments compared with unburned control areas have been described (Rice 1932, Heyward & Tissot 1936, Buffington 1967, French &

Keirle 1969, Brabetz 1978). Schaefer (1980) estimated that only one percent of the spiders survived an intense fire in regenerated pine. Hurst (1971), on the other hand, has established an increase in populations of ground living spiders and wolf spiders after burning of vegetation in transmission lines in Mississippi, USA. The results in the individual studies vary significantly, and additional detailed studies are necessary.

Studies on fire surfaces in Finland have also proven changes both in the composition of species and the number of individuals among species of the spider fauna. Spiders that are pioneers in burned forest areas are the species *Meioneta rurestris*, *Erigone dentipalpes* and *E. atra* (Huhta 1971, Schaefer 1980, Hauge & Kvamme 1983). These are among the most common astronauts, i.e. spiders that spread by spinning long, free threads with a subsequent “take-off” with air currents (Wikars 1997). It can take several years before the original fauna is restored (Huhta 1971). This succession includes both pioneer species and species that occur in transitional phases before the spider society is re-established.

Studies in Finland have not shown endangered or vulnerable species or groups of species of spiders particularly linked to fire-induced living areas (Rassi & Väisänen 1987). Several studies have, however, documented changes in spider communities in successions after forest fires (and clear-cuts) under Scandinavian conditions (Huhta 1971, Hauge & Kvamme 1983). Some species can occur in greater numbers on fire surfaces than in surrounding closed populations, and must thus be regarded as fire profiteers.

In Norway the spider fauna in previously burned areas has been investigated in locations both in Elverum, Heddal and Rendalen after fires in 1976, 1976 and 1980, respectively. A certain increase in the number of species was confirmed through the first years after the fires. There was also a qualitative change in that “pioneer species” occurred in the areas in the first years and then disappeared (Hauge & Kvamme 1983). A total of ten species were described as new to the Norwegian fauna in these studies (Hauge & Kvamme 1983).

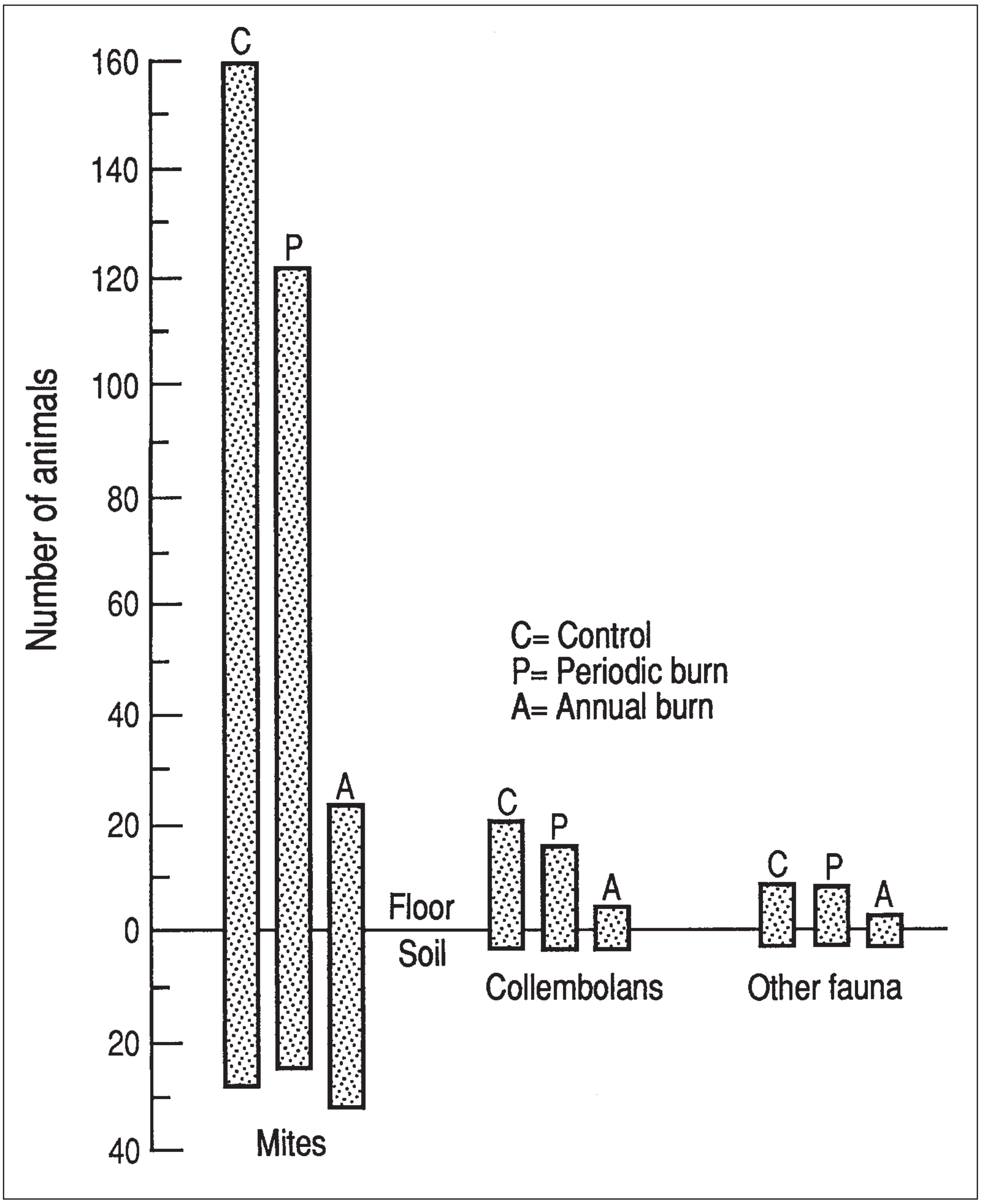


Figure 8.12. Average numbers of animals extracted per 20 cm^2 soil sample in three treatments of ten days in areas that burn yearly (A), periodically (B) and in control areas that do not burn (C) (Redrawn from Metz & Farrier 1971).

In connection with burning (and cutting) of test surfaces in experiments with habitat improvements for willow grouse in mountain birch forests, only small changes were observed in the community structure of spiders (and beetles), considerably less than was previously established in similar studies (Bretten 1995, Pedersen 1997)

Order Mites (Acarina)

Mites constitute one of the largest groups of ground living animals, and the mite fauna varies significantly according to region, both as regards numbers and composition of species. Heyward & Tissot (1936) have estimated that the population of mites in pine forests (*P. palustris*) constitutes from 71 to 93 % of the fauna in fire areas, depending on soil depth. The studies that have been conducted show that the mite populations are reduced through burning (Rice 1932, Heyward & Tissot 1936, Pearse 1943), sometimes significantly (Metz & Farrier 1971). (Fig. 8.12 and 8.13). The latter study showed that only 24 hours after the fire, no more than 30 % of the animals were left in the upper 7 cm of the mineral soil. However, the reduction was not as marked in the humus layer. The population levels "restored" themselves in less than 43 months.

In Finland, a sudden reduction in the population of mites in the upper 5 cm of the soil after a prescribed fire has been established (Karppinen 1957). Re-colonization of mites after fires can take place both through vertical movements from deeper layers of soil as well as through horizontal movements from unburned patches (Athias-Binche 1987). The succession of mites in the soil has also been examined in burned heather moors (Webb 1994). Mites as a group is another that has not been studied in detail on fire surfaces in Norway.

Class Entognaths (Entognatha)
Springtails (Collembola)

The populations of springtails are also generally reduced in connection with fires. Tamm (1986) found that many of the dominating springtail populations were sharply reduced, some also exterminated. Springtails had maximum diversity in a milder fire frequency where the fires reduced the most common species. Studies have shown that the reductions were especially evident in the humus and organic surface layer, and that there was little effect on the populations that lived in the mineral soil. The populations "restored" themselves to the pre-fire levels in the course of 3 to 4 years (Heyward & Tissot 1936, Metz & Farrier 1971).

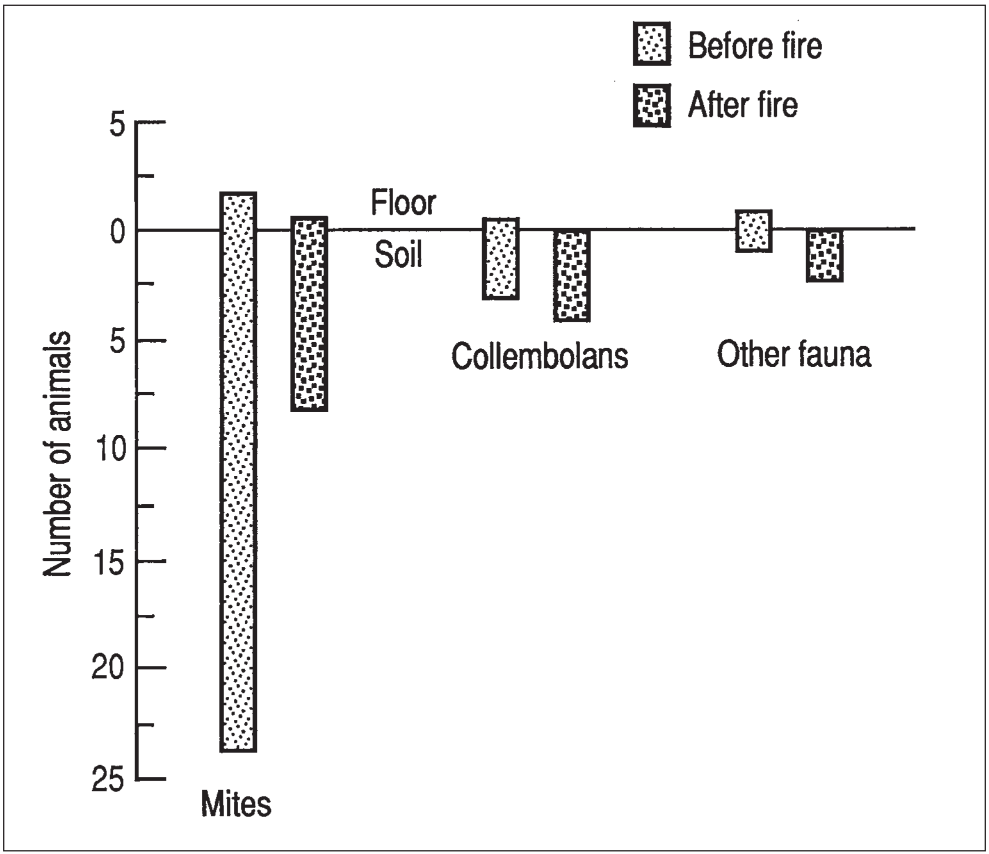


Figure 8.13. Average numbers of animals extracted per 20 cm^2 soil sample immediately before and 24 hours after a fire in the summer season 1970 (Redrawn from Metz & Farrier 1997).

Class Insects (Insecta)

Insects are a numerous and important animal group, and studies in forest fire areas have shown that they are affected to a significant degree by fires (Phillips 1965, Winter 1978, Chandler et al. 1983). Reference is made to Wikars (1997) for a recently developed, broad summary of the effects of forest fires on insects, including a description of their evolutionary adaptations and life history traits. Some insect species have also been examined thoroughly in boreal coniferous forests in Fennoscandia.

Fires affect insects in highly variable ways, from direct influences of the fire itself to changes in living areas, nutri-

ents, light, temperature and moisture, or that dependency arises with fungi, plants, and other fauna found in the burned areas, etc. (Wikars 1997). Many species benefit from high temperatures on fire surfaces, particular nutrients in trees recently killed by fire, or they have developed life history traits for dispersal, reproduction or for improving their competitiveness.

As mentioned, fire losers (Section 8.1.3) are made up of species in many systematic groups that have their populations reduced in forest fires or in the periods immediately after fires (Tab. 8.7). However, some species quickly reach the population density they had before the fire, while some may increase in numbers. Species in some groups may be knocked out for relatively long periods of time, while still others are reduced gradually as a result of changes in the habitat. The degree of survival is species-specific and related to the type of fire (Wikars 1997).

Pyrophilic species, or fire specialists, among the insects form a surprisingly heterogeneous group viewed from both a systematic and an ecological viewpoint. In some cases, they have primitive characters that indicate an early evolutionary origin (Wikars 1997). Such species are found on all continents (Tab. 8.8).

In contrast to the fire-adapted species, many species of insects are linked with succession stages with older vegetation and climax phases, and are sensitive to fires (fire losers).

Some studies exist that address how the species find their way back to the forest fire areas. As mentioned, the buprestid beetle *Melanophila acuminata* is equipped with a sense organ for receiving infrared radiation that makes it possible to track fire fields over long distances (Section 8.4). Other factors in forest fire areas which can attract insect species include chemical changes in the bark, high temperatures that are favorable for development of larvae, large accumulations of prey animals in the form of microarthropods, the odor of burned trees or fungi on burned trees than can constitute nutrient resources, particularly a group of mould fungi. However, there are few studies of population dynamics that show how these species survive in the time periods between fires. In addition, the dispersal mechanism of many species is not completely known (Rolstad 1993). A species complex of fire specialists among the insects is also found in Scandinavian coniferous forests, which may require special management measures if the effective level of firefighting in Norway is maintained (Section 9.4.3). While many studies have been made of an insect group such as beetles, there are other large groups that remain nearly uninvestigated.

Research work aimed at the fauna will be required in order to develop a more complete overview of species, partly in order to better clarify these species' special relationship to forest fires.

Order Orthopterans (grasshoppers, locusts, katydids, crickets) (Orthoptera)
Grasshoppers (Califera)
Since many grasshoppers winter as larvae in the upper layers of the soil, fires, particularly in the spring, can contribute greatly to reducing the populations. Among other things, this has been used to fight grasshoppers in some countries (Komarek 1970). Some species of grasshoppers that live in burned areas on the African savanna exhibit melanism (see also section 8.4.5.5 Mammals), i.e. they occur as a dark form ("morph") in burned areas and a paler form in unburned areas (Poulton 1926, Hocking 1964). Another way to change the color is through physiological mechanisms. Two days after a fire, individuals of the species *Phorenula werneriana*, which is also found on the African savanna, change color from gray to coal-black (Uvarov 1966). This group has not been studied in Norway.

Order Hemipterans (Hemiptera)
Suborder Bugs (Heteroptera)
Among the specialized insects linked with fire habitats are bark bugs in the genus *Aradus* (Heteroptera) (Tab. 8.8). These species subsist *inter alia* on various mould fungi under the bark of burned trees. Studies in Finland have listed the following species: *Aradus angularis*, *A. anisotuomus*, *A. aterrimus*, *A. crenaticollis*, *A. laeviusculus*, *A. signaticornis*. Of these, the status of *A. crenaticollis* is uncertain, while the others have not been observed after 1960 (Rassi & Väisänen 1987). This group is an example of insects that can be affected by management that maintains effective fire fighting over lengthy periods.

Suborder Homopterans (cicades, leafhoppers, planthoppers, spittle bugs, aphids, psyllids, scale insects (coccoids), whiteflies) (Homoptera)
The large and thick-walled galls in certain scale insects (Coccoidea) protect during fires. Many species live on plant species in dry areas in Australia that burn often. Here the formation of galls may be a life history trait that ensures survival in areas with frequent fires (Koteja 1986).

Table 8.8. Pyrophilic insects, i. e. species that are attracted to burning or newly burned areas and species having their main distribution in burned forest areas 0 – 3 years after the fire. Data grouped from Krogerus (1946), Palm (1951), Evans (1971), Chandler (1978), Lundberg (1984), Ehnström & Waldén (1986), Paulian (1988), CSIRO (1991), Wikars (1992) and Muona & Rutanen (1994).

Distribution: Af-Africa, Au-Australia, E-Eurasia, NA- North America, SA-South America. *-attraction to ongoing fires is documented (open fire, warm ash or smoke) (After Wikars 1997, slightly changed).

Systematic order Order/Suborder/Family	**Species**	**Larval food**	**Distribution**
Hemiptera (bugs)			
Anthocoridae	*Scoloposcelis obscurella*	Small arthropods under bark	E
Aradidae	**Aradus lugubris*	Wood-living ascomycetes	E,NA
-»-	**A. crenaticollis*	-»-	E
-»-	**A. laeviusculus*	-»-	E
-»-	**A. signaticornis*	-»-	E,NA
-»-	*A. aterrimus*	-»-	E
-»-	*A. angularis*	-»-	E
-»-	**A. anisotomus*	-»-	E
Lepidoptera (butterflies)			
Noctuidae	*Actebia fennica*	Plants	E,NA
Pyralidae	*Apomyelois bistriatella*	Wood-living ascomycetes	E
Diptera			
Empididae	**Hormopeza obliterata*	?	E,NA
-»-	**H. copulifera*	-»-	E,NA
Asteiidae	*Astiosoma rufifrons*	Wood-living ascomycetes	E
Platypezidae	**Microsania pectipennis*	Fungi (?)	E
-»-	**M. pallipes*	-»-	E
-»-	**M. collarti* (=*stigmaticollis*)	-»-	E
-»-	**M. occidentalis*	-»-	NA
-»-	**M. imperfecta*	-»-	NA
-»-	**M. australis*	-»-	Au
Drosophilidae	*Amiota alboguttata*	Wood-living ascomycetes	E
Coleoptera (beetles)			
Carabidae	**Pterostichus quadrifoveolatus*	Omnivorous	E
-»-	**Sericoda* (*Agonum*) *obsoleta*	Small arthropods	NA
-»-	**S. bogemanni*	-»-	E,NA
-»-	**S. quadripunctata*	-»-	E,NA
Micropeplidae	*Micropeplus tesserula*	Ground/living fungi	E
Staphylinidae	*Paranopleta inhabilis*	Wood-living ascomycetes	E
Scarabaeidae (Cetoniinae)	*Coptomia* sp.	?	Af
-»-	*Euchroea* sp.	?	Af
Elateridae	*Denticollis borealis*	Cambium and wood of trees	E
Buprestidae	**Melanophila acuminata*	-»-	E,NA
-»-	**M. consputa*	-»-	NA
-»-	**M. coriacea*	-»-	E
-»-	**M. ignicola*	-»-	E
-»-	**M. nigrita*	-»-	Af
-»-	**M. notata*	-»-	NA
-»-	**M. occidentalis*	-»-	NA
-»-	**M. picta indica*	-»-	E
-»-	**Merimna atrata*	-»-	Au
Bostrychidae	*Stephanopachys linearis*	Cambium and bark	E,NA
-»-	*S. substriatus*	-»-	E,NA
Acanthocnemidae	**Acanthocnemis nigricans*	?	Au
Cleridae	*Trogodendron fasciculatum*	?	Au
Cucujidae	*Laemophloeus muticus*	Wood-living ascomycetes	E
Cryptophagidae	*Henoticus serratus*	Ascomycetes	E
-»-	*Cryptophagus corticinus*	Wood-living ascomycetes	E
Latridiidae	*Corticaria planula*	Ascomycetes	E
Biphyllidae	*Biphyllus lunatus*	Wood-living ascomycetes	E
Salpingidae	*Sphaeriestes stockmanni*	-»-	E
Cephaloidae	*Stenotrachelus aeneus*	Cambium and wood of trees	E
Cerambycidae	*Arhopalus apertus*	-»-	SA
-»-	*Acmaeops septentrionis*	Cambium of trees	E
-»-	*A. marginata*	-»-	E
-»-	*A. proteus*	-»-	NA
Anthribidae	*Platyrhinus resinosus*	Wood-living ascomycetes	E

Order Butterflies (Lepidoptera)

Some Fennoscandic butterflies are reported to be linked with fire habitats. Among these is the Finnish turnip moth (*Actebia fennica*). The females are presumed to be attracted to fire fields for laying eggs (Pulliainen 1963). A different species, *Apomyelois bistriatella*, lives on the fungus species *Daldinia concentrica* on burned deciduous trees (Ehnström 1991). *Scythris noricella* is also linked to fire habitats (Rassi & Väisänen 1987). There are no studies available in Norway.

Order Beetles (Coleoptera)

It is well known that a substantial number of beetles (Fig. 8.14) occur in burned areas (Tab. 8.8), and this group has been studied both in North America (Evans 1971, Harris & Whitcomb 1974, Lyon et al. 1978, Richardson & Holliday 1982, Holliday 1984, 1991) and Europe (Schauerman 1980, Winter et al. 1980, Restin 1995, Wikars 1997). A large species complex is linked to fire areas as specialists or profiteers, also in boreal coniferous forests (Tab. 8.8). However, the populations of many species decline after fires. Fires generally cause major changes in the beetle fauna in all areas where this has been studied.

Rice (1932) reported a 15 % decline in the population of beetles immediately after forest fires, followed by rapid re-colonization. A 60 % decline was established in pine forests in the southern USA by Pearse (1943) and Heyward & Tissot (1936). Buffington (1967) has proven four times more beetles in unburned control areas, and Ahlgren (1974) discovered fewer beetles on burned areas as compared with unburned areas three months after a prescribed fire in pine forests (*Pinus banksiana*) in Minnesota, USA. Hurst (1971) reported an increase in the number and biomass of beetles after burning in cleared transmission lines.

Studies in the Nordic countries

Several studies have examined the changes in the species inventory of beetles in burned areas, both in Finland (Rassi & Väsänen 1987, Muona & Rutanen 1994), Sweden (Forslund 1934, Palm 1955, Ehnström 1977a,b, 1991, Lundberg 1984, 1991, 1995, Wikars 1992, 1994, 1995, 1997, Wikars & Ås 1992, Cederberg & Wikars 1993, Pettersson 1994, Ehnström et al. 1995) and Norway (Thunes 1993, 1997, Bakke 1996).

In Finland and Sweden, it has been demonstrated that

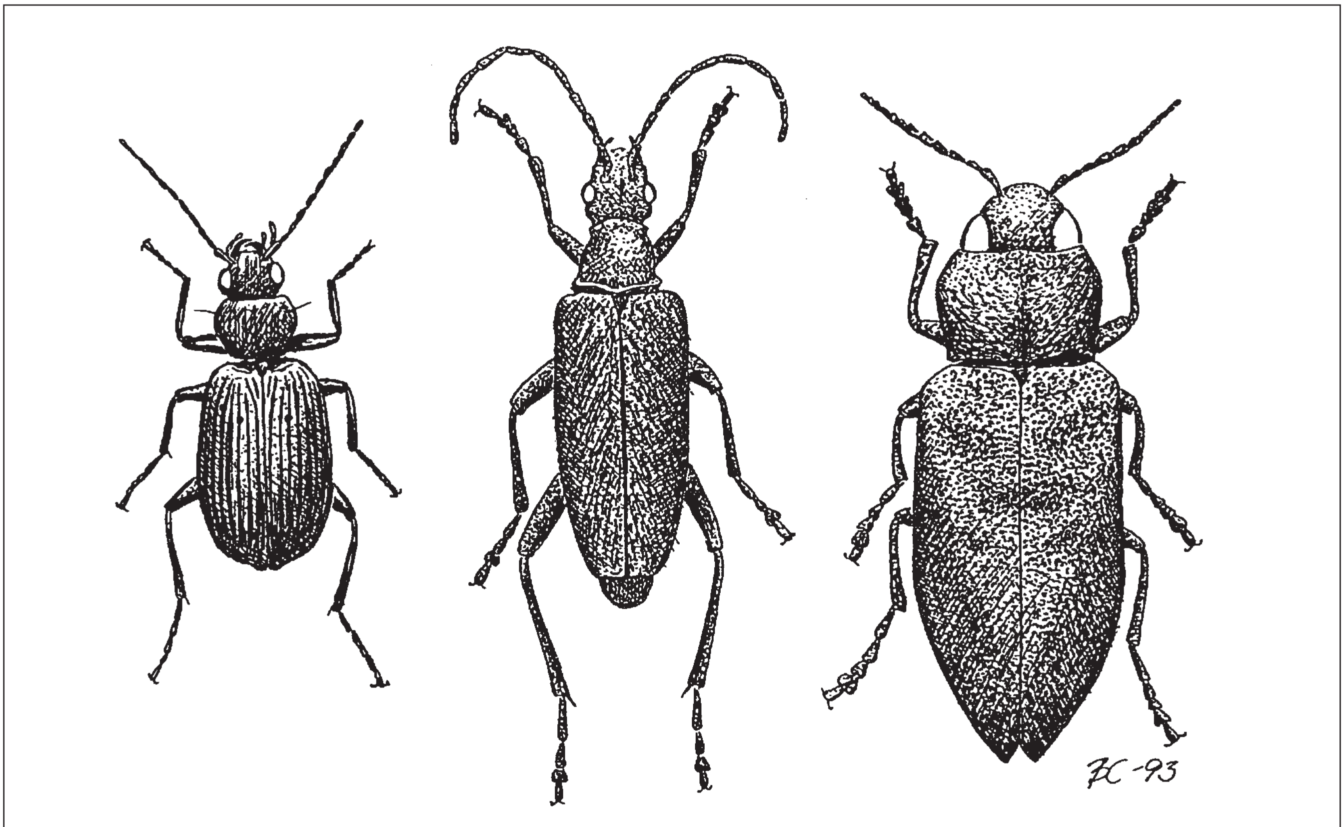


Figure 8.14. Three examples of fire specialist beetle species from the Swedish "red list": *Agonum quadripunctatum* (left), *Acmacops septentrionis* (center) and *Melanophila acuminata* (right) (After Cederberg & Wikars 1993).

fire fields provide a basis of existence for a large species complex of beetles, including some species that today must be characterized as rare. In the proposed ecological grouping of beetle fauna (Tab. 8.9), several important groups are represented by many species on fire fields in Finland (Muona & Rutanen 1994).

Table 8.9. Ecological grouping of the beetle fauna on fire areas in boreal coniferous forest (After Muona & Rutanen 1994).

	Grouping of beetle fauna
1.	Ground living species that are not predators
2.	Species that develop deep in the soil
3.	Species associated with rodents
4.	Species specialized on temporary resources (fungi, excrements, carcasses)
5.	Predators that live under the bark of trees
6.	Species that develop in wood that is attacked by fungi
7.	Species attracted to damaged and dead trees
8.	Herbivores
9.	Predators that live on vegetation
10.	Species associated with agriculture

The most important species that occur on the fire fields can be roughly divided into two main groups: those which live as predators on the forest floor, and those which are living on dead timber as wood or fungus eaters, or as predators (Tab. 8.9).

As mentioned, the pyrophilic species (Tab. 8.8) occupy a special position. They normally occur relatively rarely in the coniferous forest, but show up after fires, often in large numbers (Saalas 1917, Palm 1951, 1955, Lundberg 1984).

Fire-damaged forests may also easily become a reproduction site for species that foresters regard as insect pests. Bark beetles can, for example, increase in numbers and damage trees in such areas (Ehnström et al. 1995). Reference is made to the cited literature for a discussion of these problems.

Studies in Norway

The beetle fauna in burnt areas has also been studied in Norway, but a compiled overview of the species was not published until the 1990s in studies from Telemark (Bakke 1996, 1997) and Hordaland (Thunes 1993, 1997). We will examine some of the details from these studies.

Lisleherad, Notodden, Telemark

A larger fire during the days 21–24 June 1992 affected 225 hectares of productive forest, of which 166 hectares of seedling forest in Lisleherad, Notodden in Telemark. Studies of the beetle fauna on the burned surface were carried out using various types of traps during the period May-August in the years 1993, 1994 and 1995. At the same time, observations were made of the forest around the fire field with a view towards charting potential damage caused by bark beetles on unburned forests (Bakke 1996).

A total of 8 419 individuals divided among 472 species of beetles were registered. The trunks of pine trees damaged by fire were exploited by pine shoot beetles (*Tomicus*). The fire-damaged trees were also heavily attacked by bark beetles, and 25 species of bark beetles were registered in the traps. As early as 1992, the damaged spruces were exploited by the double-eyed bark beetle (*Polygraphus poligraphus*) and in the next years by the large spruce bark beetle (*Ips typographus*), double-toothed bark beetle (*Ips duplicatus*) and the small spruce bark beetle (*Pityogenes chalcographus*). None of these species developed mass invasions into the healthy forest surrounding the fire field, nor did they inflict damage worth mentioning. The pine weevil (*Hylobius abietis*) was numerous on the field in 1993. It is a well-known fact that the pine weevil is attracted to fire surfaces where it can inflict substantial gnawing damage on young plants (Sylvén 1927, Solbraa 1981, 1997b). The fire-damaged trees were also exploited by longhorn beetles.

The buprestid beetle *Melanophila acuminata* was captured in traps in 1993 and 1994, but not in 1995 (Bakke 1996).

Profiteers that live on fungi in the timber were also numerous, as well as several species of the typical predators that occur on fire surfaces.

After the pine weevil *Hylobius abietis*, the two ground beetles *Pterostichus quadrifoveolatus* and *Sericoda quadripunctata* were the most common species (in the fall traps). *P. quadrifoveolatus* was only captured in the first two years, while *S. quadripunctata* was also captured in the third year. *P. quadrifoveolatus* is found in Scandinavia only in recently burned areas, and it is known that the species is one of the very earliest colonizers of burned forests (Winter 1980b). *P. quadrifoveolatus* has an extremely great ability to disperse, and reproduces very quickly with large numbers of offspring (Parmann 1966, Thunes 1993, Wikars 1992). It is also suggested that this species may be equipped with sensors to discover fires at great distances (Thunes 1993). In Norway, this species has only been established in the

outer parts of Aust-Agder, but it has now also been found on several of the fire fields in eastern Norway (Thunes 1993), for example at Notodden (Bakke 1996).

Bembidion lampros showed up in the second year (Bakke 1996). Of the 19 total species of pyrophilic beetles listed by Wikars (1992), eight were registered on the fire field in Telemark (Bakke 1996).

Hopsfjellet, Sveio, Hordaland

A similar study was conducted in Hopsfjellet in Sveio municipality in Hordaland county where about 3000 decares of various habitat types burned in the summer of 1992. Several forest types were represented in the burned area, and large parts of the area were of a high quality class (Thunes 1993).

Using various methods, 803 beetles (including larva), divided between 25 families and 92 species, were captured. However, the field studies were slow in starting such that some of the first species that colonize burned areas may be underrepresented in the material (Thunes 1993).

The two typical pyrophilic species, the ground beetle *Pterostichus quadrifoveolatus* (Fam. Carabidae) and the salpingid beetle *Sphaeriestes stochmanni* (Fam. Salpingidae) (Tab. 8.8) were found in Sveio, each species with only one individual.

Sphaeriestes stochmanni lives under the bark of young burned trees (Hansen 1950). The species actively seeks out fire areas, without this being the only potential development site for this species (Lundberg 1984, Wikars 1992). In addition to these two fire specialists, a number of profiteer species were established which are drawn to fire fields, but which are not presumed to be totally dependent on fires. Many of these are linked to dead timber, dying or sick trees, either as larvae or adults. The smell of fire exerts a strong attraction on the weevils *Hylobius abietis* and *H. pinastri* (Lundberg 1984). *H. abietis* was particularly dominant on the Sveio surface, making up 14 % of the total material.

Thus only two individuals of pyrophilic species were found in Sveio. This may be due to the fact that the survey started late. Therefore, we do not know whether the individuals were remnants of a larger population that had occurred on the field earlier in the season, or whether they constituted the last active individuals before the population went into “hibernation” (Thunes 1993).

It has thus been documented that fire specialists among beetles can occur all the way out to the coast, even though the number of individuals found in these first studies is extremely low (Thunes 1997). Many pyrophilic species found in Fennoscandia have an easterly/northeasterly distribution pattern (Wikars 1992). Therefore, it is still uncertain whether they are found in western Norway (Thunes 1993, 1997).

Several of the pyrophilic beetles are thought to be relatively rare in this country. However, none of the registered species established in Lisleherad have been entered on the Nordic lists of endangered or vulnerable species (Nordic Council of Ministers 1995), although several of them are on the Norwegian list of endangered species (Størkersen 1992). Both of the species from Sveio are listed in the Swedish “red list” of endangered species and are placed in Category 4 – requiring care (Thunes 1993). The mapping of the beetle fauna in burned areas in Norway must still be characterized as very incomplete.

Order Wasps (Hymenoptera)
Family Ants (Formicidae)

Ants often place their colonies deep in the soil. This makes them less vulnerable to being killed directly in fires (Ahlgren 1974, Andersen 1988). Reactions to fires vary substantially also in this group. Pearse (1943) has demonstrated a one-third reduction in the ant population as a consequence of fire, and Buffington (1976) has observed a reduction in the number of ants in burned pine forest areas in New Jersey, USA. However, the decline was not as marked as for other arthropods that live in the soil. On the other hand, two of the species, *Solenopsis molesta* and *Lasius flavus*, were more numerous on burned areas. This is probably due to their preference for dry living areas and their feeding habits of collecting dry seeds.

It has also been shown that the diversity of species of ants can increase after fires, possibly due to changes in competitive conditions (Andersen & Yen 1985).

Rice (1932) found that the ant populations were 30 % higher in burned areas than in unburned areas. Heyward & Tissot (1936) found quite a few more ants in the upper 0–5 cm of the mineral soil layer in burned pine forests in the southern USA than in comparable unburned areas. The population of fire ants (*Solenopsis* spp.) increased after burning of the vegetation in transmission lines (Hurst 1971). This increase is probably due to the rapid colonization of the burned areas com-

bined with the fact that ants can survive fires in the upper layers of the soil (Chandler et al. 1983).

As a group, ants are among those insects that are least affected because of their adaptation to heat and dry periods in the upper soil layers (Ahlgren 1974). Both their social organization and habitat conditions enable ants to be among the first insects to colonize burned areas.

For this reason, ants may have great significance as spreaders (vectors) of seeds of various plant species on burned surfaces. Both pill-headed sedge (*Carex pilulifera*) and hairy woodrush (*Luzula pilosa*) are spread by ants, i.e. there is reason to believe that seeds are dug up and moved around by ants that are found in large numbers on fire fields (Skogen 1989, 1997). In the Nordic countries, ant colonization of fire surfaces has been studied in particular in Finland (Punttila et al. 1994, Punttila & Haila 1996).

Order True Flies (Diptera)

The so-called saltwater flies (Ephydridae) can develop in great numbers on fire surfaces. They are adapted to living areas with large concentrations of ions. The saltwater flies often use pools of water that have accumulated in hollows on the fire surfaces where ash from the fire has accumulated.

Species from the Chironomidae, Sciaridae, Cecidomyidae and Empididae families have been observed to utilize the large amount of nutrients that are released. They develop in great numbers from the ground layer on fire surfaces (Winter et al. 1980).

Class Centipedes (Chilopoda) and Millipedes (Diplopoda)

The population of centipedes and millipedes is generally reduced in connection with fires, sometimes by as much as 80 % (Rice 1932, Heyward & Tissot 1936, Pearse 1943). The large numbers of centipedes identified in unburned areas is probably an effect of the high populations of other arthropods that the centipedes feed on (Heyward & Tissot 1936).

8.5.6 Vertebrates

The vertebrates consist of five classes: fish, amphibians, reptiles, birds and mammals, all of which can be affected by fire (Kuleshova 1981, Chandler et al. 1983). The effects on the individual species, however, are quite different (Ahlgren & Ahlgren 1960, Komarek 1969a, Bendell 1974, Peek 1986, Whelan 1995, Kimmins 1997).

8.5.6.1 Fishes (Pisces)

Forest fires can lead to significant changes in rivers and watercourses through sudden disturbances in run-off and erosion in the drainage basins (Tiedemann et al. 1979, Schindler et al. 1980, Chandler et al. 1983, Minshall et al. 1989, 1990, Minshall & Brock 1991). This can affect populations of fish directly through mortality and indirectly through changes in the living conditions. In some cases, the changes can be extensive. Significant effects have also been shown as regards chemicals used to put out fires (Section 10.2.5).

The most important effects on the fish populations are indirect. The effects are related to changes in the living areas themselves and the production environment in the drainage basin. Negative influence and destruction of the living areas of fish species can primarily be caused by an increase in soil erosion, increased water flow, changes in the nutrient content of the water, and removal of vegetation along beaches, creeks and riverbanks. Litter from this vegetation makes up the so-called allochthonous material, which is important for the food chain in the watercourses.

It has been observed that an increased supply of sediments in the streams where spawning takes place has a negative effect through reducing the average size of the pulverized material that is normally used to cover the eggs (substratum change). In addition, the effects have counteracted the emigration of progeny. Losses to predation have also increased while, at the same time, populations of important food species such as mayflies (Ephemeroptera), caddisflies (Trichoptera) and stoneflies (Plecoptera) have been reduced.

Eggs can also be crushed or moved to unfavorable environments by a faster water stream. Greater flow rates can also lead to changes in the size of the gravel material so that the quality of the spawning areas is diminished. Erosion can start movement in the gravel material and swirl it around, so that both eggs and spawn are affected. When the vegetation disappears along the banks, erosion often increases, living areas deteriorate and the water temperature increases. The latter will increase the fishes' need for oxygen, while it simultaneously reduces the amount of oxygen available in the water. Many species that are adapted to cold-water environments have low tolerance limits for changes in temperature, and cannot survive in such elevated water temperatures. They often die out in the course of the summer following a forest fire (Chandler et al. 1983). An increase in fish diseases may

be another consequence that can be expected when living areas deteriorate when water temperatures become higher.

It is also known that fish are particularly vulnerable to water soluble chemicals used during fire extinguishing work. It has been reported that such chemicals have greater ecological effects on water ecosystems than on land ecosystems (see Chandler et al. 1983). This relates both to substances with direct toxic effects and to chemicals that can lead to eutrophication, i.e. accumulation of nutrients, resulting in increased growth of algae and oxygen deficiency in the watercourse.

It appears that no special studies have been conducted of fish in drainage basins where forest fires have occurred in Norway. However, there has been a discussion of whether run-off from fire areas can have a favorable effect on acidity, and that the fighting of forest fires has contributed to the acidification of watercourses with resulting fish mortality (Section 8.6.6).

8.5.6.2 Amphibians (Amphibia)

In general, there appears to be little information available regarding how this group reacts to fires. The amphibians use both pools, lakes, wet areas and terrestrial environments which one would expect would be greatly affected by run-off after fires in the drainage basin.

It has been documented that insect-eating amphibians increased their predation on beetles after a fire in moor landscapes in Florida (McCoy 1987) and that larger numbers of amphibians have been captured on burned surfaces as compared to on control areas in a study in Pennsylvania, USA (Kirkland et al. 1996).

8.5.6.3 Reptiles (Reptilia)

As is the case for amphibians, there is little information available regarding the relationship of reptiles to fire (Chandler et al. 1983). In some areas it is reported that the population of certain species of lizards has temporarily increased on fire surfaces, probably as a result of increased access to food and improved possibilities to hunt. Reptiles increased their predation on beetles after a fire in Florida (McCoy 1987). The food resources appear to be more diverse, common and easily accessible in burned areas, particularly as a result of the development of a more productive vegetation (Chandler et al. 1983). There is a lack of studies regarding the relationship of this group to fires in Norway.

8.5.6.4 Birds (Aves)

The bird fauna in burned areas usually increases as regards species diversity and numbers (Fox 1983). In general, it must be said that there are few species among the birds that are fire specialists, but they do exist (Chandler et al. 1983). The American Kirtland warbler (*Dendroica kirtlandii*) is an extremely rare bird that apparently only nests in early succession stages of forests with the pine species *Pinus banksiana* (Miller 1963, Stoddard 1963, Handley 1969). Many species are fire profiteers that are attracted to recently burned areas without being totally dependent on fires (Stoddard 1963). Among these, certain gallinaceous birds occupy a special position. Here in Norway, interesting observations have also been made of ortolan bunting (*Emberiza hortulana*).

A number of studies have been conducted of changes in bird populations after fires, also in Europe and the USA (Bendell 1974, Chandler et al. 1983, Fox 1983). The direct mortality of adult birds as a result of fires is small, because they can fly out of the fire areas. During the hatching season, however, eggs and young birds in the nests will be particularly vulnerable, and fires in the nesting period can lead to marked effects on the population in local areas (Whelan 1995).

As for animals in general, the effects on bird species are generally that fires modify the habitat conditions (Marshall 1963, Emlen 1970), so that the bird fauna in areas that burn undergo changes both in the number of individuals and the composition of species. In Yellowstone National Park, an increase in bird species was registered in the first 25 years after a fire, with a gradual decline as the vegetation communities grew older (D.L. Taylor 1973, 1979). Some species have far worse conditions in that bushes and trees disappear, while others benefit from the formation of e.g. open areas and low ground vegetation.

Very different causes can provide a foundation for population increases in birds after forest fires (Fox 1983). An important factor for many species is higher production of available food items. For example, seedeaters react positively if the plants that colonize the burned area produce more seeds. The same applies to species whose nutrition is based on production of insects.

The most important effects of fires are linked to species that exploit the resources in dying and dead wood formed in fire areas. Some species are favored in that dead and dying trees produce large amounts of food

resources in the form of insects, or that many dead trunks of trees killed by fire provide suitable trees for nesting. Many examples have been described both in Europe and North America of woodpeckers in boreal areas invading burned areas because of the new food resources that are offered by insects that attack dying and dead trees (Blackford 1955, Koplin 1969, Aldentun et al. 1993). The species that appear to profit most from forest fires are the three-toed woodpecker (*Picoides tridactylus*) and the black-backed three-toed woodpecker (*P. arcticus*), the latter found only in North America (Blackford 1955, Taylor 1979). In Sweden, the gray-headed woodpecker (*Picus canus*) and white-backed woodpecker (*Dendrocopos leucotos*) have most likely had their largest numbers in "deciduous burns" (Norw. "løvbrenner") (Wikars 1992). However, the same species can also react to dead trunks that are created for example after attacks by insects. In other words, these species are dependent on the dead trunks and the deciduous forest and the food resources that accompany these, and not on the fires themselves.

Other species are not able to exploit the altered living conditions, and the populations decline. Fires can make some species disappear because the amount of litter or the consistency of the forest floor is modified by the fire to such an extent that it becomes unsuitable as a living area (Chandler et al. 1983).

Ortolan bunting (*Emberiza hortulana*)

After a major fire in Elverum in 1976 (Strømsøe 1984), the population of ortolan bunting flourished 3– 5 years later, and has now remained high for many years.

The ortolan bunting is originally a prairie species that requires sunny, open living conditions. Earlier, it was common as a nesting bird in the Norwegian cultural landscape, more specifically in grazing lands with some trees and shrubs and in pastures. Today, however, it is rare and its numbers are largely restricted to peat bogs and fire surfaces (Fremming 1984).

It is presumed that there are now fewer than 200 pairs of ortolan bunting in Norway. However, there is a significant population on the fire field in Elverum (Rønning 1983, Berg 1994). The population still comprises about 50 singing males, and today it constitutes a significant part of the country's ortolan bunting population (Dale 1997). Which of the conditions created by the fire that favors this population of ortolan bunting has not been clarified (Section 9.2.4.6).

Gallinaceous birds (Galliformes)

The gallinaceous birds are a large and varied group of birds that has been subject to both research and management where fires have been used, also in Norway (Section 9.2.4.6). There is thus a broad ecological discussion regarding the use of prescribed burning as a step in the management of certain species of gallinaceous birds, both in Europe, the USA and Canada (Chandler et al. 1983).

The classic example of fires being an important factor in maintaining living areas for birds is the American gallinaceous bird, the bobwhite quail (*Colinus virginianus*), which was studied as early as the 1930s (Stoddard 1931, Hurst 1971).

Burning of heath vegetation as a wildlife management measure in Norway has primarily had the objective of improving nesting and brood habitats for willow grouse (*Lagopus lagopus*) and black grouse (*Lyrurus tetrix*). The results of such measures have been discussed, particularly possible negative effects in the form of loss of nutrient substances through smoke and run-off (Evans & Allen 1971, Råen 1978). There are also a number of questions linked with the issue of whether the experiments that have gradually been carried out can justify an expansion of heath burning into a large-scale and widespread wildlife management measure (Pedersen 1989, Rognebakke & Smukkestad 1989).

The discussion led to new research, and a number of projects were carried out in Dovrefjell in the period from 1989 to 1994 in order to illuminate the effects of burning (and cutting) alpine heath vegetation on willow grouse populations, run-off of nutrients, vegetation and invertebrate fauna (Pedersen et al. 1991, 1992, 1993). The conclusion was that it did not seem to improve the quality of the areas as a habitat for willow grouse (Pedersen 1996, 1997). The results seem to indicate that the same fertilizing effect after burning is not achieved in Norwegian outlying fields as in Scotland (see Section 4.2.9), but the circumstances have not been clarified.

8.5.6.5 Mammals (Mammalia)

Studies have shown that the effects of fires on mammals vary according to habitat conditions, nutrient conditions, adaptation to cover, etc. (Chandler et al. 1983, Peek 1986). The same large variation in the relationship to fires that we saw in birds also applies to mammals. There are hardly any fire specialists among mammals, but there are many profiteers, i.e. species where popula-

tions react positively, with the ability to adapt to very different vegetation communities (Nelson 1974, Chandler et al. 1983).

Effects on adaptive traits

Even though fire will influence the development of populations of most species in some way or another due to its effects on the habitat structure, the areas may not have burned enough (i.e. fire frequency has been too low) for animals to have evolved traits, for example to exploit the increased amount of food created after fires.

However, a potential example of fire-adaptive traits in mammals is so-called “fire melanism” (Guthrie 1967). This is the same phenomenon previously described for insects (Section 8.4.5.4), where populations consist of a certain percentage of dark-colored individuals that survive better on dark substrata in ash areas, and can therefore multiply after fires.[8.13)]

Another example of fire adaptation may be found in some deer. This relates to the development of increased flexibility to produce more calves when the food conditions suddenly become good. The deer are an important group of ruminants that are classified according to adaptations to various types of food resources (Hofmann 1989). They are also the group of mammals that has been studied the most in relation to fire, both as regards life history adaptations and population dynamics. Of the four species found in Norway, roe deer (*Capreolus capreolus*) and moose (*Alces alces*) are so-called “concentrate-eaters”, i.e. species that are physiologically adapted to easily digested food such as herbs and newly green leaves. Red deer (*Cervus elaphus*) is characterized as an “intermediate grazer”, i.e. its food contains a relatively large amount of grass, but not as much as typical roughage-eaters such as sheep and cattle. Wild reindeer (*Rangifer tarandus*) is also often classified as intermediate grazers, but it is unique in its exploitation of lichens as winter food.

In boreal coniferous forests, fire surfaces may be few and far between, and it is impossible for deer to know where the areas are located in advance. An individual that finds such a fire surface at an early point in time will therefore experience little competition for significant food resources. A comparative study of life history traits in a total of 35 deer species concluded that, among the concentrate-eaters, younger females are especially capable of dispersal in the living areas. They regularly give birth to more than one offspring and occur alone (solitary) (Liberg & Wahlström 1995). This can be interpreted as being adaptations to favorable conditions created by habitat disturbances, where forest fires have probably been the most significant factor. Today there is broad agreement regarding this hypothesis (Cederlund & Liberg 1995), which has previously been presented on several occasions (see e.g. Geist 1974, McCullough 1979).

In order to emphasize this difference between the species, we will use deer as a point of departure. There are no special observations of deer in fire areas in Scandinavia. However, the deer is adapted to climax societies in areas that do not burn often, and the competition among the individuals is often great because the habitat conditions are more stabile (Liberg & Wahlström 1995). Therefore, the dispersal conditions are such that young deer will have trouble leaving the flock because there are so few favorable areas to go to. Thus, younger females do not spread to any great extent. This determines the social structure in the population that lives in family groups with the hind as the center. The intense competition has in reproduction terms favored the production of one, large competitive offspring (“the K strategy”), rather than several small (“r strategy”). Almost without exception, the deer give birth to only one offspring. Obviously, the ideal situation would have been to produce one offspring when competition was great, and many offspring when the conditions allowed doing this. However, it has been shown that deer species that have certain *flexibility* with regard to producing one or more calves, are not able to produce a single offspring that is as large as that of a species that has *specialized* in producing just one offspring. In other words, there is a physiological trade-off between flexibility and the production of a single large offspring (Liberg & Wahlström 1995). Therefore, of our four wild deer species, only moose and roe deer have this flexibility in Norway. It may therefore be worthwhile to focus on these species with regard to forest fires and life history traits. [8.14)]

Effects on populations

The effects of fires on the size of mammal populations will vary depending on which factors initially regulate or limit them. If, for example, the population is regulated by the amount of food, a fire can have a positive effect through opening parts of the living areas so that more pasturage is produced.

For example, according to the studies conducted in the 1970s, an increased number of individuals was registered in the mammal populations in the first 25 years after fires

in Yellowstone National Park, and that the number then decreased gradually along with the aging of the plant societies (D.L. Taylor 1973; see also Wood 1981).

If, on the other hand, predators control the population, it is not certain that fires will have any effect, since there is initially enough food. The decline in cover after fires may either increase or decrease the danger of predation depending on which species of predators are present (hunting strategy) and, not least, the size of the prey (how easily it can hide itself). Population effects of forest and field fires have been described for many species.

Rodents (Rodentia)

Populations of small rodents on fire surfaces have proven to vary closely with the degree of influence on plant cover and what type of species composition arises in the new plant cover (Fox 1983, Kirkland et al. 1995). Ecological factors that have created effects for small rodents after fires are changes in light conditions (Udvardy 1969), in cover and microclimate (Ahlgren 1966, Gashwiler 1970, Beck & Vogl 1972), in the amount of litter and consistency of the ground cover (Cook 1959, Tester & Marshall 1961, Gashwiler 1970, Sims & Buckner 1973) and changes and variations in the food conditions (Ahlgren 1966). See Fox (1983) for a summary.

Medium-sized rodents such as squirrels are typical fire losers and do not benefit from fires. Populations of the American red squirrel (*Tamiasciurus hudsonicus*) are knocked out by forest fires for a period of 10–25 years. This species can only live in forest stands that are so old that the trees can produce cones (Ward 1968). Forest fires can, on the other hand, be favorable for beavers (*Castor canadensis*) (Chandler et al. 1983) through lush increase in amounts of newly grown leaves on the fire surfaces, particularly on mineral soil adjoining watercourses.

In coniferous forests in North America where it is common for large areas to burn, there are also fire profiteers that undergo major and marked population fluctuations. The snowshoe hare (*Lepus americanus*) is known to invade early succession stages a short time after fires. Maximum populations have been reached on average about 10 years after a fire (Grange 1965), but this varies within wide limits. In some areas it has been documented that the hare population has declined after fires (Keith & Surrendi 1971). Research that has attempted to describe the relationship between sunspots, forest fires and ten-year population cycles in the snowshoe hare has been carried out in Canada (Sinclair et al. 1993).

Also the Norwegian hare (*Lepus timidus*) thrives in areas where there is new growth of vegetation after fires, for example in areas where there has previously been charcoal burning and swidden cultivation. To date, there have been no special studies of the hare's relationship to fire areas in Norway.

Cervids (Cervidae)

No special studies in fire areas have been conducted for any of the deer species in Scandinavia. Most studies that have attempted to describe the relationship of deer to fires have been done in North America (Peek 1986), and we will refer to some of these in the following discussion.

Moose (*Alces alces*)

There has previously been broad agreement in North American studies that, with few exceptions, forest fires increase the quantity of food, also winter food for moose (*Alces alces gigas*). Fires normally create dense stands of willow (*Salix* spp.), birch (*Betula* spp.) and aspen (*Populus* spp.). These are food plants that can lead to an increase in the population of moose (Miller 1963). Therefore, the moose has traditionally been characterized as a fire profiteer, and in connection with forest fires, it has been described as a typical "fire follower" (Bendell 1974).

According to Miller (1963) and Spencer & Hakala (1964), the increase in the moose population is limited to a ten-year period after fires, while the forest is still relatively open. Dense stands of forest do not produce enough food to maintain large populations of moose. Twenty years after fires, the majority of the food is produced too high for the moose to browse on it. From the moose management point of view, the huge fires on the Kenai Peninsula in Alaska were generally positive because they produced plants for winter grazing in sufficient quantities to maintain a dense population of moose. The relationship between moose and forest fires in North America have, however, been much discussed (Bendell 1974), and it is far from easy to interpret the relationships in general. This is because fires do not lead to a growth of food plants such as birch and willow in all places. In some areas, fires are immediately followed by a succession dominated by more or less pure spruce stands (Leopold & Darling 1953). Both the composition of species and the quality of the plant material in the succession that follows the individual fire participate in determining the reaction of the moose population (if it is regulated by food at all).

Other ecological factors connected with fires can also

influence the behavior of moose. It has been claimed that the moose avoids large, open fire areas in the winter due to the increased wind speed, and that moose can also withdraw from burned areas because of changes in the snow conditions. A deep cover of loose snow in continental fire areas can make the moose seek out ambient unburned forests where the snow cover is shallower, or has a crust which makes it easier to walk (Kelsall & Prescott 1971, Scotter 1971). This can explain why fire fields have not been used even though they apparently contain an abundance of food plants. Studies in Alaska as early as the 1950s also showed that *borders* between burned areas and intact forest stands could be important with regard to increasing the population of moose on the Kenai Peninsula in Alaska (Buchley 1958).

Studies have been conducted of radio-tagged moose before, during and after fires in and around a 500 km^2 fire field in Alaska. This has documented important aspects of this species' relationship to forest fires. In certain cases, traditional movement patterns in moose seem to prevent them from locating new fire fields if they do not lie in the areas the moose used before the fire (Gasaway & DuBois 1985, Gasaway et al. 1989).

The movement of moose to forest fire areas to exploit the nutrients there is also familiar here in Norway. Extensive browsing on large pine regenerations has been reported (see Strømsøe 1961).

Reindeer (*Rangifer tarandus*)

Wild reindeer (*Rangifer tarandus*) occurs in several subspecies in northern areas, and seem to be well adapted to stabile habitat conditions.

Tundra reindeer (*Rangifer tarandus groenlandicus*) reportedly react sensitively to effects of forest fires. The reindeer's main nourishment in the winter is composed of lichen, which is more fire-sensitive than other food exploited by the reindeer because lichen regenerates slowly. Fires can completely destroy lichen mats, and restoration of the lichen flora in some areas may take nearly a century (Morneau & Payette 1989). After fires in the winter areas, one of the clearest effects is a reduction in the amount of food plants. Plant production both in the ground layer and the tree layer are also affected (Scotter 1970, 1971), so that the carrying capacity is reduced. If the reindeer's food partly disappears from the winter areas, this can have a short-term and often dramatic influence on the degree of exploitation of the area.

A number of other effects in fire areas can also have a negative influence on reindeer. In many areas, they avoid open fire areas in the winter, possible because it is exposed to strong winds (Scotter 1971), but also because the snow has a tendency to be deep and, in certain local climate areas, develops crusts that make it difficult to dig up food (Pruitt 1959).

In the case of the American forest reindeer (*Rangifer tarandus caribou*), fires destroy slow-growing lichen on trees. This can cause a serious local shortage of winter food. The changes after major fires may have become so significant that populations of reindeer have been forced to change their traditional migration routes (Scotter 1971).

The conclusion from these earlier studies was that forest fires were fairly unilaterally negative for American wild reindeer based on the observations and short-term studies conducted in fire areas. The main reason was destruction of lichen mats (Leopold & Darling 1953, Scotter 1964, Geist 1974). However, recent studies have modified and changed this view. There is now relatively broad agreement that fires are strongly negative over the *short* term because of local destruction of grazing, but that lichen, which is a key resource for the adaptation to winter of reindeer in the taiga areas, profits from periodic fires that ensure optimum production over the *long* term (Miller 1980, Schaefer & Pruitt 1991, Thomas et al. 1996, Arsenault et al. 1997). However, it is not very likely that this can be transferred to apply also to wild reindeer's use of habitat below tree line in Norwegian outlying grazing areas. There, the mats of lichen have developed on a far poorer nutrient substratum because the landscape has been covered by ice several times and the soil has been leached over long periods of time. Because of problems in controlling fire severity, fires can lead to further deterioration of the actual production conditions. Fires as renewers of lichen grazing lands may, however, have had a certain relevance for the previously *wild forest reindeer* farther to the east, for example in areas in Finland more rich in nutrients.

Red deer (*Cervus elaphus*)

It has been reported in several places that also the American wapiti deer (*Cervus elaphus canadensis*) is attracted to fresh burn areas. Young branches and buds of bushes are among the most important food plants for deer, which can mean ample winter nourishment after fires in layers within reach for browsing (Chandler et al. 1983). The wapiti deer can reach plant material at a

browsing height of up to 2 meters. As the vegetation gradually develops, however, the bush vegetation becomes too high for the animals to reach and exploit. Therefore, when the vegetation that develops after the forest fire reaches a certain age, the deer population can decline (assuming that it is regulated by the availability of food). It has been established in local areas that, before fires, the deer could only reach 28 % of the plant parts that could be grazed. After a fire, however, it could reach 100 % of the plants, and 90 % two years after the fire (Leege 1968). In Idaho, USA, studies have shown that the population of deer was the highest and in the best condition 20 years after major wildfires.

Carnivores (Carnivora)
Predators often have far larger living areas than plant-eaters. For them it is primarily the indirect effects of the fire surface's production of food animals that is crucial, and whether there is sufficient cover that makes it possible to exploit the prey animals on the surfaces.

Studies of marten (*Martes americana*) in North America have shown that it is sensitive to forest fires in its living areas. After large fires, the population can be reduced for several decades as a consequence of a decline in the food base (Rowe & Scotter 1973, Viereck 1973, Koehler & Hornocker 1977). Mink (*Mustela vison*) is widespread in North America along ocean beaches, marshes and riverbanks. Forest fires are assumed to be beneficial for this species (Chandler et al. 1983). Studies of the effects that forest and outlying field fires have on such species have not been conducted in this country.

8.6 Effects on ecosystems and ecological processes

By influencing the soil, plants and animals, forest fires can lead to extensive changes in the environment and have significant effects both on ecosystems and ecological processes (McArthur & Cheney 1966, Chandler et al. 1983, Kimmins 1997). The effects include influences on the structure and function of the ecosystem, as well as the energy flow, bio-geochemistry (carbon, nitrogen, acidification) and abiotic conditions. Only some of these extensive effects are commented on below.

8.6.1 Ecological processes

Severe forest fires influence and may in reality have effects on *all* ecological processes. This has been known for a long time, and we will first present the classic list of the famous pioneer and fire ecologist Edwin V. Komarek, Sr. of the impact fields from the discussion in the 1970s (Tab. 8.10).

Among the ecological processes, the successions are most radical and have received the broadest treatment in international literature. As we have commented on in several places in this report, the course of the successions varies according to a number of parameters, such as the absence of competition, formation of special resources (burned substrata and dead wood) and a number of other factors linked *inter alia* to the intensity and severity of the fires (chs. 2, 8). The Nordic successions can be roughly divided into three periods (Hörnsten et al. 1995, Gundersen & Rolstad 1998b). In the first five years, a colonization takes place by the most specialized species. More than 40 species of fungi, mosses, lichens, vascular plants and insects are directly dependent on fire

Table 8.10. Entries for biological conditions and ecological processes that can be affected by forest fires (After Komarek 1971a, 1979).

1. *Change* – there are always change processes in various ecosystems. All living organisms change by metabolic processes and by natural selection and evolution.
2. *Continuity* – species cannot live successfully as individuals, but only through reproduction. Individuals are born, grow, mature, and die.
3. *Diversity* – number of species and density of individuals vary. Individual variation is extensive. No two individuals, plants or animals, are exactly alike and so no two species or communities can be exactly alike. *)
4. *Succession* – a more or less orderly pattern of events and processes in the ecosystem whereby plant and animal species replace each other as a result of a changing environment.
5. *Competition* – living organisms compete with each other for nutrients, light, water, space etc.
6. *Cooperation* – plants and animals live together in the same environment, each to its niche, and frequently contribute to each other's biological economy.
7. *Metabolism* – waste results from the metabolism of organisms. They have to be recirculated or removed because no organism can live in its own waste for a long time.
8. *Adaptation* – living organisms demand a habitat determined by specific environmental requirements.

* Note the specific definition of "diversity" that Komarek (1971a) presented at that time (see Section 9.1.6).

for establishment and reproduction (Essen et al. 1992, Wikars 1992, 1997, Bakke 1996, Bendiksen 1997).

The second period is characterized by regeneration of forest plants and decomposition of dead wood. This period favors pioneer species and species linked to this type of resources.

In the third phase, the pioneer trees have formed closed forest stands, often in the form of deciduous forests ("deciduous burns", Norw. "løvbrenner"). Species that require more moisture and tolerate more shade are favored. The deciduous forest thins itself over time, and large amounts of snags and fallen deciduous trees are formed, which are important for many species throughout long periods (Gundersen & Rolstad 1998b).

We know that "change processes" (read: fires) (Tab. 8.10) in areas where they have led to repeated losses of chemicals can also convert entire types of nature, for example, forest ecosystems to heather-dominated moors, so-called "fire barrens". This is particularly common in areas with coarse, nutrient-poor oligotrophic soil. The so-called coastal heaths in Europe, which we have previously discussed in detail (Section 4.2.6), are an example of this. Such systems are found in local manifestations and have been examined in many places around the world, such as Canada (Damman 1971, Strang 1972), USA (Forman 1979) and, as mentioned, on the British Isles (Gimingham 1972). Fires pave the way for the spread of heather species (*Erica, Calluna*, etc.) which gradually dominate the vegetation in such heaths, and which are presumed to further deplete the soil. They do this by promoting podsolization and preventing re-colonization of trees through influencing the trees' ability to form mykorrhiza partnerships, *inter alia* through the use of allelopathic chemicals (see Section 8.4.5.1).

Other examples which illustrate the fact that, in terms of forest history, fires have been the dominating force with regard to determining the species inventory in ecosystems, are large areas of oak in Europe and the eastern USA (Brown 1960) and the enormous areas in the world that are dominated by pine, Douglas fir or eucalyptus species (Spurr & Barnes 1980).

Examples of the global relevance of forest fires are their ability to release radioactive material, that has accumulated in the vegetation in certain polluted areas, to the atmosphere (Dusha-Gudym 1996).

The same applies to a number of emissions from forest fire areas than can be active and important in a climate context (Goldammer 1994). Models have demonstrated that the relationship between fires, fuel (biomass) and climate cycles literally include "volatile" ecological issues (Bond & van Wilgen 1996).

8.6.2 Energy flow

The energy flow out of the ecosystem can be greatly increased through a forest fire, which can also accelerate the decomposition. However, certain elements, such as trees and logs that are covered by a layer of carbon, decompose more slowly than similar unburned material. Primary production can be reduced over a long period as a result of reduction or elimination of plants. Also, as we have seen, fires can reduce moisture and nutrient status in the soil. The variation is, however, high. Primary production can also increase *inter alia* due to an altered composition of species, improved soil conditions and higher moisture content through the influence on hydrological cycles.

After a fire, the succession in the burned area is first characterized by plant species that are on the scene for a short time and accumulate little biomass. These species are gradually replaced by perennial plants and scrub, and much of the first accumulation of biomass can take place in the soil below the surface. It is only when trees colonize the area that a significant accumulation of biomass appears on the surface (Kimmins 1997).

The secondary productivity of plant-eaters generally increases after fires, except in areas where there is a serious deterioration of the soil.

8.6.3 Bio-geochemical conditions

The biogeochemistry of a forest can be significantly altered by fires (Swanson 1981). We have already discussed the export of nutrients in smoke and fly ash (Section 8.1). Reduced infiltration leads to increased surface run-off, which in turn can wash ash directly down into the water stream. Even where run-off from the surface only occurs over short distances, there may be a significant redistribution of nutrients in and close to the burned areas.

As previously mentioned, there may also be significant changes in the availability of nutrients for plants and in the vertical distribution of chemicals down into the soil (Section 8.1).

When comparing burned areas and unburned control areas

just after a fire, higher contents of cations have been registered in precipitation falling near the site of the fire (Lewis 1974). Smaller losses of calcium and magnesium have also been established as compared with potassium and sodium two weeks after a fire than one would expect in an area where leaching can be ruled out (Grier 1975). If we assume loss of substances to the atmosphere through ash convection, this is primarily assumed to be caused by the loss of potassium and sodium as gas to the atmosphere (Gluva 1984).

Reduced capacity to retain water, and exposure to direct effects from raindrops, makes burned areas particularly vulnerable to soil erosion. However, lighter fires can develop without any proven increase in erosion (Biswell & Schultz 1957).

The quantity of nutrients that are carried out of the system depends on how severe the fire has been, the amount of ash deposited on the surface, the slope, infiltration capacity, slope stability and obviously, the intensity, duration, timing and form of the precipitation after a fire (Woodmannsee & Wallach 1981, Gluva 1984). If all vegetation and humus is removed in severe fires and the landscape is very hilly, a large loss of ash through erosion is likely (Grier 1975, Wright 1976, Woodmannsee & Wallach 1981). Ash that disappears through convection can either be carried back to the same ecosystem, to nearby ecosystems or deposited in the sea (Boerner 1982).

In certain types of soil formed on sandstone, fires can act as weathering factors and cause direct “deterioration” through crumbling and the formation of hollows (Selkirk & Adamson 1981, Adamson et al. 1983). There are documented horrifying examples of erosion after fires in steep areas with soil that is easily eroded, particularly from the western USA (Chandler et al. 1983). Such erosion may also have been significant in Norway with its extensive areas of steep terrain. If the fires convert large amounts of litter and humus, and the following precipitation is substantial, the area may transform into a lower quality class (Section 4.2.5).

Changes occur on all levels. On a small scale for example, surface water can redistribute mineral nutrients and organic material in accordance with the topography in the burned areas. Micro terraces and small hollows can concentrate the charred organic material and capture seeds that are released after the fire (Whelan 1995) and create a completely new vegetation mosaic.

Several thorough quantitative studies have been carried out as regards the loss of nutrients through evaporation, ash and run-off. All such effects are highly variable because of the enormous variation that characterizes forest fires. Reference is made to Kimmins (1997) for a further overview.

The influence on the biogeochemical conditions may have a long-term character because both flora and fauna, and thereby the food chains and production, are changed in a radical way. As we have concluded in several places in this report, forest fires can create more variation in both the plant and animal communities than any other disturbance that affects the coniferous forest system. With regard to influencing the distribution and density of organisms, it is as mentioned that the fire’s intensity/severity and speed that are among the most important factors (Section 2.2.5). [8.15)]

As an example, let’s look at what changes in *vegetation* can mean for direct and indirect biogeochemical effects that include soil conditions, hydrology and geomorphology (Fig. 8.15). If one were to expand a similar flow chart to include the effects of changes in *animal life*, one would understand the enormous potential that forest fires have on ecological change processes. The effects also include abiotic processes on all levels all the way up the global scale. Therefore, fighting forest fires will also, in principle, have an effect on all of these processes (Komarek 1979).

8.6.4 Release and storage of carbon

A number of forest ecosystems are characterized by large accumulations of carbon and other organic materials in the period between fires and a significant release of this material during and after fires (Kimmins 1997). Forest fires are important in the carbon cycle; an overview may be found in Mach (1994). A severe forest fire can release large amounts of both carbon dioxide and energy (see above) that are returned to the atmosphere. Forest systems that have a history of high fire frequency therefore have a tendency to have little carbon stored on the surface of the forest floor in the form of rotting branches and windfall, and standing dead wood. Such types of forests are usually more open with relatively few trees per hectare. As a contrast, we have forests in wet climates that only experience fires at intervals of many hundreds of years. They can store large amounts of organic material in the form of living and dead trees, rotting trunks and, depending on the climate, thick mats of organic material on the forest floor. Depending on the severity of the fire, a highly variable

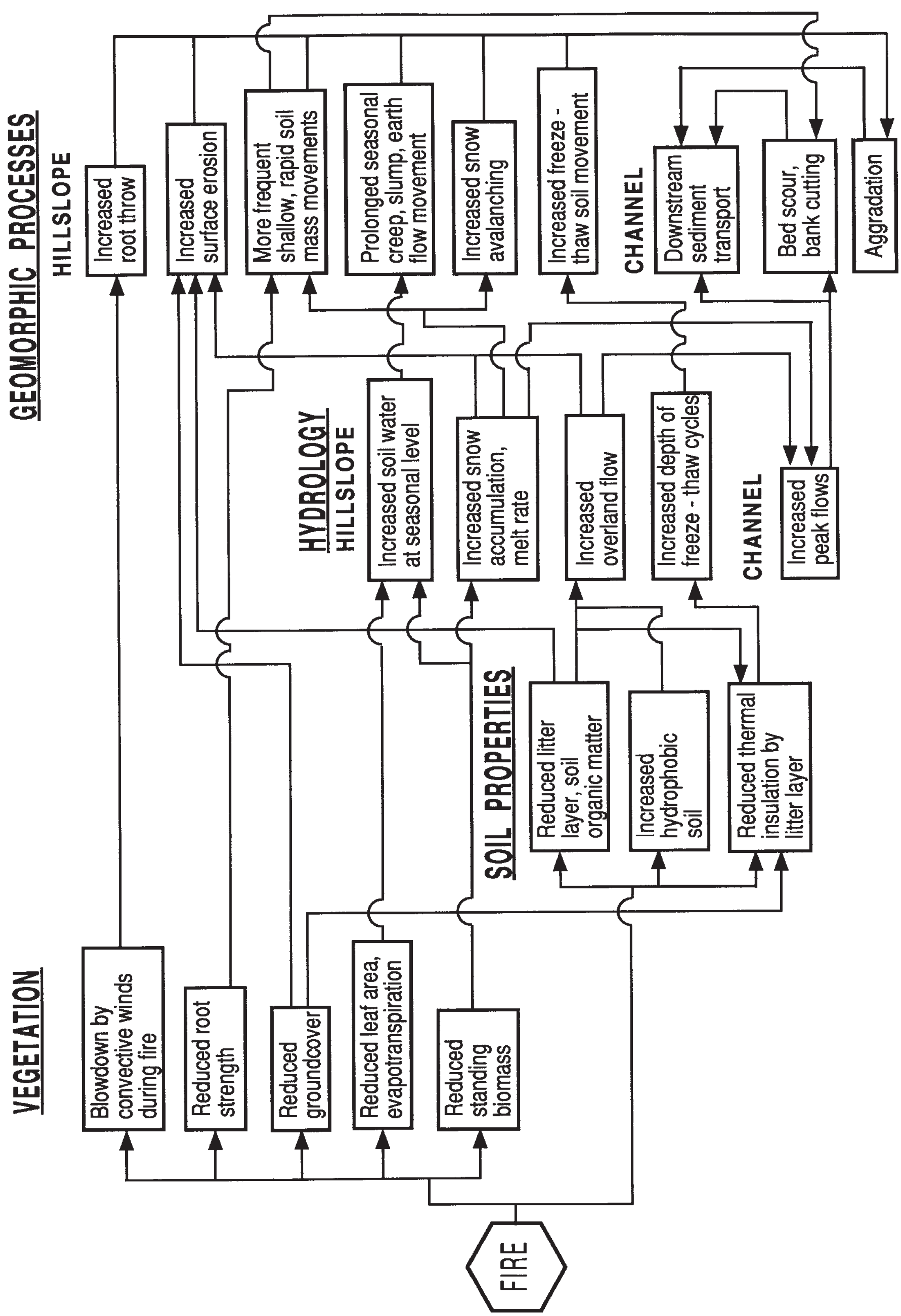


Figure 8.15. Direct effects of forest fires on vegetation and the indirect effects these may have on conditions in the soil, hydrology and geomorphology under suitable conditions (Swanson 1981, redrawn from Whelan 1995).

amount of this accumulated biomass on and above the surface is returned to the atmosphere in connection with fires. In certain types of forests, much of the organic matter that is not “consumed” in the fire will be broken down in the subsequent period.

It has been postulated that such a build-up of stored carbon took place in boreal coniferous forests in Canada during the “little Ice Age” (Section 3.1.6), and that much of this accumulation was released in massive forest fires that swept through this region in the beginning and middle of the 1800s. Thus, climate changes can cause great fluctuations in the regional storage of carbon through its effects on forest fire frequency. This has important implications for our understanding of the role forests can have in regulating concentrations of CO_2 in the atmosphere (Kurtz & Apps 1992).

8.6.5 Influence on the nitrogen cycle

The relationship between fires and the nitrogen cycle of the forest ecosystem is complicated and not yet completely understood. For an overview, please refer to Weiss & Goldammer (1994), Goldammer & Furyaev (1996) and Kimmins (1997).

In connection with burning of vegetation, litter and humus, nitrogen will be lost from the terrestrial ecosystem to the atmosphere. Studies have registered a higher percentage loss of nitrogen from material that contains little nitrogen as compared with sources that contain a lot of nitrogen, such as living and dead pine needles (DeBell & Ralston 1970). Dead pine needles lost 58 % of their total nitrogen, green pine needles lost 66 % and fuel with low nitrogen content lost 85 %.

In laboratory experiments, no loss of total nitrogen (t-nitrogen) was registered at temperatures lower than 200 ˚C. At temperatures higher than 400 ˚C, losses of 50–75 % were registered, while at temperatures higher than 500 ˚C only traces of t-nitrogen remained in the material (White et al. 1973).

Litter and humus have been burned in controlled experiments at different temperatures and durations where the nitrogen loss has varied between 25–64 % (Knight 1966, Gluva 1984). An attempt has also been made to register what types of nitrogen compounds disappear in smoke, and which of these may be restored in connection with precipitation (DeBell & Ralston 1970). The studies concluded that the t-nitrogen disappears to the atmosphere as N_2, and that little was returned in connection with precipitation. It is claimed that NO is the main oxidation product of nitrogen in connection with combustion of organic material (Cadle & Allen 1970). Nitrogen bound in incompletely burned material can also be lost to the atmosphere as suspended matter through convection (Lewis 1974, Woodmannsee & Wallach 1981).

In connection with burning, however, there are also factors that are changed in a positive way and benefit the nitrification carried out by bacteria. The pH increases, the quantity of available mineral substances is larger, the share of available organic substances increases, toxic substances are decomposed and a temperature increase occurs in the burned areas (Gluva 1984).

Weak fires can increase the amount of t-nitrogen and organic material in the upper layer of soil, presumably due to partially burned material, stimulated nitrogen fixation or increased plant production. As a rule, there is either no effect or a positive effect connected with an increase in the C/N ratio. On the other hand, severe fires may reduce the amount of t-nitrogen, but simultaneously provide the opportunity to produce accessible nitrogen (Raison 1979, Gluva 1984, Kimmins 1997).

It has very recently been demonstrated that nitrogen can be bound in charcoal remnants in forest fire areas, and that plants can exploit nitrogen directly from such material. Charcoal can thus catalyze important ecological soil processes in the earliest succession stages of boreal coniferous forests, effects that decrease gradually as the succession progresses. This can have important long-term consequences for the development and productivity of populations, particularly in forests where fires are effectively combated (Brown 1996, Zackrisson et al. 1996). Knowledge of the ecological effects of charcoal remnants is clearly incomplete. Studies of production, storage and loss of nitrogen in connection with fires is an important part of a comprehensive research now underway in boreal coniferous forests (Weiss & Goldammer 1994, Goldammer & Furyaev 1996).

8.6.6 Acidification of watercourses

The significance of forest fires on the pH conditions in run-off water and watercourses in Norway has been discussed in connection with the so-called SNSF project (effects of acid rain on forests and fish) (Drabløs & Tollan 1980). This led to a comprehensive discussion regarding the significance of geochemistry and soil conditions in landscape development as regards acidification of watercourses. The acidity of streams and lakes is

largely determined by the type of soil in the drainage area, and by the hydrological run-off pattern. Accordingly, the acidification of soil may partly be due to the fact that the so-called base saturation degree of the soil has declined, i.e. that a given weight of soil has become more acid, and partly that the amount of dead organic material, acid raw humus or boggy soil within an area has increased during a specific period of time (Rosenqvist 1981).

Based on soil chemistry arguments, Rosenqvist (1981) has claimed that forest fires affect the water quality in a favorable way, and has emphasized the potential significance that changes in the use of area and fighting of forest fires may have had on the acidification of Norwegian watercourses. The hypothesis is that, through fighting of forest fires over the past 150–200 years, the total burned area has declined considerably, and the reduced fire frequency may have contributed to increasing the degree of acidity in the soil and watercourses. The argument was supported by results from measurements taken from a forest fire area in Heståsen near the Lifjell area in Telemark. Sample tests showed significant differences in pH in run-off streams from burned and unburned areas. It was assumed that this was due to the fact that the original acid humus cover in Heståsen was oxidized in the fire areas, while it was left intact in the unburned areas (Rosenqvist 1981).

The discussion led to expanded soil ecology studies in the fire area in Heståsen (Gluva 1984), as well as studies of the run-off water from burned areas (Hegna 1986). However, it has not been possible to quantify the significance of forest fire fighting and potential changes in the forest fire frequency as regards acidification in Norway (Gunnar Abrahamsen, pers. comm.). This will require expanded studies. Forestry interests have also claimed that burning may have positive effects against acidification.

8.6.7 Forest fires and climate changes

Forest fires and their effects on the atmospheric conditions on a global scale are viewed primarily with a background in CO_2 and other gases that are released and can lead to changes in the earth's atmosphere (Weiss & Goldammer 1994, Bond & van Wilgen 1996).

This applies particularly in connection with the problem of large-scale climate changes, i.e. the greenhouse effect, which is due to human influence on global atmospheric chemistry, particularly the accumulation of CO_2 (Crutzen et al. 1979, Crutzen & Goldammer 1993, Weiss & Goldammer 1994). Aspects of this biomass combustion are presumed to constitute an immediate threat because of a significant reduction of the world's biological diversity. This is one of the reasons for the comprehensive international work that has been implemented to develop global models for monitoring forest and field fires (see Weiss & Goldammer 1994). The potential enormous and complex biological consequences of large-scale climate changes, depletion of stratospheric ozone and connection between the biosphere and the ozone layer are discussed as a part of comprehensive research programs, also with a view towards the forest fire problem (Crutzen & Goldammer 1993, Weiss & Goldammer 1994, Ennis & Marcus 1996, Santer et al. 1996, Kaufmann & Stern 1997), but no clarifications are available at this time.

An important fact is the potential feedback such warming might have on the Norwegian fire regime. [8.16)]

As of today, Norway's contribution to the amount of gas from forest fires, with the country's cool climate regime and effective fighting of forest fires must be regarded as modest (ch. 6). Greater interest, however, is linked to the changes a potentially warmer climate can lead to in Norway. Great variations are expected (Braaten & Stordal 1995), but the ecological and economical effects that may entail are still regarded as being highly uncertain.

The complexity of the effect of fires on the nutrient cycles in ecosystems is so great, and our knowledge is so lacking, that quantitative predictions regarding long-term effects of fires are not possible for most of the ecosystems that are affected by forest fires (Kimmins 1997). Most studies have focused on changes in the distribution of nutrients caused by fires. Few studies have quantified long-term effects on the functioning of the ecosystem (see MacLean et al. 1983). A main challenge for future fire ecology research will clearly be the development of models that make it possible to scale up from forest fire effects on individuals and populations to how the landscape more generally reacts to changes in fire regime and how the fire regime itself will be changed in the future.

8.7 Summary

Forest fires as an ecological factor and disturbance regime can cause everything from minor impacts on individuals to radical changes of entire ecosystems. The effects depend on the fires' intensity and severity, quantity and quality of fuel and factors such as air tempera-

ture, wind speed, topographical exposure and steepness of terrain (slope). The variation from fire to fire is great.

Short-term effects are that fires can very rapidly eliminate a greater or lesser part of the community of living organisms, create mineralized nutrients and dead organic material with a high energy content and promote an increase in the pH of the soil and higher daytime temperatures both in soil and wood structures.

Relatively speaking, as regards ecology, heating of the soil is less important than the effect of the flames on the organic material in the ecosystem. The direct heat does not travel far down into the mineral soil. Even during fires with high temperatures on fields with substantial logging waste, the temperature seldom exceeds 90 ˚C 2.5 cm down into the mineral soil. Light running fires only heat a very thin layer of the soil up to nearly 100 ˚C. The survival of individual organisms in fires will be determined by their life history and the anatomical, physiological and behavioral traits they have evolved.

Long-term effects are primarily connected with altered succession of species and nutrient factors that follow after fires, and which can manifest themselves throughout the entire cycle or for even longer periods of time.

Loss of organic material can be one of the most important effects fires have on the soil. Fires increase the speed of the mineralization process and can accomplish in a few minutes what would take microorganisms several years to achieve. In cooler fires, however, only the uppermost layers of the soil are usually affected due to the moisture conditions.

Fires can reduce transpiration, reduce the system's ability to capture sunlight and precipitation through reducing the biomass of foliage, reduce the infiltration capacity, affect the soil temperature over the shorter and longer term and cause a great number of physical and chemical changes.

When organic compounds oxidize, substances that form anions (e.g. nitrogen, phosphorus and chlorine) are generally lost in much greater quantities than cation-forming substances (e.g. calcium, sodium and magnesium). The ash that is left behind by fires is most often composed of more or less soluble oxides of earth alkaline elements that are immediately accessible for fungi and plants. For the same reason, the pH of the soil increases after fires; the degree and duration of this increase depends on the fire's severity, the amount of organic material that is converted and the soil's buffer capacity. Effects such as these are presumed to be the most important prerequisites for various types of swidden cultivation.

Species with life history traits that make them specially adapted to and often completely dependent on fire areas are often called pyrophilic species or fire specialists. Examples of such species may be found among fungi, mosses, lichen, higher plants and animals, and are most numerous in areas that burn often. The other extreme is species that avoid or make way for fires, the so-called fire refugees or fire losers. The individual numbers and population density of some species are significantly reduced in fires, and it takes a long time to restore their populations in burned areas. The majority of organisms fall somewhere between these extremes. Species that may benefit from or profit from fires, are called fire profiteers or fire winners. Use of these terms is often imprecise, *inter alia* because we often do not have adequate knowledge concerning the life histories of the species.

Due to the dispersal capacity of spores and other reproductive mechanisms, bacteria, fungi and other microflora are normally able to quickly re-invade and colonize burned areas. Some of the same applies to the microfauna (body size < 0.2 mm), for example protozoans, mites and nematodes. Here the colonization takes place both from deeper soil layers and from unburned patches. Many of the effects of a fire can be determined by the conditions after the fire. Leaching and erosion processes, factors that vary extensively with the individual location and fire, can cause significant physical and chemical changes.

Fungi are often divided into four groups according to their relationships to burned areas (Tab. 8.1). As early as the first weeks after fires, slime molds, mould fungi and Ascomycetes may become numerous on burned fields, and a great many species are linked with fire areas. The species have different strategies for spreading spores and reproductive bodies to burned areas, and certain factors indicate that some species have spore banks (resting spores) stored in the soil. Many specializations exist. A number of beetles have special "mycangia", pouches on the body, to carry fungal material. These may be important vectors with regard to spreading fire-related fungi. Here in Norway, the succession of fire-related fungi has been studied in an area north of Oslo, but there is generally a great lack of knowledge regarding the relationship between fungi and fires.

As regards higher plants, fires have effects *inter alia* on the competition for light, nutrients and water. Many plant species use chemical substances in competition with other species (allelopathy). Various terpenes, phenols, alcaloids and other organic chemicals that prevent germination and growth in other species can be affected and even removed by fires, thereby allowing access for other plant species.

The conditions on some burned areas can become cooler and wetter, the soil can develop and get a more fine-grained structure with a high organic content, or it may also become warmer and drier, with a more coarse-grained or water-repellant soil and a lower organic content.

Characteristics such as small particle size and high solubility make the ash minerals more accessible for the plants. At the same time, it makes them more vulnerable to leaching and erosion by surface water (precipitation). When the ash minerals ionize, the movement of the water in the area will largely determine the distribution.

Plants can develop adaptations both in the vegetative phase, during flowering, fruit setting or in the resting stages. Vegetative adaptations can be the development of protective tissue types such as thick and fire resistant bark, or particularly rapid growth to lift vital parts up from the ground level and out of the reach of fires, or the development of vital parts that contain a lot of moisture. Some plants have root nodules that ensure germination after fire, or underground stems (rhizomes) that can germinate immediately after fires. Some species have particularly rapid development from germination to flowering. Many species have specially developed seeds and spreading mechanisms, or establish perennial stored seed banks in the soil that can germinate directly, often as a response to “heat treatment” by the fire.

Fires can lead to radical effects on the animal society. Some species, particularly in the meso- and macrofauna in the soil and ground layer can be directly affected already during the fire. The effect on most of the species, however, is that they must adapt to new living areas due to an altered composition of species of fungi, plants, food and cover. The effects can vary widely depending on the character of the fire, the development of the plant community, and the ecological conditions created in the area. The changes often have long-term character.

As a selective force, fires have clearly been important in the development of life history traits, also for animals. The effects are of a different type and are more complex than those in plants, *inter alia* because of great ability of animals to disperse. Adaptive traits are best known among insects.

Fire-adapted insects form a surprisingly heterogeneous group both from a zoological, systematic and ecological point of view. Many of these species exploit specific resources on burned ground in the form of dead and dying wood, ash substratum and other conditions where fires have recently raged. For example, they may be attracted by the smell of fire over long distances, they can mate near glowing wood and have larvae that utilize the high temperatures in the soot covered wood that is heated by the increased radiation. Such species are also found in the Norwegian fauna.

The vertebrates are larger animals with far better dispersal abilities. Therefore, they are more rarely exposed to direct mortality and have developed few fire specialists. However, all species react to fires; some directly, but most species indirectly, to the habitat conditions created by fires and the subsequent succession.

Fish species may have their living areas significantly altered as a result of an increase in soil erosion, increased water flow and removal of vegetation along beaches, streams and riverbanks in the drainage basin. Fish can also be exposed to water-soluble chemicals used in fire fighting. The effects on amphibians and reptiles have not been studied to any great extent, but in some areas there are more individuals occurring in burned areas than in unburned control areas. Direct mortality of adult birds is rare, but they may be vulnerable during the nesting period with eggs and chicks. In Norway it is primarily certain species among the woodpeckers that profit from the dead wood created in the fire areas. Ortolan bunting is a species that receives special attention in Norway because of its rapid and prolonged positive population reaction on a fire field near Elverum in southern Norway.

No Norwegian mammal is associated only with habitats in fire areas. Fire successions with growth of herbs and leaves will favor pioneer herbivore species such as field mice and certain cervids, which in turn may be reflected in population increases in their predators such as weasels, foxes (and wolves). Fire melanism, i.e. the appearance of dark-pigmented individuals (genotypes) that can reproduce in ash areas is described in certain mammal species.

With their radical effects on soil, plants and animals, forest fires can have significant effects on both the flow of energy and a great number of biogeochemical factors in various ecosystems. Examples are influences on nitrogen, sulfur and carbon cycles. Few studies have been made of such effects in Norway, but a potential acidification of watercourses as a result of fighting forest fires has been discussed. There is a growing focus on forest fires and their potential effects on atmospheric conditions and climate changes. This discussion is of interest for the evaluation of potential future changes also in the Norwegian fire regime.

9 MANAGEMENT OF FOREST AND RANGE FIRES

By Ivar Mysterud, Iver Mysterud and Erik Bleken

The guiding principle in international management of forest and range fires in this century has been and still is suppression; this is also the case in Norway. However, suppression has become so efficient the last 100–150 years that unintended consequences of this influence on natural ecosystems has come ever clearer into focus. The importance of forest fires as ecosystem disturbance regimes are therefore given more emphasize both in national and international management as knowledge about the consequences from suppression has increased. In a short time the management of fires in forests and range areas has actually developed into a large discipline with considerable demands on specific expertise. It has emerged in the tense field between ecological knowledge of fires as disturbance regimes, the multi-faceted economic situations which are linked to the use of natural resources and the foundation developed today by international conventions and national rules and regulations. Today management also encompasses recommendations about direct impacts on plant and animal life, especially in connection with conserving diversity and specific attempts to recreate certain qualities of the landscape lost as a consequence of fire suppression, both in multiple use areas and national parks. The following account is an overview of the basis and the most important use and problem areas for fires in international management, with comments concerning Nordic conditions. For a more comprehensive presentation of international forest fire management with detailed descriptions of the organizational and practical aspects, we refer to broader accounts (Slaughter et al. 1971, Brown & Davis 1973, Wright & Bailey 1982, Alexander & Dubé 1983, Chandler et al. 1983, Fuller 1991, Weiss & Goldammer 1994, Goldammer & Furyaev 1996, Goldammer et al. 1997). With particular reference to Norwegian conditions, we refer to chapters 10, 11 and 12.

9.1 The basis of management

During the 1960s and 70s ecological principles for forest fire management of particular nature areas were developed, a work which later was intensified (Haapanen 1965, 1973, Heinselman 1965, 1970a, 1978, Stone 1965, Hendrickson 1971, Van Wagner 1973, Wright & Heinselman 1973, Addison & Bates 1974, Wright 1974, McClelland 1977, Van Wagner & Methven 1980, Alexander & Dubé 1983, Weiss & Goldammer 1994, Brown et al. 1995, Goldammer & Furyaev 1996, Page et al. 1997).

Where forest fires are a natural disturbance regime with considerable capacity to make an impact, an increasing understanding has developed that it is not possible or wishful to maintain some natural areas totally prevented from natural and/or consciously ignited fires. In many regions on other continents management comprises the use of prescribed, controlled fires for several reasons: to reduce the intensity of future fires, to maximize the runoff in water catchment areas for drinking water, to restore and maintain diversity in areas where forest fire-suppression has been particularly effective (Tab. 9.1). We will comment on these fields of use later. The simplest point of departure to conserve biodiversity linked with forest fires may be to manage areas already burned. In areas where effective suppression is conducted, however, this may be insufficient.

The conflict between the consideration for ecological processes and ecosystem diversity and social and political conditions related to important economic resources has prevented a liberal application of principles and tools from fire-ecological theory, even in management of wilderness areas. Management with fire presuppression has been most pronounced in countries where fires traditionally have been and still are a major problem. But also in areas where fires have moderate or less importance it is now a focus for nature management. It has been emphasized that if we seriously mean to maintain the “natural” distinctive character of wilderness areas, national parks, and other nature reserves, the “elementary forces” that have been at work earlier in the ecosystem must be able to continue working also in the future (Alexander & Dubé 1983). However, as is discussed earlier in this technical report (ch. 4), it can be difficult to impossible to decide what in this connection is “natural” due to the considerable historic influence of humans.

Table 9.1. Areas in international management where the use of prescribed fires has made it necessary to have ecological knowledge about effects from certain applied fire regimes (Modified and expanded from Chandler et al. 1983, Edwards 1984, van Wilgen et al. 1992, Brown et al. 1995, Whelan 1995).

Management area	Aim and use area
Forestry	• Hazard-reduction burning • Protection of timber resources • Systematic and rotational burning of smaller areas to reduce the amount of fuel and to decrease the risk for/prevent extensive wild fires on larger areas • Fight down “unwanted” species • Removal of species competing with desired (economic) timber species • Control of soil-dwelling pathogens and weed species • Management fires • Stimulation of regeneration of desired tree species with fires of varying intensity and amount of organic matter converted • Clear-cut burning • Patch burning • Shift of vegetation cover
Constructing “fire barriers”	• Preventive burning • Division of forest communities (types) into smaller units through the development of fire barriers etc.
Production of flowers	• Production fires • Maximization of production of inflorescences on woody perennials (especially Proteaceae in Africa)
Water resources	• Removal of vegetation cover • Maximization of runoff from water catchment areas without creating erosion
Primary production	• Production burning • Stimulating production of husbandry animal grazing plants • Pasture burning
Game production	• Production burning • Stimulating production of game species • Game management burning
Parasite control/grazing animals	• Control and removal of pathogens and parasites affecting livestock
Protecting installations	• Hazard-reduction burning • Reduction of the fuel load around buildings and installations, particularly in cities and densely populated areas
Conservation biology	• Nature conservation burning • Cultural landscape conservation burning Conservation of coastal heathlands
Management of ecosystems Nature management Management of cultural landscapes	• Nature management burning • Management of “wilderness areas”, national parks, landscape protection areas, reserves, cultural landscapes, other restricted areas • Protection of installations/neighboring estates/neighbors on and around restricted areas
Diversity	• “Diversity burning” • Maintenance of particular habitats for species/communities which have the need for resources or succession stages which are made by specific fire regimes • Maintenance of ecosystems made by anthropogenic activity • Cultural landscape
Pathogen control/nature areas	• Control of soil-dwelling pathogens (e.g. Phytophthora) and species which are considered as “weeds”
Esthetic conditions	• Creation of wildflower fire meadows for esthetic reasons

Among the Nordic countries the understanding and use of fire in management generally has progressed farthest in Sweden (see Hörnsten et al. 1995, Page et al. 1997) and Finland (Piri 1994, Hallmann et al. 1996). However, fire has been used in forest management for a long time in Norway, for example as a part of regeneration on clear-cut areas (Norwegian Forest Research Institute 1977). Also, Norwegian management authorities now indicate that the ecological importance of fires should be given more emphasis (Directorate for Nature Management 1992, Solbraa 1997a), also inside national parks (Directorate for Nature Management 1996a,b).

Many believe that boreal coniferous forests in Norway are partly fire dependent ecosystems that will lose diversity of flora and fauna in the absence of fires. This is one of many reasons that it is important in Norway to understand the fire regimes for future management of the country's natural areas.

9.1.1 Goal

In areas where it is desired to use fires in management, the aim must be clearly formulated and caution exercised in the trade offs. Fire is a sensitive "tool" which demands particular expertise used in a correct manner. The supposed character of fires in a particular ecosystem and experiences from use in specific/local areas will determine which types of ecological knowledge are necessary and which considerations should be taken. Knowledge of laws, rules and regulations is important. Use of fire in management varies a lot from country to country; in many countries it still consists of suppression only.

9.1.2 Ignition strategies

There are two main strategies for ignition: randomly and planned ignition. Planned ignition of fires, so-called "prescribed fires" or "prescribed burning" and management of wild fires which already are ignited by natural or anthropogenic sources of ignition, so-called "wildfire management", have both been used internationally in many different ecosystems. In international fire management one has to an ever-larger extent discussed the strategy of seizing ("take over") randomly ignited wild fires to manage these according to certain aims which are determined beforehand. Management programs in national parks favor one type of liberal programs with strategies developed for fires that are randomly ignited. It is often easier politically to manage wild fires than to get acceptance to ignite prescribed fires. For various reasons where one cannot tolerate this or there are specific environmental situations, one has to apply traditional "prescribed" fires with planned ignition or even total fire-suppression (Alexander & Dubé 1983).

Security reasons may make it necessary to use planned ignition close to borders, near building structures and installations, in very small reserves and in areas that are heavily used by visitors. By only using prescribed fires with planned ignition, the system might gradually become more "unnatural". However, it will not necessarily be any strict control with the local physical qualities of fires nor will the effects on or the responses of plants and animals be stereotypical. In the management of ecosystems (Section 9.3.5) there is a sharp distinction between undesired fires, which still have to be fought and with all means, and wishful fires which are part of long term management (Barrows 1977). It is often a delicate balance between a wild fire and a randomly ignited fire which management can seize and manage as a prescribed fire.

Mapping of the fire history of an area encompasses more than determining or estimating the average return period or mapping the fire free intervals. Normal fire intensity, the season for fires and the relation between fires and weather cycles should be known before prescribing a "correct" fire regime (Section 2.2.5). This has led to the reluctance of many countries to burn in national parks; this also is the case in Nordic countries. Recently, however, the importance of having the fire history of an area as basis for management was presented, including the anthropogenic part of it (Page et al. 1997).

9.1.3 Control of intensity and matter converted

When managers decide to use fire in an area to accomplish a particular goal, there are two important conditions that need to be thoroughly evaluated. Will the *fire regime* (see Section 2.2.5) suggested actually hit management target? This may depend on the possibility of unforeseen ecological effects of the fire(s), especially concerning the vegetation and development of the intensity of the fire and the amount of organic matter converted. For example in pasture burning frequent fires combined with grazing too intensively may lead to considerable reduction of preferred pasture plants so grazing is impossible to maintain. Consequently, the opposite of the desired result is achieved. Also, how will the directed fire regime affect conditions other than the ones targeted? There is seldom only *one single value* connected with a particular area that is focal to the manage-

ment. Fire is a “multifactor disturbance” in any ecosystem (Section 2.2). Burning to improve habitat conditions of one species may lead to invasion and population increase of totally new species, some of which may not be desired. Moreover, a goal is seldom “one-dimensional” in management; often it contains both primary and secondary elements that may be difficult to evaluate. In other words, management often has several intended outcomes at the same time.

For example, protection of vegetation cover in a catchment area may be a primary goal in a specific management program, while at the same time, the conservation of particular species may be equally important (Whelan & Muston 1991). The most topical types of prescribed fire in the Nordic countries seem to be diversity fires to maintain or create habitats for fire specialists and selected fire profiteers (ch. 8). In this instance it is possible to burn for several (many) species at the same time. In Norway, such management is related to several international conventions.

9.1.4 Conventions and international rules

The World Commission on Environment and Development (The Brundtland Commission) developed the concept of *sustainable development* as a frame for both the world community and individual countries to work within. In St.meld. No. 46 (1988–89) *Environment and development* the Norwegian Government adopted the main views and conclusions of the commission. Regard for sustainable development should be incorporated in all administrative planning, sector politics, and business activity. It is emphasized that all sectors and businesses are directly responsible for the environmental consequences of their activity. Resource management of the Norwegian forests is therefore going to be conducted within the framework of sustainable development (Bö & Haugen 1993).

The principle of multiple use is another basic principle that often has been emphasized in conservation biology when it concerns management of land areas, particularly forested ecosystems (Meffe & Carrol 1994). Today a large number of conventions and programs have been developed to conserve the diversity of the earth on both global and regional levels and which is now used as basis in this work (Tab. 9.2).

This is such a comprehensive discipline that we refer to broader accounts (Council of Europe 1996). These management instruments constitute the basis and framework for practical development of management plans to secure national diversity of flora and fauna. The Council of Europe already has presented an overview of the development of action plans for species (Machado 1997), even though the work with “fire species” seems to be limited. The current national and international strategies for conservation of biological diversity have emphasized the necessity of conserving diversity in landscapes outside national parks and landscape protection areas (*ex situ* conservation). It will become increasingly important to ensure that activities such as management of areas already burned, prescribed burning and wildfire management, satisfy scientific standards in conservation biology and simultaneously are accepted by other user interests.

9.1.5 Norwegian forest management

Increasing areas of the Nordic coniferous forests are becoming extensively managed multiple use areas. Most of the public and privately owned forests in Norway are managed for multiple products such as wood, production of grazing plants and recreational activities.

The Planning and Building Act of Norway (Norw. “plan- og bygningsloven”) places priority on forest conservation, forest production, and range management. Forested areas are labeled under the category “Agricultural, natural and recreational areas” (Norw. “Landbruks-, natur- og friluftsområder”, called “LNF-areas”) (Bö & Haugen 1993).

Within the LNF-areas use is regulated by various specific legislations. For forested areas the Law of Forestry (Norw. “skogbruksloven”) takes priority (Bö & Haugen 1993). The Law of Forestry gives forest protection, but the law also presupposes that there will be forest managed for profit. Therefore, it is not a true law of protection. However, the Law of Forestry is not a hindrance for landowners who may decide that some areas should remain untouched, so-called *administrative protection*.

In addition to the constraints of the law, several other incentives are used to accomplish forest management that further preserves and develops environmental values. An example is the economic support given to stimulate forestry planning for multiple use considerations, and actions to promote nature and environmental values (Bö & Haugen 1993).

There is still no agreement on how fires can and should be given priorities as a part of land management in

Table 9.2. Some important international and regional conventions and programs developed to conserve the earth's diversity (After Council of Europe 1996).

Name	Secretariat/focal point	Aims
CONVENTIONS AND LEGAL INSTRUMENTS		
GLOBAL		
Convention on Biological Diversity	UNEP	The conservation of biological diversity and sustainable use of natural resources
Washington Convention	CITES Secretariat	To regulate the trade in endangered species of wild fauna and flora
World Heritage Convention	UNESCO	To protect cultural and natural heritage of outstanding universal value
Ramsar Convention	Ramsar Convention Bureau	To ensure the conservation of wetlands, especially those of international importance
Bonn Conventionn	Bonn Convention Secretariat	To provide a framework for the conservation of migratory species and their habitats
PAN-EUROPEAN		
Bern Convention	Council of Europe	To maintain populations of wild flora and fauna with particular emphasis on endangered and vulnerable species
REGIONAL		
Wild Birds Directive	European Commission DG XI	To protect wild birds and their habitats, such as through the designation of Special Protection Areas (SPAs)
Habitat Directive	European Commission DG XI	To conserve fauna, flora and natural and semi-natural habitats of importance in the EU
INITIATIVES AND PROGRAMS		
GLOBAL		
World Conservation Strategy	IUCN/UNEP/WWF	To provide a strategic conservation framework and practical guidance to all nations to 1) maintain essential ecological processes and life support systems; 2) preserve genetic diversity; and 3) ensure the sustainable utilization of species and ecosystems
Agenda 21	UNCED	Outline priorities and guidelines towards sustainable development to be implemented at the national level
Man and Biosphere Programme (MAB)	UNESCO	To develop within the natural and social sciences a basis for the rational use and conservation of the resources of the biosphere
PAN-EUROPEAN		
European Conservation Strategy	Council of Europe	To provide governments with the basis for developing policies to safeguard and manage natural resources

Norway. Any fire management has to identify and consider possible conflicting decisions and needs. Persons with international experience regard this as a relatively easy task if an area already is managed through formal management plans (Egging & Barney 1979), something that is not always the case in Norway. Internationally one has often accomplished the best results with various zonation models for areas in much the same way as in game management (Mealey & Horn 1981).

Ideas of multiple use emerge with ever increasing clarity in Nordic fire management. For example, in Swedish forest management clear-cuts are burned both as part of soil preparation, forest regeneration and production of specific substrates (resources) for species which profit from fire (diversity) (Section 9.3). Regional plans in Norway have not been developed, but the main framework of a management strategy is available.

The government has defined precisely that the aims for management of forest resources are: "to secure long-term ecological balance so that today's use of the resource in business conserves the possibilities of future resource use and so that nature's diversity is not reduced" (St.meld. No. 46 (1988–89). This is also followed up in St.prp. No. 8 (1992–93) concerning "Agriculture in development" (Norw. "Landbruk i utvikling").

9.1.6 Types (categories) of diversity

Norway has signed and ratified "The Convention of Conservation of Biological Diversity" from the UNCED World Biodiversity Summit conference in Rio de Janeiro, Brazil, June 1992 (St.prp. No. 56, 1992–93). The convention obligates the countries to develop national strategies to conserve biological diversity (Tab. 9.2).

In the work with this Convention on biological diversity [9.1] a three-leveled definition of the concept of biological diversity was used (Tab. 9.3). These were diversity of ecosystems, diversity of species, and diversity of genetic variation within species, i.e. genotypes (Tømmerås 1994).

The aim to conserve genetic diversity within species also implies to conserve melanistic types, i.e. prospective "fire morphs" (see ch. 8 and later).

All sectors affected by biological diversity in Norway have to develop sector strategies. These strategies are going to be summarized in a national strategy for conservation of biological diversity (Tømmerås 1994, The Research Council of Norway 1997). This work will obviously encompass concern for fire specialists and fire profiteers from various groups of organisms.

Table 9.3. Biological diversity[1)]
(After Bö & Haugen 1993, Tömmerås 1994).

To preserve the biological diversity means that living animal and plant communities are preserved or managed so that their associated species are given environmental conditions to exist in the future.

Biological diversity thus is a complex concept that encompasses:
- diversity of ecosystems
- diversity of species
- genetic diversity within species and populations

1) Notice that the concept "diversity" is defined in several different ways in ecological and management related literature.

9.2 Problems and areas of practical use

The most common use of prescribed fires in international management of land areas has probably been to prevent the possibility of highly intensive and large wild fires. Fire presuppression includes all activity before a fire occurs that are directed at ensuring safe and effective fire suppression, i.e. anything reducing the risk and prevent the occurrence of such fires (Goldammer 1978, Chandler et al. 1983). One often applies frequent fires in "cold seasons" as part of such a risk management. This can, however, lead to unintended side effects, which has to be weighed against the primary management aims in a cost-benefit analysis. Such analyses should without any exception be conducted for all kinds of prescribed fires. Extensive experience from areas where burns are frequent has taught us that if fires are used to preserve diversity, populations or communities, one should be careful with prescribing frequent fires in the cold season (Whelan 1995). It is unlikely that there ever will be enough ecological information before a management intervention is conducted so that one can be totally sure of the effects of a prescribed fire regime. The management will have to be experimental. It should also be differential: It seems to be an unwise strategy to apply the same stereotypic fire regime across a whole landscape. It is unlikely that all different aims for a landscape under

multiple use management can be attained with one and the same fire regime.

In areas with few fires and cool fire regimes one should be particularly aware that many areas seldom or may never burn; this may be important for the nature management in Norway (Ohlson 1997).

Several researchers have warned and argued that we may expect difficulties concerning imposing nature appropriate fire regimes. For one reason the time window available between the months of high fire danger and the months in which it may be totally unacceptable to burn may be small (Van Wilgen et al. 1990). Hence, there may be only a few weeks per year available for large areas to be burned as part of any specific management program. Also, in many areas it may be difficult to decide what possibly may be the result of natural and anthropogenic fires in the management of nature, respectively (see later).

In forest fire terminology “hazard” is often defined as the part of the forest fire that can be due to the fuel that is available for burning. From this it follows that the concept “hazard-reduction” often is used synonymously with treatment and modification of the fuel load in the system.

9.2.1 Management of fuel

Native populations/aborigines in all parts of the world have practiced burning of slashing or other natural occurring “hazardous” fuels under easy burning conditions to prevent large fires during dry and windy weather periods. This is the case in every part of the world that has a recurrent fire season. Burning for hazard-reduction is so universal that it was probably the first use of prescribed burning. Subsequent use for various purposes has probably evolved from observations of the consequences of hazard-reduction burns (Chandler et al. 1983).

There are several ways to treat fuel to accomplish hazard-reduction. A coherent biomass of fuel may become isolated in fragments through establishment of “barriers”, i.e. various types of firebreaks or fuel breaks. The volume of fuel in these “breaks” may either be reduced by burning or removing. The compactness of the fuel may be increased by lopping off or splitting so that it does not burn as easily. The vertical distribution may be broken by thinning or other selective biomass removal. The humidity content may be increased by artificial irrigation and removal of dead matter. The chemistry of the fuel may be changed by species manipulation, for example by planting of less burnable species (due to high mineral content); this has been done along railroads in fire prone areas of Norway to prevent ignition by locomotives (Strømsøe 1961).

The simplest circumstance for applying hazard-reducing fires is when the residual living material is undesirable or immaterial to future land management objectives. Then the objectives of a hazard-reducing fire are identical to those of a prescribed fire for land clearing. This means disposal of the maximum amount of material possible without lasting damage to the soil and consistent with safety. The burning of slash from clear-cutting is an example of such an activity in North America where slash is often burned without regard for the residual stand. In countries with dry and fire hazardous areas, roadside clearing of grass and shrub lands is done to reduce the risk of fires being started by vehicle accidents or careless throwing of smoking materials (cigarette ends etc.) by motorists (Chandler et al. 1983).

Preventive burning to protect forest resources has been the most important objective in carrying out risk minimizing burns both in North America and Australia (Whelan & Muston 1991). The conditions that have led to this kind of management strategy, have been the same on both of these continents – an ethical heritage from North European agricultural cultures, that extensive fires with high intensity are not good. It is the same ethics and aims that is beneath every intense fire-suppression program: first and foremost to conserve economically important timber resources. In North America this has been articulated in the so-called “Smokey the Bear” philosophy (Fig. 9.1), where some institutions have invested large resources to undertake attitude campaigns to influence the public to be careful with fire in forested areas. Successful fire-suppression leads, however, to large regional accumulations of fuel where ignitions are hard to avoid. When fires first get started in such environments, they can quickly develop into uncontrolled, large wildfires. Researchers are painfully aware of the importance of managing the fuel load in the ecosystems. This led to the development of strategies to reduce the risk for large-scale fires with high intensity, by burning larger or smaller sections of the landscape in a planned rotational pattern with the intention of fuel reduction (Good 1981).

9.2.2 Fire-suppression and accumulation of fuel

Even though fire-suppression has not resulted in equally dramatic effects concerning accumulation of fuel and forest fires in the high-precipitation Norway, it is important that Norwegian managers know the history to understand why and how the view of forest fires has changed.

Effective fire-suppression as practiced in many areas in USA and Australia in the first part of the 20th century led to accumulated amounts of fuel over ever-larger parts of the landscape. This gave increased risk for highly intensive large fires as one of the consequences. However, there was strong resistance (especially in the USA) against changing the management policies. This was true even after empirical documentation was given that showed productivity in pine forests in southern USA actually increased as periodic burnings under controlled conditions were undertaken (Schiff 1962). Therefore, episodes with large scaled wildfires were needed to change this opinion, first in USA during the 1940s and thereafter in Australia during the 1950s (Schiff 1962, Shea et al. 1981). These experiences resulted in influential stakeholders in the forestry profession to adopt step-by-step changes and new strategies for extensive use of hazard-reduction burning to reduce fuel load and thus prevent future “catastrophe fires”. What turned the opinion in forestry were the highly intensive crown fires; this caused the lumber industry to suffer sizeable economic losses by destroying timber-producing forests. Frequent hazard-reducing fires led to less damage of established timber stands. Therefore, hazard-reducing burning was aimed at protecting economically important timber resources through short-term preventive burns.

The development of this new strategy was based on the knowledge researchers had presented about fire behavior in certain forest types. This research was started in North America by Byram (1959), Rothermehl (1972) and van Wagner (1990) and in Australia by McArthur (1962). The amount of fuel is the most important parameter that determines the intensity of fires and (together with the weather conditions) the speed of its spread. The frequency of hazard-reducing fires therefore has to be large enough to keep the amount of fuel below the level where it is supposed to accommodate uncontrolled fires. This may mean that a given section of vegetation in some forest areas should burn as often as every fifth year if productivity is high. If productivity is low and accompanying speed of accumulation of fuel slow, lower frequencies might be appropriate (Whelan 1995). Nordic countries with their low-intensive, cool fire regime hardly need this kind of management.

9.2.3 Classical problem areas

In this section we are going to comment on some of the classical problem areas in fire management. In some countries there was so good marketing of the concept of hazard-reducing fires and easy application of accompanying practical techniques, that burns were undertaken without enough careful evaluation that this use of fire could compromise other management aims (Good 1981, Whelan & Muston 1991). Even in forest communities (types) that are used especially for timber production there were multiple use interests that were affected by the burning procedures of forestry. The basic thesis from evaluation of management strategies is that fire regimes cannot be transferred from one area to another *without thorough testing and evaluation for every new area.* Internationally, several problems have been experienced from the application of hazard-reducing burning programs. This is especially the case in Australia where burns are frequent, and management fires are most commonly ignited in the cool season of the year when they are easiest to control (Whelan 1995). What we can learn from this, is that fires may have unintended effects; these now have been reported often in the literature.

9.2.3.1 Local extinction of obligate seeders

Some plant populations respond to fires by germinating only from stored seed banks, so-called obligate seeders. Such species may be killed or affected too strongly by fires (Section 8.4.4). If a second fire hits before the new generation of seedlings get the opportunity to develop, drop seeds and add their contribution to the seed bank after a first fire, the population may decline radically. Local extinction of such species is documented both in Australia and California, USA (Zedler et al. 1983, Nieuwenhuis 1987, Whelan 1995).

Before predicting effects of increased fire frequency in an area, one should therefore have detailed knowledge of the life history of the existing obligate seeders. This is especially true if it is probable that the intensity of the fire is high enough to kill established seedlings before or at the same time as their first reproduction. This may be difficult to judge because such characteristics may vary between plant populations at various sites. However, there often is a certain “elasticity” in a population of obligate seeders in their relation to frequent fires. There often is a spatial distribution of fuel from topographic

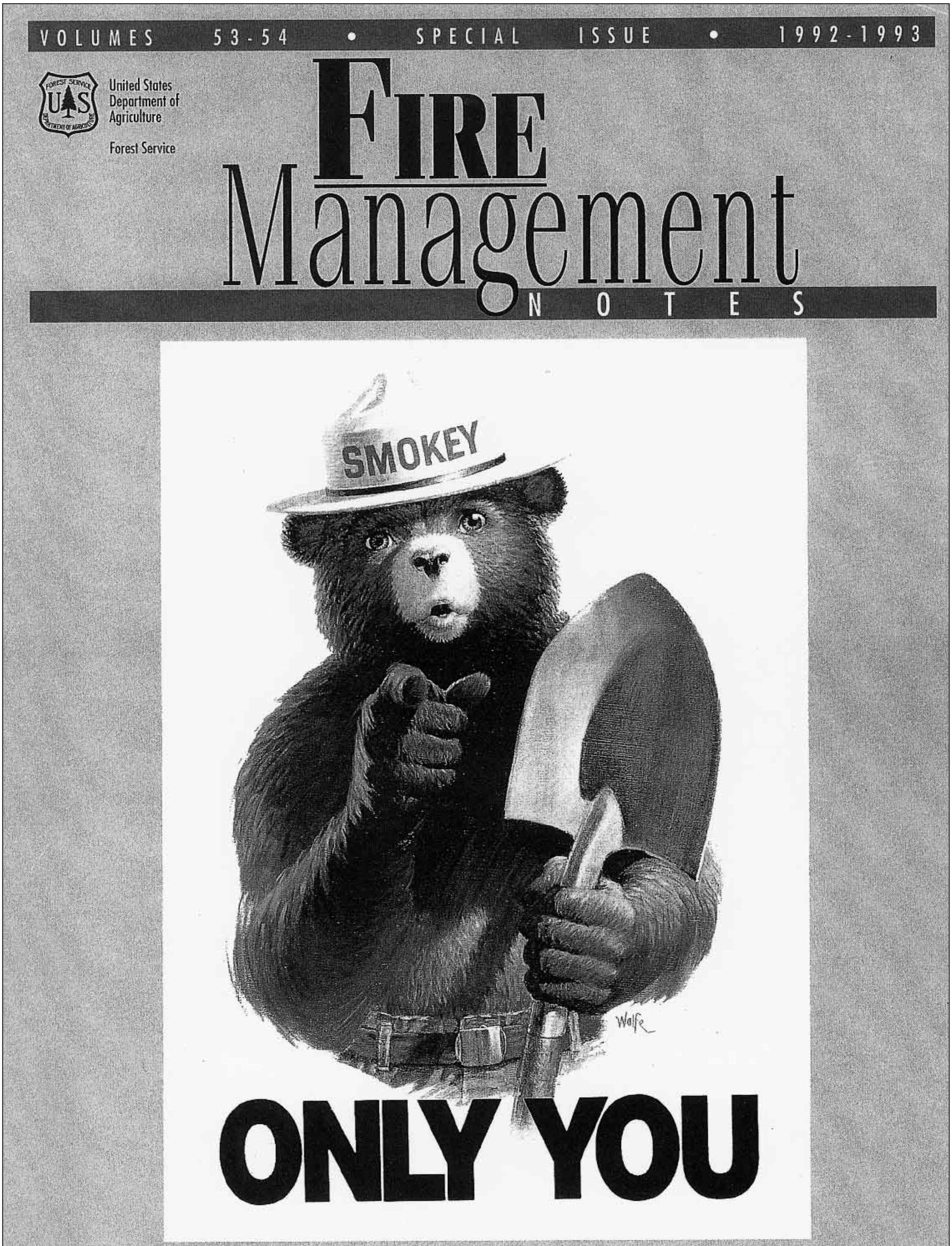


Figure 9.1. Animals as symbols have been used in various attitude campaigns to suppress fires, here the well-known "Smokey the bear" from the forest fire management in North America (see Morrison 1976).

variation etc. that might offer refuges from burning in two fires that follow quite closely after each other. Frequent fires also can lead to fires of lower intensity, creating a pattern of ever more unburned patches. This is due to the fuel not having enough time to accumulate and become continuous in the interval between the fires (Whelan 1995).

9.2.3.2 Promotion of weed-dominated communities

Internationally there is a connection between fire interventions due to management and the establishment and spread of exotic species ("weeds") (Whelan 1995). This may be plant communities that produce "weed species" amassing a larger biomass of better fuel and doing so faster than the original vegetation is able to regenerate itself. In such incidents the vegetation of the area might change character, and thus also the fire regime; this is a highly undesired effect where one actually burns preventively to reduce fire hazards.

9.2.3.3 Unintended deterioration of habitats

A fire regime that is effective in reducing the danger from wild fires may also reduce the value of the habitat for fauna. Therefore, it becomes an even more important task for nature management in all countries to give priority to the perpetuation of habitats for wild animal species (Goldammer et al. 1997, Machado 1997). Protection of faunal habitats on various scales is an important reason (Tab. 9.2) for the setting aside reserves and large protected areas. Conservation of fauna (and flora) is a priority goal of all range areas, also in ecosystems that are used exclusively by forestry. However, pre-suppressive burnings can also increase the value of an area for fauna, especially for some species (Section 8.5). It is important to evaluate effects of fire on faunal communities. Giving preference to fauna (and flora) in a burning program is an important goal for the Nordic countries (Section 9.4); international experiences should be useful for the development of national management plans.

9.2.3.4 Choice of burning season

Traditionally, hazard-reduction burns have been undertaken at a time of year when it is easiest to control fires (Whelan 1995). This principle has been debated. Environmental organizations have pointed out that local burning outside the natural burning seasons may have potentially devastating ecological effects. This is especially true regarding important production processes in the plant cover. However, the timing of the burns also may impact animal populations. Timing of important life history phases, for example the breeding and nest-building season of some birds, may make their populations more susceptible to fires in some seasons than others. Therefore, one of the most important problems of fire management is to conduct the fires in the best season, to avoid or lessen the impacts of the above scenario. Unfortunately, as mentioned, the window of opportunity for burning may be small.

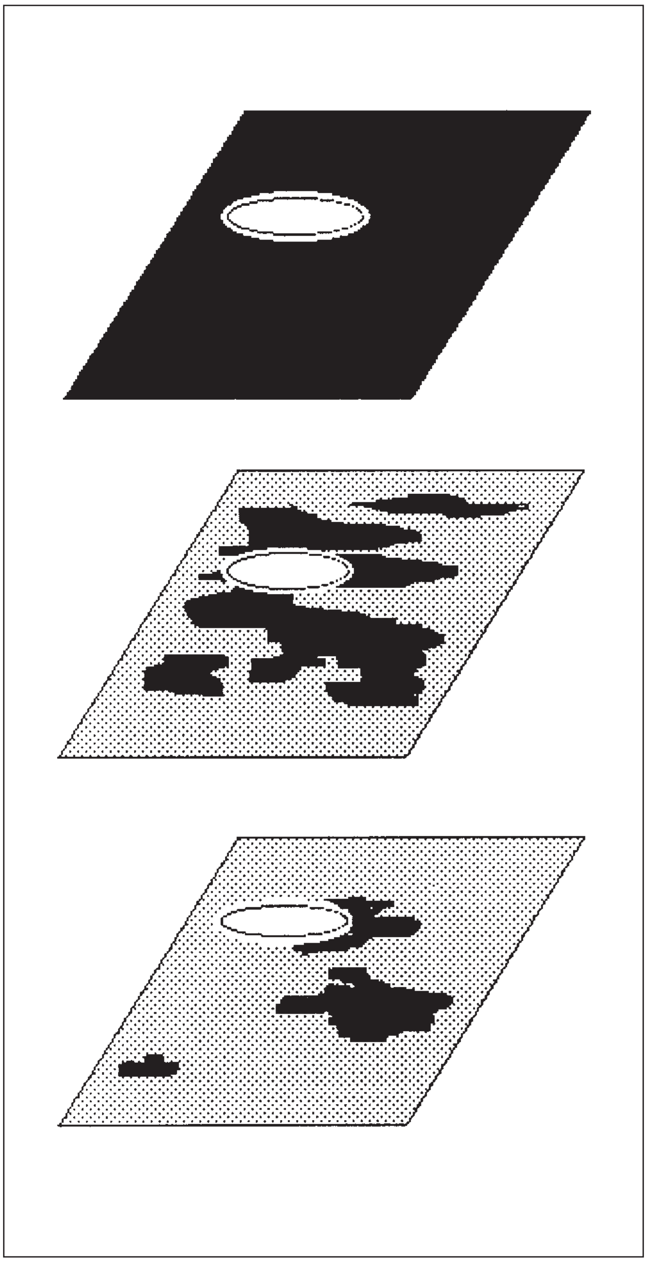


Figure 9.2. The scale problem visualized as changing conditions in the areas surrounding a national park (ellipse). The protected area originally lay in a larger continuous nature area (top), but the surrounding area has been more affected and fragmented (middle) so that only the main park area has kept the "virgin forest" features (bottom) (See text).

9.2.3.5 Establishment of "islands" and fire refuges

Another problem is linked to establishing "refuge" areas a fire should leave behind. Ecosystems rarely burn continuously over larger areas. The distribution of burned and unburned areas after a fire is an important characteristic that fire management must evaluate. It will always be a goal that a certain area *does not* burn. In some areas of Australia the fire objective may actually be achieving only 40 % burn (Whelan 1995). By burning in the cool season or in shorter periods with cool and damp weather conditions, one may actually produce a desired mosaic of burned and unburned vegetation. Ignition by fire drops or flying drip torch ("burning torch") from helicopters makes it possible to create desired patterns. Aerially, many ignitions may be started at approximately the same time; thus, there is no possibility that the fires will develop into a continuous fire front.

Creating a pattern of unburned refuges provides animals with better possibilities for movement and escape from the fire front. Larger and smaller areas with unburned vegetation provide refuges from which herbivores can move back into the burned patches to forage. This leads to another utility distribution of the burned areas. Therefore, management of vegetation includes deliberate alternation of burned and unburned patches to maximize populations of herbivores. An international example is burning of heather moorlands (see Section 4.2.9) for grouse production (Lovat 1911, Hobbs & Gimingham 1987).

The scale problem is important in all forest fire management (Fig. 9.2). When is an area that is to be restored to some kind of "natural condition" too small to be burned by a prescribed fire (Husari 1995, Mutch 1995)? How is one to manage a small area that might be characterized as "fire adapted", and which earlier existed surrounded by large areas of similar ecosystems, but today is located as an island surrounded by ecosystems totally changed by humans? The keyword for evaluating such problems is scaling.

9.2.3.6 Predicting intensity and matter converted

As mentioned earlier, the main problem with prescribed range fires is to predict their intensity and amount of organic matter converted. In ecosystems with mixed and varied vegetation there will be seeds of many species remaining dormant in the soil at different depths, ready to germinate by the heat of a fire. Cool fires will produce germination of seeds from the upper layer of the soil, while a more intense fire may kill seeds near the surface and stimulate germination of those buried deeper (Whelan 1995). Botanical and forest fire ecological expertise is needed to judge or evaluate such conditions (Section 8.4).

9.2.4 Areas of practical use

An overview based on keywords of the most important areas of use of fires in management is presented above (Tab. 9.1). In the following some of these areas of practical use will be discussed in more detail.

9.2.4.1 Reservoir burning for water resources

Prescribed fires have been used in dry areas to increase water runoff to reservoirs. Management is aimed at removing plant cover or possibly completely shift the composition of the vegetation. Where the primary management objective for an area is water production, fire management should be aimed at maintaining maximum grass cover with minimum incursions by shrubs and trees. Transpiration requirements of trees and shrubs greatly exceed those of grasses, and water yields are greater where the land is kept on grass (Chandler et al. 1983).

9.2.4.2 Burning to clear for agricultural purposes

Burning to clear (Section 4.2.4) is still used in most of the world as the primary tool to clear land in preparation for planting crops, developing pastures and installing forest plantations (Chandler et al. 1983, Myrdal 1995). The advantage of fire over mechanical methods of site preparation for agricultural purposes is that the nutrients released by burning are available for successional vegetation at the time of emergence and in the earliest growth phase when the nutritional demands are highest.

Burnings that are carefully prescribed and skillfully managed also can be less destructive for several site qualities than mechanical clearing methods. Soil disturbance is minimized and there is no soil compaction by heavy equipment.

The principle disadvantage of fire is that the effect will not be uniform across the whole treatment area. Some patches will be heavily burned, while others barely gets scorched on the surface. The problem can be reduced by scattering slashings to get a more uniform combustion.

Another drawback is that biological material larger than approximately 5 cm in diameter is seldom completely incinerated. This poses a problem for forestry in connection with mechanical planting. Therefore, it is essential

that felled green material be given sufficient time to dry prior to burning.

9.2.4.3 Burning for grazing resources

The primary objective of using prescribed fires in management of grazing areas ("pastures") (Section 4.2.6) is the same as for water resources, viz. to maintain as much grass or heather cover as possible with as few trees and bushes as possible (Chandler et al. 1983). Grass-dominated sere belong to the earliest stages of plant succession. Grasslands represent the ecological climax stage of natural succession only in limited areas with specific combinations of soil and climate conditions. On the rest of the 25 % of the earth's land surface with grasslands or grass characterized or dominated savannas, frequent anthropogenic fires are necessary to prevent the development towards shrub systems and forest (Kayll 1974).

The potential for herbivores is determined by the plant production that constitutes the carrying capacity of the area. In areas that are expected to produce enough forage for large populations, the return period of fires is usually short – from one to two, maximum five years (Chandler et al. 1983). Most "primitive" pastoralists practice annual burnings of their range, usually prior to or at the start of the growth season (Steensberg 1993). Annual burning is an acceptable practice when ranges are understocked or marginally stocked with individuals, i.e. having an animal number far below the carrying capacity. Overgrazing and fire are, however, ecologically an unfortunate combination. Overgrazing early in the season weakens plants by reducing their ability to store nutrient reserves below ground, and also reduces the amount of plant material left to serve as fuel for fires during the resting period of the plants. This may result in fires with such reduced intensity that they fail to kill invading brush and seedlings of trees, but still burn with high enough temperature to weaken the grass plants even more. The consequence is a reduced grazing capacity the following year so that grazing pressure is increased even if no additional number of animals are pastured. Within a few years the site may be permanently occupied by species that are obligatory seeders and that are almost impossible to eradicate. Proper use of fire in grassland management therefore requires careful regulation both of grazing and fires. However, fires are important in the management of herbivores (Hilman & Hughes 1963, Touchan et al. 1995), also in national parks and reserves (Alexander & Dubé 1983), and we generally refer to chapter 8.

There are examples where management burnings led to marked population reductions, actually extirpation of certain mammal species in local areas. This is documented after burning of small protected areas that were surrounded by agricultural and urban areas (Robinson 1977, La Maitre 1992). Burning of *small areas* now receives more attention since this is what management in many countries is confronting as the practical possibility, cf. what is said about scaling earlier on (Fig. 9.2). Burning for grazing plant production is still of interest in the Nordic countries, especially in Norway, which has extensive grazing in outlying areas (see Mysterud & Mysterud 1995). When husbandry in outlying areas was common everywhere and meant much to rural economics it led to extensive use of fire in Norwegian ecosystems (see Section 4.2.6).

9.2.4.4 Shift of vegetation cover

Fire is often an applicable method when converting from one cover type to another. This is already mentioned in connection with management of drinking water resources (Section 9.2.4.1). If the intention is to revert the vegetation to an earlier stage of ecological succession, properly prescribed fire alone may be sufficient for this purpose. Examples could be converting brush fields to grasslands or removing hardwoods from mixed pine-hardwood stands. If the intent is to control the species composition within a mixed stand of species at approximately the same successional level, it is usually necessary with postfire treatments of the site with plowing and planting of seedlings (Wright & Bailey 1982). The secret to successful use of fire in vegetation type conversion is a thorough understanding of the ecological requirements of each species in the area so that the "proper" fire regime can be used.

9.2.4.5 Forest management burning

Management of fires in forestry both in North America and other places has usually been by means of suppression (see Section 4.4). In forests established and developed for specific forest products/production, for example tree plantations and intensively managed forests in the USA, it has been customary that fire management be based on purely economic considerations. However, it is acknowledged as important that the local fire regime is known when one is to produce forest, particularly in areas where new tree species are introduced. This should demand intimate cooperation among stakeholders in fire management and forestry from the time the stands are planned. Severe problems increased where the earlier extensive practice of planting trees in large plantations

with highly flammable pine species when one lacked experience with the fire regime (Chandler et al. 1983). However, this has been an important motivator for more research on fire ecological questions in North-American forestry.

Management of forest related to forest fires has two traditional focal areas. The first is management of areas already burned to regenerate new forest. The second is use of fire on clear-cut areas after final cuttings to remove slash and stimulate regeneration (clear-cut burning). In connection with the latter patch burning (see Section 4.2.8) is an interesting alternative method to clear-cut burning (macro scale) through its intention of burning and regeneration on small patch scale (micro scale).

Management of burned areas

Several countries have conducted research associated with problems of cutting and regeneration of burned forests (Fabricius 1929, Jahn 1959, Chandler et al. 1983, Goldammer et al. 1997). In Norway, researchers at the Norwegian Forest Research Institute have conducted extensive examinations of problems concerning cutting of burned forest and attempts with silviculture (Norw. “skogkultur”) on burned clear-cuts. This has mainly been done through designation of test clear-cuts in fire areas, where influences on seedlings and regeneration were studied (Strand 1956, Solbraa 1997b). The background for this work has been to elaborate practical guidelines for quick cutting and regeneration of forest on already burned sites (Solbraa 1977, 1981, 1982, 1983, 1997b, Bogen & Holt 1993, Brunvatne 1993). This led to a broader general interest in research on the effects of forest fire (Norwegian Forest Research Institute 1977).

Clear-cut burning

Clear-cut burning to regenerate forest (see Section 4.2.8) is in principle the same as conducting swidden agriculture or burning to create and improve grazing areas or clear areas for various kinds of cultivation. It aims at burning the floor vegetation and burn off the slash. If there is much slash evenly distributed over the whole clear-cut after the final cutting, it was possible to achieve a satisfactory burning already a few days after snow had melted in spring (Stømsøe 1964).

Because of the combustion of all accumulated slash, clear-cut burning is not comparable with a natural fire when considering temperature. In the recent past burning of clear-cuts was the most common preparation of some forest stand types after final cutting in the Nordic countries (Section 4.2.8). These earlier experiences found that forest stand types were easy to regenerate and pine had good growth after burning (Tirén 1937, Arnborg 1949, Strømsøe 1956, 1964, Lundmark 1988, Hallsby 1995). This led to more extensive use of burning as a regeneration method in forestry.

Clear-cuts in boreal coniferous forest will usually burn best the first and second summer after the final cutting. In the third summer some of the slash will have rotted, and the raw humus sites will be grass covered, thus less combustible. Unusually strong periods of drought are needed to be able to burn 5–6 year old felling waste on clear-cuts with a desired effect. Gradually clear-cut burning became less used in Norway due to reasons that are mentioned elsewhere in this technical report (see Section 4.2.8).

Patch burning

A new method which forestry now consider for application in management, is called “patch burning” (Hedman & Mattson 1996, Laakko 1996, Øyen 1996a,b). Patch burning means that smaller patches on the forest floor are swidden to improve the regeneration of tree species. Research now suggested to determine what potential this method may have for regeneration of coastal pine forest in the western part of Norway (Øyen 1996a,b). As a method, patch burning is interesting for management because of the ability to conduct precise burnings on small scale.

9.2.4.6 Burning for game production

Some of the earliest and most successful examples of modern fire management are use of fire in connection with game production and management (Gossow 1978).

A low-intensity fire will almost always produce a net benefit for wildlife provided that it occurs outside nesting seasons. Most species of birds and mammals prefer habitats with high diversity. Low-intensity fires promote diversity by creating edge and edge effects (Riess 1980, Chandler et al. 1983).

It was not until Stoddard’s (1932) classic monograph “The bobwhite quail” that the use of burning as a carefully prescribed ecological tool for habitat manipulation broke through in science and research.

A well known example on the use of burning for game

production in Europe is the British heather moorland (McVean 1964, Gimingham 1970, 1972, 1975, Webb 1986), where English and Scottish game managers for nearly two hundred years have used fire to manage heather moorlands for grouse (see Section 4.2.9). Extensive experimentation has shown that burning of one-hectare patches or stripes, and approximately six patches per km^2, results in high populations and optimal yield of grouse production. The grouse is a herbivore which feeds on buds. It needs well-developed and unburned heather systems for breeding and protection against predators, but finds nutrition of high quality in the regrowth on burned patches.

Today, prescribed fire is used to produce optimal habitats for a wide variety of game and non-game species (see ch. 8). In such instances the ecological requirements of the species in question were not known beforehand. A manager must have the expertise to recognize that a fire regime that favors one species may work against the spread of another.

The type and timing of prescribed fires is dependent on the species to be favored. In management of the American tetraonid species bobwhite quail (*Colinus virginianus*) the fire with lowest intensity, to reduce a sufficient amount of litter is preferred. However, to improve the habitat conditions for the Kirtland warbler (Section 8.5.6.4), crown fires of high intensity are needed.

Small game

Burning of heathlands according to the Scottish pattern affects the fauna of the burned areas to a considerable extent. Therefore clarifying the relationship between game species and vegetation where burning is a part of the process is very important (Hobbs & Gimingham 1987). Recently, burning of heathlands has also been part of Norwegian game management (Aalerud & Phillips 1984, Myrberget 1988, Rognebakke & Smukkestad 1989, Pedersen et al. 1994, Pedersen 1997).

The objective of Norwegian game management has been to remove undesirable vegetation and promote the production of nutritious forage for willow grouse, black grouse and hare (Rognebakke & Smukkestad 1989). The succession of mountain postburning vegetation has been studied in connection with game management efforts to improve habitats of willow grouse (Wilmann 1992, 1996). Such burning has been judged as current management actions both in lowland areas and in mountain forest. However, during the 1990s the interest in such actions seems to decline because burning did not meet expectations (Solbraa 1992).

The discussion that followed the burning of heathland in game management seems identical to the one that followed the clear-cut burning in forestry (Section 4.2.8). The conditions in outlying areas in Norway are variable, the potential for negative effects is large, and it is evidently difficult to control amount of organic matter converted by fire. Therefore, burns may result in unexpected effects. In spite of a lack of positive effects, heathland burning is once again advocated in Norway. This time it is emphasized that the earlier burning programs were undertaken on too small a scale (Storaas 1997). However, there is a question about the bedrock and soil being too acid and of low productivity and the humus resources so small on many higher elevation ranges in Norway that such a treatment regime should not be applied on a large scale (see ch. 8).

Other "game species"

The new game law in Norway has broadened the concept of "game". Both woodpeckers and a species like the ortolan bunting will be embraced by this concept. Today, burning for "game production" of such species has to be seen as part of nature conservation burning.

Woodpeckers are a group of birds where burning as a management tool may become topical in Norway. They are dependent on dead wood, either to find nesting sites (dry trees) or for foraging (snags, fallen trees, other old wood). Dead wood in modern forests often is located in limited amounts (Samuelsson et al. 1994). Therefore, leaving standing dead wood on burned clear-cuts and management burns would mean much for a local and regional regulation of woodpecker populations (see Stora Skog AB 1995b).

The ortolan bunting is judged to be on the brink of extinction in Norway, and it is reclassified to the list of species that are directly threatened. Based on experiences from the burned site at Elverum, South Norway this species seems to be a fire profiteer (Section 8.5.6.4) having population characteristics that should be considered in a management program that uses prescribed fires. The burned sites should eventually be located near or adjacent to agricultural fields (Dale 1997).

A research project was initiated in 1995–96 at Elverum to examine the relation to burned clear-cuts of the ortolan bunting. The burned clear-cut at Elverum was

judged to have few insects, sparse production in ground layer vegetation, and therefore few small rodents. Therefore, the site possibly has a low preference as hunting habitat for birds of prey and carnivores. The hypothesis is that the ortolan bunting colonizes the site because of low predation risk (Dale 1997).

Generally, no fire specialist is known among the bird species of the Norwegian fauna, i.e. species that demands specific actions in fire management plans. They are all able to nest under other conditions (Section 8.5.6.4).

However, it may be of management interest to examine more closely if there are fire profiteers that are either directly threatened, threatened or vulnerable, and clarify what adaptations lie behind their relations to burned fields and eventually promote plans to increase their populations.

Cervids

Cervids are likely the most widely discussed group in relation to international fire management (See section 8.5.6.5). There have been several success stories using prescribed fires as a management tool (Peek 1986).

Fires influence all cervids through changing the amount of nutrients and cover in their habitats. In older forest stands, while there is enough cover, nutrients often are a limiting factor. Large amounts of herbs and young deciduous trees will grow on burned clear-cuts. These areas produce nutrient resources that both roe deer and moose are adapted to digest (Hofmann 1989). Therefore, a shorter or longer period of postfire succession offers good opportunities for such species. At the same time, under Norwegian conditions there will rarely be a long distance from burned clear-cuts to cover in the surrounding unburned forest.

It is probable that nutrition directly may cause an increase in for example the moose population in burned areas. Amount and quality of forage plants seems to be excellent in many burned areas. Already during the 1950s it was proved higher content of ascorbic acid (vitamin C) and protein and totally more carbohydrate in the forage in the early successional stages utilized by moose than in older forest stands in the same area (Cowan et al. 1950, Rowe & Scotter 1973). However, it is clear from the preceding discussion of effects of fires (Section 8.4.6.5) that it is not possible to generalize about postfire conditions.

Among the cervids in Norway roe deer and moose are fire profiteers with flexibility to use burned areas. However, under the prevailing conditions the logging pattern of forestry with extensive use of clear-cutting has not only taken over the function of earlier burned areas, but probably led to a nutrient basis for cervid production far above what any natural Norwegian fire regime could ever contribute.

This species group therefore needs no particular consideration in a possible fire management plan. From what we know at present the same is true for all mammal species in Norway.

However, uncertainty is associated with a possible existence of melanistic morphs (black colored individuals) selected for by fire in some mammals, known both among small rodents and some species of carnivores. These will eventually get into conservation work as “fire morphs” (Section 9.4.3) representing genotypes within the species that are a part of the genetic diversity.

9.2.4.7 Nature conservation and burning for diversity

The new practice where management of already burned areas and “diversity fires” are used as tools, seems to be increasing in some countries that have conducted intense fire-suppression programs and cleared burned areas through longer periods of time. Use of prescribed fires to maintain and create diversity in management regimes that are responsible for nature and landscape are ever more frequently brought into the planning process (Hemser 1932, Zimmermann 1978, Granström 1991c, Goldammer et al. 1997, Machado 1997). This has led to a broader scientific discussion and debate about the principles of such management. If conservation of diversity is the basic management objective of an area, many argue that one should mimic the “natural fire regime” of the area as close as possible (Whelan 1995). This is a “nature knows best!”-ethics based on the argument that an “unnatural” fire regime (read: affected by culture and manipulated by humans) might create ecological problems because species and elements of the living community in a given ecosystem has evolved under a “different” fire regime. This may be a reasonable argument regarding some areas, but not always. The problem is that it most often is difficult to decide exactly what has been the natural fire regime (Section 2.2.5, ch. 4). To use such a strategy in a country with nature conditions that are so varied as Norway demands far more basic understanding of the fire regime than is available today. For

example, what is the “natural fire regime” in countries like Norway that actually has been affected by fires from anthropogenic ignition sources through almost the entire postglacial epoch? The reconstruction of long-term fire history is not reliable for any continent, even not for the relatively short time that has passed since the large colonization periods (Whelan 1995). Even though studies of fire scars in tree rings of wounded trees may offer information about the historic frequency of high intensity fires in local areas (Section 2.2.6), it will demand an extensive research effort to collect the necessary amount of data on a regional scale to get information of the distribution of such fires. Another problem with such research is that it is almost impossible to decide at *what time* of the year historic burning occurred.

Methods that are based on interpretation of pollen and carbon remnants in sediment cores of lakes or bore samples from soil profiles often suffer from such problems (Section 2.2.6). The possibilities for clarifying fire regimes in the past are through expanded stand and forest history studies. There is archaeological and anthropological evidence of extensive anthropogenic fire patterns resulting from aborigine activities. The impact that all this anthropogenic burning may have had on the evolution of characteristics of contemporary species and life communities is debatable (Bird 1995). This must be taken into consideration in the planning of management fires.

9.3 Nature conservation and fire management

The interest for nature conservation burning is increasing in the Nordic countries, and Sweden (see Granström 1991c, Hörnsten et al. 1995) and Finland (Karjalainen 1994, Piri 1994, Hallmann et al. 1996) have as mentioned reached farthest in practical forest fire management. Even in Norway a larger focus is now aimed at a possible use of fire for nature conservation objectives. Concerning international use of fire in national parks and reserves, we refer to an own account (Section 9.3.5). In the following we are first going to take a look at some more recent features from Swedish management.

The basic premise of Swedish management of coniferous forest is that the landscape earlier has had a large-scale dynamics caused by disturbance regimes, first and foremost fires (Zackrisson 1997). One then states that management should build on this. Another important premise is that management should be planned in landscape perspective; where plans also should consider conservation of culture, landscape esthetics, recreation, hydrology and biological diversity (Anonymous 1995). Management should be based on the multiple use we have referred to several times (Section 9.3.5).

Swedish forest management wants to consider biological diversity in its broadest sense, and therefore necessitate extensive ecological landscape planning and hence new management methods. Conserving biological diversity implies that one has to conserve the genetic variation within the species and that all species which “naturally” occur are to be maintained in viable populations. Diversity is to be retained through the continuation of ecological processes at the landscape level. Examples of such processes are fire, succession after fire and senescence, and death and decomposition of trees. They are the origin of various stand structures and substrate in various biotopes. The different ages and multi-storiness that often characterizes a burned pine forest, may serve as an example.

The emphasize of the Swedish forest management on environment and multiple use has led to an extensive focus on ecological landscape planning and development of new management methods. The progressive work in Sweden has partly taken place in cooperation with nature conservation organizations, and has already led to an interesting range of new strategies in Swedish forest management. The Swedish program has developed a new set of terms and a model for fire management (ASIO, see Section 9.3.2).

9.3.1 “Consideration biotopes” and “consideration areas”

Biotopes of particular importance for maintaining biological diversity and which should especially be taken into account are called “consideration biotopes”. This is a wider concept than the previous concept “key habitats” (“hot spots”) incorporated earlier into the forest and nature conservation laws of Sweden (Anonymous 1995).

Management with respect to particular needs is to be based on the natural disturbance regimes at the growth site of the stand. Examples of important *processes* are fire, changes in the succession after fire, “self thinning”, natural regeneration, formation of dead wood etc. Examples of important *stand structures* are uneven age structure, multi-storiness, group patterns, undergrowth, and mixed stands. Examples of important *substrates* are

old trees, big deciduous trees, trees of low vitality, fire wounded trees, high stumps, dry trunks, large wind-blown trees and ashwood. Important substrates in a pine forest characterized by fire are burned stumps, dry trunks and fire wounded trees.

Conservation of the biological diversity demands that variation in such processes, structures and substrates in the forest landscape is conserved and partly recreated. This may be achieved through carrying out various management actions that attempt to mimic the natural processes of the forest. Part of this is also that certain biotopes are conserved totally or relatively untouched by interventions from management, while one specifically considers the management of others ("consideration areas", i.e. special treatment areas) (Anonymous 1995) and which comprises the basic or core material for the ecological landscape planning. All information concerning valuable biotopes in the focal areas is to be emphasized.

A proposed objective is to create large "consideration areas" (core areas) in what are called "stable networks" with dispersal corridors where a variety of areas are built in. Large consideration areas should be established or developed in areas with a concentration of consideration biotopes where the connection between these are reinforced and kept together by so-called "intensifying zones". Stable networks should be created in forests that seldom or never have burned and that are located at the lowest elevations in the landscape, often in connection with water systems.

Judged from how the natural landscape might have looked, it is recommended to define an aim for how many possible "shortage biotopes" are necessary to recreate. First and foremost this concerns a number of burned areas, deciduous forests, pine forests with various ages and virgin-like natural forests (Anonymous 1995).

9.3.2 The ASIO model

The ASIO model has been developed based on the fact that fire has been the most important disturbance factor in Swedish forests with various frequencies in different nature types. The ASIO model is meant to give practical advice for developing and adjusting new or renovated management methods and used to define new fire regimes in various nature types and on different scales (Tab. 9.4).[9.2] The thought and purpose behind the ASIO model is to burn nature types in four categories with a frequency in time and space that corresponds with what "naturally" has occurred in the respective area, see table 9.4.

Table 9.4. The Swedish planning model ASIO with classification of forest communities (types) in four classes based on differences in fire frequency (After Anonymous 1995).

ASIO classes
A-community (type) Encompasses forest communities that practically never (Swed. "**A**ldri") have burned. Consists of wet communities (types) and humid areas characterized by herb vegetation. The location in the terrain may also have prevented the stand from fire. Examples of this are ravines, certain forest islands surrounded by bogs and lakes in addition to northeast slopes in humid areas.
S-community (type) Encompasses forest communities (types) that seldom (Swed. "**S**jelden") have been affected by fire. These encompass first and foremost humid types except from stands rich in herbs that are classified as A-communities. Also "fresh" stand types in very humid areas, for example in areas close to mountains, or in north slopes of high mountains often belongs to S-communities. The S-community is supposed to have a fire frequency of approximately 1 time/150–250 years.
I-community (type) Encompasses communities that have burned now and then (Swed. "**I**blant"), i.e. with approximately 100 years intervals. These constitute all "fresh" stand types that have had conditions to burn.
O-community (type) Encompasses forest communities (types) that has burned often (Swed. "**O**fte"), i.e. has a fire frequency of around 50–60 years. These are the dry stand types.

It is important to adapt management methods to forest stand types which seldom or are never disturbed by fire; this is strongly emphasized to conserve various kinds of *continuity* (Anonymous 1995).

Based on the special features of the landscape, treatment and management on stand level is to be formulated. Therefore, management plans will be different from area to area. In Norrland 5 % of the area is estimated as composed of A-communities (types), 10–15 % of S-communities (types), 70 % of I-communities (types) and 10–15 % of O-communities (types) (Anonymous 1995).

The ASIO model is described and discussed by Angelstam et al. (1993) and Hallmann et al. (1996). It has already been implemented as part of the formation of management strategies. However, there is some concern against uncritical use of this kind of model thinking; the empirical basis for such a model is meager and it only rests on hypotheses generated on the basis of correlation analyses and not on causal connections (Ohlson 1997).[9.3)]

9.3.3 Diversity fires in practice

The main objective of so-called diversity fires is to use them as tools to preserve the biological diversity of the forested landscape – to maintain a rich and varied plant and animal life by conserving, maintaining and recreating a variety of biotopes, stand structures and substrates so that all species can survive. Variation is to be conserved and if possible recreated on all levels; also within the larger geographical areas we call “landscapes”. The ASIO model is one practical model for developing such desired fire regimes.

Complex evaluations are linked to developing criteria to specify *fire regimes* that should be directed for various areas. Because one lacks knowledge of fire historical conditions (ch. 5) these are evaluations that often are difficult. We refer to Granström et al. (1995) for an overview and discussion of problems linked to use of the term “fire regime” in such a connection.

The many “fire theoretical” problems connected with more safer planning of how prescribed fires qualitatively and quantitatively are to be undertaken, has led to making a practical decision of carrying out a program on a more approximate basis.

For example, a practical guideline for fire insect species may be to burn 1–2 hectares forest stand types annually in a “landscape” to give their populations a chance to reproduce. In the Särna project 10 hectares annually are suggested; this corresponds to approximately 5 % of the average area influenced by fire annually. This is the “natural condition” in that particular area (Johansson 1994).

Therefore, such practical evaluations have to be done for each focal area. Norway is expected to have more A- and S-areas than Sweden because of a cooler coastal fire regime. The application of such models possibly may be adapted to the Norwegian situation with far smaller areas of continuous forest and a totally different property pattern. It is also unclear how much the anthropogenic burning eventually has meant.

9.3.4 Management of species

The reason pyrophile species are threatened is due to fire areas are seldom found with abundant dead wood in the forests of today versus earlier. Modern fire-suppression and clearing of burned areas are the reasons. Surveys of the frequency of forest fires among others in Sweden have shown that number and extent is extensively reduced the last years compared with earlier times (Zackrisson 1977a, Zackrisson & Østlund 1991). Also, in Norway intense suppression of forest fires was conducted for more than a hundred years.

Work to preserve diversity has focused on threatened and vulnerable species. These species are in the management on so-called “red lists” (see Gundersen & Rolstad 1998a). The Council of Europe now concentrates on revising all “red lists” in Europe to get a reliable overview of which species are in need for special action plans (see Machado 1997). Unfortunately, the work with fire species is limited, because many countries do not have the needed knowledge about such species. In the Norwegian red list 1,839 species are listed; 45 are classified as extinct, 150 as threatened and 279 as vulnerable (The Research Council of Norway 1997). Only a small number are related to forest fires. A natural start for management would be to identify the fire specialists that need burned areas. Then action plans should be developed to improve their conditions. Such work should also include the evaluation of which range areas should have such species in Norway.

Even though the work with mapping fire fungi is now well underway (Section 8.2.2), more work remains before we may know which of these species are potentially threatened. The same is true for plant species. The conditions for plants need particular evaluation since they do not have opportunities for dispersal like animals. Important for protection is how long-lived the seeds are, i.e. how long they may remain in the soil without getting damaged. They require fires in the same area with certain intervals. Many vascular plants in the Norwegian flora are profiteers, but there seem to be few exclusive specialists (Fig. 9.3).

Among plants and plant communities in Norway created by burning there should be a focus on diversity in the coastal heathlands (Section 4.2.6). This cultural landscape will demand specific management programs

GROUP OF ORGANISMS		EXAMPLES
FUNGI		**ASCOMYCOTA**
	Specialists:	*Anthracobia melaloma*
		Geopyxis carbonaria
		Peziza echinospora
		BASIDIOMYCOTA
		Fayodia maura
		(See Tab. 8.1)
	Profeteers:	Several (See Tab. 8.1)
MOSSES	**Specialists:**	?
LICHENS	**Specialists:**	?
VASCULAR PLANTS	**Specialists:**	Cranesbill *(Geranium bohemicum)*
	Profeteers:	Groundsel *(Senecio vulgaris)*
		Fireweed *(Epilobium angustifolium)*
		Pill-headed Sedge *(Carex pilulifera)*
		(See Tab. 8.4)
INVERTEBRATES		**INSECTS**
	Specialists:	Bugs
		Bark bugs (*Aradus* spp.)
		Butterflies
		Apomyelois bistratiella
		Diptera
		Beetles (many)
		Melanophila acuminata
		Sericoda quadrifovelatus
		Sericoda bogemanni
		(See Tab. 8.8)
	Profeteers:	Several
VERTEBRATES	**Specialists:**	None
		Fire melanism?
	Profeteers:	Birds
		Woodpeckers
		Ortolan Bunting *(Emberizia hortulana)*
		Mammals
		Roe deer *(Capreolus capreolus)*
		Moose *(Alces alces)*

Figure 9.3. Species' various relations to fires visualized as selected examples from different groups. Vascular plants, which are stationary and dependent upon growth site, will demand individual action plans, while for example several invertebrates, which have a large dispersive capacity, probably can be managed collectively in "species parcels" (See text).

where one should view several species together.

Several species also may be viewed together when one looks at the organisms that are adapted to resources and environments in recently burned areas. It seems to concern a whole "species parcel" with specialists, amongst others invertebrates, especially insects, which are linked to such environments (Section 8.4.5).

Some of these invertebrate species are regarded as threatened or vulnerable and are nominated in the lists of such species in the Nordic countries (Ahnlund & Lindhe 1992, Nordisk Ministerråd 1995). For these it will be relevant with a number of action plans. However, it is not sure that the number of annually burned areas needs to be extensive because they may be viewed as a "group". One point of departure would be to find out how far one can get with management of already burned areas, where one does not clear the sites, but let half-burned and dead trunks remain (see Levende Skog 1998).

Through research one must examine what is required to maintain future populations of such species and at the

same time get their status clarified. Particular action plans can then be developed.

Concerning vertebrates, the situation is simpler. From the knowledge of today, there are no specialists in Norwegian fauna; many are profiteers (Fig. 9.3). Few of these are in need of particular management plans to create suitable habitat conditions. They can be benefited through ordinary forestry. However, there can be certain exceptions; these are for example some woodpeckers, especially white-backed woodpecker, and among the passerines, the ortolan bunting. It is possible that specific action plans should be developed for these species.

A phenomenon that occurs in some mammals, is individual variations within the populations, so-called "fire morphs" (Sections 8.5.5.4 grass hoppers, 8.5.6.5), genotypes which eventually will fall into management. If there are such genotypes in the Norwegian fauna, it will be a necessity to develop specific action plans also for these species.

One thing is to get better management planning on *the species level*, strategies which add to the broader work to conserve diversity in forest. Something totally different is arrangements to bring fire and burning in as an element of a potential forest management and long-term perspective of the whole landscape.

The latter will demand development of models to scale fires on a totally different and much higher level, and also an evaluation of methods to differentiate such programs based on *where* the site is located in the Norwegian landscape. Here it will among others be critically important to evaluate consequences towards species which are *not* favored by fires, what we have termed "fire fleers" and "fire losers", which also is an important part of diversity. The most difficult evaluations are associated with management of fires of reserves and national parks. It is hardly even possible to see the problems without knowing some of the experiences that has been done in international management of ecosystems.

9.3.5 Management of ecosystems

Fire management of ecosystems is a difficult and demanding task that will vary depending on the type of area in question and which objective one has for burning (Goldammer & Jenkins 1990). Has management, for example of a national park, as a primary intention to maintain widespread possibilities for recreation like hunting, camping and hiking, or should the area be conserved as specific examples of "national nature or cultural heritage" (Alexander & Dubé 1983)? In some instances this may involve conserving particular historic or esthetic areas as close to a "pristine condition" as possible (Chandler et al. 1983).

Irrespective of objectives, the use of fire to maintain ecosystems necessitates a thorough understanding of the area's fire history and knowledge of responses of the systems' species and communities from fires earlier on. This appears not least if one is going to manage systems like the Norwegian coastal heathlands. One has to maintain a whole specter of interventions if one want to preserve them for the future (Fig. 4.6).

Planning of prescribed fires on the system level depend on knowledge and demands a continuous dialogue between researchers, landscape managers and fire specialists. Fire management of ecosystems that are set aside and regulated as "wilderness areas", national parks or reserves make up a class for itself. In such areas there has been argued that fires should play its "natural role" to as large an extent as possible when the safety of the public and possible risk for damage of surrounding areas have been closely evaluated. This is, as we have touched upon several times in this technical report, not easy. First, the fire regime is affected and the fuel often manipulated by humans, second, any prescribed fire that is ignited by humans poses more anthropogenic burning.

Efforts to keep fires out also affect risks if suppression is maintained over long periods of time. The first is accumulation of fuel up to a level where extensive high-intensity fires suddenly may erupt irrespective of degree of protective and preventive efforts. The other is a gradual loss of diversity of flora and fauna through the aging of the system, which we have discussed. In many instances effective and total or lasting exclusion of fires in many ecosystems has been a procedure that only may be defended until one has developed more elaborate fire management plans (Chandler et al. 1983).

9.3.5.1 "Wilderness areas", national parks and nature reserves

One of the most discussed area of use for fires on the ecosystem level is management of so-called "wilderness areas" national parks and nature reserves. The necessity of taking fires into consideration in management of such areas now seems to be ever more accepted, especially in

North America. The alternatives to fire management and their environmental consequences were described relatively thoroughly already in the 1970s, and for a broad discussion we refer to a large literature (Heinselman 1970a,b, 1971, 1973a,b, 1978, Agee 1974, 1977, Makowski 1974, Tüxen 1974, Alexander & Dubé 1983, Chandler et al. 1983, Parsons et al. 1986, Kilgore 1987, Kilgore & Heinselman 1990, Brown 1991, Christensen 1993, Brown et al. 1995, Goldammer & Furyaev 1996, Goldammer et al. 1997).

9.3.5.2 Restoration of "natural" conditions

The basic aim of fire management programs for "wilderness areas", national parks and nature reserves is most often to "restore" the area after cultural influence or to maintain the fires' "natural role" as environmental factor. If nature itself is left to choose time, place and fuel (i.e. irrespectively let fires ignited by lightning burn), one supposes that this will result in a natural succession and hence a more "natural system" (Alexander & Dubé 1983). This philosophy can be seen articulated in its purest form already in USA's "Wilderness Act" of 1964 and in Canadian management in "Canada Parks Policy" (1979). The objective is that the management is to preserve representative nature areas for all time. The ecosystem is allowed to follow its natural line of succession and fire should be allowed to play its natural role in this succession (Van Wagner & Methven 1980).

To reach this aim in practice has, however, turned out to be easier said than done. Reestablishing the "natural" role of fire in an area that has been subject to human influence for many decades, centuries or even millenniums, may be difficult or unrealistic both due to ecological, socioeconomic and political factors. Plant and animal communities in what today are national parks and reserves have been considerably changed by earlier landscape use and historic suppression of fires. The philosophy and ethics of what is "natural" in most instances seems unrealistic and rigid.

9.3.5.3 Maintenance of "status quo"

Another philosophy concerning maintaining the ecosystem of many national parks, is a conservation of the landscape as it exists or existed at a particular moment in time. In management this is called maintenance of "status quo" or a "freezing strategy" (Chandler et al. 1983). In practical management one has many good examples that freezing the landscape in the long run is almost impossible to attain.

In parks where the intention is maintaining status quo, it was suggested that a natural fire cycle be ignored since the objective is to "freeze" the development of the ecosystem at a certain stage, i.e. not contribute to changes. This kind of conservation is ecologically "unnatural", and attempts to achieve this by overlooking natural fire regimes are self contradictory (Van Wagner & Methven 1980). The status quo philosophy has been recommended in North America as appropriate in isolated areas where there are reserves of large timber resources (Chandler et al. 1983).

Many conflicts have emerged associated with maintenance of status quo in management of some national parks (Chandler et al. 1983).

9.3.5.4 National parks and reserves in the Nordic countries

Toward the first half of the 1980s an extensive survey was undertaken of fire management of national parks and reserves in the boreal areas where the conditions of Norway, Sweden and Finland also were evaluated (Alexander & Dubé 1983). It was concluded that forest fires generally were not viewed as equally important or as ecologically positive as one did in North America. Finnish legislation for nature conservation was at that moment under revision, and the new suggestion also contained guidelines for the management of fires in parks and reserves (Alexander & Dubé 1983). Norway still has not developed management plans for fires in national parks; however, the interest for this seems to be increasing (Directorate for Nature Management 1992, 1996b). Strategies that make clear the view of forest fires, should be incorporated as part of the basis to manage the national parks (Directorate for Nature Management 1996a). It is now established that "in the larger conservation areas the biological diversity is to be conserved and taken care of" (Directorate for Nature Management 1996b, p. 65).

Regarding Sweden, Alexander and Dubé's (1983) review indicates that in Swedish forests there was an overrepresentation of old forest as a consequence of fire-suppression (Uggla 1974, Zackrisson 1976, 1977a, and that fire should be reintroduced in some of the larger forest reserves and national parks (Alexander & Dubé 1983).

A project to evaluate the necessity of fire management in parks and reserves in Sweden was started in 1979 through a reconstruction of the fire history of Muddus

National Park (Fig. 9.4). This is one of the largest areas with "untouched" forest in Northern Sweden (492 km^2).

It has been clear through research that one should consider the anthropogenic part of fire history also in national parks. In several national parks in other countries, for example from Kluane National Park in Canada, it was proved that forest fires ignited by lightning strokes were relatively rare, and that anthropogenic ignition have dominated through a long period (Hawkes 1983).

The importance of viewing influences from both natural and anthropogenic fires together was emphasized in a survey of the fire history of Tiveden National Park in South Sweden (Page et al. 1997). There was a documented increase of anthropogenic fire activities from the end of the Middle Ages and until the middle of the 19th century. Through this period the average time interval between fires was reduced from 15 to 5 years and season of burning changed from the middle of the summer to spring. With the increasing fire frequency the portion of fires burning small areas also increased. This fire patterns may be explained by various ways of using the forest in different historic epochs (among others production of char coal, swidden agriculture and tar burning) (see ch. 4). It is recommended that the old ways of using the forest should be restored and built into future management plans for this national park (Page et al. 1997). This is an interesting principle that we would call *management of national parks based on its fire history*. The principle is justified by the fact that it as mentioned earlier *regarding fires and burning would be close to impossible to find nature areas untouched by anthropogenic activities.* A such point of departure would be logic for the management in Norway where we must suppose that anthropogenic burning might have been particularly important. It will demand both a somewhat revised general view of the national parks[9.4] and as a starting point projects which carry out a mapping of the fire history of the relevant areas.

The first step to bring fires into Finnish management of parks and reserves was the establishment of a project in 1972. The project encompassed six chosen study areas – four parks and two reserves that are representative for the coniferous forest in Finland (Fig. 9.4).[9.5]

The first report from this work was published in 1978 (Haapanen & Siitonen 1978). It has been burned in several Finnish reserves. A burning in Kolperinkangas Nature Reserve was recently justified among others with maintenance of diversity, like rare beetle species (Veikkolainen 1996). However, it has not been possible to bring forward any detailed overview of the development of fire management in Finnish national parks from 1983 until today.

9.3.5.5 Russia and former Soviet Union

Fire has had and still has an important historic-ecological role in the northern forest ecosystems in the former Soviet Union, for example in the northern part of European Russia (Vakurov 1975) and northern Siberia (Shcherbakov 1975).

Fire-suppression is the only kind of fire management that has been practiced in Russian nature reserves.[9.6] However, the aim of preserving "natural conditions" can not be considered taken care of under a management policy with nearly total fire-suppression in such areas (Alexander & Dubé 1983).

There are extensive regional differences among fires in northern Eurasia. In Fennoscandia and the northern part of European Russia surface fires of low or medium intensity are prevailing, and intensive crown fires that break down and dispose large amounts of biomass are rare. In Siberia on the other hand fires having large ecological effects are more common, often as intensive and severe fires; for example very severe crown fires may shift out stands over large areas (Alexander & Dubé 1983). For a survey of the problems for forest fires in these enormous areas see Valendik (1996); we also refer to Goldammer & Furyaev (1996).

9.3.5.6 Multiple use management

In ecosystems where recreation activity is important and the intention is to give multiple use consideration, fire management often aims at maximizing a kind of "emotional satisfaction" of the majority of visitors to the areas. Important aspects of this are maximizing number and diversity of species (especially game species) combined with a considerable emphasize of hazard-reduction. The latter point means minimizing the possibility for high-intensive wildfires that may threaten the safety of the visitors. For the area to have a high recreational value, it should be aimed at conditions giving high visibility on the forest floor and improved access to make it possible to walk outside trails (Chandler et al. 1983). It is in such areas where burns are conducted to create par-

ticularly luxuriant flower meadows of aesthetic importance for the visitors (Tab. 9.1).

Fire management is both difficult and controversial, and in any case subject to discussion. Arguments for or against burning have been the point of departure for this debate. Fire-suppression is emphasized as artificial and "unethical" or "not ecologically correct" because it often burned in nature areas up to early in this century, and fire is in addition the most powerful ecological disturbance factor operating in nature areas. The debate started with the management of "wilderness areas" and national parks, but has since spread into multiple use areas (Jolly 1995). That debate is still not settled, and various research projects have been initiated to improve our knowledge base.

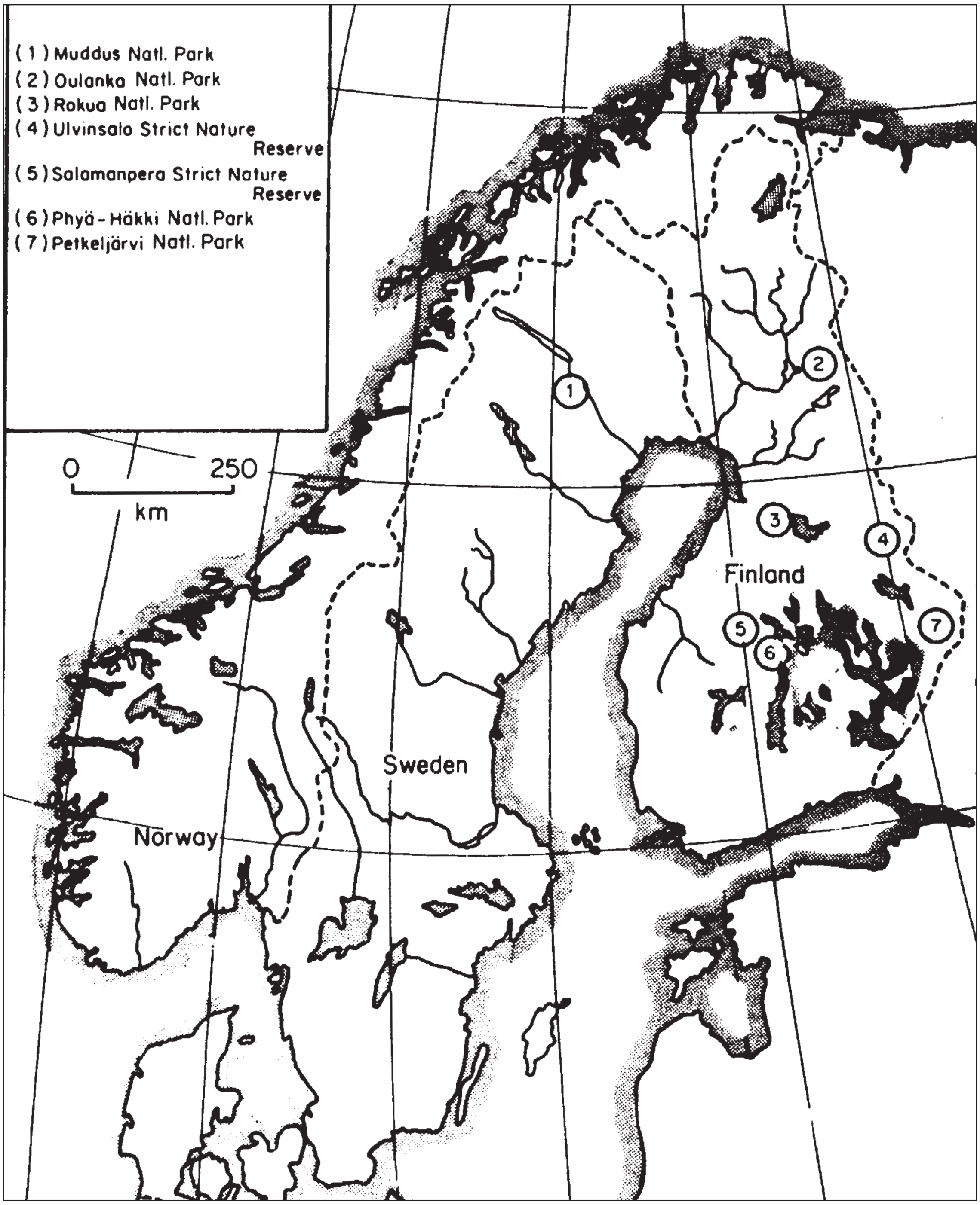


Figure 9.4. National parks and reserves in Fennoscandia mentioned in the first review of the fire management in the boreal areas. As one can see, no Norwegian area is described (From Alexander & Dubé 1983).

9.3.5.7 Conservation of cultural landscapes

It may also be necessary to use fire to conserve cultural landscapes. The basis for this is formulated in the World Heritage Convention (Tab. 9.2) whose task it is to conserve both cultural and natural heritage of large common interests.

A good example of a cultural landscape in Norway where use of fire is part of management, is coastal heathlands at Vestlandet and in Trøndelag, i.e. the western and middle part of Norway (Skogen 1974, 1987, 1989, Kaland 1986, 1997, Steinnes 1988, Fremstad et al. 1991) (Section 4.2.6). These heathlands had their widest distribution in the middle of the last century (Fig. 4.5). The area has decreased, and in the last twenty years large changes have occurred in area use. Natural regrowth with deciduous trees, pine or spruce is on the verge of changing the whole coastal heath section (Fremstad et al. 1991). Extensive planning and management will be necessary if larger parts of these unique cultural landscapes are to be conserved for the future.

9.3.5.8 Experiences from Yellowstone

A management strategy emerged in USA, where there are large continuous areas with natural forest ecosystems. The “let wildfires burn” strategy lets naturally ignited fires develop undisturbed. This principle has created considerable discussion and criticism (Dills 1970, Carlson et al. 1993, Wagner et al. 1995). Few national parks and reserves have proved to be large and isolated enough so that the “let wildfires burn”-strategy could be applied directly. [9.7)]

The “let it burn-principle” was applied in 1988 to a forest fire in Yellowstone National Park. The fire burned out of control and became much larger than anyone had imagined; a considerable debate followed (Christensen et al. 1989, Romme & Despain 1989, Schullery 1989, Wakimoto 1989, 1990, Despain & Romme 1991, Wagner et al. 1995).

The large 1988 forest fire in Yellowstone became a turning point for important judgements both in USA and in international forest fire management. Before 1988 economical resource considerations often were given highest priority in the prescribed fire programs, even in national parks. After 1988, the pendulum swung so that the basis of knowledge in the scientific fire and nature management was given more weight. In future management it is assumed that the pendulum will swing somewhat back so that implications both from nature and resource management will be more equally weighted and that plans become more nuanced and better adapted to the specific area (Kilgore & Nichols 1995).

The conclusion of the discussion after Yellowstone 1988 was that it is not enough to simply abandon aggressive suppression of fires, a policy previously found in our century inside wilderness areas. The suppression procedure has created an artificial accumulation of fuel with considerable anthropogenic influence of ecosystems over large areas.

The message from Yellowstone seems to suggest that fire management should go for varied strategies. This means that one “merges” various forms to suppress and manage wild fires with different kinds of prescribed fires. Planning should be based on thorough knowledge of landscape and fire ecology for any relevant area (Christensen et al. 1989).

9.4 Future fire management

Humans have fragmented ecosystems, influenced the succession of fuel through cutting, grazing and other use of the landscape through several thousand years (ch. 4) and have themselves carried out burns (Bird 1995). Central questions emerging are: How has this affected the system condition compared to imagined reference areas that are (almost) untouched by humans? How has human activity through long-term changes of the fuel load affected the possible course of wild fires? How has all this anthropogenic burning affected the organisms and their distributions?

In this technical report it is emphasized that the management of fires on ecosystem level today is a broad scientific discipline (see Brown et al. 1995).

This is clearly reflected in the international debate concerning fires that also involves our changing views of “nature” through the eras. Thus, a steadily more difficult interpretation of the importance of human activity and influence has come into focus (Bird 1995, Pyne 1995b, Stankey & McCool 1995).

9.4.1 Management based on fire history

The lack of knowledge of historic fire regimes in a landscape constitutes the most important obstacle for progress in the fire management of national parks. Various ways of approaching this problem are sug-

Table 9.5. Some guiding and basic questions to managers who wish to use "the effect principle" in fire management (Adapted from Whelan 1995) (See text).

1. What is the natural response of the target ecosystem(s) to the fire regimes to which it might be exposed?
2. What are the fire and land-use histories at the site? What environmental and cultural factors produced the present site conditions?
3. What are the life histories of the species of concern (endangered, keystone, dominant, indicator)? How do they respond to different fire regimes?
4. What are the community dynamics and how do community structure vary under different fire regimes?
5. What component or processes of the ecosystem are missing or irreversibly altered by anthropogenic influence (e.g. lack of intercommunity connections, species extirpations or extinctions, exotic species introductions)?
6. How important is the seasonal component of fire to each of the above? Can other facets of fire regime be manipulated to achieve the same result?
7. Can a reasonable facsimile of the natural fire regime be created? What compromises need to be made for safety and public relations, or because of conflicting uses?

gested. Kilgore (1973) suggested that a future fire management should attempt to "produce" the range of *fire effects* found historically, rather than attempting to discover and mimic fire season, intensity, severity, frequency and size of burns in an area. This "effect principle" is the same as suggested by Page et al. (1997) for Tiveden National park in South Sweden and which we have called *management of national parks based on fire history*, i.e. that one considers the elements of the historic fire regime.[9.8)] Researchers have constructed a list of what the management of a natural area based on this principle should consider before one makes decisions about prescribing a certain fire regime (Tab. 9.5) (Robbins & Myers 1992).

9.4.2 Large demands on expertise

Several countries have through firm demands required that management plans and strategies for fires shall accomplish ever more ambitious aims. Fire management representing both nature and resource management often has induced strong disagreements.

Developments in North America have given us clear examples of everything from how the understanding of nature and ethics by journalists is decisive for how they present their views of fires in the media (Smith 1995) to how political matters affect the planning through various views of the utilization of nature (Hurd 1995, Kilgore & Nichols 1995).

Some key words from the political argumentation about economics (resources) and quality of life (nature) that influence the decision-making process in the fire management of national parks are:

- nature vs. jobs
- wilderness vs. economic interests
- threatened and vulnerable species vs. progress and development
- plants and animals vs. money
- natural fires vs. air quality.

Various concepts of what is "nature" is important for the argumentation of any interventions being done in management, determined by social, economic and cultural definitions of resources and how they should be preserved and used (Kilgore 1985, Stankey & McCool 1995).

With background in this technical report we know that management of fire ecosystems encompasses many different topics such as handling of air quality, social conditions and political considerations, planning of prescribed fires, management of wildfires, measurements of fire effects on different scales, knowledge of fire ecology, evaluations of fire hazards and fire-suppression, and coping with media and other information service aiming at the general public (See among others Brown et al. 1995).

This can only be done by developing expertise in fire ecology, which will involve a certain concentration on research in fire ecology. This fact is already acknowledged by main research authorities also in Norway (see Solbraa 1997a).

9.4.3 Norwegian fire management for the future

There are several challenges Norwegian nature management has to meet in the future. We are going to comment upon some of them here (Fig. 9.5).

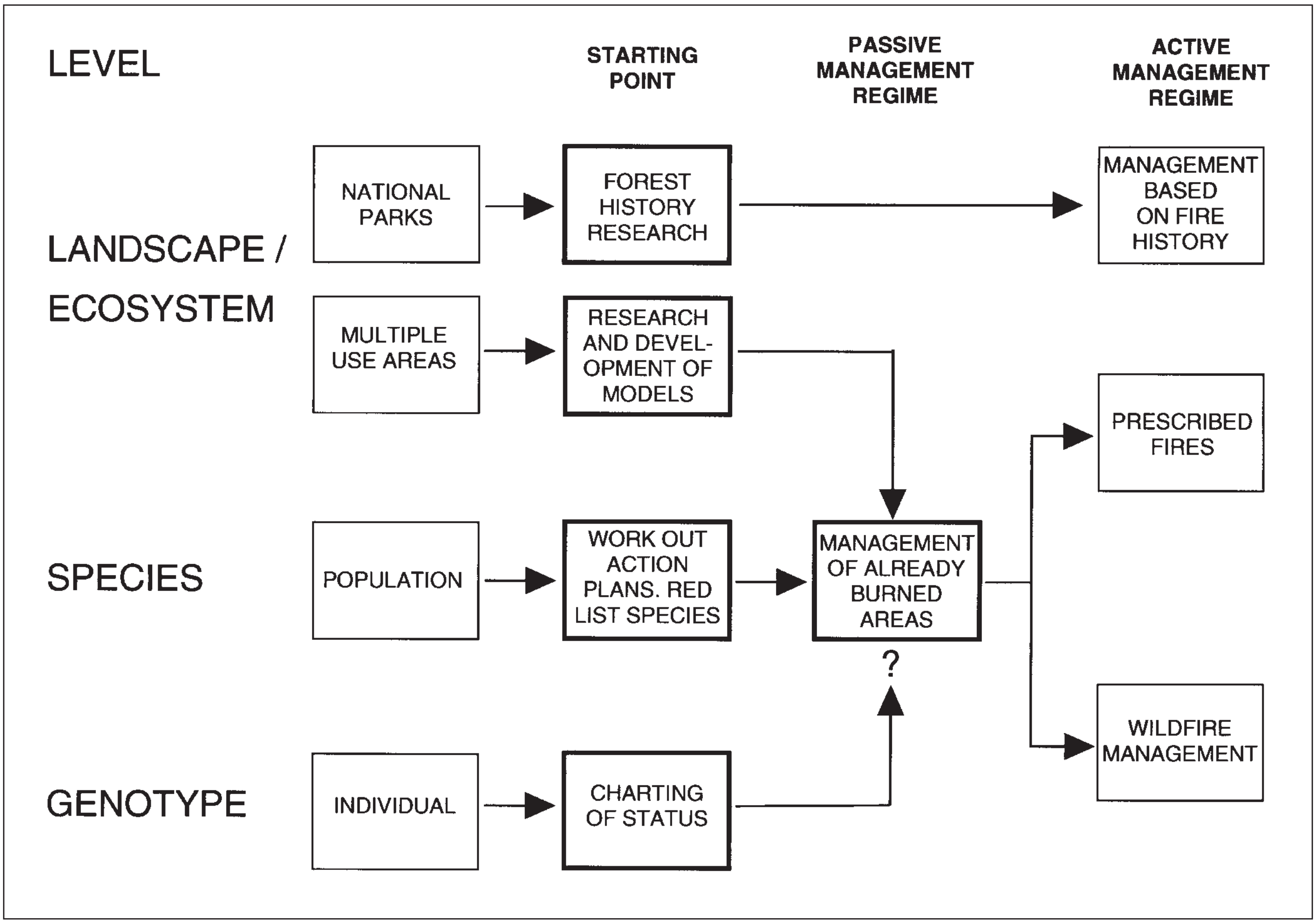


Figure 9.5. Flow chart showing management levels (genotype, population, ecosystem) which are covered by the diversity convention (left) and the tasks that are the challenge for today's Norwegian management (point of departure). The management is classified into a passive (management of already burned areas) and an active management regime (use of fire). Tasks in boxes marked by thick lines may be started at once. The active management regime will demand further research and development (See text).

In northwestern Europe fire suppression has proceeded for such a long period that it has led to a dramatic decline, even elimination, of some species of fire adapted insects (Heliövaara & Väisänen 1983, Lundberg 1984, Ehnström & Walden 1986). Environmental conditions linked to the dramatic reduction in fire frequency in most boreal coniferous forests (Heinselmann 1973b, Zackrisson 1977a, Wright & Bailey 1982) does not necessarily have to be the result of active fire suppression (see Stein et al. 1992), but may also indirectly be traced to structural effects from a forestry which among others used changed composition of forest tree species and where the amount of dead wood is significantly reduced (Romme & Despain 1989). Even the removal of burned trees is negative for species that are fire specialists (Heliövaara & Väisänen 1983, Ehnström 1991, Wikars 1997). Fire adapted insects need a continous access to dying and dead wood and other particular resources that are present in burned forest areas.

Management trying to counteract such changes, may as a point of departure adopt a different *management of already burned areas* (Fig. 9.5); this is being suggested by the Levende Skog project in Norway (1998). If research shows that this is not sufficient to favor the species of interest, the use of well planned *prescribed fires* and even *wildfire management* may be evaluated (Fig. 9.5). If wildfire management in the future is to be considered in Norway, this will probably be on impediment and in low productive forest/forest of low value in particularly steep and inaccessible areas. These are areas where the costs of extinguishing fires may be high, and where the burning of a somewhat extended area is more acceptable.

9.4.3.1 Conserving diversity

There is (ch. 4 and 6) considerable uncertainty about the impact of a natural source of ignition as lightning strike

has had in Norway, or how the historic fire regime (Section 2.2.5) has affected the ecosystems in various regions (read: fire regions, see ch. 7). This has to be the basis in a management that preserves and secures the biological diversity in Norway, genotypes, species or ecosystems (Fig. 9.5).

9.4.3.2 Genotypes

It is unsettled if there are genotypes in animal populations in the form of particular color morphs associated with fires in Norway (Section 8.4). This should be examined closer so that a possible Norwegian status may be clarified (Fig. 9.5).

9.4.3.3 Species

The basis for doing species management is that one has identified fire specialists and possible profiteers which have such threatened status that they need particular action plans. This should be explored closer and the Norwegian red list revised so that the real status of the fire species emerges. This will demand expertise in both botany and zoology, and the work is already well under way (Gundersen & Rolstad 1998a,b). Then action plans should be developed similar to those of the Council of Europe (Section 9.1.4) for species that require particular and/or long-term actions (Fig. 9.5).

9.4.3.4 Ecosystems

There are some experimental prescribed burns in the landscape of Norway, and considerably more in Sweden and Finland. This is advantageous for increasing our knowledge base concerning the practical sides of burning in range areas. However, it is important that thorough, research-based pilot studies are undertaken if burns are planned as a routine procedure in landscape management. There are internationally several advanced models that today may be of help in fire management. In this field Norway lacks expertise.

As basic principle in management of ecosystems we will recommend the effect principle, or management based on fire history, in protected areas (Section 9.4.1). This will involve the initiation of research with the aim of mapping the fire history, to the extent possible, in all national parks and larger forest reserves where one wishes to recommend the use of fire in management (Fig. 9.5). Not until one has a more certain historic platform which to rely upon, can one formulate a management plan. Broad research and development (Fig. 9.5) will be necessary to clarify a possible use of fire in Norwegian multiple use areas. We will not go into details here regarding what will be required, but extended research activity is now planned in Norway where this may be focused in suitable projects (Solbraa 1997a). Concerning all management at the landscape level, we would, however, urge for caution.

9.4.3.5 Critical attitude required

The discussion concerning fire management in Norway is strongly influenced by the extensive and advanced research that has been conducted in Sweden (especially in the north) over several decades. However, we should have a critical attitude towards viewing forest fires in general as an equally important ecological factor in our geographically diverse country (ch. 3). The association between forest fires and today's structure and function of the forest ecosystems is very complex, and the fire regime may vary over short distances (ch. 5). Ohlson (1997) warns that it may lead to serious negative consequences if we uncritically and stereotypically assume that natural forest fires have had a big impact in a broad specter of various forest ecosystems in Norway. The reasons for taking a critical attitude are summarized by Ohlson (1997) in the following points:

1. Basic studies that document the frequency and distribution of previous/historic forest fires in Norway are lacking.
2. The areas in Sweden, where the best studies were conducted, are characterized by a continental climate that has limited distribution in Norway. Since the climate of Norway is more maritime and precipitation rich and there is a connection between climate and fire frequency, lightning ignited, natural fires have been less common in Norway than in Sweden.
3. Because of topographical conditions we may expect a large spatial variation concerning the course and importance of fires within limited geographical areas. As an example forest ecosystem that looks similar and are located just a few hundred meters from each other, may have totally different influences from previous fire history (ch. 5). There are fire refuges in Norway, i.e. areas that have never been touched by fire, close to forest ecosystems with a past that is strongly affected by fire.
4. Studies conducted so far indicate that forest ecosystems that totally or partly lack traces of direct influence from fire, may be common (see ch. 5).
5. High frequencies of fire that actually occur in many areas, often may be anthropogenic and can therefore not be used as an argument that forest fires are important as a *natural ecological* factor.

If the Norwegian future management should ever be aimed at undertaking something that returns forests to a larger degree of “naturalness”, we would have to decide what impact natural forest fires may have had in Norway. If this becomes possible, we know that the fuel in the Norwegian forest landscape is manipulated by man to a degree that makes it impossible for any fire to take a “natural” course even if ignited by lightning (see Section 4.3.9). An uncritical introduction of fire as a strategy to make future forestry more “ecologically correct”, may even be thought to make more damage than gain (Ohlson 1997). The reason that we have to be careful is that burning remnants of cut forests that have not been affected by fire earlier, cannot be expected to conserve any “natural” biological qualities or move anything closer to a “natural” condition (see Section 9.3.5.2). We have to remember that every time we ignite a prescribed fire or “seizes” and starts managing a wildfire (Section 9.1.2), we contribute to more anthropogenic burning in Norway.

9.4.3.6 Integrated part of forest management

The management of forest resources in Norway should be done in a way that long-term ecological “balance” is secured (Bö & Haugen 1993). The use of a “balance concept” perhaps should not be emphasized too categorically in connection with fires, particularly in light of new ecological theory that points out the role of “chaotic” processes in nature. However, it is emphasized that when forest areas and forest resources are to be managed and utilized, it is of particular importance that the forest are taken care of as *ecosystem*, so that the basis for biological production and diversity are maintained (Bö & Haugen 1993). It is our hope that Norwegian management will remain at its stance that management should be knowledge based also concerns fires. If so, forest fires in management and research will be able to become an important topic in Norway.

9.5 Summary

The paramount principle in international management of forest and range fires in this century has been and still is suppression. This also applies in Norway. Such fire fighting has been so effective over the past 100–150 years that unforeseen consequences may have also contributed to changes in flora and fauna.

Therefore, management of forest and range fires and how one chooses to look after burned areas is regarded by an increasing number of people as being of critical importance for managing stands, maintaining diversity and in part recreating certain qualities in the landscape that many industrialized countries have lost as a result of fire fighting and clearing of fire fields. In areas where forest fires constitute a natural disturbance regime, there is growing recognition that it is neither possible nor desirable to maintain all nature areas completely without fires. The three most important management strategies as regards this are 1) care of already burned areas, 2) deliberate ignition of so-called prescribed fires and 3) “take over” or “guidance” of wildfires that are already ignited (wildfire management). This often entails conflict-filled combinations of scientifically founded management based on ecological goals and resource management of economic values. Obviously, fire management is most important in areas which burn a lot, but also in countries such as Norway with a pronounced oceanic climate and a cool fire regime, the development of strategies for nature management in these areas have become relevant. The foundation for such work is to obtain an improved mapping of the country’s fire regime, an improved historical perspective and an overview of the species that are relevant in this context.

In this report, we look at the management of forest and range fires in a broad perspective. Our review starts with an overview of the ranges of application where prescribed fires have been used in international management work (Tab. 9.1). Then we comment on the two main strategies for ignition, random and planned ignition, with emphasis on the importance of evaluating the objectives of the management compared with the potential consequences of fires. Fire is an ecological “broad-spectrum disturbance”, and an impact analysis of prescribed fires will almost always be encumbered with some major uncertainties as regards the outcome.

The basis for management of Norwegian coniferous forests in the future is to ensure a sustainable development where all sectors and industries are directly responsible for the environmental consequences of their own activities. This work rests on two important foundations. The first is a number of international conventions and environmental agreements that will generally address the problem areas surrounding maintaining diversity (Tab. 9.2). These will also have special significance as framework conditions in the work with fire-adapted species. The second is a number of acts and regulations that explicitly apply to Norwegian forest management. These will be determinant with regard to developing national strategies in this part of nature man-

agement. The challenge to this management will be to ensure that activities connected with care of already burned areas, prescribed burning and potential wildfire management meet scientific objectives in the conservation work which can simultaneously be accepted by more pure user interests.

The most common use of prescribed fires internationally has been in the work on preventive fire fighting, i.e. lowering the risk of high intensity and large wildfires ("risk reduction"). As the fuel load is important to the intensity and severity of a fire, fires in areas that are "over-saturated" with fuel can run completely out of control and develop into "catastrophic fires" that can more or less strip the ecosystem of organic material.

This can be prevented through the construction of barriers in the form of "fire breaks" or "fuel breaks" where combustible material is manipulated. This form of burning has been and is so universal that we are probably talking about the first usage of prescribed fire. Manipulation can encompass everything from cutting, lopping, thinning and removal of combustible material to planting of species that do not burn as well.

In many areas, routine use of preventive fires has exposed problems that must be regarded as being classic in today's fire ecology. Among these is the fact that fires can lead to local extermination of obligatory seed setters through the elimination of seed banks. In a number of countries, management-related fire intervention has also led to the advancement of societies dominated by weeds, often with more combustible species than were present originally. This is a highly undesirable effect in areas where one burns to reduce the risk of fire. Selection of the fire season and the practical organization of the fire programs are of the utmost importance for the results one wants to achieve. The same applies to planning of refuges and partial areas that are not to burn. Among the recognized practical application areas for prescribed fires in international terms is the removal of vegetation in water reservoirs to increase the run-off, clearing fires for agricultural purposes and burning to increase the occurrence of grazing plants for game species and domestic animals. "Primitive" pastoralists often practice annual burning of their areas, but in many places, the relationship between grazing and burning is a multifaceted problem. There are numerous examples showing that the combination of overgrazing and burning constitutes a particularly unfortunate combination. Also in Norway there has traditionally been extensive burning to improve grazing for domestic animals in outlying ranges. This practice has lasted all the way to the present.

Fire is often a useful method of accomplishing a shift from one type of vegetation to another, and burning has also been used for various purposes in the care of forests, for example in the form of clear-cut burning. In terms of temperature, however, the burning of cut areas is often not comparable with the combustion of all logging waste that has accumulated. The interest in clear-cut burning appears to be on the rise again. Focus is now also being aimed at so-called "patch burning", i.e. scorching of smaller patches on the forest floor to improve the conditions for establishing forest trees, which may be a potential management method for future forestry in Norway. A relevant research topic in Norway has also been the problems associated with removal of wood and regeneration of the forest in burned areas.

Some of the first and most successful examples of the use of fire in modern nature management can be seen in connection with the care and production of game species. A classic example is the use of fire on the Scottish heather moors to increase the grouse production. Burning of heath according to the Scottish system has also been attempted in Norway with the objective of promoting production of grouse, black grouse and hares. The results from such burnings appear to be highly variable. This may be due to difficulties in controlling the severity of the fire. These are factors that indicate that the bedrock and the soil are so poor and the humus resources are so small in many outlying ranges that such a treatment regime should not be applied on a large scale in this country.

In international fire management in the northern areas, the cervids constitute the animal group that has been discussed most widely, and it is also the group for which we can refer to examples where prescribed fires have been successful.

In this report, great emphasis has been placed on presenting the background for the scientific debate on management of forest and range fires, and also the potential ideas and management strategies that are now being discussed in the new field of "diversity burning". Conservation of diversity as it is expressed in Norwegian management documents means conservation at three different levels: genotypes, species and landscapes/ecosystems. The interest in burning in connection

with nature conservation is also on the rise in all of the Nordic countries.

One of the basic premises in Swedish management is that the coniferous forest and the landscape have previously been shaped by large-scale dynamics caused by disturbance regimes, primarily fires. A number of new ideas have been presented in Swedish management in connection with formation of strategies with the objective of burning more. One example is the so-called ASIO model, the use of which has been proposed as a tool to define new fire regimes on different scales. ASIO proposes a classification of forest lands into four categories based on different fire frequencies: fields that have *N*ever burned, those that are *R*arely affected by fire, those that have burned *O*ccasionally and those that have burned *F*requently (ASIO is the Swedish acronym). However, stereotypical use of such models in areas where the fire regime is not well known should be avoided, and it is clear that extensive testing and research is needed before such systems can be put into use on a landscape/ ecosystem level in this country.

As regards management at the species level, which will primarily include vulnerable or threatened species according to revised red lists, the Council of Europe now recommends that the future management should develop plans for special measures. Only a smaller number of red-listed species are relevant in the forest fire context. This applies primarily to certain types of fungi, lichen, and among the higher plants, particularly seed bank species as well as a larger species complex of invertebrates, particularly beetles linked with ash wood and other substrata/resources that are formed particularly in burned areas. If melanistic forms exist, i.e. special genotypic color variations in species of Norwegian fauna that can be characterized as “fire morphs”, these must be studied in more detail. There are no fire specialists among the vertebrates in Norway, but several species, such as the white-backed woodpecker and ortolan bunting can profit in population terms from forest fires, and are thereby relevant in connection with the management of already burned areas or with potential active programs for burning in nature management.

By far the most difficult fire theory problems and evaluations are linked with management on the landscape and ecosystem level. Introduction of potential prescribed fires on a landscape level will require the development of new models to scale fires at a totally different and much higher level, and also the evaluation of methods to differentiate such programs according to location in the Norwegian landscape. Here we cannot automatically transfer experiences from management and research in other countries, not even from Sweden. However, that is not to say that we cannot start to do something for the fire species today. This primarily means to evaluate retaining larger or smaller quantities of damaged and dead lumber. This management is called management of already burned areas, and it may simply be an expansion of the forestry research already established in burned areas.

The most difficult assessments are in connection with management of fires in reserves and national parks, i.e. ecosystems that, according to specific criteria, are to be conserved for posterity. The objective of such management programs may be everything from restoration of an area’s “naturalness”, preserving the “status quo” (“freezing strategy”) or creating special types of conditions that are regarded as being particularly worthy of conservation in terms of history or nature. In many countries, disagreement has resulted in hesitation to introduce fires as a part of the management of national parks.

Through fire historical studies in certain national parks, it has been documented that forest fires ignited by lightning strikes may be relatively rare, and that it is the anthropogenic ignition sources that have dominated for long periods of time. This has resulted in suggestions for a management strategy that this report has referred to as management of national parks based on fire history. If burning in Norwegian national parks were to be considered in the future, this work could be started today with research to clarify the fire history of park areas.

A number of central features of the development of North American fire management in particular have been given special attention. With regard to burning in the landscape, the message from the discussion after the great fires in Yellowstone is that future fire management should direct its efforts to varied systems which “mix” various types of suppressing and managing wildfires with various forms of prescribed fires, all based on thorough landscape and fire ecology knowledge concerning the areas in question. This will place great demands on the development of fire ecology expertise. Finally, the chapter summarizes strategies that may be relevant for Norwegian nature management, but also emphasizes the necessity of having a critical attitude as long as so many uncertainties prevail regarding the character of the Norwegian fire regime. The reason that we must be cau-

tious is, for example, that burning the remnants of forests where wood has been removed (e.g. through clear-cut burning) and which have not previously been affected by fire, can hardly be expected to conserve "natural" biological qualities, or bring anything closer to a "natural" state. We must remember that every time we ignite a prescribed fire or "take over" and start to "guide" a wildfire, we are contributing to more anthropogenic burning. We emphasize the importance of Norwegian nature management maintaining its position that the management must be based on knowledge, also as regards forest and range fires.

10 FIRE LIMITING MEASURES

By Erik Bleken

As mentioned several times in this report, for many years, the leading line of management in Norway has been suppression of forest fires as fast and effectively as possible. The intention of this chapter is to summarize measures that are or have been used for limiting the extent of forest fires based on this philosophy. In addition, we refer to chapters 4 and 9, which also partly cover this important side of modern fire history.

Measures against forest fire can be divided into two categories, *forest fire prevention measures* and *forest fire extinguishing*. The former aims at reducing the likelihood of forest fire occurring. Prevention measures may include the clearing of forest, increasing awareness and improving attitude through information and training, satellite surveillance of forest structure and desiccation conditions. The effect of such preventive measures is recognized internationally.

For those who shall participate in forest fire extinguishing, it is important to be aware of the following: Forest fires vary with respect to extent, rate of spread etc., depending on type of terrain, wind conditions, degree of desiccation etc. (ch. 2). Therefore, at the outset, every forest fire must be treated as a unique event. This places great demands upon the fire chief's creativity and flexibility, and requires that the task force taking part in the work is well organized. Experience has shown that larger forest fires which last for longer periods of time demand good leadership, supply service and administration of personnel. It is therefore of the utmost importance that the command is well qualified.

Below, we begin by reviewing some fire prevention measures, and then continue with aspects of forest fire extinguishing. The description is mainly based on Norwegian conditions, but also includes information from other Nordic countries and international literature.

10.1 Forest fire prevention measures

Forest fire prevention measures include a wide variety of activities. Below, we present various ways of managing the terrain, methods for early detection of fires, development of regulations and collaboration between authorities, education and information measures, and Norway's participation in cooperative forms of forest fire preventive efforts.

10.1.1 Forest fire hazard prevention measures in the terrain

An important strategy to prevent spread of forest fire is fuel isolation. Several measures have been and are in use for this purpose. The measures fall naturally within two groups i.e. measures to isolate the fuel and measures to remove the fuel.

10.1.1.1 Measures to isolate fuel

There are several measures which, with varying effect, can isolate the fuel or indirectly decrease flammability.

Setting up vegetation free zones

The idea of establishing a strip or path that is "naked" down to the mineral soil in order to prevent forest fires from spreading into cultivated areas is as old as agriculture itself. When forest resources became valuable, this process was expanded to building similar firebreaks between roads and trails to section the forest. This reduces the risk of fires spreading through larger sections or the entire forested area (Chandler et al. 1983).

A benefit with such measures is that they can be concentrated on quite small areas such that the cost of establishment is relatively low. However, the maintenance costs can become very high, for example, the areas need to be cleared at least once a year. In USA, asphalting has been tried to cushion this, as well as using chemicals to sterilize the soil, and hormonal herbicides. However, none of these measures have turned out to be economically profitable. In light of this and other environmental concerns the use of chemicals and herbicides, which in the USA has been used since the Second World War, has declined strongly in recent years. Another disadvantage of this approach is that only the least intense fires are stopped. For instance, these measures were only effective against 46 % of a series of intense fires in California (Chandler et al. 1983).

Setting up zones with low combustibility

Measures to set up zones where the ground vegetation has low combustibility were introduced into USA during

the 1950s to overcome the disadvantages of the traditional vegetation free zones (Green 1977, Chandler et al. 1983). The principle behind these measures is to make a permanent change by introducing ground vegetation, which contains less fuel per acreage, and/or a type that is less combustible. In practice, this would mean planting either grass or bush species. The aim of these zones is not to stop the fire, but to serve as places where fire personnel can enter and suppress the fire. The zones therefore have to be wider than the aforementioned vegetation free zones to allow fire personnel to avoid fire and radiation damage. These wider zones are also preferable for the prevention of ecological edge effects and are judged to be a great improvement on the establishment of vegetation free zones. However, disadvantages include higher establishment costs per kilometer, zone maintenance, and periodic clearance of fuel that would otherwise accumulate in the ground layer.

Setting up zones that do not burn

The next logical step is to set up zones with ground vegetation that does not burn. On such areas the ground vegetation is totally transformed to a non-combustible type, and the areas maintained by watering and mechanical treatment, a golf course being a typical example. Such areas are expensive to establish for forest owners, but Chandler et al. (1983) recommend landscape planners to establish golf courses, parks and similar areas around densely populated areas as protection against forest fires. However, these are measures that are often met with opposition from environmentalists because forests can be fragmented in a way that is not consistent with other management objectives.

Planting of deciduous forests

Instead of changing the ground vegetation the hazards from forest fires can also be reduced by substituting existing tree species with less inflammable ones. We here refer to the planting of strips or belts of deciduous forest within surrounding coniferous forest, in planned mosaics and patterns. Such planting has been adopted in a number of latino-speaking countries like Portugal, Spain, France and Italy. However, in Norway the method is not widely used. It may, however, be desirable for exposed municipalities to undertake a general evaluation of the forests, with the intention of planting deciduous forests as fire barriers. It should be possible to use this measure to section large stands and establish barriers against densely populated areas. The introduction of more deciduous forest is also assumed to be far less problematic and raises fewer environmental concerns.

Species manipulation

It has long been a wish, in fire prone areas, to be able to reduce the fire hazard by introducing species that hardly or never burn. However, attempts to accomplish this have not been a success. It seems to be a trend in such areas that the most inflammable species invade. Recent findings appear to support a hypothesis that the flora of fire prone areas will evolve toward the most inflammable plant community, which can survive in the actual type of climate (Chandler et al. 1983). In spite of these somewhat discouraging results, Rico Rico (1977) suggests a number of measures that can reduce the hazard of large fires. These include planting of mixed stands instead of monocultures, perennial grass species instead of bushes, and careful use of fires to prevent invasion of fire adapted species.

10.1.1.2 Measures to remove fuel

This section presents a review of important measures used to remove fuel and illustrates benefits and costs of such measures. Any combustion is dependent on fuel, oxygen and heat (Section 2.2.1). If one removes one of these factors, the fire stops. Throughout history various measures have been implemented to remove inflammable matter in the forest. These measures can be classified into three types. The first two involve the use of fire, and constitute “prescribed burning”. The third type, which has previously been adopted in Norway, consists of specific removal of fuel by, for example, clearing. “Prescribed burning” is presented in chapter 9, and is only mentioned here as a forest fire preventive measure. One type of prescribed burning burns away accumulated dead matter in the ground layer below upright stand. The other method, where upright stand is lacking, deals with open clearings (clear-cut burning).

Burning under standing forest

The aim of this measure is to limit available fuel, and thus limit both the likelihood of forest fire and the extent should fire occur. This measure is most easily carried out with greater success in older stands; in younger stands the fire can easily spread to the trees and cause damage. It is recommended that the fire intensity and hardness be kept to a minimum so that one doesn’t burn too much humus, or in the worst-case burn down to the mineral soil. This implies that the method must be undertaken a few days after rainfall; alternatively, early in the spring in areas with snow, so that the humus layer is protected from burning by frost or dampness, while the surface litter is dry enough to be ignited (see Section 4.1.9).

Clear-cut burning

In Norway, clear-cut burning has in modern times (until 1947–48) been carried out with two objectives in mind, viz. soil improvement by making the nutrients more accessible, and removal of inflammable matter to reduce the forest fire hazard (Strømsøe 1964). Later, there was a break in the use of clear-cut burning in Norway, but it has recently, to some degree, come back into use (ch. 9).

Such clear-cut burning has to be undertaken very carefully. It should be controlled and planned to prevent the burning from escalating into an unintended forest fire. Therefore, one has regarded it as necessary to regulate the clear-cut burning with acts and regulations. Hence *Regulations No. 906 of 15 December 1987 relating to Fire Prevention, etc., with amendments, the most recent by No. 405 of 3 May 1995* has a specific chapter 9 (which supplements § 13 in regards to common attention in *Act No. 26 of 15 June 1987 relating to Fire Prevention etc.*); with provisions concerning clear-cut burning. The regulations give specific and detailed instructions concerning preparations for clear-cut burning, the implementation itself, and the follow-up measures. Amongst other things, specific instructions are given regarding leadership, warning, establishment of fire lines, the process of burning, post-extinguishing and guarding.

Sweden and Finland have also reintroduced clear-cut burning. In Sweden this was initiated in 1994–95, with two objectives in mind: to do research, and in addition to achieve soil improvement on Stora Skog's properties. In Finland, the main purpose was to achieve soil improvement.

It is important, amongst other things for security reasons, to be aware that "all farmers who owned forest" in these three countries in earlier times, carried out clear-cut burning and had experience with it. This experience can now be said to have been lost, and presently clear-cut burning only occurs on a very small scale (Strømsøe 1987). If clear-cut burning again should become common, it is essential both that experience is built up once again, and that regulations are closely followed.

10.1.2 Detection of forest fire

It is well known from times gone by that the best way of reducing loss of forest is through early fire detection, and to attack them quickly and thoroughly (Chandler et al. 1983). In accordance with this philosophy the USA established patrols early on, that searched the terrain from high observation sites to detect fires. The patrol routes covered high hills and ridges that offered a good overview of the terrain. With time, observation towers were built on such ridges and staffed in the most fire prone seasons. In Norway monitoring from such towers was an important measure in the forest fire preparedness (Fig. 4.10) until it was replaced by airplane monitoring in the 1960s (whereas in the USA planes were adopted as early as the 1920s). In all these phases of development the sightings have been based on observations by the human eye. Some countries have recently also adopted infrared detectors, in addition to establishing round-the-clock video to replace traditional observers. In recent years, a number of electronic instruments have been introduced connected with satellite surveillance stations. The observation methods used vary a lot between countries, and the traditional use of observation patrols and fire towers still exist in some places. It must also be mentioned that a fair share of the fires are detected by the public, particularly near densely populated areas (Chandler et al. 1983). We comment in the following section on airplane monitoring, satellite surveillance and public warning duties, all of which are relevant to Norwegian conditions.

10.1.2.1 Airplane monitoring

Fire tower observations were, as mentioned, abandoned in Norway during the 1960s and replaced with airplane monitoring (Strømsøe 1987). One has seen the same trend in other countries, for example in North America (Chandler et al. 1983). The two most important reasons for this shift were high costs of maintenance and manning of towers, and the greater flexibility achieved through the use of planes. Today there is a well developed airplane monitoring system in Norway implemented by two active parties, the Norwegian Air Club and the commercial airlines. The primary active party, is the Norwegian Air Club (Norw. "Norsk Aero Klubb", NAK, see Section 11.5), which carries out extensive monitoring by means of its various plane clubs. This activity is run on a volunteer basis around the districts in cooperation with relevant municipalities, and every year agreements are set up between the municipalities and NAK concerning airplane monitoring. These agreements specify, for example, how often plane monitoring is to be undertaken, how many hours are to be used, how the monitoring is to be organized and the costs of monitoring. The Directorate for Fire and Explosion Prevention (DBE) requires that any forest fire pilot has to have undergone specific training by NAK in cooperation with DBE.

The airplanes are also of benefit to the fire service during the extinguishing work itself. From the air, the pilot can give instructions concerning choice of roads, water sources etc., and where personnel can best advance over the terrain. The pilot will also be able to supply information pertaining to status and any changes in the course of the fire due to, for example, wind direction.

The other contributory active parties are the commercial airlines. To some extent their pilots report observed forest fires, but the routines for reporting are still not satisfactory. The reports are not collated systematically and are frequently not passed on to the appropriate authorities. Work is in progress to establish an organized warning and reporting system over the whole of Norway. This process is conducted in cooperation with the pilots' organizations.

The environmental impacts of airplane monitoring primarily concern noise pollution. Such noise pollution can be particularly critical in periods when animals are forced to stay in the same area, for example during periods of nesting and breeding. In many places such disturbances are considered to be quite damaging by the Norwegian nature management. It can, for example, be mentioned that it is not permitted to land on Hardangervidda specifically because of possible damage to wildlife.

10.1.2.2 Satellite surveillance

In 1999 the UN and NASA launched "Fire Sat", a surveillance satellite intended for observing and tracking forest fires worldwide. The data gathered from the satellite are to be stored in a common archive to create a continually updated assessment of the global forest fire situation. This means that, from the turn of the millennium, it will be possible to observe forest fires from satellite in each individual country. Finland has already developed a satellite system for national forest fire surveillance that extends to areas in neighboring countries Still, this surveillance is in its initial stages. If Norway were to enter into cooperation with Finland in this field, the extent of this would be dependent upon costs and the availability of alternative satellite surveillance solutions.

A number of computer programs have been developed in different parts of the world that utilize the information gathered from airplane and satellite surveillance. When used in conjunction with climatic data and lightening frequencies one tries to predict when and where forest fires may be expected. The development of such models is a research field in rapid growth (Weiss & Goldammer 1984, Goldammer & Furyaev 1995).

10.1.2.3 Forest fire monitoring by the public

As mentioned the public can be a useful resource in the detection of forest fires. It is therefore important that people in general are alert to fire and smoke in forests and outlying ranges during the fire season. In Norway this requirement is pursuant to §15 in the *Act No. 26 of 15 June 1987 relating to Fire Prevention etc*. which states that anybody who detects or learns that a fire has started or could start is obliged to warn the fire services immediately, unless the person can safely extinguish the fire without assistance.

10.1.3 Regulations and cooperation between authorities

An important aspect in the preventive management of forest fires is appropriate legislation and the establishment of effective preparedness and response measures. Since forest fires have a potential to become both long lasting and cover large areas there might, in some cases, be a need to utilize large quantities of resources (personnel and equipment). The responsibility for these various resources lies under several authorities and is regulated by different rules. In addition, volunteer efforts, and contracts between authorities and private firms are to be taken into consideration. The structures for organizing this apparatus are more thoroughly presented in chapter 11.

10.1.4 Education and information

Developing conscious attitudes and responsible behavior in the population towards forest fire, and in addition establishing efficient prevention and preparedness measures, is dependent on correct education and information. Extinguishing forest fires puts large demands on the task forces. This applies both to demands on physical strength, perseverance, self discipline, self-motivation, and also on the leadership and competent organization of the forces (Strømsøe 1987). Here, we briefly mention some of the prevailing educational offers in Norway, and information activities in the field of forest fire protection.

10.1.4.1 Education

Education within forest fire protection is currently directed towards the fire service and primary schools. In addition, education for holiday cabin owners is under consideration.

Fire service and the forest fire reserve

The Norwegian Fire Protection Training Institute (Norw. “Norges brannskole”) at Tjeldsund, Nordland county, conducts most of the education courses for the Norwegian fire service. The institute offers two different forest fire courses: one course is primarily aimed at implementing practical fire extinguishing while the other focuses on forest fire leadership.

The forest fire protection course was developed by Gudbrand Mellbye, Østfold Skogselskap, who has run the course for a number of years. The course is held at Sønsterud Forest College in Akershus.

The course in forest fire leadership was developed in 1993 by personnel at the former military academy Gimlemoen in Kristiansand in Vest-Agder county on the instructions of, and in cooperation with, DBE. The course is now given at the Norwegian Fire Protection Training Institute. Both courses are currently held annually.

10.1.4.2 Education in primary school

As is well known many of our attitudes and values are formed early in life. A program in forest fire protection zhas therefore been targeted at 3rd, 5th, and 8th grade of primary school (4th, 6th, and 9th grade after the “ six-year-olds” reform). The program includes both teaching instructions and pamphlets for pupils. The importance concerning careful avoidance of forest fires is introduced and discussed at all three grades, with particular attention being paid to the 8th grade (9th grade after the “ six-year-olds” reform). The education material is developed in cooperation between DBE, Norwegian Insurance Association (Norw. “Norges Forsikringsforbund”), and Norwegian Fire Protection Association (Norw. “Norsk Brannvern Forening”) with financial support from other sources. The cartoon figure “Trygge” (a green dragon whose tail forms an extinguishing hose) is used throughout all three sessions to increase the degree of recognition and thus assist the memory-based learning process.

10.1.4.3 Other groups

In the last decades large holiday cabin towns have evolved in Norway, many of which are located in areas with high fire hazard potential. The education of cabin owners in such areas is therefore under consideration to enable them to take fire extinguishing measures should such be necessary. Such educational measures will, if realized, be undertaken under the supervision of the local Chief Fire Officers.

10.1.4.4 Information

The information manual “Forest fire and forest fire protection” (Skogbrand Insurance Company 1988) was developed by the insurance company Skogbrand and DBE. It is obligatory and distributed to all Norwegian Chief Fire Officers. The manual is formed to enable its use as course material in addition to being a source of information. It consists of four parts. Part 1 deals with the forest as a fire object, the natural development of forest fire, and the suppression of forest fire. Part 2 deals with forest fire suppression itself and deals with, amongst other, the problems concerning manning, organization, equipment demands, and air support. Part 3 gives specific checklists for use by the different categories of personnel that take part in the forest fire extinguishing process. Group work exercises are also included. Part 4 consists of a set of transparencies for teaching purposes.

The public is kept informed by forest fire awareness posters which are hung up on tourist hut and cabin walls and on trees along frequented forest trails. The municipal forest management is responsible for the distribution and posting of this material, which is performed in cooperation with the local fire service.

An important source of information about forest fire hazard is the two minutes warnings broadcast by the Norwegian Broadcasting Corporation on days with high forest fire index. These are shown on television during the evening weather forecast and broadcast on radio weather forecast throughout the day.

In addition to these measures, both DBE and the Norwegian Fire Protection Association issue press releases before the start of the forest fire season (April 15), and also during the season should exceptional cases of forest fires occur.

10.1.5 Cooperative models in forest fire prevention

Several cooperative models for prevention of forest fires have been established in Norway. In addition, Norway participates in forest fire cooperation on both Nordic and global levels.

10.1.5.1 On a national level

A national “Liason Committee for Forest Fire” (Norw. “Kontaktutvalg for skogbrann”) has been established to coordinate forest fire efforts. The committee discusses the premises for the forest fire service in Norway. It is repre-

sented by DBE, the Directorate of Nature Management, the Directorate for Civil Defence and Emergency Planning, the Agricultural Ministry, the Norwegian Meteorological Institute, the Fire Service, Skogbrand Insurance Company, Norwegian Air Club, the Norwegian Fire Protection Association, and the Helicopter Service. The committee regularly convenes twice a year. The first meeting is held during April just before the start of the forest fire season to plan the year's strategy, while the second meeting is held after the season, in November, to summarize and exchange experiences.

10.1.5.2 On a Nordic level

Denmark, Finland, Norway, and Sweden participate in "The Nordic Forest Fire Group" (Norw. "Den Nordiske Skogbranngruppen"). This is a forum where the more general aspects of forest fires are discussed, for example monitoring, mapping, storing statistics and practical combating of forest fires. A central problem related to combating forest fires, which occur in border areas between the countries, is how to achieve the best possible utilization of combined resources.

10.1.5.3 On a global level

Norway is a member of the European Timber Committee, which conducts activities directed towards forest fires in Europe and the rest of the world. The committee meets every 5th year, and DBE contributes annually by reporting national forest fire statistics. The purpose is to enable participating countries to submit and exchange standardized forest fire data, which is collocated by the central command. This information is then used by member countries to evaluate and compare forest fires and the surrounding activity and to enable them to view developments in a global perspective.

10.2 Forest fire extinguishing

Forest fire extinguishing is a complex topic, and many pieces need to fall into place to achieve success. The following is a summary of the organizing and activity measures which are necessary. Some principles that form the basis of forest fire extinguishing are mentioned in specific sections. If the extinguishing of forest fires is to be undertaken efficiently, knowledge concerning the fire's natural development as well as knowledge of local forest and terrain conditions is necessary. There are two main principles of extinguishing forest fires: direct (offensive) extinguishing as used against smaller fires (Section 10.2.5), and indirect (defensive) extinguishing as used against larger fires (Section 10.2.6). Which of these two principles shall be used is a decision which must be made by the command when the extinguishing force arrives at the scene of the fire. This especially applies when the fire has been in progress for some time before the arrival of the extinguishing force. The decision must take into account any danger of loss of life and the presence of special installations and objects of material value (houses, cabins etc.).

10.2.1 Warning

Early warning of forest fire is one of the most important measures that can limit the extent of the fire. The obligation to warn is therefore laid down both in acts and regulations. According to the *Act No. 26 of 15 June 1987 relating to Fire Prevention etc.* anyone who detects that fire has broken out or threatens to break out is obliged, to warn the local fire service, as previously mentioned, unless the person can immediately extinguish the fire and ward off the danger. According to *Regulations No. 906 of 15 December 1987 relating to Fire Prevention etc., with amendments, the most recent by No. 405 of 3 May 1995* personnel in aircraft above Norwegian territory are obliged to warn the authorities of fire that is observed from air.

In practice, all forest fire warning should go via the national fire emergency number, 110, to the nearest regional 110-emergency call center. In counties, which have established airplane monitoring in cooperation with the Norwegian Air Club (see Section 11.5), the coordination of monitoring planes is undertaken from only one of the county's regional 110-emergency call centers. This is a rational procedure that functions well.

10.2.2 Organization

The principles for the organization of forest fire preparedness and response, and for the fighting forces themselves are authorized in the regulations of May 3, 1995. These regulations encompass a number of factors: cooperation, support, reserve forces, and communication. The responsibility lies with the fire service within each municipality. This was not the case earlier. It may be mentioned that the first rules were introduced by the Royal Decree of 17 September 1900, the so-called "Forest fire rules" (Norw. "Skogbrandregler"). An important change at that time was that administrative counties were divided into fire units (Norw. "roder"). Until 1970 the forest owners were responsible for extinguishing forest fires. With the introduction of the new fire act of the same year the present system was introduced where the responsibility lies with local municipalities (Strømsøe 1987). Further discussion

on important roles in the extinguishing of forest fires can be found in chapter 11.

10.2.3 Obligation to assist

The responsibility of forest fire preparedness and response thus rests with the local municipalities. It is, however, important to mention that in accordance with legislation (*Regulations No. 906 of 15 December 1987 relating to Fire Prevention, etc., with amendments, the most recent by No. 405 of 3 May 1995; Act No. 26 of 15 June 1987 relating to Fire Prevention etc.*) any person is required to participate with available extinguishing equipment, if the Chief Fire Officer so demands. This duty also applies to adjacent areas in neighboring municipalities.

10.2.4 Communication

Long experience has shown that a competent communication network is of utmost importance in the fighting of forest fires. A specific forest fire frequency (161.475 MHz) has therefore been established. The forest fire helicopter is equipped with this frequency and communicates with the fire service on the ground.

Communication between the fire service out in the field and the 110-emergency call center is conducted over the ordinary communication frequency of the fire service.

10.2.5 Direct fighting (offensive extinguishing)

During direct fighting the fire is attacked as a stationary fire, with available forces and equipment (see Strømsøe 1987). Most small forest fires are extinguished in this way. However, this requires early warning, good preparedness, and a fast turnout to enable the force to be present at the initial stage. Somewhat more extensive forest fires can also be attacked in this way, but only if there are sufficient resources (personnel, equipment, good accessibility to water). The main point with direct fighting is to break open the fire front through a concentrated effort at one point. It is recommended to concentrate on an area where the forest fire is “down on the ground”, and then gradually expand the effort to either side.

“Direct extinguishing” of forest fires that move quickly, like high head fire in older pine forests, cannot be recommended due to the high risk level. This is because direct fighting always involves the necessity of fire personnel to work close to the flames in intense smoke and heat. This results in high stress levels and the need for frequent renewal of personnel. All these factors are intensified in quick head fires in better developed, young forest stands.

Below is mentioned some of the most important contributing factors used in connection with direct extinguishing. This encompasses extinguishing from helicopter/airplane, smoke jumpers, explosives and chemicals, respectively. The list is not complete, and all of the mentioned techniques are not used in every single forest fire. This will vary from fire to fire within a region, between regions and between different countries.

10.2.5.1 Helicopter/airplane

Helicopters and airplanes are important aids in forest fire extinguishing. The main function is the distribution of water directly onto the fire. The planes have specially designed containers on board, which can both be filled and emptied from the air. The helicopters have transport buckets hanging underneath which can also be filled and emptied from the air. In addition to this water supply the plane crew, who in many instances have seen far more forest fires than the extinguishing command on the ground, contribute with strategic advice. A particular benefit of helicopters is their flexibility. It makes the helicopter perfect for transporting various equipment and forest fire personnel. In addition, helicopters are not dependent upon large open lakes or oceans for refilling their containers, but can acquire water from relatively small streams and tarns (see also section 11.4 about use of helicopter for forest fire extinguishing in Norway).

Helicopters and planes are today used for forest fire extinguishing all over the world. In steep alpine areas the helicopters have obvious benefits and are most frequently used. In areas of flat topography and difficult water accessibility light aircraft come into their own. Both helicopters and aircraft are in use in Europe, Russia, USA, and Africa.

Chandler et al. (1983) give a good overview of the history of the plane and helicopter in various parts of the world. On a worldwide basis planes were used before helicopters in the fighting of forest fires, for the simple reason that planes were manufactured first. The benefits from the use of both types of air transport made them fully utilized in the forest fire extinguishing service only a few years after they were invented.

The USA was first to use planes for forest fire monitoring, already in 1915. From 1926 planes were also used to drop equipment, and 10 years later to take aerial pho-

tos that were dropped to the ground personnel for the planning of activities for the coming day. The first serious attempt to develop “water bombing” in the USA began in 1947–48, but water bombing did not come into extensive use until after 1954, when a good technique for dropping cascades of water directly down from planes onto the terrain was developed. Helicopters were put into operation for extinguishing forest fires in 1946.

In Canada planes were not used in forest fire extinguishing until the 1920s. However, interest in planes increased rapidly, and in 1924 as much as 60 % of all flights in Canada were attributed to forest fires and forestry. As in the USA the use of water bombing started during the 1950s. Canada has developed several types of planes specifically constructed for use in forest fire extinguishing.

In Europe extinguishing from the air started somewhat earlier than the 1970s, and the first attempt with water containers was performed in France in 1963. The Canadair CL-215 came into extensive use early in the 1970s in several countries in southern Europe (France, Spain, Greece, and Yugoslavia).

In the Soviet Union the use of planes started relatively late, after which there was a rapid development. The first attempt was in 1932, but by 1939 the Soviet Union had an operative force of both smoke jumpers, water bombers with chemicals, and a unique airborne watering system (Norw. “sprinkler system”). After the Second World War they began to experiment with helicopters, and by the middle of the 1970s the Soviet Union had the largest special force of skilled helicopter personnel in the world.

In Norway the large scale fire at Elverum in 1976, was the starting-point of extinguishing activity from the air by the introduction of the Catalina Amphibium plane, later replaced by helicopters in 1986 (cf. section 11.4). Finland has also adopted helicopters, which have been in use over the last ten years. On the other hand, Sweden has, from 1995, chosen to use the Canadair.

Forest fire extinguishing from the air is carried out in all three Nordic countries. Norway has, in addition to extinguishing on a national basis, on occasion given assistance in Sweden. Norway has also contributed more indirectly in forest fire fighting, with the development of a special type of bucket to transport water, an innovation that has received broad international recognition. It was developed as a cooperative effort between Lufttransport A/S and DBE, and financially supported by the insurance company Skogbrand. The bucket has unique mechanisms to portion out and spread the water during the dropping operation, creating totally new opportunities for directed dropping in one or several broad or narrow stripes, and for one or more point drops. The bucket is today used worldwide, and is distributed by a Canadian company (cf. section 11.4).

Sweden is involved in the extinguishing of their own fires, as well as those in Finland and Estonia, whereas Finland have concentrated on their own fires. However, both Sweden and Finland are preparing a possible extinguishing agreement with Estonia.

Norway has five helicopters permanently available for fighting forest fire. One of them is particularly earmarked for this purpose, and during the forest fire season is posted at Hønefoss. The other four helicopters are summoned on demand, and are posted at Sola near Stavanger and Flesland near Bergen. In recent years NOK 2.7 million has been allocated over the State Budget for financing the use of helicopters in extinguishing forest fires.

10.2.5.2 Smoke jumpers

The technique of smoke jumping was primarily developed in the USA in 1939, just before the Second World War, and was utilized after the war when military forces with special training went back to their civil lives. Use of the method has later declined in the USA in preference to using helicopters. zIn the USA there are today approximately 400 smoke jumpers. Canada also has a certain number. In these two countries this activity takes place in cooperation with the planes that undertake water bombing, albeit to a high monetary cost.

In Russia there were as many as 8 000 smoke jumpers up until 1991, when the number was reduced to 1 000. Here the work is performed in teams of six, with the use of explosives, backfires and chain saws; i.e. one does not use water (no so-called wet methods). This approach is cheap, but requires a high level of competence to be efficient.

The Nordic countries do not make use of smoke jumpers to extinguish forest fires.

10.2.5.3 Explosives

In fighting forest fires explosives have mostly been used in indirect fighting to make fire lines. The use is widespread in America and Russia, and the principle can be compared with ditch blasting. In addition, explosives have been brought into use to blast wells for providing extinguishing water. A new technique developed in Germany involves the use of explosives in the direct fighting of forest fires. This combines the use of water-filled hoses and a lengthwise core of explosives. The hose is located at a strategic site relative to the flame development, and on detonation of the explosives the water contributes to extinguishing the fire.

10.2.5.4 Chemical additives

Water has always been used to extinguish forest fires, and it works *inter alia* lowering the temperature, by thinning the fire gases so that the fire is hampered or stopped, and by covering the fuel with noncombustible matter reducing the contact between fuel and oxygen. Although water is a good and well known method of extinguishing, the use has its drawbacks. Firstly, water evaporates without leaving behind fire retarding substances. Secondly, water has a high surface tension, which prevents penetration of water into the interior of the fuel. Thirdly, water has low viscosity, something that readily makes it drip or run off the fuel (Chandler et al. 1983, Rosvall & Andersson 1995).

One has therefore attempted to improve the qualities of the extinguishing water by adding various chemicals with different effects. To prevent the water from evaporating too quickly, and to get the water to attach more efficiently to the fuel, thereby forming more dense films against the oxygen, one can add so-called “viscous water”. The viscous water can comprise various salts, organic polymers, jellied alginates or clay. The advantage of viscous water is that it forms a film. The drawback is that it does not penetrate deeply into the fuel. Viscous water is in English referred to as “short term retardant”, and was produced and used mostly in the 1950s and 60s.

One can also add directly fire retarding substances to the extinguishing water. These are substances that remain on the fuel after the water has evaporated, thus having long term effects (in English called “long term retardants”), lasting from 30 minutes up to several hours. The two main constituents are ammonium phosphate and ammonium sulphate (Rosvall & Andersson 1995).

To improve the penetration of the water into the fuel one can add chemicals that lower the surface tension of the water. A better penetration into the fuel contributes to improved extinguishing power, particularly during post fire extinguishing. Such extinguishing water is called “wet water”, and can have three times as effective extinguishing ability as ordinary water. It has been in use since the Second World War.

Another agent that has also been used in fighting forest fires is various types of foam. Foams act to blanket the burning surface and exclude oxygen. In addition, water is released as the foam breaks down. Foam has been in use since the 1930s, with a large increase during the last 20 years.

Even though there are a number of substances that in various ways improve the extinguishing ability of ordinary water, the adding of such chemicals has been of relatively little importance in fighting forest fires. This is partly due to conservative attitudes (Chandler et al. 1983), but even more importantly because most of the substances either are directly toxic, corrosive and/or can lead to environmental problems. It is known that the use of some of these substances can have negative effects on aquatic organisms, such as different species of fish, and invertebrates like, for example, small crustaceans (daphnia). At present, considerable research is taking place in this field (see e.g. Holm & Solyom 1995, Rosvall & Andersson 1995, Persson 1996 for a review).

The knowledge concerning environmental effects of various chemicals is still highly incomplete. Norway, because of environmental concerns, and because we have such good access to extinguishing water, adopted a waiting attitude towards the use of chemicals as additives to extinguishing water, and the use of such substances is not permitted for this purpose in Norway. This standpoint will not change before new research has shown that the environmentally negative consequences are negligible. Sweden has also refrained from adopting chemicals in forest fire extinguishing. However, in the USA and Canada an extensive use of chemicals for this purpose takes place. This is partly motivated by poor accessibility to water in some areas.

10.2.6 Indirect fighting (defensive extinguishing)

Indirect fighting aims at limiting forest fire. By utilizing and enhancing natural limitation lines in the terrain, the forest fire is pushed down to the ground, and can then be fought along these natural, established limitation

lines.

Indirect fighting is used in the instances where the fire command judges the extent of the forest fire to be so considerable that the fire cannot be fought with efforts directed at the fire itself. It is then important to analyze the probable further course of the fire within the first few hours. It is necessary quickly, by means of map, to locate the natural limitation lines: rivers and streams, bogs, roads or transmission lines, as well as the “hind edge” of ridges (Fig. 2.11).

Below, some important measures are mentioned which are used in connection with indirect fighting, i. e. fire breaks, fuel removing preventive burning, and ignition of backfire. The outline is not complete, and not all measures are taken into use at each forest fire. Again this will vary from fire to fire within a region, between regions and between different countries.

10.2.6.1 Fire breaks

In some instances natural “defense lines” (Norw. “forsvarslinjer”) will be strengthened, for example by establishing a wet belt along a forest road, or by wetting the vegetation along a river or stream. In addition, it may be necessary to make new defense lines by felling the forest and transporting the trees in towards where the fire will arrive. In addition, ground cover is cleared. Such newly established defense lines are called fire breaks, and these should also be moistened if possible. Fire breaks may vary in breadth from as much as 20 meters for crown fires down to as little as 3 meters to stop low head fires on the forest ground.

In Norway it is recommended to establish such fire breaks as considered necessary during large-scale fires, and the method is recognized throughout the world.

10.2.6.2 Preventive burning

Preventive burning is important to strengthen the effect of fire breaks, when this cannot be done through moisturizing. By undertaking a controlled burning of established fire breaks combustible matter is completely removed. It is important that preventive burning is completed, and extinguished, before the forest fire arrives.

10.2.6.3 Back fire

Ignition of backfire means starting a fire ahead of the fire front or along the flanks in front of the forest fire (Fig. 2.7). The decision to start a backfire has to be thoroughly evaluated, due to the great risks which are involved (Strømsøe 1987), for example increased danger for the fire personnel. It is important to start such burning in the correct manner to achieve successful results. In addition, the use of backfires also includes the sacrifice of forest. Backfires have shown the best effects where the fuel is of a light type and with uniform distribution. The success of the method is inversely proportional with the wind speed (Chandler et al. 1983).

Back fire is an extinguishing method which was used earlier, based on the same reasoning as applied to preventive burning. In Norway the method was used before the Second World War, but is not used any longer, mainly due to the risks involved. The experience with the use of backfires as an extinguishing measure has thus disappeared in Norway. On the other hand backfires are used a lot in the USA, Canada, Alaska, and Siberia, but mainly against much larger fires than those which occur in Norway.

10.3 Summary

Measures aimed at forest fires can be divided into forest fire prevention and forest fire extinguishing measures. The preventive measures can be further divided into measures implemented out in the field, and the early detection of forest fires. Key measures out in the field include establishing zones free of vegetation, zones that have low combustibility, zones that do not burn, planting of deciduous trees (which do not burn as well as coniferous trees), and species manipulation. Other measures are carried out in the field to remove fuel. These include clearing, burning under the upright stand, and clear-cut burning; the last two mentioned require extreme caution.

It has long been recognized that the best way to reduce the loss of forests in fires is through early detection of the fires. Therefore, monitoring fires is important. Earlier, this was accomplished using observation towers. In recent times, airplane monitoring has taken over, and satellite surveillance has been implemented in some areas. Other preventive measures are the development of regulations, promoting education and information, and the building up of better forest fire cooperation. In Norway, training is directed towards the fire service, for example, under the direction of the Norwegian Fire Protection Training Institute, and students in primary schools. Amongst other, information is provided to the fire services through an obligatory information manual, and to the general public through The Norwegian Broadcasting Corporation’s (NRK) forest fire notices

during the weather forecast, shown in conjunction with the evening news program, as well as press releases and public notices. A national "Liaison Committee for Forest Fires" has been set up in Norway to discuss the terms of the forest fire service. In addition, Norway participates in "The Nordic Forest Fire Group", which discusses coordination of the efforts in Nordic countries. On an international basis, Norway is a member of the "European Timber Committee" and contributes forest fire data to the committee's international forest fire activities.

A good and early notification of forest fires is a central element with regard to the extinguishing. In Norway, the duty to report is mandated by law. Furthermore, organization of the emergency preparedness and response forces are crucial, and this is now the responsibility of the municipalities in Norway. A dedicated forest fire telecommunication frequency contributes to improved communication during forest fire fighting.

Extinguishing can be divided into direct (offensive; used against smaller fires) and indirect (defensive; used against larger fires) fighting. A key tool in direct extinguishing in Norway is the use of helicopters, aided by a specially developed bucket that has received international recognition. Helicopters are particularly well suited to steep areas. Airplanes are useful in flat areas, and are used extensively in a number of other countries. In some countries, such as Russia, specially trained parachute fire fighters are used. A new technique using explosives as the core in a water-filled hose has been developed in Germany. A number of countries make use of chemical additives of various kinds and for various purposes (to prevent evaporation, restrain fire and increase water penetration in fuel) to alter the physical properties of the extinguishing water. The use of such substances is not permitted in Norway, *inter alia* for environmental reasons.

Indirect fire fighting may consist of cutting firebreaks to restrict the fire, of protective burning of firebreaks, or of starting backfires. Backfires entail great risks and are therefore no longer used in Norway.

11 ORGANIZATION OF FOREST FIRE PREVENTION IN NORWAY

By Erik Bleken

Several public authorities and private organizations in Norway play key roles in forest fire prevention and extinguishing. Efficient preparedness against forest fire is entirely dependent upon cooperation between these groups, for example, between forest owners and their organizations, volunteer organizations, public emergency organizations and national authorities. In this chapter relevant information about some of these central contributors is presented. The intention is to outline the main features of the apparatus presently involved in the effort to prevent and fight forest fires in Norway.

11.1 The fire service's preparedness and response and role in the event of forest fire

In this section, we present a short history of the fire service and forest fire fighting, discuss available resources for forest fire preparedness and response and forest fire monitoring, and finally highlight a forest fire preparedness plan and the practice of forest fire extinguishing.

11.1.1 History

Forest insurance is mentioned for the first time in Norwegian history in a report from the Forestry Commission (Norw. "Skogkommisjonen") dated 1849. Our first fire act (in Norwegian called "Verneskogloven") was passed in 1893, and the first two fire towers were established in Hedmark in 1895. It was not until the 20th century that practical arrangements for forest fire preparedness and response were established, and the new forest fire act was passed in 1921.

Fire observation towers were built at a number of sites in the forest municipalities (Fig. 4.10). The first attempt with airplane monitoring took place during the 1950s. Up to 29 May, 1970, the forest owners were instructed to organize their own forest fire services. These were often divided into units called "roder", with their own responsible unit leaders (Norw. "rodeleder").

During periods of drought, watch was kept from fire towers using goniometry to gain site location by cross bearing. The towers were often staffed by students/school pupils who stayed in the tower on 24-hour duty. In this way, early warnings and good observations were normally received.

Emergency preparedness for forest fires became the responsibility of the municipal fire services in 1970. Many places in Norway organized airplane monitoring at county level based on agreements between air clubs and municipal fire services.

In some vulnerable forest municipalities good forest fire emergency preparedness has been established adapted to local conditions and available resources. A broader overview of this important part of Norwegian forest fire history is referred to in section 4.3 and literary descriptions can be found in Strømsøe (1987) and Vevstad (1987).

11.1.2 Available resources for forest fire preparedness and response

By mapping all available resources that can be used during forest fires in a municipality or area, one will often discover that there are many more resources than first anticipated (Tab. 11.1).

11.1.3 Monitoring and forest fire watching

Monitoring and forest fire watching can be organized based on the following alternatives:

– Airplane monitoring, for example, through inter-municipal cooperation between fire services in one county and local air clubs. Good communication with frequent tests of the communication system is important.

– Fire observation towers, by staffing particular look-out sites in drought periods. This method has almost disappeared from use.

In addition, air traffic reports as well as public sightings contribute to a certain degree.

Table 11.1. Cue word presentation of available resources for use in case of forest fires in a municipality or region.

PERSONELL RESOURCES:

Municipal fire service and forest fire reserve forces/forest owners

Other resources in the municipality:	• Supplementary forest fire resources (reserve forces/forest owners) • Norwegian Red Cross/Norwegian Peoples Aid, other organizations • Corporate fire services • Forest management
Public resources:	• Home Guard • Armed Forces • Civil Defence • Police/Sheriffs
Neighbouring municipalities;	• Neighbouring fire services in accordance with mutual cooperation agreements

MATERIAL RESOURCES:

Municipal fire service:	• Ordinary fire trucks • Water tankers • Non mobile water tanks and containers • Self raising open containers • Irrigating systems • Hand saws • Communication equipment
Technical department:	• Water tankers • Mud tankers • Water containers
Forest owners/farmers:	• Skiders with furtiliser tanks • Forest equipment • Irrigation equipment
Public resources:	• Helicopter with water bucket (DBE) • Terrain vehicles (Armed Forces) • Fire pumps (Civil Defence) • Tank lorries (Public Roads Department)
Norwegian Red Cross/Norwegian Peoples Aid, etc.:	• Board, food, sanitary appliances
Forest-/machinery contractors, etc.	• Forest machinery
Air Clubs:	• Small aircraft with radio communication for monitoring and observation

11.1.4 Forest fire contingency plan

A contingency plan for forest fires must always be adapted to local conditions and must be based on local resources, organizational conditions, etc. Risk evaluations and mapping of natural topographical conditions must be thoroughly prepared. The plan should be adapted to three levels:

In the case of *small forest fires* and *forest fires of limited development*, the Chief Fire Officer (officer on duty) shall determine whether to extinguish using just own resources. In the event of *larger forest fires*, the fire service shall determine whether additional available local resources shall be brought in during the first phase. In the case of *large-scale forest fires*, a Local Rescue Center (LRC; Norw. "lokal redningssentral", LRS) shall be established and national resources called in.

11.1.5 Fighting forest fires

It is natural to divide fighting of forest fires into two phases; turnout to the location of the fire, i.e. the turnout phase; and combating when the forces have arrived on site, i.e. the action phase.

11.1.5.1 The turnout phase

In numerous instances the fire is small when discovered. However, a small forest fire can easily develop into a larger forest fire.

In case of forest fire reports – irrespective of level – a watch team shall be sent immediately to locate the fire and sources of extinguishing water, to map access roads, to report back, and begin extinguishing activities if necessary.

It is important to get good firsthand observations and ensure that the supply and input of larger resources is not unnecessarily delayed by mistaken choice of route.

Airplane observations will often be of great help, and maps are necessary to define the best approach alternatives by road. A meeting location for private cars and organized common transport into the area has to be organized in accordance with the contingency plan.

11.1.5.2 Command of forest fire operations

It is, as mentioned, appropriate to define forest fire operations according to the seriousness of the fire. In the event of *small forest fires* and *fires of limited development*, the Chief Fire Officer shall lead the extinguishing work (Fig. 11.1).

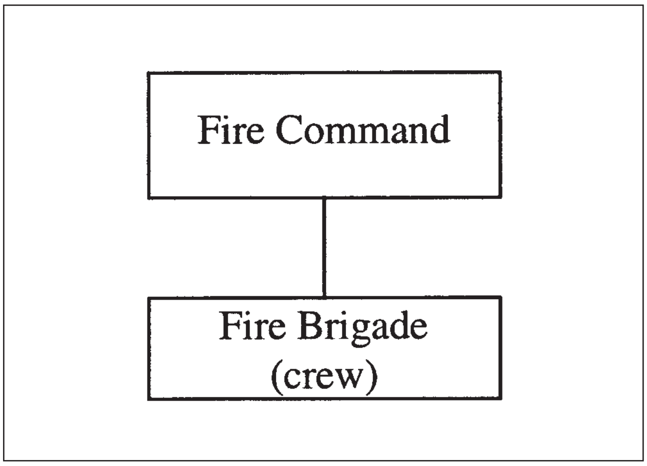


Figure 11.1. Sketch illustrating organization of forest fire incidents. *Small forest fires* and *forest fires of limited development*.

If the forest fire is judged to be a *larger forest fire*, or there is a risk that it might escalate into a *large-scale forest fire*, the forest fire personnel shall be summoned, and shall consist of (Fig. 11.2):

- Chief Fire Officer
- Sheriff/Police
- Forestry Chief at county or municipal level
- Red Cross, Norwegian Peoples Aid if necessary
- Representatives for other recruited units, for example leaders for neighbouring fire services (cf. cooperative agreement), area chief of local military home guard (Norw. "områdesjef, HV"), other military leaders, and Civil Defence leaders.

In the event of larger operations, the Chief Officer, Chairman and Technical Manager of the municipality shall be informed and called in, if necessary. In the event of *large-scale forest fires a* Local Rescue Center (LRC) shall be established under command of the Chief of Police (Fig. 11.3).

The command should preferentially be located in the municipality where the forest fire occurs, for example in a suitable command room at the fire station, and advisors from the local forest fire personnel should be utilized effectively.

11.1.5.3 Radio communication and supply service

The fire service's radio communication must be planned and built up systematically in cooperation with the local resource units within the municipality, in neighboring municipalities, and on a national level. Food supplies and beverages required by personnel should be agreed upon in advance with food suppliers. Military units with field kitchens can beneficially be utilized.

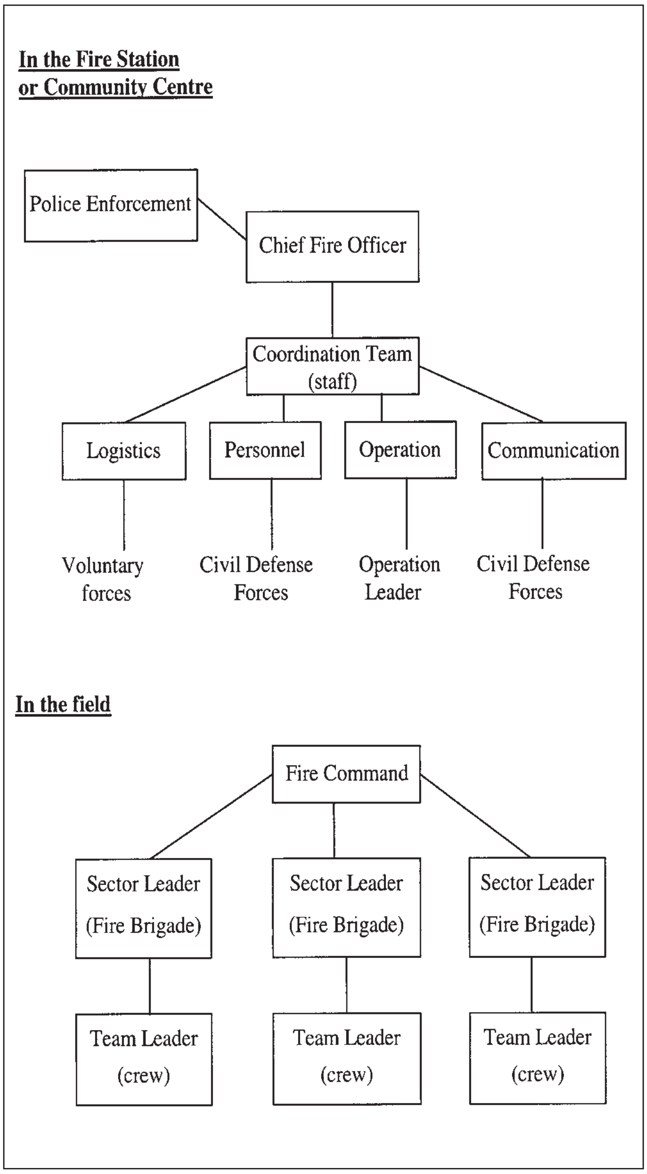


Figure 11.2. Sketch illustrating organization of forest fire incidents. *Larger forest fires*, but not a "LRC-situation" (see Figure 11.3).

11.2 Participation of the Norwegian Civil Defence in forest fire protection

Provisions regarding engagement in forest fire protection are established by Royal Decree of 24 November 1961 and in "Directive for the participation of the Civil Defence in forest fire protection" (Norw. "Direktiv for sivilforsvarets medvirkning i skogbrannforsvaret") issued by the Directorate for Civil Defence and Emergency Planning (Norw. "Direktoratet for sivilt beredskap") 26 June, 1978. The purpose of the directive is to increase the efficiency of the Civil Defence in forest fire preparedness and response in peacetime, and to intensify the assistance of the Civil Defence to local

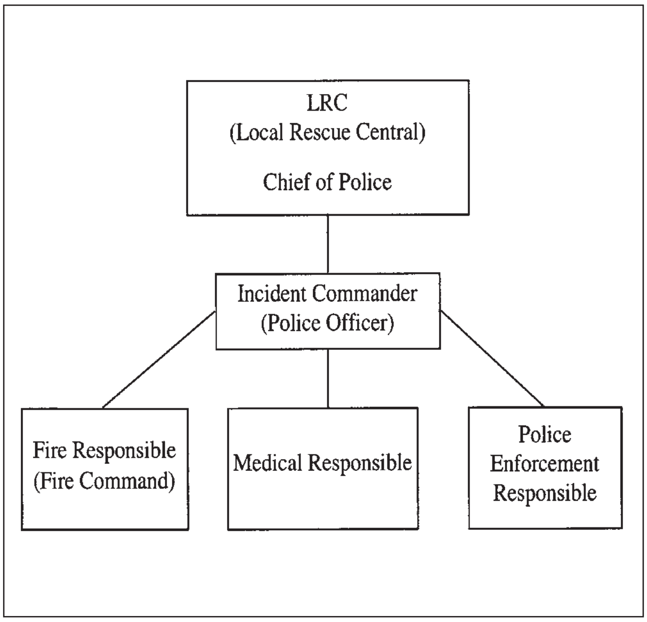


Figure 11.3. Sketch illustrating organization of forest fire incidents. *Large-scale forest fires* where life and health are in danger, and a Local Rescue Center is established (a so-called "LRC-situation").

municipalities should larger fires occur in forest areas and other outlying ranges.

11.2.1 Purpose

Contributions and assistance from the Civil Defence are rendered according to available personnel and material resources and can include:

- Help with advance planning and summoning of outside reinforcements to the fire incident in question when local extinguishing resources are insufficient
- Help with administration and supplies of summoned reinforcements
- Assistance to the command of the forest fire fighting team regarding information to mass media
- Material and ready equipped Civil Defence units and Peacetime Contingency Teams (PCT) (Norw. "fredsinnsatsgrupper")
- Civil Defence personnel with particular knowledge of forest fire fighting

Plans for warning and quick transport of organized and self-sufficient units must be developed.

11.2.2 Forces at disposition

The Civil Defence has 104 Peacetime Contingency Teams. Forest fire fighting reinforcement is primarily drawn from this force. Each team consists of 22 persons

and an equipment unit containing fire/rescue equipment, a motorized fire engine (1600 liters/minute), and medical material loaded on trailers.

The PCTs are available for local authorities, mainly in municipalities that have limited resources within the local fire and rescue services.

“Civil Defence Catastrophe units” is the term used for the organization’s turnout forces that are utilized during peacetime. The force comprises 1/3 of the total mobilization force of the Civil Defence and constitutes approximately 15 000 persons on a national level. This force is available when serious accidents and catastrophes occur during peacetime. The force is organized into action groups, each consisting of 3 action troops. An action troop consists of one fire/rescue team and one medical team. The personnel is expected to have full interdisciplinary knowledge of the team’s primary function and elementary inter-team competence.

In addition to action forces, the Civil Defence must be prepared to set up staff units (command/communication) to support the forest fire command. The staff unit shall, amongst other, have competence in coordinating communication between the different services (fire service, police, Civil Defence and armed forces) that are in action.

11.3 The Armed Forces and forest fire

In order to meet the instructions of the Norwegian Parliament, personnel in the Armed Forces must be educated and trained with the demands of war in mind. The Armed Forces are therefore to a large extent dependent upon access to shooting and practice fields. The Armed Forces manage more than 1 000 000 decares of practice fields, of which approximately 100 000 decares are self-owned and partly covered with productive coniferous forest.

Several of the weapons and ammunition types used by the Armed Forces are directly fire creating. Forest fires initiated by the use of weapons and ammunition or other military activity constitute provoked fires. The Armed Forces have made great efforts to avoid such situations and to introduce measures to limit such damages (Anonymous 1987).

Some practice fields are of such a character that it would be hazardous to enter them in the event of fighting a forest fire. These fields are used for practice with explosive ammunition of various kinds and a fire could act as a detonator. In these fields, the fire has to be extinguished by means of helicopter, or one must front the fire in safe adjacent areas of the fields.

The following information centers on fire in shooting fields, fire protection of shooting fields, and environmental consequences of fires in the wake of the Armed Forces’ activities.

11.3.1 Fire in shooting fields

In the event of fire in the shooting fields, one has to distinguish between fields where there is no danger of unexploded shells and one therefore can enter and extinguish, and fields with hazard from unexplored shell, where personnel cannot be sent in.

Fire caused by tracers can often be extinguished by “shooting them out” with a rapid volley in the fire area itself. This acts almost like a “dry extinguishing”. However, the method is unreliable. The largest number of such fires has developed from the use of white phosphorous. Many of these break out randomly in connection with drying of the ground; often a long time after the shooting has taken place. It will then be quite incidental whether personnel are present in the field and whether these immediately observe ignition. However, when using common explosives and pyrotechnical ammunition, any possible ignition will always take place in the period of observation of the shooting and the detonations, and in most instances, the ignition will be detected immediately.

The Armed Forces must clear fields for unexploded ammunition. During some instances, the Armed Forces have entered fields and slashed and burned to secure against later forest fires. Such conditions are analogous with corresponding activities in forestry, and the Armed Forces follow the same guidelines that apply for this kind of civil activity (Anonymous 1987).

11.3.2 Fire protection of shooting fields

Fire extinguishing in shooting fields is a public affair. However, protection against such fires is the responsibility of the Armed Forces, and the Armed Forces attempt to participate in fire extinguishing of their own areas and their “own fires”. In most instances, one can accomplish extinguishing with one’s “own force”. The most important precautionary measure against forest fire is to stop the military activity when the risk of forest fire exists, for

example, by putting restrictions on use of various types of ammunition during droughts.

In fields where there is fire hazard, fire-extinguishing equipment will be placed in accessible locations. This includes everything from fire smacks (Norw. "branns-mekkere"), watering cans and small portable extinguishers to fire engines. Great emphasis is laid on having accessible water at vulnerable sites, and escavated fire ponds and water containers shall be supplied at such locations. Firebreaks are constructed around the most vulnerable fields, which are also combined with military roads primarily constructed to fight forest fire. This is important when there are restrictions on use of personnel due to the hazard of uncontrolled explosions. Extinguishing within such fields is most often dependent on extinguishing from airplane/helicopter. These have to stay at a designated safe distance due to splinters; in most instances 600–700 m above ground.

11.3.3 Environmental consequences of the fires

The Armed Forces, are, with respect to their shooting and practice fields and the environmental consequences of forest fires, faced with the same problems as in forestry. For example, the burning of dead vegetation can coincide with the nesting period for birds. One therefore has to consider conducting burnings when this is permissible, i.e. when the snow has melted, but there is still some degree of moisture in the ground. Since the Armed Forces normally do not wish to keep much vegetation in such fields, it is not regarded as critical to burn off parts of the humus layer. The positive effects registered by the Armed Forces regarding such burning are first and foremost the regeneration of the vegetation. Newly germinated and fresh vegetation on such fields is assumed to have a high protein value and is attractive to a number of animal species (see chs. 4 and 8).

In fields where burning is more or less provoked regularly, the ecological importance of forest fires is particularly apparent. Positive influences are, for example, observed in the Armed Forces' shooting field Terningmoen at Elverum. This is the field that has been used continuously for the longest time by the Armed Forces. The field contains a smaller area where there are larger or smaller fires almost annually. No surveys or registrations of particularly fire-adapted organisms have been made (ch. 8), but a rich and complex animal life has been observed, particularly as regards high ornithological diversity. Also in the shooting field Hengsvann at Kongsberg and in the field Steinsjøfeltet at Totenåsen forest fires have occured. At Hjerkinn shooting field there is no exposure to any fire hazard worth mentioning, but here one has burned the vegetation to increase the grazing potential, mainly for grouse. It is important that such burning is conducted while there is still frozen ground to prevent the humus layer from burning (Sections 4.2.9 and 9.2.5.4).

Construction of fire ponds is regarded as being a secondary environmental measure. A number of animals receive new and alternative water sources, and it has been observed that birds have settled here. In the future, these could also become habitats for aquatic insects and amphibians. The problem for organisms in such temporary ponds is the danger of drying out during long-term droughts.

Established firebreaks might constitute grazing areas and edge habitats, particularly for certain mammals and birds, for example owls.

11.4 The role of Lufttransport A/S – use of helicopter

During the spring of 1986, the Directorate for Fire and Explosion Prevention (DBE) wanted to test an alternative to traditional fire extinguishing in Norway. Instead of the Catalina amphibian plane, which had been in use since the middle of the 1970s, it was proposed to test the use of helicopters.

The benefit of using helicopters instead of planes is that the helicopter can pick up water from relatively small water sources, as for example forest tarns, as long as they have a depth of at least 2 m. In addition to direct use for extinguishing fires from the helicopter, the bucket (see Section 10.2.5) can be filled and flown in toward the fire area and be left without assistance from ground personnel. Thus, the fire personnel can link directly to the bucket with their pumping equipment, and then have 3 000 liters at their disposal, while the helicopter can do other transport missions, or refuel.

In addition to being quickly available to place the bucket with its 2 700 – 3 000 liters of water, the helicopter can also transport pumps, hoses and other necessary equipment, as well as fire personnel.

The preparedness for such work is coordinated via the Joint Rescue Coordination Center Southern Norway

(Norw. “Hovedredningssentralen”) at Sola, where individual fire services can requisition helicopters as necessary for extinguishing. This coordination is essential, as several fires can break out at the same time. Coordination and giving priority to each single mission must therefore be decided. In addition, the Joint Rescue Coordination Center Southern Norway has an overview of extra available helicopters should these be required.

11.5 The role of Norwegian Air Club – use of monitoring planes

Airplanes from Norwegian Air Club (Norw. “Norsk Aero Klubb”) make important contributions, both in forest fire preventive work and during forest fire extinguishing.

11.5.1 Preventive activities

The routine monitoring is in itself of great value. This is not restricted to the possibility of discovering fires during air patrols, but also includes the preventive effects. Experience shows that most people will not attempt to light a fire in outlying ranges if they know that the forest fire plane is in the air. If the monitoring plane detects smoke and by flying over ascertains this to be a campfire with people present, the plane then makes some low altitude flyovers to indicate to the persons on the ground that the camp fire has been detected. As the planes have BRANNVAKT (English: FIRE PATROL) painted with capital letters under one of the wings, in most instances this leads to immediate extinguishing of the campfire.

11.5.2 Endeavors in connection with smaller and larger forest fires

When rendering assistance in fighting forest fires, the plane’s full potential for efficient and valuable assistance can be utilized if the contractor and pilot are aware of the possibilities. By correct utilization of the planes better extinguishing is attained, and the contractor could also benefit economically.

Smaller or larger forest fires are not always clearly defined in reports to the fire service. Often the report describes smoke development in a specific direction, observed from a particular location. Experience shows that smoke development do not always originate from a real fire. “The smoke” can be several things, for example, it can arise from the spreading of lime on agricultural lands, or be dust from traffic on dry forest roads. A turnout of the fire service to search for the smoke/fire is often both quite needless and costly. Instead, it would be correct, regarding time and economy, to utilize the forest fire plane to locate and clarify the cause behind the fire report. In the event of a real forest fire, the pilot of the plane can immediately provide valuable information about the extent of the fire, access routes, water sources in the area, natural firebreaks, etc.

In 1976, the southeastern and southern parts of Norway (Østlandet and Sørlandet) were divided into seven monitoring areas. One municipal fire service within each area was designated to coordinate plane monitoring within its own area, and instructed to be a contact body between the air clubs and the contractors. The delimitation of the areas mainly follows county borders.

11.6 The Norwegian Meteorological Institute – warning of forest fire danger

The Norwegian Meteorological Institute (Norw. “Det Norske Meteorologiske Institutt”, DNMI) received, during the beginning of the 1970s, a mission from the State to develop a national system for warning of forest fire danger in Norway. Before this time, little was done in this field in Norway. DNMI went abroad to gather background material to formulate such an arrangement.

DNMI based itself on a forest fire index developed in what was East Germany at that time. This index was relatively easy to adapt to Norwegian meteorological data, and in addition, the climatic conditions in East Germany were not qualitatively different from those in Norway. The index, hereafter called WBKZ (German “Waldbrannkennsziffer”), is a number without denomination, and is estimated, with some seasonal modifications, from the following formula.

$$WBKZ = 1/100\ (t_{12} + 10) - Ae_{12}$$

where t_{12} = air temperature, and Ae_{12} = saturation deficit in the water vapor pressure, both given at 12 AM UTC (Norw. “kl. 12 UTC”).

The index expresses the degree of dryness in the air. The estimations are carried out for all telegraphing Norwegian weather stations (today somewhat less than 100) (Fig. 11.4). WBKZ sums itself up from day to day, and is initiated as soon as the forest floor is snow free in

the spring. WBKZ is reduced by precipitation during the last 24 hours. In addition, vegetation constants are applied as appropriate to capture the changes that occur to the material on the forest floor from when the snow has melted in the spring to when the season's new ground vegetation is fully developed (some time during the beginning of the summer). DNMI assumes that this period is divided into two phases.

The first phase is the time from when the snow has melted to when the season's new ground vegetation begins to develop. During this phase the forest floor can be partially covered by dead organic matter from the previous year that can easily dry. As a rule, it does not take many days with sunny, warm weather before this material can become easily ignitable. This is the time for grass and heather fires.

The second phase is the time from sprouting of birch leaves and one month thereafter. The season's new ground vegetation gradually grows to full development, and during this period it is reasonable to assume that the danger of ignition of the forest floor gradually declines.

WBKZ can be divided into degrees of danger in the following way:

WBKZ	Degree of danger
5–20	little forest fire danger
21–40	medium forest fire danger
41–70	high forest fire danger
>70	extreme forest fire danger

The highest index values during 1996 were measured on August 21 (Fig. 11.4). As an example of an extremely high index value it can be mentioned that the index was above 200 in the forest fire year of 1992 in large areas of inner Agder and Telemark counties. The absolute peak in the area was close to 280. This is the highest measured WBKZ level since the calculations began more than 20 years ago.

DNMI distributes reports on forest fire danger in connection with weather forecasts on the radio and television. Usually, the report service begins when the WBKZ indicates that there is high forest fire danger in an area of some extent, but a certain judgment is practiced, amongst other, during weekends and festival days when DNMI assumes many people to be out in the countryside.

DNMI also distributes reports via fax to the ground contacts in the local air clubs that conduct monitoring of the forest areas in the summer season. The rescue centers and crew of the dedicated helicopters that conduct extinguishing of forest fire are also informed.

By request to DNMI one can get additional details regarding calculation and use of the forest fire index.

11.7 The Directorate for Fire and Explosion Prevention – organization of forest fire preparedness and response

Based on the preceding descriptions there are certain important considerations relating to the organization of forest fire preparedness and response.

Forest fire preparedness and response, and organization, are presently a municipal responsibility, and shall therefore be conducted by the Municipal Fire Services through the Chief Fire Officer in the respective municipality.

The organization of the municipal forest fire preparedness is to be done in close cooperation with Peacetime Contingency Teams (Norw. "fredsinnsatsgrupper") of the Civil Defence and the municipal forest chief, in addition to the forest owners' organization.

A permanent rule is that the Chief Fire Officers in municipalities with access to personnel from the Armed Forces discuss and review with them any necessary action required.

A forest fire drill shall be arranged each year in all municipalities where the danger of forest fire is present. This annual forest fire drill shall normally be carried out as an inter-municipal drill.

The State, represented by the Directorate for Fire and Explosion Prevention (DBE), gives direct assistance to municipal forest fire preparedness and response. The national forest fire helicopter is placed at disposal for the municipal Chief Fire Officers when needed. Each year, the entire country is covered by this emergency preparedness during the period from 1 May until 1 September. In the event of large and difficult forest fires, the service can be supplemented with several helicopters and in certain instances with support from one of the Air Force's helicopter squadrons.

Requisition of and use of the national helicopter service is coordinated by the Joint Rescue Coordination Center Sothern Norway at Sola, and is regulated by a set of specific instructions from DBE. The Norwegian municipalities are informed each year about these instructions for the service.

DBE has the professional and superior responsibility concerning the organization of forest fire preparedness and response in Norway, ensuring that established agreements and existing laws and regulations are followed.

11.8 Summary

A number of personnel play key roles in forest fire prevention and extinguishing. Preparedness and response for forest fires became the responsibility of the municipalities in 1970. This chapter provides a brief overview of the personnel and material resources available for use against forest fires in a municipality. Fighting forest fires is divided into two phases; the turnout to the location, and the actual action phase when the forces have arrived on site. The organization is viewed at three levels of forest fire incidents, scaled according to the extent of the forest fire. At the lowest level, the organization consists of a Chief Fire Officer/superior officer who leads the action with just his or her own fire service resources. At the next level, a larger organization is required with forest fire staff established at the fire station or municipal administrative headquarters, led by the Chief Fire Officer and police/sheriff's department, as well as an organizational structure in the field led by the head of the extinguishing team. The top level of forest fire incidents is large-scale forest fires. They require the establishment of an LRC (Local Rescue Center – Norwegian: LRS) that is led by the Chief of Police. The LRC is part of a management hierarchy and is placed above an incident leader (a police officer), who in turn gives instructions to the Fire Officer, the Medical Officer and the Order Officer (see Figure 11.3).

In addition to the fire services, the Civil Defence forces are a vital resource in combating many, usually larger, forest fires. The Civil Defence can contribute significant manpower and material resources. The Armed Forces have a number of shooting ranges and military exercise fields where they exercise measures to prevent forest fires. Lufttransport A/S plays an important role with its use of helicopters (see ch. 10). Norwegian Air Club (NAK), with its aviation clubs, carries out both work to prevent forest fire by use of surveillance, and also participates in fighting forest fires. During actual fighting of forest fires, the pilots of both helicopters and small airplanes make a significant contribution by providing information and advice to the extinguishing managers on the ground.

The Norwegian Meteorological Institute (DNMI) has developed its own forest fire index based on a set of meteorological data measured at a network of weather stations in Norway (see Figure 11.4). The degree of forest fire danger (little, medium, high, extreme) is indicated for the various dates in the forest fire season based on the value of this index (e.g. see Figure 11.4). DNMI also makes vital contributions with their information activities directed towards the general public; their notices of forest fire danger are broadcast during the weather forecast on the evening news. These notices are based on calculations using the aforementioned index.

The Directorate for Fire and Explosion Prevention (DBE) contributes to forest fire work *inter alia* through regulatory development, collection, systematization and analysis of forest fire statistics, issuing press releases, participation in national and international forest fire cooperation work, and through its directing role in the helicopter-based forest fire preparedness.

Figure 11.4. The 95 stations that were used to estimate the forest fire danger index (WBKZ) in 1996 (left) and the forest fire danger index measured on August 21, 1996 (right) (From Jensen 1996).

12 ACTS AND REGULATIONS

By Erik Bleken

In the last chapter of the report we present an overview of the most relevant legislation on subjects which affect or may affect activities associated with forest fires. In order to limit the extent, provisions etc. have been selected in accordance to the relevance of the extracts. Regulations are presented directly following the acts in which they are laid down. For the whole text, reference must be made to the respective acts and regulations.
On the 1 July 2002 a new Act relating to the Prevention of Fire, Explosion and Accidents involving Hazardous Substances and the Fire Services' Tasks in Rescue Operations (Act relating to Fire and Explosion Prevention) came into force. This act supersedes three acts, of which one, the Act relating to Fire Prevention etc. (1987), mentioned in 12.1 below, is of relevance for this report.

12.1 Act No. 26 of 15 June 1987 relating to Fire Prevention, etc.

§13 *General exercise of care etc.*
Each and every person has a duty to exercise care in order to prevent risk of fire and to handle open flames/other sources of ignition and readily ignitable objects in such a way that fire cannot easily break out, and in the event of fire, to do what is possible to limit the damaging effects.

§14 *Other preventive duties*
The owner or user of buildings, areas etc. is under obligation through internal control to ensure that these are safeguarded against fire in accordance with the provisions laid down in or pursuant to the Act or other legislation, and in other respects to make arrangements so that fire cannot easily occur. In addition, internal control shall be practised in accordance with further rules issued by the ministry. The required rescue, fire fighting and alarm equipment, as well as fireplaces, chimneys etc. shall be kept in proper working order, and it shall be ensured that stairways, corridors and other rescue routes are passable.

Each and every person has an obligation to supply a person performing duties in accordance with this Act with the information requested by the person concerned in order to carry out such duties and, for the same purpose, to grant the person concerned access to buildings, apartments or other rooms and premises, installations, stores, etc.

§15 *Obligation to report*
Each and every person who discovers or learns that fire has broken out or threatens to break out is under obligation to inform the persons exposed to danger and to notify the local Fire Service immediately, unless the person concerned is able to extinguish the fire at once or avert the danger.

§16 *Obligation to assist*
In cases of fire, each and every person who finds himself at or in the vicinity of the site of the fire is under obligation to try to the best of his ability to extinguish the flames or avert the danger. Furthermore, each and every person shall, at the demand of the Chief Fire Officer, assist in the rescue and fire-fighting operations. After a fire, the owner or user of the fire sustained property is under obligation, at the demand of the Chief Fire Officer, to arrange for clean up, surveillance and other necessary safety measures.The Ministry may lay down provisions concerning the obligation of public authorities or response bodies to provide assistance in the event of fire or threat of fire.

§17 *Other obligations in the event of fire*
In cases of fire each and every person is under obligation to grant the Fire Service access to property, buildings etc., to make use of sources of water and to use the telephone and other aid equipment.

The owner or user of fire-fighting equipment, transport vehicles or other equipment is under obligation in cases of fire to place this equipment and available personnel at the disposal of the Chief Fire Officer on demand.

The owner or user of a building threatened by fire is under obligation to keep it under close surveillance in order to prevent it from catching fire, and to call the Fire Service if there is obvious risk of fire breaking out.

§18 *Impingement on private rights*
The owner or user of buildings, fences, forest and other property must submit to impingement upon such material values when the Chief Fire Officer finds this necessary in order to limit or extinguish a fire.

12.2 Regulation No. 405 of 3 May 1995 concerning the organisation and dimensioning (composition) of the Fire Services

§ 4-12 *Forest fire*
In areas where there is considerable risk of forest fire the Chief Fire Officer shall, in deliberation with the local forest management authorities, organise a separate reserve force for response to such fires. The aforementioned reserve force shall be held in training for relevant tasks.

12.3 Regulation No. 960 of 15 December 1987 relating to Fire Prevention, etc., with amendments, the most recent by No. 405 of 3 May 1995

§ 4-5 *Special obligation to assist in the event of fire on or in the vicinity of forest land*
In the event of fire on or in the vicinity of forest land, each and every physically capable person between the ages of 18 and 55 years, who is resident in the municipality and who is not prevented by illness or some other just reason, is under obligation, upon request from the Chief Fire Officer or other leader of the fire-fighting operation, to meet immediately at the scene of the fire with available fire extinguishing appliances, and to participate in the rescue and fire-fighting operation cf. the first subsection in §16 in the Act. This obligation also applies in the event of fire in adjacent areas in nabouring municipalities.

Provisions in the aforegoing subsection apply correspondingly to those who are present in, or are an owner of, forestland in the municipality without being resident there.

§ 4-7 *Fire Service's encroachment upon properties etc. in the case of fire*
(Subsection 2). Owner or user of forestland or ground must, in order to limit the spread of fire or to allow fire extinguishing, submit to tree felling, ditch digging, the employment of counter firing or other necessary measures. The decision to commence such measures shall be made by the Chief Fire Officer.

§ 6-2 *Obligations and prohibitions*
It is prohibited to light fires or handle objects which represent danger of fire outdoors under circumstances, or in such a manner, that fire may occur. Lighted fires must not be left before they are completely extinguished.

Rubbish burning, camp fires, scorching of straw, grass or heather etc. must not be undertaken at such times and in such places that the fire can easily spread, unless safety measures have been taken to prevent spreading.

The local municipal council may lay down bye-laws concerning firing as mentioned in the second subsection, hereunder the prohibiting of such firing or the procurement of prior approval to fire. Furthermore, bye-laws may be laid down concerning the setting up of asphalt boilers, coke ovens, incinerators for rubbish and similar appliances.

Surface firing, the firing of felling waste on forest land, and also grass and heather scorching on or in the vicinity of forest land, must only be undertaken in accordance with the provisions in chapter 7 of the regulation.

All other forms of firing on or in the vicinity of forestland than those mentioned in the previous subsections are prohibited, without permission of the Chief Fire Officer, between 15 April and 15 September. This prohibition does not apply to nomadic Lapps who journey between places where they have traditionally stayed, or for persons who have their occupation in forest areas and in this capacity need to light fires.

Special provisions for protection against forest fires caused by railway tracks, or by power lines and similar, may be laid down.**Chapter 7. Surface firing and other types of firing on or in the vicinity of forest land**

§ 7-1 *Introduction*
The provisions in this chapter supplement Section 13 in the Act concerning general exercise of care etc. and Section 6-2 in the regulation.

§ 7-2 *Leader responsible for the firing*
Surface firing must only be undertaken under the leadership of a person (leader responsible for the firing) who has been approved by the Chief Fire Officer. The responsible leader must ensure that preparations for, and the execution of, the firing are carried out in accordance with the provisions stated below.

§ 7-3 *Notice of firing, etc.*
At least one week before firing shall start, the owner or user of the property in question where the firing is to take place, shall give notice to the Chief Fire Officer with information relative to the place, the extent of the planned firing, which safety measures shall be carried out, who shall be the responsible leader, which crew and equipment shall be at disposal etc. Owners of nabouring forest shall also be notified.

On the day the firing is to take place, the responsible leader shall again notify the Chief Fire Officer. In addition, the sheriff and owners of nabouring forest shall be notified.

The Chief Fire Officer may instruct the responsible leader to take yet further safety measures. In especially dry periods, the Chief Fire Officer may place a ban on firing.

§ 7-4 *Staking out the firing zone*
The surface that is to be fired shall, if possible, be limited by natural fire hindrances such as ponds and lakes, rivers, streams, wet marshes, roads or similar.

If there are no natural fire hindrances, the boundaries shall, as far as possible, form straight or slightly curved lines. The zone should not border onto rising territory, dried-up marshes or earlier burned-off land that is not yet bound together by new vegetation.

On hillsides and slopes the upper boundary should, if possible, be made on the ridge top or preferably slightly over the top of the ridge, if possible on the far side of flatter areas. The side boundaries should, to the greatest possible degree, be laid so that the terrain inside the zone is positioned higher than outside. The same applies when staking out areas in undulating terrain.

§ 7-5 *Preparatory work*
A fire line, approximately 20 metres wide, shall be hewn along all boundaries where there are no natural fire hindrances. The fire line shall be cleared of all trees and scrub. The outer belt (approx. 5 metres) in the fire line shall be cleared of felling waste, which shall be dragged onto the ground that is to be burned.

Along the fire line's extreme perimeter – not more than 1 metre inside the area cleared of felling waste – a safety line shall be made. For this purpose mineral soil in a breadth of at least 0.3 m and with a depth that covers vegetation may be laid. As an alternative to a line of mineral soil, the fire line's outer edge, in a breadth of 0.5 m, may be sprayed with water (power pump for water spraying, watering can or similar) immediately before igniting.

Approximately 1 litre per metre shall be used, and the process must be repeated as often as is necessary according to conditions. Alternatively, a retardant line of chemical that has flame-inhibiting property may be laid.

In the vicinity of the fire line, water access shall be secured by cleaning up natural water sources and by blasting or digging water holes. If access to water is insufficient, mineral soil can be used for extinguishing purposes. Mineral soil must be piled up in advance in easily accessible heaps at the outer edge of the fire line.

Ant hills which are on or in the near vicinity of the zone should be protected either by clearing away felling waste and laying a line of mineral soil around the ant hill at a distance of at least 5 meters from the hill, or by covering the ant hill completely with mineral

soil. The anthills may alternatively be burned up on frozen land during the previous autumn.

Breeding birds should be removed well before burning takes place.

§ 7-6 *Crew, equipment and weather conditions*
The size and composition of the crew during the process of firing must be adapted to prevailing conditions (the size of the zone, natural fire hindrances, topography and fire danger in the proximity, access to water and available equipment, competence level of personnel, etc.) The responsible leader shall in each and every case evaluate the need for personnel to be divided between the ignition and extinguishing patrols. The responsible leader shall report the list for approval to the Chief Fire Officer.

Ignition patrol personnel shall be equipped with ignition appliances (including one in reserve) and fuel for these.

Personnel in the watch and extinguishing patrol shall be equipped with watering cans, water buckets, axes, spades, flay hatchets, fresh sprigs from coniferous or deciduous trees (flame swatters) and motor saws. The responsible leader shall ensure that first aid equipment, necessary power pump sprayers with water hoses and other pertinent equipment, and also smoke masks shall be found at the locality.

The firing must not commence if the wind force is as heavy as strong breeze or if it is calm. Neither must the firing commence if the wind is changeable or unpredictable, e.g. thundery weather. The same applies if such weather is forecast.

§ 7-7 *Executing the firing*
Before ignition takes place a plentiful number of fresh coniferous or deciduous sprigs shall be cut and spaced out along the fire line on the leeward side of the zone at gaps of approx. 30 meters. Buckets and sprayers filled with water shall be likewise placed. In addition, the responsible leader shall instruct the crew on the individual duties for which each is responsible.

The process shall commence with prevention firing by igniting the inside of the safety line farthest up the leeward side of the zone. When the leeward side fire line is burned off, prevention firing shall be continued along the fire lines of the flanks. Simultaneously, strips shall be lit straight across the zone, so that the firing takes place in belts upwind. The flame front out in the zone must be as much as possible at right angles to the wind direction and the firing alongst the flanks' fire lines should be 10 – 15 metres ahead of the flames out in the zone. Ignition from the windward boundary must first take place when the fire lines of the flanks are burned off right up to the windward boundary.

In zones with mainly fire safe boundaries or surroundings without risk, the main fire may be ignited from the windward boundary, on condition that any possible fire lines on the leeward side and flanks have been well burned-off in advance.

Steep and undulating terrain demands a varied and careful firing technique. A general rule is that ignition must be conducted to ensure that steep slopes are burned off from the top and downwards.

The extinguishing patrol shall move along the fire lines as the firing progresses and all unsafe stretches shall be patrolled in such a manner that each man has alternating contact with the fire crew along both edges. In the event of black smoke or whirlwinds turning towards the forest outside of the zone, the area in question must immediately be patrolled to ensure the extinguishing of ember showers.

§ 7-8 *Postfire extinguishing and surveillance*
When the firing has progressed somewhat into the zone, it is normal that some of the crew are left unoccupied and these should then be reassigned to postfire extinguishing from the leeward side and the flanks. The postfire extinguishing shall continue over the whole zone immediately it is burned off. Special attention must be paid to ensure that flames are completely extinguished in ant hills, hollow trunks, decaying lumber, resinous pinewood stumps and similar. All smouldering glow should normally be extinguished in the course of 24 hours after the area in question has been burned off.

The responsible leader for the firing operation bears responsibility until the firing itself is completed. Subsequently, the owner or the user of the forest (or the user's representative) has the responsibility for postfire extinguishing and surveillance. The owner or user (or the user's representative) shall give written confirmation to the leader that he has taken over responsibility as mentioned from a fixed point in time.

In the case of a zone measuring 200–300 decares, a watch force of 2–4 persons is required for the first 24 hours. The watch force may be reduced gradually, but should not be completely withdrawn before 3– 4 days after the last sighting of smoke in the zone.

§ 7-9 *Exemption*
The Chief Fire Officer may, in individual cases, give consent to modifications based on proven needs that he finds warrantable. Terms for such exemptions may be stipulated.

§ 7-10 *Firing felling waste, grass or heather on, or in the vicinity of, forestland*
The provisions in §§ 7-2 to 7-9 concerning surface firing also apply accordingly to firing felling waste, grass or heather on forestland.

When the firing of felling waste, grass or heather in the described vicinity of forest land may lead to the danger of fire on the forest land, the provisions for surface firing apply accordingly to the degree they are suitable, and in accordance with the Chief Fire Officer's further decision.

12.4 Act of 21 May 1965 relating to Forestry and Forest Protection

§ 17a *Concerning roads and other construction etc. in forestry*
The Ministry may establish regulations governing road planning and road construction and other permanent works and technical encroachments in relation to forestry, including a provision deciding that plans for such construction and encroachments may not be accomplished unless the plan previously has been submitted to and approved by the Forest Service Authority. The regulations may also contain a provision deciding that the Forest Service Authority may refuse to approve such a plan if it detects that its realisation will reduce the possibility of arriving at other more appropriate overall solutions or seriously impair outdoor recreation or the natural environment (cf. the third period of §1).

§ 17b *Forest areas of particular value to outdoor recreation and nature protection*
Regarding forest areas of particular value for outdoor recreation and nature, the King may due to these interests establish further regulations that, in addition to such restrictions that otherwise are justified by the Act, may include other and more extreme forestry restrictions. The King stipulates the boundaries of the areas where the regulations may apply. The regulations may include bans or restrictions against clear-cuts, felling of certain species or types of trees, harvesting of wooden vegetation in certain areas, the use of

larger off-road harvesting machinery, forest road construction and other projects, measures and operations related to the logging and management of the forest that may cause significant damage or inconvenience to outdoor recreation activities or significant harm to the natural environment (cf. the third period of §1). Similarly, the regulations may include an obligation on forest owners in the relevant area to report without further request to the Forest Service Authority about any plans and operations included by the regulations.

The Ministry may establish temporary regulations as referred to in paragraph one. The regulations apply until the case has been settled by the King, however not exceeding 3 years.

Regulations and area delimitation pursuant to this Section shall be published in Norsk Lovtidend and in one or more newspapers that are generally read in the district.

§ 22 *Measures when forest is damaged by fire etc.*
When forest is damaged by fire, wind felling, landslides, attacks by rodents or insects, the following rules shall apply:

1. An insurance company or another that is liable to compensate for the damage, is obliged to pay the Forest Service Authority compensation for replanting and up to 30 % of the remaining compensation in accordance with more detailed guidelines established by the Ministry. The Forest Service Authority may to ensure regeneration order that the amount, or part of it, shall be used on silvicultural tasks following more detailed instructions made by the Authority. If such order only refers to part of the amount, the surplus is paid to the policyholder. The part of the compensation to be used on silvicultural tasks shall be deposited in a separate bank account. The amount including interest may at the permission of the Forest Service Authority be withdrawn as the prescribed silvicultural tasks are accomplished.
2. Where it otherwise may not be expected that satisfactory regeneration may be reached by other methods within a reasonable time, the County Agricultural Board may order that silvicultural measures shall be accomplished by utilising a certain portion of the amount on deposit in the Forest Trust Fund plus any possible public grant.

§ 23 *Remedial measures of inappropriate forest management etc.*

1. If forest as a result of harvesting or other reasons is in such condition that the circumstances for the forest productivity and for germination or growth, either by natural or artificial regeneration, evidently is unsatisfactory, The County Agricultural Board may:
   a. order silvicultural measures to be accomplished, including the clearing of regeneration areas, using a portion of the deposited Forest Trust Fund plus any possible public grant, and further decide that a certain portion of the Forest Trust Fund shall be retained to cover the expenses of the work to be done.
   b. order felling to be accomplished to promote the revegetation and the growth of the young forest if the local harvesting conditions permit financially viable operations.
2. If the forest is badly damaged by decay that obviously significantly reduces its value, the County Agricultural Board may, where the local operating conditions are financially viable, order the felling of damaged trees to the extent considered necessary to prevent further deterioration. Equal consideration applies where the forest has such great age that there is an evident risk of a larger amount of trees dying if felling is not accomplished.
3. If the drainage system is not maintained in forest where it is previously issued public grants for proper establishment of a drainage system on bogs where this establishment is feasible or on swampy forest land, and if it may be assumed that the area in the future once more may turn into wetland if the drainage system is not maintained, the County Agricultural Board may order the forest owner to execute needed maintenance corresponding to the amount issued as public grant for the establishment of the drainage system, plus a certain amount on deposit in the Forest Trust Fund.

12.5 Other acts, regulations and directives

Pursuant to section 75 of the Constitution and The Agricultural Act

Regulation of 20 May 1994 relating to compensation for major loss of livestock due to a natural disaster

According to § 1 of this regulation compensation can be given for major loss of livestock in case of natural disaster.

Regulation of 15 February 1993 concerning The Specific Agricultural Landscape Support Scheme

According to § 1 of this regulation support can be given to maintenance and development of the agricultural culture landscape, including areas in forest, heathland and other outlying ranges influenced by agricultural activity.

Act No. 53 of 4 August 1995 relating to the Police

§ 27 *Accident and disaster situations*
It is incumbent on the police to initiate and organise rescue, operations in cases where people's lives or health are threatened, unless such responsibility is assigned to another authority.

The King lays down further provisions on the rescue service's functions and organisation.

In case of accident and disaster situations it is incumbent on the police to implement such measures as are necessary to avert danger and limit damage. Until responsibility is assumed by another authority, the police shall organise and co-ordinate the relief work.

General instructions for the police service

§ 8-4 regulates the duties of the police in case of fire in regard to securing of the fire site, rescue, patrol duty and investigation.

Act No. 9 of July 17. 1953 related to the Civil Defence

§ 1 The object of the Civil Defence is to plan and execute measures of a non-military nature, for the purpose of preventing or alleviating harm to the civilian population by acts of war, which are not assigned to other authorities pursuant to special regulations.

Regulation of 24 November 1961 regarding Civil Defence efforts to prevent and make up for damages not caused by actions of war.

§ 1 It is a Civil Defence objective to help prevent and remedy damages caused by incidents other than war. This implies that Civil Defence will contribute to avert or limit the consequences of natural disasters or other serious accidents, in cases where the ordinary rescue services are unable to provide the adequate resources.

Directive of 26 June 1978 regarding Civil Defence assistance in forest fire protection

The purpose of the directive is to increase the efficiency of Civil Defence peacetime fire-preparedness, and to intensify Civil Defence assistance to local authorities in cases of large fires in forest and field.

In addition the directive contains regulations about organization and dimensioning of the effort.

Act No. 6 of 13 March 1981 relating to protection against pollution and relating to waste.
(**The Pollution Control Act)**

§ 6 of this act defines pollution, including the release of solid, liquid or gas pollutants to air, water or the ground.

§ 8 describes limitations in the demand to avoid pollution, including pollution from agriculture and forestry.

§ 11 concerns special permission for polluting releases.

These sections are relevant in connection with forest fire and burning of forested areas.

Act No. 66 of 19 November 1982 relating to Municipal Health Services

Chapter 4a Environmental health protection (Norw. "Miljørettet helsevern")

Environmental health protection encompasses the environmental factors that at any time directly or indirectly can influence health. These include among others biological, chemical, physical and social environmental factors.

§ 4a-6 contains provisions about the duty to inform the public of activities which may influence health, and

§ 4a-10 contains provisions about stopping activities that entail risk of health damage.

These sections can be used in connection with forest fire and burning of forest.

Act No. 69 of 16 June 1989 relating to insurance contracts

§1-1 *Scope and extent of part A of the Act*
(Subsection 2:) Non-life insurance means insurance against damage to or loss of things, rights or other benefits, insurance against liability or costs, and other insurance that is not insurance of persons.

Act No. 70 of 16 June 1989 relating to natural damage insurance

§ 1
(Subsection 1:) Things in Norway that are insured against damage by fire are also insured against natural damage, if the damage is not covered by other insurance. With natural damage is understood damage that is directly caused by natural disaster, such as avalanche, storm, flood, storm surge, earthquake or volcanic eruption.

Regulations of 21 December 1979 relating to directive for Norwegian Natural Damage Pool

This regulation regulates the insurance conditions in more detail for the casework in connection with natural damage.

12.6 Summary

The Fire Protection Act is the most central legal tool pertaining to forest fires. The authority in this Act is found in two regulations that also apply in connection with forest fires. The regulations relating to organization and size of fire services stipulate requirements for organization of a special reserve force for forest fires, if this is deemed necessary. The regulation relating to fire protection, etc. governs *inter alia* the duty of the general public to provide assistance in particular, in addition to duties and prohibitions in connection with the use of fire outdoors. Here it is especially important to note that it is prohibited to light fires in forests and fields during the period from 15 April – 15 September, except by permission from the fire chief (with certain restrictions, see Section 6-2 of the regulation). The regulation have a separate chapter, Chapter 7, concerning clear-cut burning and other burning in or near forestland, which provides specific rules for how such burning shall be carried out. The rules include everything from notification and preparation work to the execution of the fire, post-extinguishing work and security watches.

The Act relating to forestry and forest conservation governs the building of roads and other facilities in connec-

tion with forestry and carries the authority for potential restrictions on forestry in areas that have special value for outdoor recreation and nature conservation. The Act also provides provisions regarding measures to be taken when forests are damaged by fire, and measures to correct the consequences of unfortunate forest management.

The chapter also lists other statutes that relate to forest fire, such as statutes relating to catastrophic loss in connection with animal husbandry, subsidies for special measures in cultural landscapes, political efforts, civil defence efforts, pollution in connection with fires, statutes aimed at the pollution and health aspects of fires, as well as statutes aimed at insurance aspects.

13 NOTES

Chapter 1

1.1. In Australia, the vegetation was first transformed by the aborigines' fire stick farming and thereafter changed by the European settlers' various forms of burning (Singh et al. 1981, Kershaw 1986, Pyne 1991, 1995a).

In Africa the evergreen forest declined at the same rate as burning of savannas and grasslands increased. In the tropics, the burning of savannas continues to displace the borders of the tropical forest areas (Stott 1988, Crutzen & Andreae 1990, Backeus 1992, Weiss & Goldammer 1994).

In North America, the indians burned prairies and forests for production purposes to improve their survival. When the first settlers arrived, they also lit fires, expanded the prairies and cleared the way for settlements and new vegetation types in the remaining forest areas (Pyne 1982, Axelrod 1985).

Human use of fire has also a long history in Europe, for example, in the Mediterranean area (LeHouerou 1974, Goldammer & Jenkins 1990). Compared with the conditions in the New World, use of fire has peaked in Europe the last centuries as a consequence of high population density.

In the forested areas of Eurasia, the extent of fires on ecosystems has been enormous (Weiss & Goldammer 1994, Goldammer & Furyaev 1996).

1.2. The species changes which are described in fire ecology reflect differences in the growth rate and life span of the species, and not only their position in a competitive hierarchy. Traits that are judged to be important to predict changes in fire succession are related to the individual persistence and recruitment needs of individual species compared to frequency and intensity of fires.

Chapter 2

2.1. Low interest in fire ecology not only applies in Norway. The field of fire ecology has received less attention than other fields of ecological research. The focus on fires in connection with forms of applied management schemes has isolated this important topic from more theoretical interests (Bond & van Wilgen 1996). A possible explanation is that most textbooks in ecology have been written by scientists who live and work in temperate mixed forest regions, i.e. places where it does not burn regularly in outlying areas (Bond & van Wilgen 1996). Researchers from this region also created the important and disputed concept “balance of nature”. Forest fires in outlying areas do not fit particularly well into a nature “in balance”. It has taken many years to substitute the European antipathy towards fires with a more objective attitude towards the role fires play in areas that are influenced by Western research (Pyne 1982, 1991), even for fires within national parks (Wein & MacLean 1983) (See ch. 9).

2.2. It was mainly American fire research during the 1960s that focused on the biological importance of electrical processes (Komarek 1964, 1968, 1969b, 1973), and thus began this field of research. Descriptions of the electrical climate of the atmosphere have traditionally concentrated on the thunderstorm frequency.

2.3. It is documented that invasion of a few pioneer individuals on a single tree which is hit by lightning may release mass attacks on the struck tree and its neighboring trees. At a forest estate in Louisiana, USA, single pines that were struck by lightning were the center for 31 % of 2 100 tree groups infested by beetles (Taylor 1973). An explanation for beetle invasions is that lightning strikes inflict wounds on a tree (which are not always visible) that induce beetle attacks. However, it is not known if larger beetle epidemics can develop from local infections (Komarek 1973).

2.4. For a review of the literature about lightning theory and the link between lightning and forest fire, see Lundquist & Götschl (1995). They also provide a survey of PC programs with models for mapping fuel and fire risk, probability for ignition and development of forest fire.

2.5. Researchers have raised the question of whether fires influenced the evolution of entire floras (Bond & van Wilgen 1996). A controversial evolutionary question in this context is whether plants have evolved features that increase their own ability to burn (flammability). Mutch (1970) has argued that some plant communities are more "fire prone" than others because they have evolved features that lead to an increased risk of burning. The increased flammability was suggested as a way to eliminate more competitive species that would replace fire prone communities in a possible long absence of fire. A theoretical difficulty with this hypothesis is its argumentation about group selection (See Bond & van Wilgen 1996). However, a new model has pointed out that increased ability to burn may also have evolved by giving benefits to individual plants (Bond & Midgley 1995). Increased flammability may evolve if it causes less fire prone neighbors to burn and die, such that openings are created and a competitive advantage results. However, it is difficult to distinguish the relative importance of fires from other key environmental variables in such evolutionary contexts. There is a dire need to emphasize evolutionary analyses in future fire research.

2.6. The understanding of combustion processes and fire behavior have been considerabley expanded through developing models (See Chandler et al. 1983, Burgan & Rothermel 1984, Catchpole & de Mestre 1986, Whelan 1995). The connection between primary variables as fuel, moisture and oxygen were first described by means of relatively simple, empirical models (McArthur 1966, Noble et al. 1980). Today, these have been developed into more complex, stochastic and predictive models, e.g. of the type BEHAVE (Burgan & Rothermel 1984, Catchpole & de Mestre 1986). Generally, such models are based on factors that regulate the basic reactions in the combustion, and on a fire theoretical understanding of how climate, plant community and physical environment influence ignition and fire behavior.

2.7. The concept "ignition temperature" in equation (2) indicates that combustion is no simple or spontaneous process. Combustion necessitates a certain "activation energy" or ignition energy from an external energy source. Wood begins to burn by first providing it with enough heat from an external source to start the decomposition by means of heat. This is called pyrolysis. The lower the temperature of the fuel, the more energy is needed to ignite it. Pyrolysis is the thermal change of the fuel that results in the release of water vapor, carbon dioxide and gases able to combust, including methane, methanol and hydrogen. During pyrolysis, the reaction changes from being endothermal (i.e. needing heat to continue) to being exothermal (able to continue by itself). By applying a "pilot flame" to the gaseous components that escape from the wood and mix with the air during active pyrolysis, one can get a flaming combustion started.

2.8. A larger fire arose through self ignition in a peat store in Uppsala, Sweden in 1990 (Blükert 1992). In 1993 and 1997, fires also self-ignited in so-called growth peat (Norw. "veksttorv") in Norway. Self-ignition is a well-known problem connected to storing of hay and other husbandry forage. Microorganisms are responsible for most of the heating, but other conditions can be of importance. All the suspected occasions have occurred in the springtime during warm weather periods (Directorate for Fire & Explosion Prevention 1993). Spontaneous self-ignition is a complex phenomenon where combustible matter is ignited by heat from its own reactions without any external heat source. Of the many different heat-generating reactions, oxidation is the most common. The mechanism involved is not completely understood. Self-ignition has been shown in a number of agricultural products. For a description of the process and a review of the literature, we refer to Bøe (1984).

2.9. A grassland fire in Nebraska, USA, burned with a 5 km front towards the east for 18 km. A 90° wind shift turned it into a fire burning northwards with a front of 18 km (Komarek 1967).

2.10. Lightning that occurs when relative humidity is high, prevailing temperature is low and the litter is saturated with humidity will rarely start fires. The seasonality of, for example, lightning for a given locality, can easily be measured and related to the time of plant growth and desiccation. In so-called "fire seasons", the vegetation and litter has dried out during warm and dry periods making probability of ignition high. Typical fire

seasons caused by natural ignition sources may therefore be predicted for a given region.

2.11. A fire that has recently burned reduces the biomass at a site, and thus also reduces the potential for flaming combustion for some time afterwards. The next fire will therefore be more mosaic shaped when amount and distribution of fuel is reduced through the impact from the previous fire. The extent and mosaic formation caused by fires will vary, depending on the spatial pattern of earlier fires.

2.12. The ignition frequency is decisive for the fire frequency (Whelan 1995). Due to higher ignition frequency from human activity, a higher fire frequency exists around the large cities Melbourne, Sydney, Alice Springs and Darwin, Australia, than in other areas with comparable climate and vegetation types (Walker 1981). A correlation between ignition of wildfires and local population density has also been found in parts of Japan (Takahashi 1982). Historically, natural fires were a very rare phenomenon in these particular parts of Japan. Lightning ignited only 0.7 % of the forest fires that occurred in Japan between 1946 and 1977. The main causes were fires that spread from controlled management fires, garbage combustion and other miscellaneous unintentional causes (59.7 %). Research has also indicated that human change of the fire regime has caused marked changes in the composition of the Japanese flora (Takahashi 1982). The conditions described from Japan indicate that the proximate control of the fire frequency in historic past has been the ignition sources and not the local climate nor the occurrence of fuel. This is important information for evaluating both the Norwegian and Nordic fire regime (section 2.2.5). Historically, the Norwegian fire regions have had extensive burning independent of natural ignition sources. Burning also appears to have occurred more frequently around the large population concentrations (See ch. 6).

2.13. In a long-term perspective, the occurrence and frequency of forest fires are partly determined by the climate, where the temperatures and number of lightning strikes during the summer are important factors (Engelmark 1984, 1987, Zackrisson 1977b). The climate, and weather in the days prior to and at the time of ignition, will be the primary factors determining the moisture degree of the fuel. The composition of the vegetation at a site may also, through interactions with the climate, influence the microclimatic conditions on the ground surface.

2.14. It may be difficult to gather information and data concerning the fire history. If, for example, the interval between fires is long (decades or centuries), “chrono sequence” vegetation ecology has been used. To study a site’s fire history more holistically, a series of stands with known age since last burning should be composed. The use of chrono sequences assumes that only the age of the stand varies, and that the site can be viewed as homogenous concerning other conditions. This is often the only practical way of providing data for long-lived tree species (Bond & van Wilgen 1996).

2.15. When a ground fire burns through a forest stand, an individual tree will be exposed for maximum heating due to the leeway effect relative to the wind direction during the fire. The cambium of the tree is often killed at the leeway side, but can otherwise survive. Characteristic wounds called “fire scars” are created. From the edge of the surviving cambium, new wood will be produced to cover the wound. In this wood, growth rings are deposited. The orientation of the fire scars can therefore provide information about the direction of the fire, and the growth rings can be used to date the fire.

Chapter 3

3.1. The lapse of extensive forest fires influences the litter and organic components of the soil, and therefore may produce great differences in animal and plant species composition among regions. For example, the mycorrhiza fungi constitute a group of decomposers with hyphae that penetrate roots and live in symbiosis with forest plants. Mycorrhiza fungi decompose dead organic material and transport water and nutrient salts from the soil to the roots of the trees. Through the fungal hyphae ramification in the surrounding soil, the volume of the soil that the tree roots utilize nutrients from may increase. Fires can have extensive impacts on this system, something commented upon several times in this report (See ch. 8).

3.2. For a modern and hierarchical classification system and description of the vegetation of Norwegian outlying areas, we refer to Fremstad & Elven (1987). We provide a simplified review of dry and humid forests on mineral soil and peat soil, respectively. These main types are then subdivided into regional and local types, characteristic of particular climatic areas (Larsson et al. 1994).

Chapter 4

4.1. In Norway, it is sensible to assume that the use of forest and outlying areas, and thus ignition and impact of fuel, can be traced back to the last glacial withdrawal (Asheim 1978).

4.2. “Landnam” (Norw. “landnåm”) is a Danish word referring to the first large “wave” of clearing and settlements in the Scandinavian forest regions (Iversen 1973).

4.3. Various types of burning most likely had several functions and filled various needs and intentions. For example, a particular burning may have been followed by a year with crop plants, and must therefore, per definition be denoted as swidden agriculture (Section 4.2.5). The main intention, however, may have been to produce hay or improve existing pasture for domestic stocks (Myrdal 1995).

4.4. The grazing pressure from moose, red deer and other large herbivores might have kept parts of the landscape open. However, it should be assumed that this affected only limited areas such as soil seeped by water and areas along rivers and lakes (Ahlen 1966, Tenow 1974).

4.5. From eastern Eurasia, it has been shown that hunters burned along their trap lines to stimulate forage production for small rodents that in turn attracted prized fur species like fox and mustelids (Pyne 1996).

4.6. Documentation for such practices exists in written sources. Among others, reports of negotiations between the Hanseats and the Norwegian king (Håkon the 6th Magnussøn the younger, 1355–80) at that time have been found in Hanseatic archives. Among the charges raised was that even in times of peace, Hanseatic merchants had burned both farms and forests owned by the king and other Norwegian citizens. The fact that the Norwegian king in direct negotiations raised such severe accusations indicates that they must have been based on serious facts and that ignition of forests was extensive (Sandmo 1951).

4.7. Where fires are mentioned in written sources, sociological direct causes were occasionally reported. For example, two persons of Finnish stock (Norw. “kvener”) took up a quarrel with a merchant and ignited the forest before they left the area. They apparently believed that it was the merchant who owned the land and were trying to harm him (Skogdirektøren 1909).

4.8. In the material presented by Skogdirektøren (1909) such accusations are doubted by, among others, an informant named Carl Aasli. He claimed that the basis for this accusation was directly wrong, and most probably it was the colonizing farmers themselves who ignited the fire and burned the forest. As long as only reindeer herders and nomadic samii people were present in an area, large forest fires very rarely occurred. Reindeer herders had no reason to ignite. As nomads, they had more benefits from an intact forest.

4.9. A Norwegian historian specializing in the Nordic pest literature (See Benedictow 1992) has the opinion that prophylactic burning of this type has never been carried out in Norway. The only prophylactic aspect of burning in connection with pest concerned igniting bonfires to cleanse the air of a substance called “myasma”. One could also burn twigs, for example of spruce and pine, inside houses to remove, expel or break down smells from “myasma”. From 17th century Italy, it is also known that straw from beds and other material believed to contain “myasma” was burned. Burnings of the type Pyne (1996) mentions are unknown in any historic source material from Norway. The response to the pest has exclusively been met with religious “counter measures” (Ole Jørgen Benedictow, pers. comm.).

4.10. This is a somewhat broader definition of the concept of burning to clear land than suggested by Myrdal (1995) as “fire to establish permanent fields on areas which are to be harvested for many years”.

4.11. The first signs of agriculture in Norway are claimed to be from approximately 4000 B.C. (Fig. 4.1). Through pollen analyses, it has been established that grain (wheat, barley, millet), hay and typical grazing plants were grown in some areas. Grain production is linked to a more permanent settlement, and during this colonization, large forested areas were gradually cleared (Hagen et al. 1980). Before the time of grain production on permanent fields, agriculture was exclusively carried out as swidden cultivation, but this is disputed among historians.

4.12. An extensive discussion exists among archaeologists about the immigration to Norway and what forms of

agriculture were practiced (See Mikkelsen & Høeg 1979, Høeg 1988, Bostwich Bjerk 1988). An important part of this discussion is linked to burning and the interpretation of carbon remnants from pollen profiles. For an updated methodological discussion of problems linked to dating, production and spread of pollen, climate indicators and carbon remnants linked to human activity, we refer to Høeg (1997). While preparing this report, extensive archaeological data not discussed here were also collected. A separate report is needed to review the archaeological data on anthropogenic burning (See among others Holm 1995, Høeg 1996, 1997, Jerpåsen 1996).

4.13. Various hypotheses exist about where the earliest immigrants came from (Asheim 1978, Hagen et al. 1980).

4.14. Corresponding examinations of a valley bog in North Ireland (Smith 1981) have indicated early clearance of forest around 3 270 B.C., where pine, oak and hazel were removed by burning. This burning occurred within a shorter period than 20 years, and possibly during only a single year. This intensive burning was followed by a series of agricultural phases during 600–700 years before the forest regenerated (Smith 1981).

4.15. Presently, the huutha swidden agriculture is simulated to provide insight into how this was conducted (Birger Nesholen, pers. comm.).

4.16. Soil profiles in various studies have shown that swidden agriculture deposits a thin fire horizon just under the ground litter, consisting of humus enriched with carbon, this mixed with solid carbon pieces. However, locations where forest fires had burned showed the same type of fire horizon as the swidden areas. Irrespective of the age of the forest fires the fire horizon was located directly under the ground litter (Lindman 1995). In general, similarities were found between swidden burning, forest fire and heather burning (See Lindman 1995, s. 52).

4.17. The precondition for conducting agriculture in a more permanent and intense form than swidden agriculture was knowledge about fertilization, i.e. that they regularly added husbandry manure to the soil. Progressively, people became peasants on permanent farms and could utilize manure from domestic animals more efficiently. Typical farms similar to present ones were developed across large areas.

4.18. The effect of fires in coastal areas with extremely high precipitation and shallow organic soil must be expected to be dramatic in many cases. Subsequent high precipitation, increased running through of water and accompanying erosion in such areas may lead to severe decrease in quality class and permanent decline of ecosystem productivity.

4.19. Fires started by colonists with domestic animals were also common in North America (Alexander & Dubé 1983, Steensberg 1983), often in areas that are presently national parks and wilderness areas. The large "fire induced" coastal heathlands of Northern Europe, described several places in this report, were also common in Norway. This implies the existence of extended knowledge concerning the use of fire in rangeland management (section 4.2.6).

4.20. Examples exist in Scandinavia of burning along the shores of small tarns and lakes such that a nutritious trickle would empty into shallow water. This could transform the vegetation of rush and sedge in the shore zones into better forage (Pyne 1996).

4.21. Signs of fires in forested land soil in the form of carbon remnants ("macro coal") have been documented in the western part of south Norway (Vestlandet). However, it is uncertain whether this originates from historic wild fires or heath fires from the time when the forest conditions were far more open (Øyen & Asplin 1996).

4.22. Because of a marked decline in the use of fire in outlying areas during the twentieth century, it has been hypothesized whether a connection exists between the decline in the population of some important hunted game species (willow grouse, black grouse, hare) and fresh water fish populations (Eikeland 1956). We present research on this topic and continue its discussion in section 4.2.9.

4.23. It is hardly possible to generalize about the quality of ash in this way, see section 8.1.

4.24. By means of a fire aggregate powered by propane gas, a concentrated scorch or burn of the vegetation at selected patches is undertaken (Øyen 1996a, 1997). The size of the burned patches is recommended to be from 0.5 to 1.0 square meters. This means that 5–10 percent of a regeneration area will be burned if one aims at 2 000 patches per hectare. With the growth conditions

existing at northern latitudes, a patch burn would occur at the same area roughly once per 60–120 years.

4.25. Using this procedure for improving game production varies regionally in Norway. Conscious ignition of forest fires has rarely been used by wild reindeer hunters or nomadic reindeer herders. Present evidence that burning of forest were part of the subsistence strategy of prehistoric trapping cultures in northern Fennoscandia is lacking (Aronsson 1995).

4.26. Granström (1995) argued against this by claiming that the percentage of forest land in Sweden in young succession stages constituting prime moose habitat has probably been so considerable through natural ignited fires that additional ignition has been unnecessary. However, it is reasonable to maintain the possibility that prehistoric hunters have used fire in their hunting of moose in the cooler and wetter (oceanic) Norway. Here, the natural fire frequency must be expected to have been far lower than in Sweden (ch. 3).

4.27. There are four large "forest companies" in Sweden that have committed themselves to burning motivated by nature conservation, viz. SCA Skog, Stora Skog AB, Assidomän and MoDoSkog. Their estates encompass 2.3 (SCA Skog 1994), 1.5 (Börje Petterson, pers. comm.), 3.4 (Herman Sundkvist, pers. comm.) and 1 million hectares (Erik Normark, pers. comm.), respectively, i.e. a total of 8.2 million hectares.

These companies have also hired personnel who are going to develop action programs, start projects to clarify premises for increased burning activity and present practical plans for long-term fire management of their forest on company land (Johansson 1994, Anonymous 1995, Friberg 1995, Sundkvist 1995, Stora Skog AB 1994).

There are theoretically and ecologically no absolute criteria for what a "landscape" is. In ecological landscape planning on company forestland, "landscape" has therefore been defined as the area on which planning is based for practical work. This includes areas of 5 000–30 000 hectares (Anonymous 1995, Stora Skog AB 1995). The idea is that a certain percent of the plan areas are going to burn each year, and that the burning is going to include forests both on O-, I- and S-land (Tab. 9.4).

4.28. There are key habitats determined by continuity, disturbance and culture. For forest, we now operate with 14 types (Håpnes 1993). Key habitats are areas that are important for conservation of biological diversity because they contain nature types, elements or species that are presently rare in the landscape (Håpnes 1995).

Restoration habitats are areas where one wishes to establish key habitats that are rare in the landscape (Håpnes 1995). At Gravberget district, 21 key habitats and 22 restoration habitats were established during registration, including an area of approximately 2 980 decares of a productive forest area of 161 000 decares. This included a total of 1.85 % of the estate, of which 1 780 decares were key habitats (1.1 %) and 1 200 decares are restoration habitats (0.75 %). Most of the key habitats and restoration habitats are continuity determined which take care of themselves, and need no other form of management than no cutting. In addition, there are some restoration habitats that are disturbance determined, and it is among these that the introduction of fire is recommended as an important ecological factor on the estate. At Gravberget, for example, fire succession with both a biomass of burned wood and subsequent deciduous succession is judged as important restoration projects (Håpnes 1995).

4.29. The background for this suggestion is that in adjacent parts of Sweden, data from the State Fire Inspection (Swed.: "Statens brandinspektion") indicate that the degree of ignition by lightning per 100 km^2/year has been between 0.15–0.18 in the period 1953–75 (Skog og forskning 4–91). This area has among the most frequent lightning strike frequencies in Sweden. The same can be seen in data from Norway (Directorate for Nature Management 1994–95), where the Gravberget area has a frequency of lightning strikes of 400–800 strikes per decade. Håpnes (1995) mentions further that most forest fires are small, as a rule 5–200 decares, and that crown fire is rare in Scandinavia.

4.30. Wood was the basis and the raw material until pit coal and coke became available (Hechscher 1968).

4.31. The production of glass in Norway was initiated during the transition between the 1730s and 40s, where a number of glass factories were founded. During 1747–48 Aas' Grønne Glashytte in Sandsvær and in 1755 Hurdalen Kronglashytte (Hurdals Værk) emerged. Later, Biri Glasværk and Hadelands Glasværk emerged in 1763, Schimmelmanns Glassværk at Hurum in 1779 and Jevne Glasværk at Fåberg in 1792. This Norwegian

glass industry originally began under the protection of the state (Rugsveen 1989).

4.32. The method was relatively unknown in Sweden until the 17th century, when there was a boom in burning. The burning spread throughout the country until the middle of the 19th century. In the middle of the 17th century, a potash company was founded, which through privileges, gradually took over this activity throughout Sweden. Although it was soon disintegrated, the production of potash spread and during the 18th and 19th centuries became an industry for the commons (Norw. "allmuenæring") similar to the tar burning industry, i.e. a necessary subsidiary source of income to a marginal agriculture. During the 18th century, this constituted a considerable export product, among others from Sweden to England (Tenow 1974). The export from Sweden culminated during the middle of the 19th century and declined around 1860. Towards the end of the century, the production in Sweden had ceased. This is supposedly due to an exhaustion of raw materials (Tenow 1974).

4.33. Fire wounds from potash burning must not be confused with the "fire scars" that are created by wildfires. Fire wounds around potash fires emerge at the side of the trunks facing towards the potash fire (pictured in Östlund 1996).

4.34. Tar burning took place based on different methods such as within a ditch, kiln, so-called "tjærehjell" (elevated from the ground), cooking pot, oven and on bogs (Fossum 1992c). The tar kilns were built of wood from pine stumps broken loose, or from partly ring barked, fresh pines that were left standing for some years so that the resin was produced before the trees were cut (Tenow 1974).

4.35. Anthropogenic harvest of wood for different activities has met many demands and needs during the annual cycle in Nordic conditions (See Eknæs 1975). The cutting was traditionally a precondition for farming, and the forest provided fuel, timber for buildings, fence posts, drying racks, birch bark and a number of other resources (Tenow 1974, Eknæs 1975, Asheim 1978).

4.36. During the 20th century, the extraction of wood for home purposes declined simultaneously with the shift from renewable resource to nonrenewable resources (brick and concrete as building material and fossil material/electrical power as fuel).

4.37. For more detailed information about the forest and forestry in Norway, we refer to the five comprehensive volumes of the series "Skogbruksboka" (Wibstad 1960, Strand 1961, Wibstad & Maartmann 1961, Börset 1962a, Seip 1964).

4.38. Analyzing what the course and effects of forest fires would be in this modern forest structure compared with stands of more ancient types is so extensive that it has to be dealt with in separate research.

4.39. Skogbrand is presently an independent company owned according to the reciprocity principle (Norw. "gjensidighetsprinsippet") by the 36 000 forest owners who have their young forest insurance in the company. These owners have the right to vote at the general assembly. Skogbrand has 8 employees at its administrative office in Oslo. In every municipality, the company has an agreement with a contact person, most often a Chief of forestry (Norw. "skogbrukssjef" or "skogmester"). In addition, the company makes use of permanent specialists within insurance, forest damage, forest economy, finance, meteorology and juridical activities. The company insures an area of 34.6 millions decares of productive forest for all future through young forest insurance. This is more than half the privately owned forest area in Norway. For approximately 20 % of the forest area, the older forest is also insured through timber forest insurance (Skogbrand. Årsrapport 1991). For more information, we refer to Skogbrand (1937) and Vevstad (1987a).

Chapter 5

5.1. There is uncertainty associated with the interpretation of the origin to the carbon remnants in the profiles. Here, the possibility of anthropogenic impact occurs once again. Håkonsen (1996) assumes that the topical areas at Totenåsen, which are presently nutrient poor and maintaining a very small population, have been sparsely used for agricultural purposes prior to the Middle Age. However, this is highly uncertain, as we do not know enough about various forms of swidden agriculture and other anthropogenic burning in earlier times (Tvengsberg 1995b). The crucial point may not be whether the area has been thinly populated or has had a marginal location, but whether or not it had a nutrient content suitable for burning. In addition, there are a number of activities associated with burnings. For exam-

ple, the potash burning seems to have occurred extensively precisely in these areas (ch. 4). The hypothesis that centrally located forested areas, such as Totenåsen, should not have had extensive anthropogenic burnings of various types during some periods, is not obvious.

5.2. The upper sections of the bore sample profiles from Totenåsen indicated, with a few exceptions, a low fire frequency during this latest period. Håkonsen (1996) again put forward a climate hypothesis: It may have been the cooler and more humid conditions during the so-called "Little Ice Age" (Fig. 3.2) that determined this. The last centuries fire suppression may also have been of significance (Håkonsen 1996).

5.3. This is in accordance with reports from Finland that have established that forest fires were common in the Subboreal period, something which, among other things, supposedly has prevented the expansion of spruce (M. Tolonen 1987).

5.4. It is demonstrated in both Finland (M. Tolonen 1985) and Sweden (Segerström et al. 1995) that fires may induce stagnation and swamping through changes and impact on the hydrological cycles in burned areas. The level of ground water may rise and prepare for an increase in the amount of peat mosses after the tree vegetation has been substantially reduced or has completely vanished.

5.5. In samples from a 203 year old fire-damaged pine, signs of fires were dated to 1816 and 1839 (23 years interval), and in a 188 year old pine, fire scars occurred in 1821 and 1852 (31 years interval). On a pine snag of total age 184 years, it was demonstrated that fires occurred when the tree was 15 and 45 years old (30 years interval).

5.6. Johanson and Schneede (1995) claimed that the relatively high forest fire frequency from the 19th century and onwards, in addition to natural ignitions, must be seen in connection with certain uses like swidden agriculture, charcoal burning and use of fire for pasture improvement.

5.7. 2 556 hectares of pine forest burned in 17 fires (84.2 %), 475 hectares of mixed pine and birch forest in six fires (15.7 %) and 3 hectares of mountain birch forest in two fires (0.1 %). Of these 25 fires, the causes in seven instances were claimed or proven to be carelessness from nomadic Samii or persons of Finnish stock, while six were found to be connected to tar burning, two with peeling of birch bark, one with coffee cooking, one with fishing, one with travelers and one connected to making smoke to avoid insect plagues.

Chapter 6

6.1. Several fires have unknown causes. It is not probable that the category "unknown cause" contains any qualitative cause that are not already known. There is also no reason to assume that any particular cause would dominate quantitatively among "the unknown causes". The category "unknown cause" is therefore evened out by distributing them by percentage proportionately with already known causes.

6.2. The numbers in table 6.1 and figures 6.12 and 6.13 are absolute numbers. They are not relatively determined according to their respective parts of productive forest area in each county.

Chapter 7

7.1. Autocorrelation examines to what extent a data series correlates with itself over various time lags/intervals in the series (..... how fire in year x is correlated with fire in year x+i, where i=1,2,...). This involves making a correlation analysis between a skewed time series and itself. Lag=1 denotes that the time series means are skewed one interval (one year). Lag=2 denotes that it is skewed two intervals etc. Autocorrelation was examined for lag=1 to 14 for the time series 1966–89 (n=24) for the entire country and for each single county.

7.2. After the county-wise treatment (Fig. 7.4), we made a correlation analysis between the six fire regions (Fig. 7.5). The larger data material seemed to "wipe out" some of the differences from the county-wise comparison. As one can see, the correlation coefficient between West Norwegian and Southeast Norwegian Fire Regions was 0.64. This may seem surprising considering the pronounced differences that were registered in the pair-wise comparison of counties. The correlation coefficient for West Norwegian Fire Region (VNR) versus the county group Oppland-Buskerud-Telemark-Aust-Agder and Vest-Agder was 0.54, while VNR versus the county group Vestfold, Oslo and Akershus, and Østfold was 0.68. Thus there is far higher correlation (larger similar-

ity) between VNR and the three coastal counties in the Oslo Fiord region than between VNR and the county group close to the mountains. However, for practical reasons, a large and continuous southeast Norwegian region is maintained.

7.3. However, concerning forest fires in Hedmark, the conditions do not follow the county borders. If a continental fire region in the Hedmark area should have been naturally delimited, the adjacent parts of Sør-Trøndelag closest to the Swedish border (the Femund area) and some adjacent parts of Akershus and Østfold counties should have been included. The conditions in Hedmark Fire Region should in all ways be considered together with adjacent areas in Sweden.

7.4. Here, there could be a question of whether the precipitation rich Vest-Agder together with the somewhat less precipitation rich Aust-Agder should be distinguished as a separate fire region. The location close to the coast, frequency of thunderstorms (Fig. 2.2), common occurrence of anthropogenic ignition sources in the coastal zone (section 4.2.6), and the scattered and sparse occurrence of northern boreal coniferous forests, especially in Vest-Agder (Fig. 3.12), could have been arguments to support this. However, there is such great conformity in the fire pattern, for example between Telemark and Aust-Agder (both counties have a high fire frequency) – the correlation coefficient (0.81) was one of the two highest (Fig. 7.4) – that separating these two regions could only be for purely administrative reasons. The county group Oslo and Akershus, Østfold and Vestfold also fits well with the other east-Norwegian counties.

Chapter 8

8.1. Pasteurization means heating of organic substances and matter to temperatures below the boiling point for a period such that the number of microorganisms is reduced. The expression originally comes from the heating of milk in containers to temperatures below the boiling point, usually in the interval 62.8– 65.5 ˚C for 30 minutes, with subsequent quick cooling, to reduce the content of bacteria.

8.2. In addition to a general increase in the soil temperature, fires in particular instances can also result in reductions of the surface temperature (Kimmins 1997). However, this is a phenomenon that probably does not occur in Norwegian coniferous forests.

8.3. Albedo is the relationship between the reflected light from a surface and the total amount of light received by that surface.

8.4. Published information about effects of relatively short pulses of intense heat that plant tissues can be exposed to in fires and survive is sparse (Whelan 1995).

8.5. Allelopathic chemicals are found in certain types of soil, particularly in chaparall systems in California, USA (Muller et al. 1968, Wilson & Rice 1968). A fire of sufficient intensity can under such conditions act “sterilizing” by decomposing, and therefore removing, such substances from the surface layer and permitting earlier excluded plant species to re-invade (Ashton 1970, Christensen & Muller 1975, Granger 1984, Kimmins 1997).

8.6. The rapid and productive invasion of fire weed and its superb growth in burned areas in northern coniferous forests can probably be stimulated by this effect, even though the improved availability of nutrients is assumed to be the main factor (Kimmins 1997).

8.7. Several mechanisms seem to be operative concerning the stimulation of seed germination, for example the age of the seed, whether it prospectively passes through a vertebrate intestine, whether it is directly physically wounded or is exposed to unsuccessful predatory attempts. Fires promote altered physical environments with increased intensity of light, changed nutritive quality on the soil surface and heated soil, all of which stimulate germination.

As mentioned, a powerful outburst of seedlings is often observed following fires, where seedlings appear in much higher densities than in corresponding unburned vegetation. Increased dispersal of seeds, increased germination and increased colonization may contribute to this.

8.8. Even though such terminologies are not unambiguous, such classifications have several important areas of application. One is the possibility to compare the structure of plant communities in regions and ecosystems with various fire regimes (See Lamont et al. 1985). Another is to develop population dynamic models suited to predict possible responses of a plant community to changed fire regimes (See Noble & Slatyer 1980).

8.9. Older pine forest most often survives, but ordinarily the trees are physiologically affected, and from a for-

est industry perspective, they will most often have lowered economic value. Characteristic fire wounds (fire scars) come into being at the basis of the leeway side of the trees. This is because the forest fire's wind draught is not prevented in the same way as at the opposite side of the tree. Such fire wounds can extend relatively high up on the trunks. Often, the tissue can be weakened such that rot fungi colonize the wounds and can spread further into the tree. However, in most instances, pine will produce defense chemicals (resins) in and around the fire wound to prevent this.

8.10. Ordinarily, spruce does not become older than approximately 300 years. In Norway, slow-growing trees should still be able to reach the age of 400–500 years (Börset 1985). Recent research has documented spruce trees aging from 373 to 450 years (the oldest spruce tree in the Nordic countries) at Oppkuven in Nordmarka close to Oslo (Tilley 1995).

8.11. The distribution of many species of large mammals has been changed by anthropogenic burnings. When the first Europeans invaded North America, the caribou was distributed in the forest areas as far south as Maine and Minnesota, but the species quickly declined when the settlers changed the fire regime. The numerous large mammal flocks in Eastern and Southern Africa consist of species that utilizes plant nutrition either in the grass or bush horizon. The relative distribution of these species in many local areas is mainly determined by amount, intensity and frequency of fires.

8.12. This is documented for a flock of macaques at Borneo, where the nutrient choice before the fire consisted of fruits, seeds and flowers, and of desiccated fruits, herbs and insects after the fire. These changes were determined by changes in behavior, with a larger degree of movements in the ground layer after the fire. Before the fire, they used the crown layer considerably more. The fire also led to changes in group structure, as the distribution of the new nutrients produced a weaker group cohesion (Berenstain 1986).

8.13. Some species have color patterns that vary individually in a genetically determined pattern, so-called "melanistic polymorphy". The occurrence of the dark melanistic color phase documented for the arctic ground squirrel (*Citellus undulatus*) in Alaska assumed to be due to selection pressures that favor dark individuals on dark substrate, i.e. they survive better in ash areas than "normally colored" individuals. This may be an example of "fire melanism" (Guthrie 1967). Such dark morphs are known in several mammal species. The phenomenon is also well known in insects (Poulton 1926, Hocking 1964).

8.14. Fires influence the access to both nutrients and cover, which are the two most important habitat factors for ungulates. The effects of fires in themselves are therefore difficult to distinguish from other disturbance factors.

8.15. The intensity directly influences the scorch and fire height, and the severity will determine how much of the plant cover gets converted, killed or left untouched by the fire. The spread speed of the fire front will determine the duration of lethal temperatures at a certain site – a condition that is important for both plants and animals. For example, a continuous flame front will determine whether an animal can escape backwards through the flames to relatively safe burned ground, and the formation of unburned patches will determine the distribution of favorable "oases" for re-colonization within the burned area. How complete the combustion is will decide the amount of biomass left as cover, as prevention against erosion and as basis for a future biological production in the area. It is therefore impossible to fully predict the effect of forest fires because the variation is almost infinite.

8.16. Norwegian research into such conditions has until recently been modest. Climate models developed at the British Hadley Centre for Climate Prediction and Research indicate that the winter temperature in Scandinavia around year 2025 will be 1–2 ˚C higher than today, and within year 2065 an increase of 3– 4 ˚C is expected. Equally important is the expected changes in precipitation and wind conditions and frequency of extreme occurrences, but the predictions concerning this are very uncertain (The Norwegian Research Council 1997).

Chapter 9

9.1. Biological diversity may briefly be described as the earth's variation of life forms. In the Convention it is defined as: "The variability of living organisms of any origin, including terrestrial, marine and other ecosystems, and in addition, the ecological complexes of which they are a part; this includes diversity within the species, on the species level and on an ecosystem level." (The Research Council of Norway 1997, p. 3, translated)

9.2. The objective of Swedish management is to put large efforts into increasing the portion of areas to be burned on forested land. Most burning will be carried out as clear-cut burning, often recommended below seed trees wherever this is judged possible. In addition to this, regular burning of smaller areas or groups of standing forest is recommended.

9.3. In this context, Ohlson (1997), among others, calls attention to the existence of pine and lichen-dominated ecosystems in Sweden that are not at all fire-based (Zackrisson et al. 1995), while on the other hand so-called "Never stands" (Swed. "Aldri-bestander"), which have species indicating continuity, in many instances may have been affected by fire (Ohlson et al. 1997).

9.4. The basic view of forest fire and other "natural catastrophes" in national parks can be formulated in this way:

"National parks and other protected areas are probably the most relevant reference areas in Norway for various occurrences in nature, like e.g. forest fire. Viewed from a human/social perspective, they often emerge as "nature catastrophes". Because of increased human activity, this probably happens more often than before. As a point of departure, one should be reluctant towards preventing these if they have not originated directly due to human activity or if they do not threaten human life and extensive material resources. The reason for this is both with respect to the natural processes of the ecosystem, to biological diversity – because many species are dependent on such dramatic occurrences in nature to survive, and with respect to research and teaching" (Directorate for Nature Management 1996b, pp. 60-1).

9.5. The relevant areas were Oulanka National Park (107 km^2), Rokua National Park (4.2 km^2), Phyä-Häkki National Park (10 km^2), Peetheljärvi National Park (6.3 km^2), Salamauperä Nature Reserve (12.7 km^2) and Ulvinsalo Nature Reserve (25 km^2) (Alexander & Dubé 1983).

9.6. Forest fires, even if they are naturally ignited, are judged as a threat to the natural resources and values in Russia's nature reserves. All fires are therefore suppressed. The only natural areas where fire is not suppressed are the ones that lie in "unprotected areas", i.e. remote areas in northeastern Siberia (Anders Granström, pers. comm.). The management of the reserve Mari zapovednik may perhaps best illustrate this attitude in Russian management towards fire in reserved areas. The natural conditions in this reserve changed character after a forest fire in 1972. During 1973, it was decided to abandon Mari as a reserve (Pryde 1978).

9.7. Historically, it was not until the publication of the so-called Leopold report (1963) and the preparation of the following "Wilderness Act" (1964) where "naturalness" was heavily emphasized (See Wagner et al. 1995), that the dilemma concerning fire suppression of wilderness areas and national parks in USA was devoted to intensive studies. Many actors in the first management phase with so-called "wilderness fires" perceived the problem as such an easy task that it was just to set these "natural processes" free in such environments. In its purest form, the fire programs in "wilderness areas" were attempts to avoid fire suppression and allow naturally ignited fires to burn. However, following ecological and philosophical discussions of forest fires, this practice turned out to be far too simple. Presently, many researchers are doubtful or skeptical to the reintroduction of "historic" or "natural fire regimes", simply because we lack substantial knowledge about such regimes.

9.8. Of course, the fires will only be one side of the management of forest ecosystems. If this principle is going to be expanded, national parks and other reserved areas ought to be managed on the basis of general forest history.

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