UNDP/ICI Project
"Expansion of the Protected Areas Network for the Conservation of the Altai-Sayan Ecoregion"

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ALTAI-SAYAN ECOREGION

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FIRE DANGER MITIGATION A STRATEGY FOR PROTECTED AREAS OF THE ALTAI-SAYAN ECOREGION

Krasnoyarsk • 2012

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Fire danger mitigation: a strategy for protected areas of the Altai-Sayan ecoregion

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ABSTRACT
This book provides an analysis of actual fire occurrence in the Altai-Sayan ecoregion, levels of natural fire risk and causes of fire. The impact of fire on the flora and fauna of the Altai-Sayan ecoregion is assessed and patterns of pyrogenic succession are described. Deposited carbon stocks and fire emissions are also evaluated. A fire management strategy has been devised to assist protected areas in the effective conservation of biodiversity, rare and endangered species and communities. This publishing is a short version of the Russian-language edition. In addition to the chapters included to this book the full edition contains following chapters: Main principles of the strategy (by Shishikin A.S., Ivanov V.A., Bryukhanov A.V., Ovchinnikov F.M.); Fire prevention (by Furyaev V.V., Tsvetkov P.A., Furyaev I.V., Zlobina L.P.); Firefighting (by Valendik E.N., Kisilyakhov Ye.K., Kosov I.V.); and Assessment of strategy efficiency (by Shishikin A.S., Ivanov V.A.).

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CONTENT

INTRODUCTION

Ecosystem dynamics is a complex process which link biotic and abiotic components and results in the creation of specific types of biological community. Ecosystems subject to external impact such as fire and wind disturbance exhibit a succession of biocenoses in various stages of their development. Fires represent the most powerful destructive factor capable of determining the frequency and trajectory of secondary succession in ecosystems. The total burned area of forest fires in the Russian boreal zone is estimated to measure up to 10-12 million hectares (Conard, Ivanova, 1998; Goldammer, Sukhinin, Davidenko, 2007; Shvidenko, Schepaschenko, Sukhinin et. al., 2011)

To varying degrees, the impact of fire on ecosystems effects soil mineralization, stand composition and structure, floristic composition, as well as the rate and pattern of succession. The impact of fire can cause the total destruction of plant communities and major disturbance to animal communities (Фуряев, 1996). The extent of fire impact is determined by fire type and severity which is influenced by depth of burn, the height of flame scorch, volume of heat generated and completeness of fuel combustion. It is these factors, together with the geomorphological structure of a given area (for example, soils and topography) that produce a post-fire mosaic of habitat patches that leads to the creation of new and often different plant and animal communities. In other words, it is this pyrogenic mosaic that determines the spatial and temporal patterns of biodiversity within the landscape undergoing succession post-fire. In post-fire succession other components that shape evolving ecological communities are the burned area (opportunities for colonization) and fire severity (which affects sprout mortality).

The diversity of plants and animals is conditioned by both biotopic and dynamic factors. Biotopic factors include the habitat features of a particular area such as soil, climate and historical factors. Dynamic factors are a consequence of environmental instability in habitat conditions brought about by climatic, pyrogenic, zoogenic and intrapopulation cyclicity of biocenoses. Fire, like other causes of biomass destruction, plays a significant role in biological cycles. Given that fire is characterised by its cyclical nature and dependency on climatic conditions many organisms have evolved to cope with fire events as significant steps in their life cycle, as well as having adapted to the heterogeneous landscape mosaics that often result from fires. The landscape mosaic is in turn conditioned by the geomorphological features and structural characteristics of the corresponding area which play a role in shaping wildfire cycles and future fire events. Thus, fires and large-scale pest outbreaks contribute in important ways to the creation of a landscape's spatial and temporal diversity. Any human disturbance of these complex processes can have unforeseen consequences. Post-fire succession is evidently a highly complex area of research and represents a key component of reserve conservation programmes.

In addition to initiating change in the qualitative composition of forest communities, fires also effect biochemical soil processes and most of the functional relationships that exist within communities. This area of biological dynamics requires our attention as it determines the internal interactions within biological communities subsequent to the external influence of ecological forces like fires. Despite this fact, however, it is an area to which very little research has yet been devoted.

Monitoring environmental change represents a priority research area for nature reserves. Given that fire is a key natural factor giving rise to consistent and substantial change in plant and animal communities, it would be consistent with protected area research aims if fire ecology were to form a coherent, individual component within protected area research programs.
For these reasons, two objectives were established for this work. The first was to develop theoretical fire strategies relating to the conservation and dynamics of biological diversity; the second was to design practical plans for wildfire prevention in protected areas.

In order to achieve these objectives a number of different tasks was completed: (1) existing data on wildfires activity in the Altai-Sayan ecoregion was gathered and analyzed using a variety of methods and materials including satellite imagery; (2) the ecological significance of wildfire return intervals was determined; (3) an assessment was carried out of the impact of fires on ecological processes, species diversity, rare species conservation, and sustainability, productivity and the structure of important ecological functions of biocoenosis; (4) maps were compiled for each protected area indicating wildfire activity and natural fire hazard; (5) wildfire return intervals were estimated based on vegetation type and successional stage; (6) carbon stocks, carbon balance and fire emissions in the region were calculated; and (7) a strategy was developed to reduce fire hazard and ensure effective fire management in protected areas of the Altai-Sayan ecoregion. The strategy serves to recommend measures for fire monitoring and prevention as well as to guide effective fire control. Finally, a set of criteria were produced to evaluate the effectiveness of the proposed measures in reducing damage caused by fires to the protected areas of the Altai-Sayan ecoregion.

Wildfire occurrence and hazard as well as carbon balance have been studied in detail for 12 protected areas (Table) of the Altai-Sayan Ecoregion within the fire component of the UNDP/ICI Project "Expansion of the Protected Areas Network for the Conservation of the Altai-Sayan Ecoregion". In 2010-2011 fire management plans were designed for each PA, firefighting equipment purchased, and training courses conducted on detection and control of forest and steppe fires, firefighting tactics, and strategy in prevention of human-caused fires in the natural environment, all funded by the Project.

Nature Protected Areas, which were involved in implementation of the fire component within the UNDP/ICI Project "Expansion of the Protected Areas Network for the Conservation of the Altai-Sayan Ecoregion"

#	Nature Protected Areas	Number, assigned to the PA on the map*	Region of the Russian Federation
1	Altaisky Biosphere Nature Reserve	4.01	Republic of Altai
2	Azas Nature Reserve	5.01	Republic of Tyva
3	Ergaki Nature Park	3.04	Krasnoyarsk region
4	Katunsky Biosphere Nature Reserve	4.02	Republic of Altai
5	Khakassky Nature Reserve	6.01-6.09	Republic of Khakasia
6	Kuznetsky Alatau Nature Reserve	2.01	Kemerovo region
7	Sayano-Shushensky Biosphere Nature Reserve	3.05	Krasnoyarsk region
8	Shorsky National Park	2.02	Kemerovo region
9	Shushensky Bor National Park	3.02-3.03	Krasnoyarsk region
10	Stolby Nature Reserve	3.01	Krasnoyarsk region
11	Tigireksky Nature Reserve	1.01	Altai region
12	Ubsunurskaya Kotlovina Biosphere Nature Reserve	5.02-5.10	Republic of Tyva

*Figures: 1.1. (page 7); 1.8. (page 13); 1.10. (page 16); 1.11. (page 18); 1.12. (page 19).

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Chapter 1. SITUATION ASSESSMENT

1.1. Analysis of wildfire activity in the Altai-Sayan ecoregion and its protected areas

The Russian part of Altai-Sayan ecoregion incorporates nine territorial regions of the Russian Federation. Geographically, three regions of the Russian Federation are included in their entirety and six in part.

Data on fire statistics obtained for regions of the Russian Federation were analyzed with reference to natural ecozones and landscape categories that predominate in the Altai-Sayan ecoregion (Fig. 1.1).

1.1.1. Wildfires in the Altai-Sayan ecoregion: General statistics

According to data provided by the satellite monitoring program in 2000 – 2009, 17,928 fires were recorded in the Altai-Sayan ecoregion with a total burned area of more than 8.3 million ha (Fig. 1.2, 1.3). The Federal Forest Service database for the period 1969-2006 collects 51,392 fires covering more than 2.3 million hectares.

The quantitative data should be considered as qualitative estimate. Due to the spatial resolution of satellite equipment (each pixel represents 1 square km or 100 ha of surface) and accuracy of navigation linking (shifts in space of pixels over time are possible of 500 to 1,000 m) satellite methods are incapable of facilitating exact fire location over smaller areas. Attempts to provide exact locations can lead to statistical errors and generally, to overestimation of burned area. Nonetheless, it is the author's opinion that official statistics relating to the period prior to the year 2000 have a tendency to reflect artificially reduced burned areas.

Taking this into account, one may make the preliminary estimate that the study area is annually exposed to the impact of 1,700 fires and that annual fire damage affects an area of 50-70 thousands ha. Official long-term statistics indicate an average burned areas of 30 ha, whereas satellite monitoring system data indicate an area of 80 ha.

In the Altai-Sayan ecoregion more than 1100 fires occur in non-forest areas and up to 600 fires occur in forest areas annually. In processing statistical data provided by the Federal Forest Service for the period of 38 years, it was found that the annual burned area in non-forest territory is up to 10 thousand hectares whereas in forest areas is up to 50 thousand ha.

The distribution pattern of fire numbers in the ASER per 2000-2009 indicates a growth trend in this indicator over the past 10 years (Fig. 1.2) in the first approximation (R^2 = 0.53). The return period of extremely high fire activity, is 2-3 years in the conditions which have prevailed over the past decade.

The most significant peaks in fire activity are evident over three fire seasons: 2002, 2007 and 2008 when area burned was more than 1.5 million hectares in each of the three years indicated (Fig. 1.4.).

The maximum number of fires in 2005 did not affect an increase in burned area in the region due to the fact that non-forest fires dominated which were rapidly extinguished and therefore prevented from spreading over large areas.
It is important to reiterate that the information cited here on burned areas can only provide estimates and cannot therefore be relied upon to provide an accurate picture of actual fire damage. They do however, show general trends, comparative characteristics and fire distribution during the observation period.

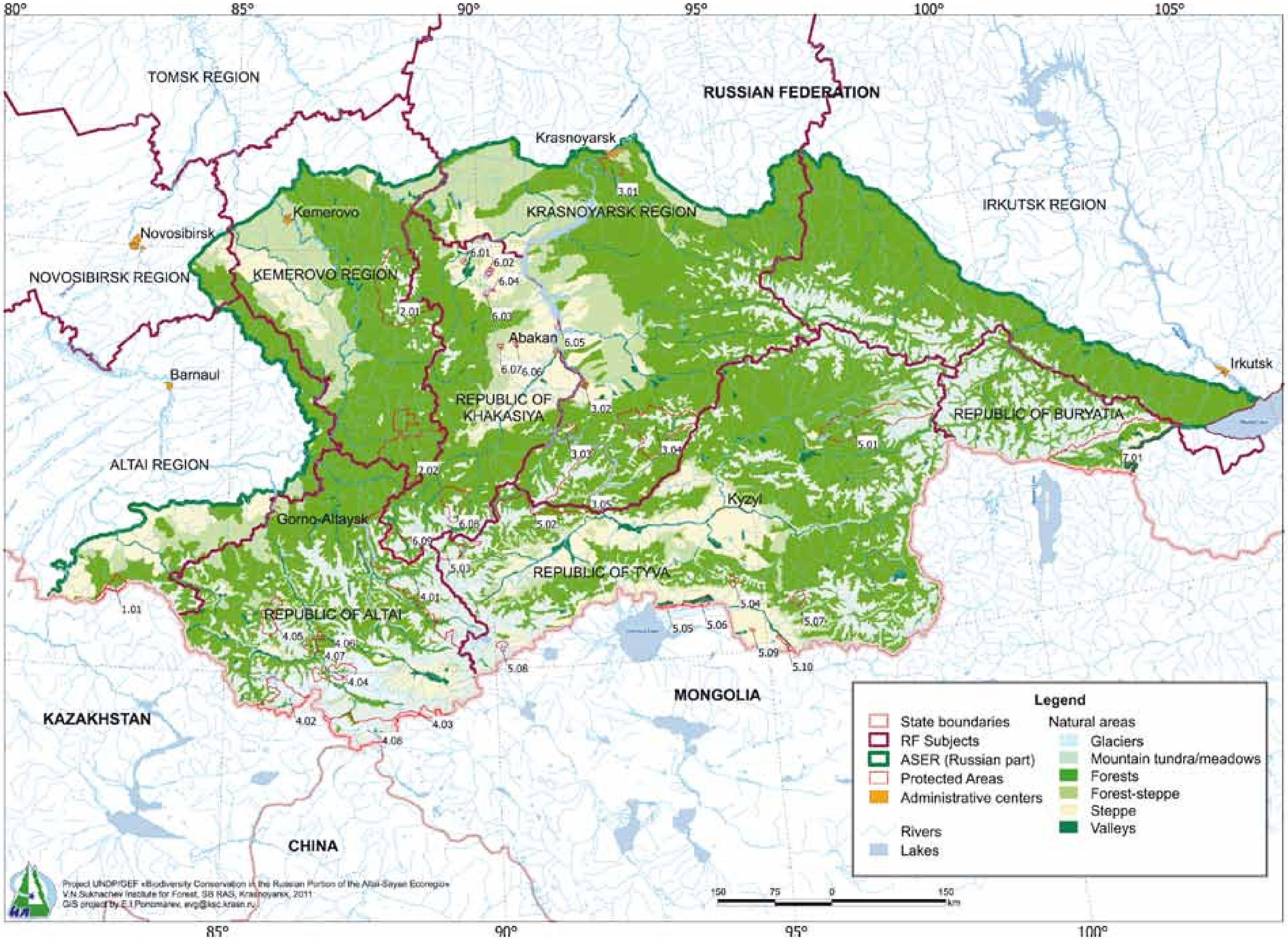


Fig. 1.1. A schematic map of natural zones in the Russian part of the Altai-Sayan ecoregion

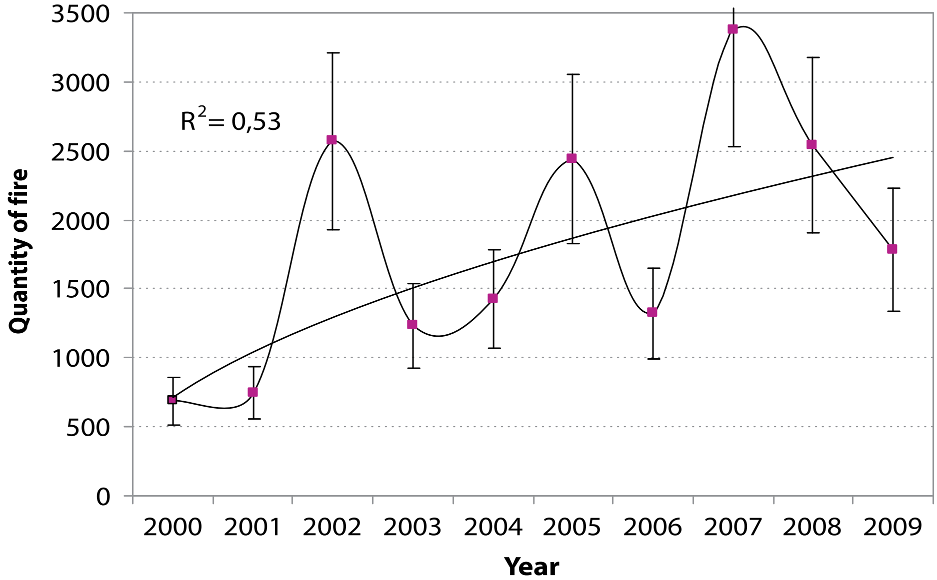


Fig. 1.2. Wildfire numbers in ASER according to satellite monitoring in 2000–2009

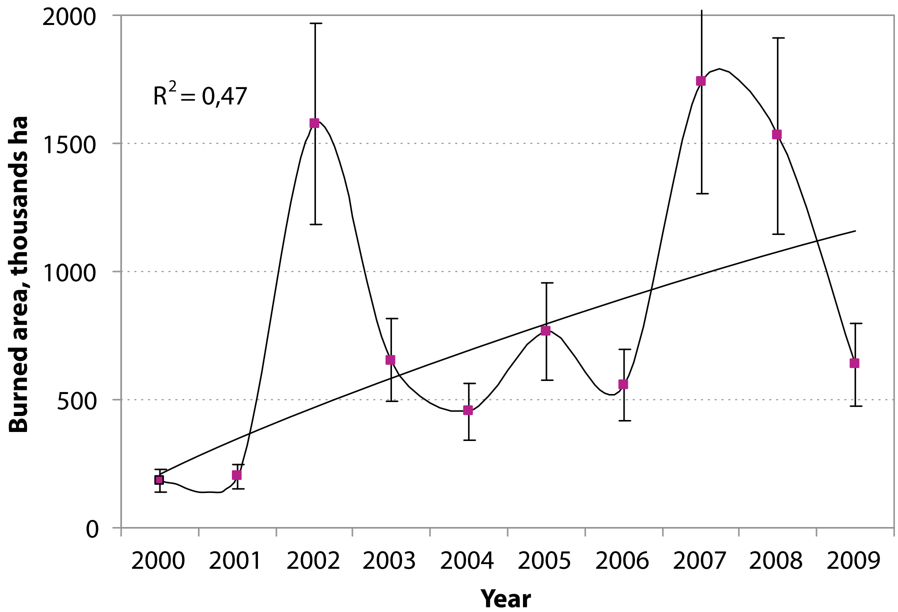


Fig. 1.3. Trends in burned areas in ASER according to satellite monitoring in 2000–2009

Statistical indicators for two years, 2000 and 2001 are significantly lower than historical averages for the given region. The subsequent period shows multiple occasions on which the indicator exceeds the estimates for 2000 and 2001. The number of fires occurring in forest areas during the period 2002-2009 averaged at 500 units per year (except 2002, 2007, 2008) and during this period varied only slightly (variation coefficient 15%). The indicator was significantly higher only in two seasons (2002 and 2007) which is probably due to the extremely dry conditions recorded over the periods indicated. Against the background of a fairly stable indicator for fire activity in forest areas, the number of fires in the steppe areas of the Altai-Sayan ecoregion during the same period increased by 3-8 times in comparison to the period 2000-2001 (Fig. 1.4).

The geographical region in question is a mountain area and is therefore, characterized by a highly complicated spatial pattern of orography. The spatial alignment of data reflecting both number of fires and burned area with terrain type is shown in Figure 1.5. It should be noted that the largest number of fires is recorded at low altitudes and in intermountain basins. The given value twice exceeds that of the quantitative characteristics of other terrain types in the ASER.

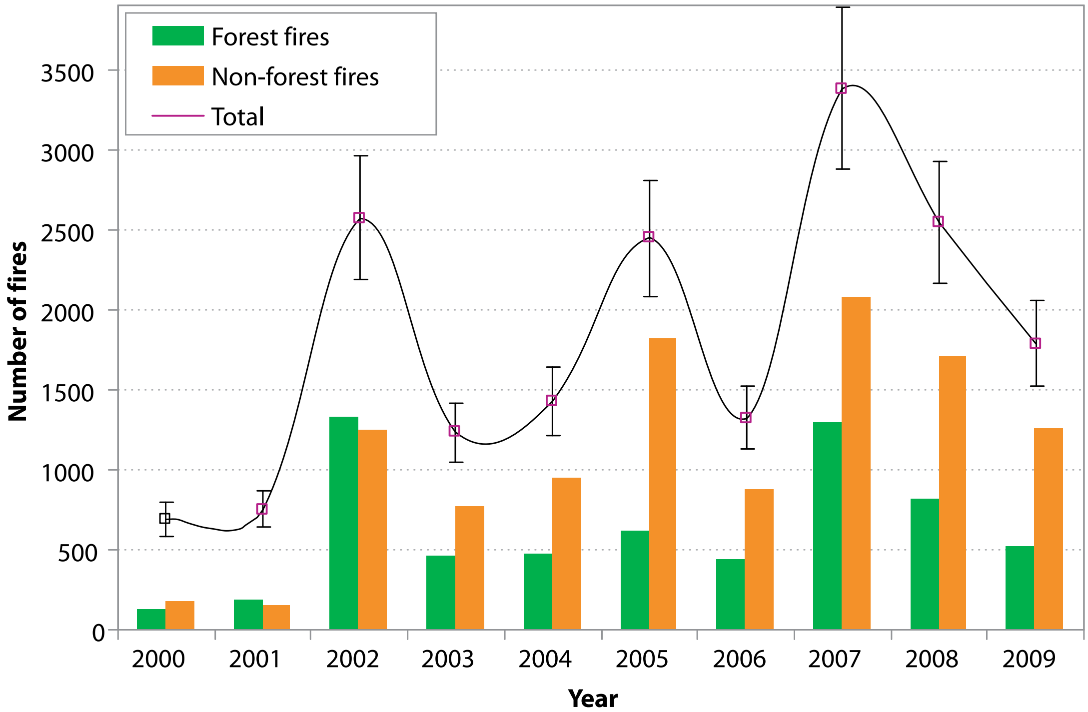


Fig. 1.4. Trends in the number of forest and non-forest fires in the ASER according to satellite monitoring in 2000-2009

This is due to a combination of factors that determine fire activity in these areas:
– high quantity of ignition sources due to high population density and a well-developed transport network;
– prevalence of high fire hazard vegetation types (steppes, pine and birch stands with grassy cover);
– early onset of fire season.

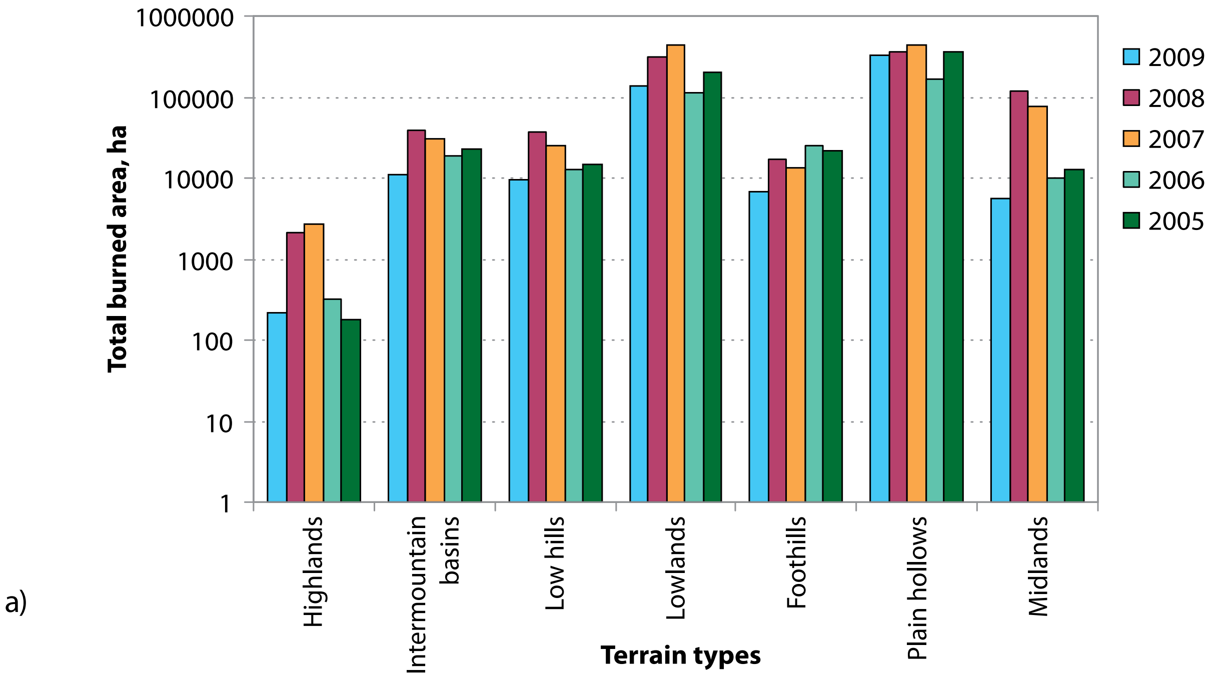
The values of total burned areas are ten times higher in lowlands and plain hollows. Isolated cases of fire occurrence in some years (2007, 2008) have been recorded at high altitude zones.

No significant differences in fire frequency or burned area have been observed relevant to different types of terrain in recent years. A slight increase can be observed in the wildfire activity for individual years at mid-altitudes. These variations are largely determined by meteorological conditions during the fire season.

Finally, the above analysis of statistical data on wildfires in the ASER confirms a growth trend in fire number and burned area during the recent period 2000-2009. The most significant change is reflected in the number of non-forest fires. Over the ten year period, the wildfire return intervals for fire seasons marked by extreme fire activity is 2-3 years and the indicator for non-forest fire activity has remained high for the past few years, 2005-2009.

1.1.2. Trends in the number and area of wildfires in regions of the Russian Federation

This section presents corresponding long-term average values for regions of the Russian Federation or their partial territories within the Altai-Sayan ecoregion. Data relating to the 38-year observational period of the Federal Forestry Service were compared with data for the 10-year period of satellite observation. The distribution of fires throughout regions of the Russian Federation during the period 2000-2009 is represented in Figure 1.5-1.6.



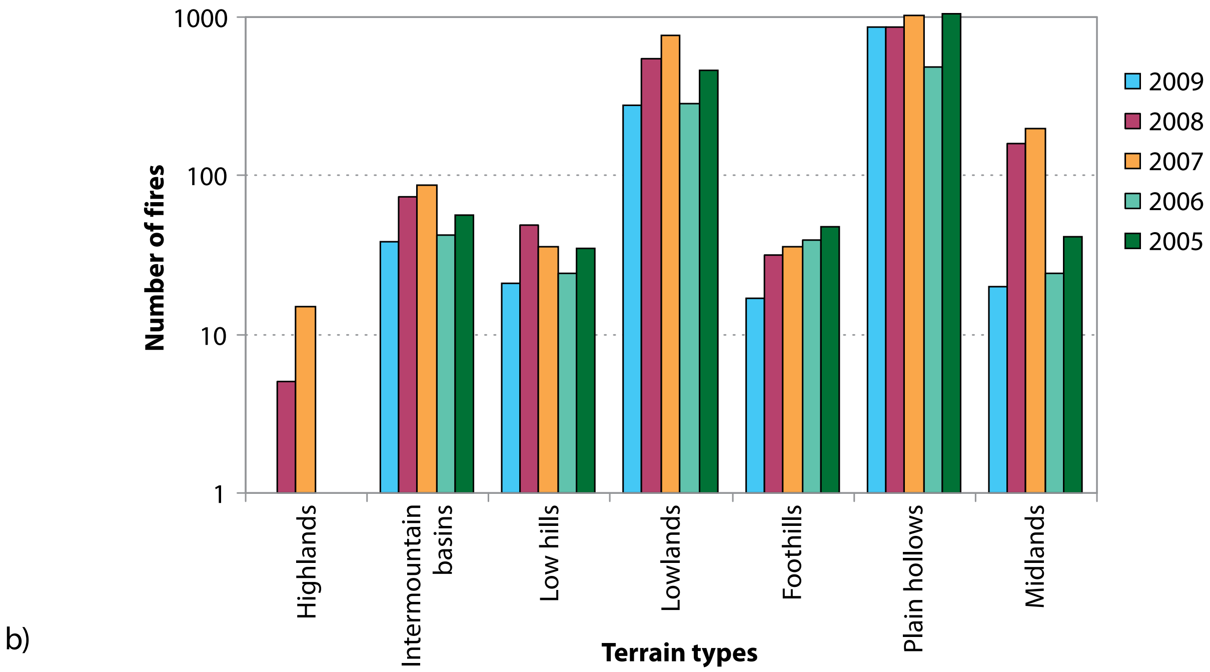


Fig. 1.5. Burned areas (a) and number of fires (b) relevant to terrain types in ASER

The regions of the Russian Federation studied for fire frequency during the fire season can be divided into three groups:

– low fire activity (15-50 fires per year): Republic of Altai, Novosibirsk region, Republic of Buryatiya, Irkutsk region;

– moderate fire activity (100-150 fires per year): Altai region, the Republic of Tyva;

–high fire activity: Republic of Khakasiya, Kemerovo region, Krasnoyarsk region (280, 375, 640 fires per year, respectively).

The above chart can also be divided into three groups of territories. The largest burned area occurs in the Krasnoyarsk region affecting more than 2.5 million hectares. The second group of regions in the Russian Federation includes the Kemerovo region, Republics of Tyva and Khakasiya, where the burned area amounts to approximately 1.5 million hectares. The third group includes the Altai region, the Irkutsk and Novosibirsk regions, Republics of Buryatiya and Altai.

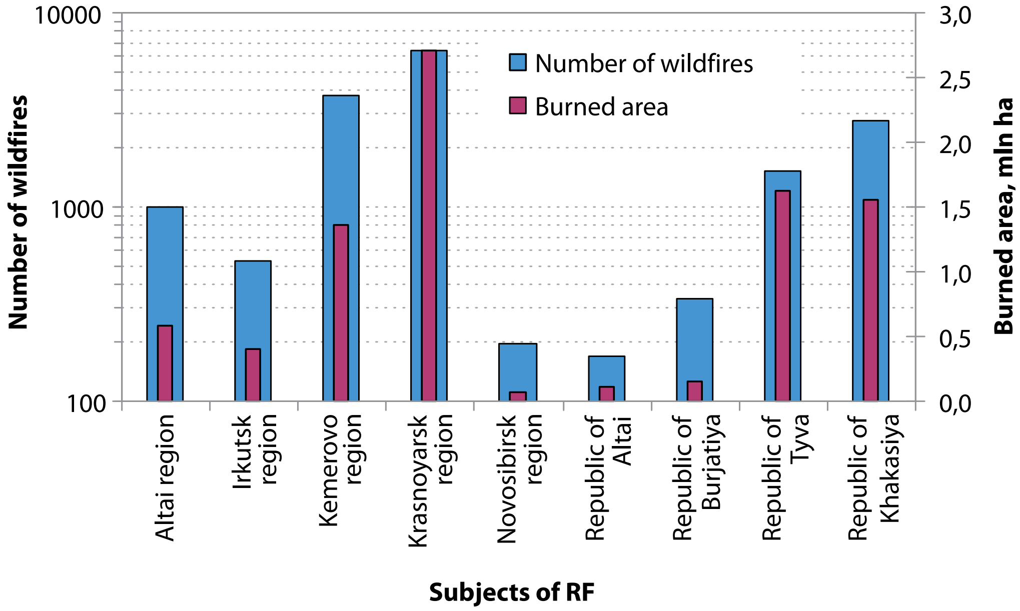


Fig. 1.6. Wildfires number in regions of the Russian Federation within the ASER during the period 2000-2009

The Republic of Tyva stands out as the average burned area at least three times higher than in other parts of the ASER. The smallest average burned area is recorded in the Altai region and the Kemerovo region. These figures largely characterize the level of preparedness of fire-fighting manpower and equipment in the region and the ability to mobilize a rapid response. One reason for the increase in average burned area is limited accessibility of areas to ground fire-fighting forces determined by the nature of local topography and density of road network.

An important feature consists in detailed information on the distribution of fires by month during the fire season. Figure 1.7 shows the distribution of fires over a ten-year observation period according to satellite monitoring system data.

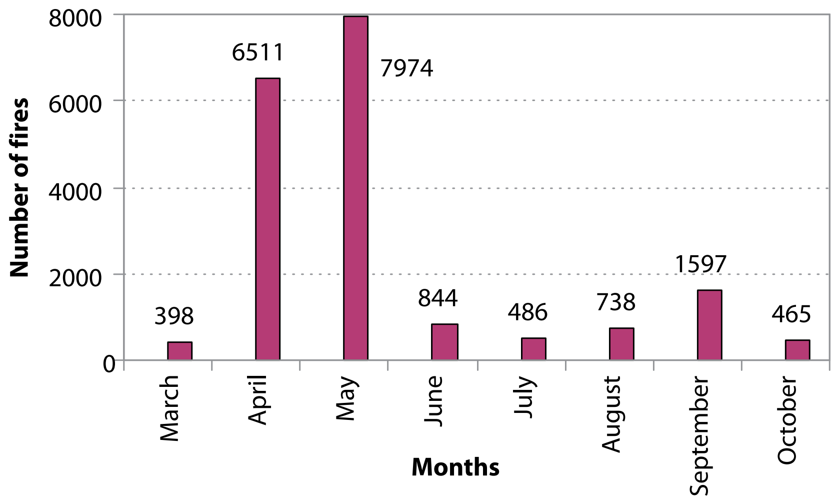


Fig. 1.7. Distribution of wildfires numbers in ASER by month during the period 1969-2006 (according to Federal Forest Service data)

It is evident that the majority of fires in the region occur in the April and May. Above all, this is related to the early onset of the fire season in steppe zones. By comparison, the summer period appears to be less hazardous. The least number of fires during the summer period occur in July. A second, less

significant season of high fire activity can be observed in September. In individual areas cases of fire have been recorded in March, and the latest fires were fixed in November.

Maximum spring fire activity levels are significant in all regions of the Russian Federation encompassed by the ASER. Up to 15-25% of fires in the Republics of Khakasiya, Tyva, Buryatiya and Altai are recorded as early as April. In all subjects, from 40% to 70% of the total number of fires occur in May. In June, a significant number of fires are recorded in Republics of Buryatiya, Tyva, the Irkutsk Region and Krasnoyarsk Region (up to 20%). Fire occurrence in the month of July remains high in the Krasnoyarsk and Irkutsk regions and Tyva.

According to data relevant to the past ten years the second peak in fire activity has to a large degree, shifted to September, while almost forty years of previous observations record maximum fire activity in the month of August. A particularly large number of wildfires in August (up to 15%) are typical for the Altai region.

The statistical data included in the analysis has been converted into vector polygonal layers, which display the results as a schematic map in GIS. All the indicators have been standardized, making it possible to classify the territory according to the respective values of fire frequency and fire activity. The indicator related to number of fire incidents over a 10-year period is shown in Figure 1.8.

As can be seen from Figure 1.8, fire activity on the territory of the ASER is characterized by the distinctly uneven distribution. The complex nature of the distribution of these indices is due to terrain, altitude, climate and weather conditions, distribution of dominant vegetation types, and level of development in a given territory.

The Altai-Sayan ecoregion is characterized by high variability in fire frequency from 0.1 to 20 over 100 thousand hectares, in connection with a wide variety of climate and weather conditions, complex orography and forest conditions. The territory is dominated by dark coniferous forests growing in a damp climate and hence is at low natural fire hazard. In the valleys of large rivers and on steep slopes with southern and western exposure there occur high level of natural fire hazard in pine and larch stands that are accordingly often exposed to fire.

In most cases, protected areas are located in regions with low fire activity (0-5 fires over a 10 year period) (Fig. 1.8). Areas with a moderate fire activity (up to 50 cases over a 10 year period) are encompassed by the following protected areas: “Azas”, “Stolby”, “Shorskiy”, “Sayano-Shushensky”, “Ubsunurskaya Kotlovina” (“Khan-Deer” cluster). The largest number of fires (more than 50 over the past 10 years) is recorded in areas bordering protected areas “Khakassky”, “Ergaki” and “Shushensky Bor”. These contiguous areas demand particular attention given that a wildfire could spread to protected area territories.

1.1.3. Trends in the number of fire and burned area in protected areas

The data available on protected areas corresponds to different time intervals making it unsuitable for an integrated analysis. In order to provide accurate results average characteristics were calculated according to data provided by the Federal Forest Service (Table 1.1). In protected areas in the Altai-Sayan ecoregion the largest area damaged by fires are found in “Altaisky”, “Khakassky” and “Ubsunurskaya Kotlovina” Reserves. In accordance with the above analysis, one may assume that the majority of fires occurring in these areas originate in steppe or forest-steppe zones subsequently spreading to forest areas.

In “Azas”, “Sayano-Shushensky” and “Stolby” Reserves one observes a large number of fires with a total burned area of over 1,500 hectares.

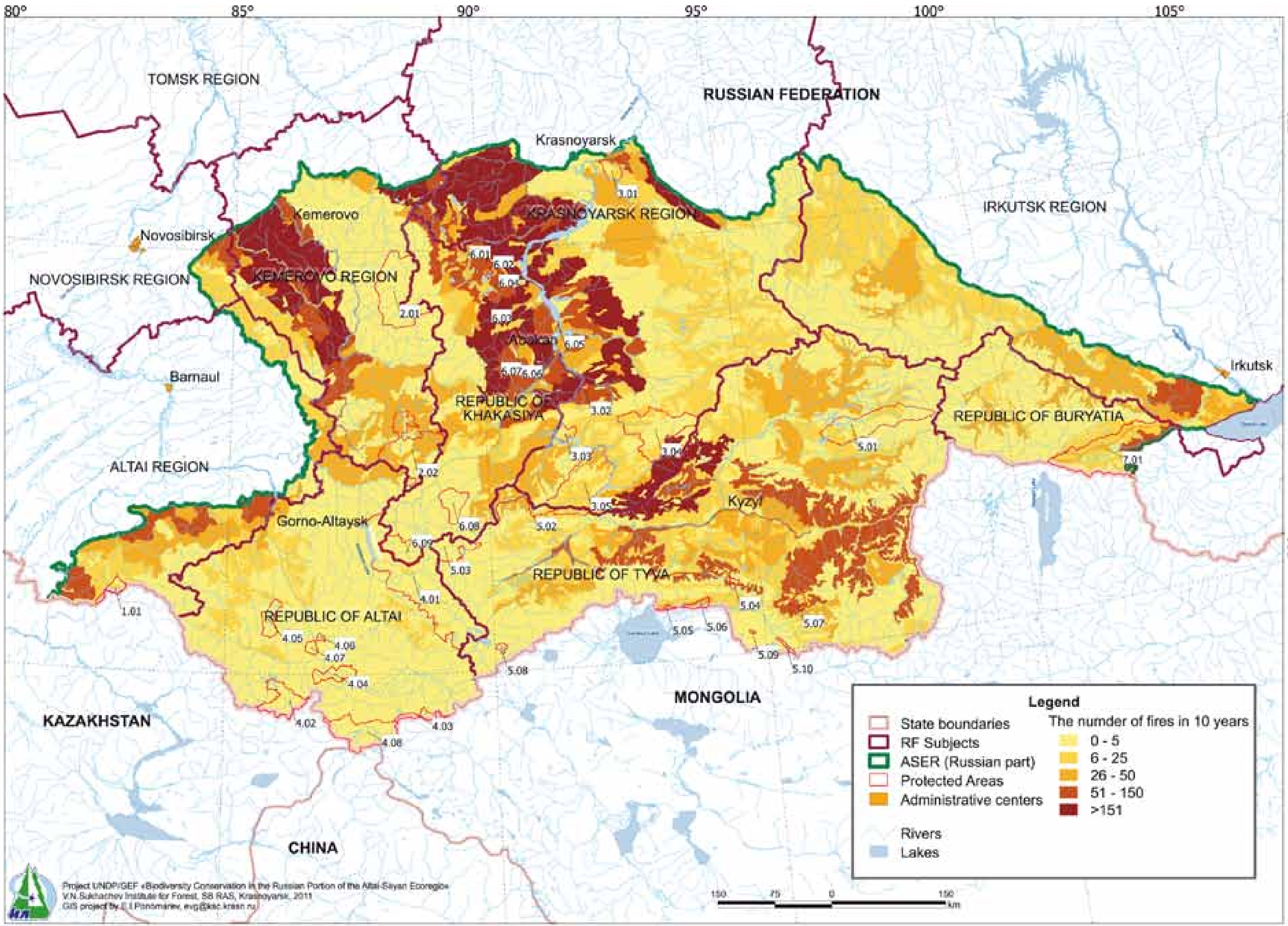


Fig. 1.8. Schematic map showing classification of the territory of the ASER according to the indicator for number of fires over a 10 year period

Table 1.1

Average fire danger indicators in protected areas according to 1969-2006 data provided by Federal Forest Service

Protected Area	Number of forest fires per year	Average forest fire area, ha	Fire frequency, number/10^5 ha	Fire activity, %
Azas	3.2	44.5	1.10	0.15
Altaisky	0.8	70.0	0.09	0.06
Ergaki	—	—	2.50	0.05
Katunsky	0.02	3.5	0.02	0.0024
Kuznetsky Alatau	0.6	2.6	0.17	0.0004
Sayano-Shushensky	2.3	19.2	0.63	0.012
Stolby	2.5	13.7	4.95	0.068
Tigireksky	0.4	5.7	0.56	0.001
Ubsunurskaya Kotlovina	—	—	0.60	0.21
Khakassky	0.2	16.5	0.16	0.003
Shorskiy	2.6	3.9	0.65	0.0025
Shushensky Bor	2.5	7.3	2.60	0.019

On the territories of “Shorskiy” and “Shushensky Bor” National Parks despite the high fire number indicator, burned areas of moderate size are recorded. In all likelihood, this is due to high levels of efficiency and performance among fire-fighting services, as well as the accessibility of the territories. Long-term statistical data provided by the Federal Forest Service were used to provide a comparative indication of fire activity in protected areas. Key fire indicators were averaged over the fire season and standardized per area unit.

According to long-term observation records (database for the period 1969-2006 Federal Forest Service) the average number of fires per year in protected areas does not exceed four. However, the average burned area varies considerably. For protected areas “Katunsky”, “Kuznetsky Alatau”, “Tigireksky”, “Shorskiy”, “Shushensky Bor” the indicator does not exceed 7 ha. The second group of protected areas includes “Sayano-Shushensky”, “Stolby”, “Khakassky” for which the corresponding indicator is up to 20 hectares. The largest average burned areas are recorded in protected areas “Azas”, and “Altaisky” (44.5 and 70 ha respectively).

Data on the number of fires occurring in protected areas “Ergaki” and “Ubsunurskaya Kotlovina” are not included in the Federal Forest Service database. Information concerning the frequency and occurrence of fires has been interpolated from statistical data on fires occurring in the area of forest districts (“lesnichestvo”), where these Protected Areas are situated.

In protected areas in the majority of cases one observes low to moderate fire frequency values. The highest indicator values were recorded for protected areas “Stolby” and “Shushensky Bor” (4.95 and 2.6 respectively). This result is explained by the influence of anthropogenic pressure and the overall high levels of natural fire hazard characteristic of these territories.

In general, the average area of a single fire, and fire frequency in protected areas is 1.5-3 times lower than average indicators in regions of the Russian Federation.

1.2. Analysis of natural fire danger

Natural fire danger levels are classified by plant community types based on topography. The first fire danger class (I) indicates very high natural fire hazard whereas the fifth fire danger class (V) indicates minor or insignificant fire hazard.

According to the results of the classification system for the ASER 8 zones have been allocated to the first and second classes of natural fire danger level. These zones make up a total land area of 30 million hectares, which accounts for 45% of the total ASER land area. According to the classification given above, forest type groups are allocated to class III natural fire danger level which constitutes approximately 5% of the total ASER land area. This explains the bimodal distribution reflected in Figure 1.9.

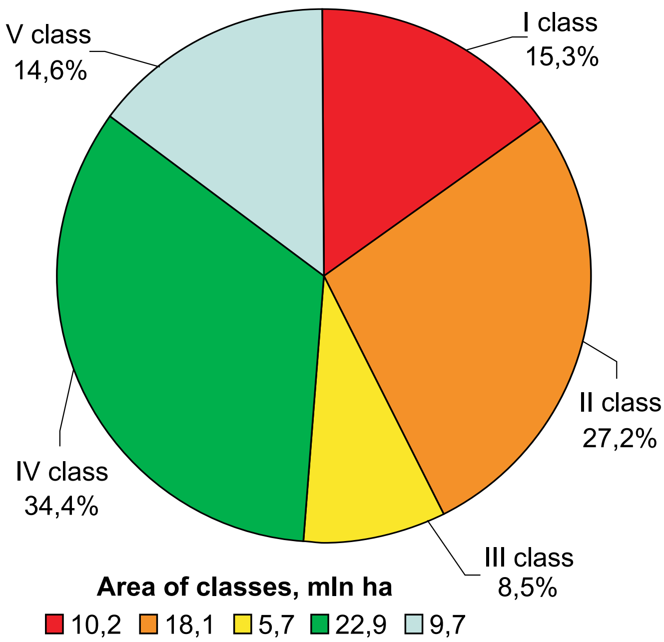


Fig. 1.9. Distribution areas showing different classes of natural fire danger in the Altai-Sayan ecoregion

A schematic map indicating natural classes of natural fire danger (CNFD) in the Altai-Sayan ecoregion was obtained by processing a vegetation type database. In accordance with the data base's GIS layers used in this analysis it is recommended that a display scale of 1:1500000 be used (Fig. 1.10).

The first and second classes of natural fire danger are most evident in the Kemerovo region, the Republics of Khakasiya and Tyva, as well as in the Krasnoyarsk and Altai region. The second class dominates in most parts of the eastern regions of the Republic of Tyva.

Third class of natural fire danger in the ASER is present in fragments, occurring mainly in the southern areas of Krasnoyarsk region. The low occurrence of this class is accounted for by particular features of the region's physical geography and climate in which the forest type groups that make up the third natural fire danger class are mostly absent.

A large percentage of the areas are allocated to the fourth class of natural fire danger, which dominates in the southern and eastern areas of the Kemerovo region, in southern and eastern parts of Krasnoyarsk region as well as in the Irkutsk region.

The fifth class of natural fire danger level is represented mainly at high elevations in the Republics of Tyva, Buryatiya and Altai, and only slightly in the Krasnoyarsk region.

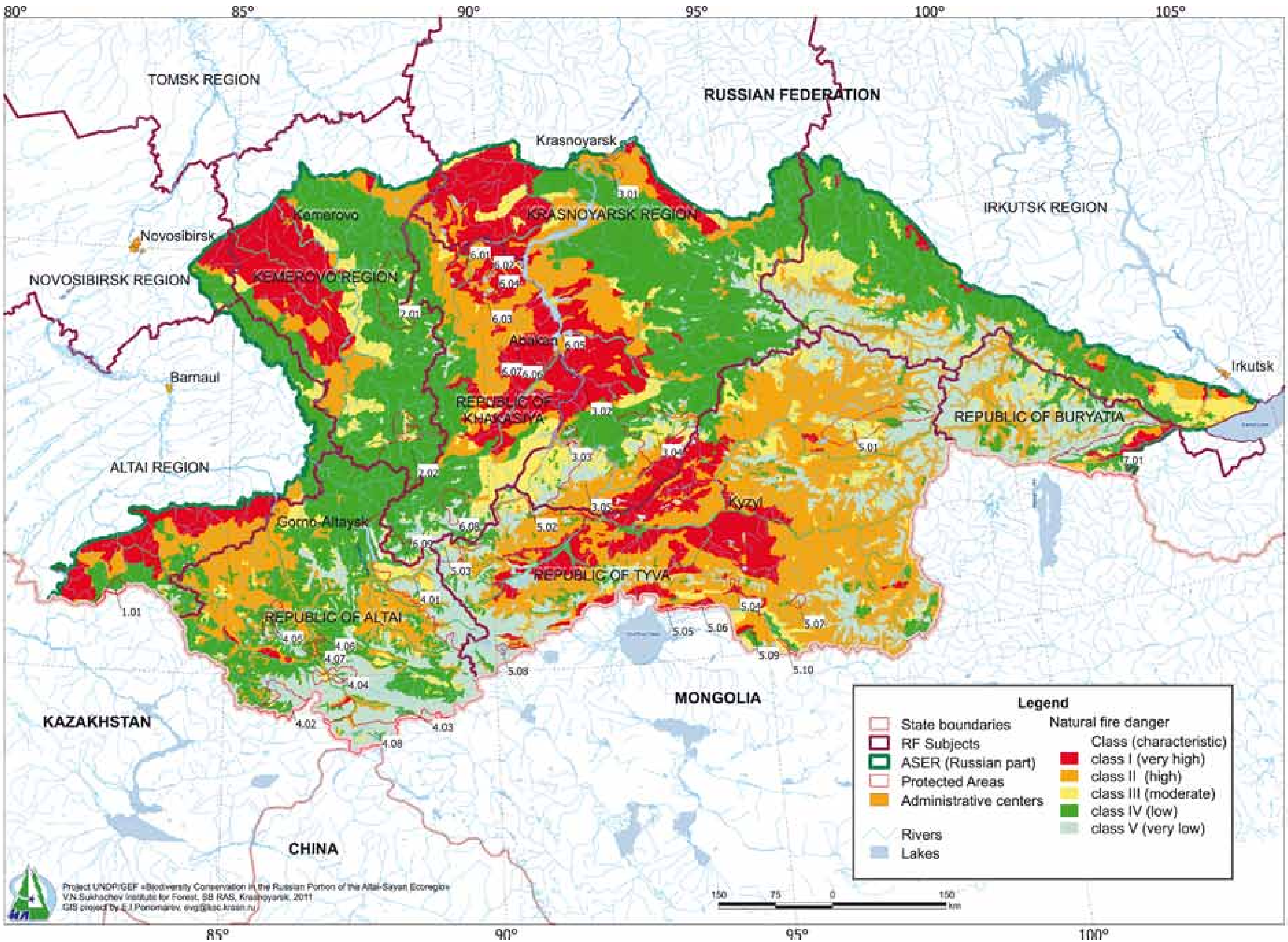


Fig. 1.10. A schematic map showing classifications of the ASER according to natural fire danger levels

The schematic map shown here accurately reflects fire danger levels in the ecoregion, as evidenced by high correlation between distributions of fires in areas with dedicated classes. On the basis of the conjugated analysis given above one may note, that up to 90% of all fires recorded in the ASER in different years both in forest and steppe zones are concentrated in areas allocated in I and II classes of natural fire danger.

1.3. Fire seasons

1.3.1. Fire seasons: Onset and duration

A schematic map showing the duration of the calendar fire season has been produced on the basis of a conjugated analysis of snow cover melt and vector layers zoning the ASER into natural zones and landscape categories (Fig. 1.11).

To zone I are attributed predominantly coniferous forests in dark-taiga and mountain taiga altitudinal vegetation belts, growing on waterlogged slopes and tundra highlands. In these areas of the ASER, the duration of the fire season is minimal. Wildfires in this area are recorded extremely rarely and the duration of the summer fire season does not exceed 2 months.

To zone II are attributed areas predominated by Siberian pine-larch forests, which are concentrated mainly in the eastern regions of Republic of Tyva. Here the main fire hazard occurs in the summer. The total duration of the fire season does not exceed 3.5 months.

Low altitude forests constitute zone III. This area experiences the greatest impact from forest fires. Fire readiness in the onset of the fire season occurs towards the end of May and the fire season lasts into the first ten days of October, accounting for a period of six months.

Forest-steppe areas, attributed to zone IV, are characterized by fairly early snow cover melt and intense surface drying due to high levels of air flow and, consequently, a prolonged fire season, which lasts for a period of 7 months.

The longest fire season occurs mainly in the steppe regions of low and intermountain basins (Zone V). In these regions, one may observe annually an early snow cover melt, rapid drying of combustible materials and the mass emergence of spring wildfires. The fire season in this area lasts for up to 8 months.

The duration of the fire season averages 160 ± 19 days (variation coefficient 12%). Furthermore, this feature indicates the region is less prone to fluctuations, in comparison with northern regions of Russia (Мелехов, 1946; Мокеев, 1961; Покрывайло, 1989; Пономарёв, Безматерных, Иванов, 2008).

In addition to the climatic and landscape characteristics of a specific area, fire season duration also depends on the presence of ignition sources (anthropogenic factor or lightning fire danger). Despite their differentiating features, the actual duration of fire season in regions of the Russian Federation varies only slightly, primarily because each region has its territory within the ASER is characterized by steppe and forest steppe complexes, attributed to the longest fire season zones IV and V.

The duration of lightning fire danger period in the study area are shorter than that of the actual fire season. Thus, the average lightning fire danger period lasts for approximately 100 days, which does not exceed 60% of the duration of the fire season.

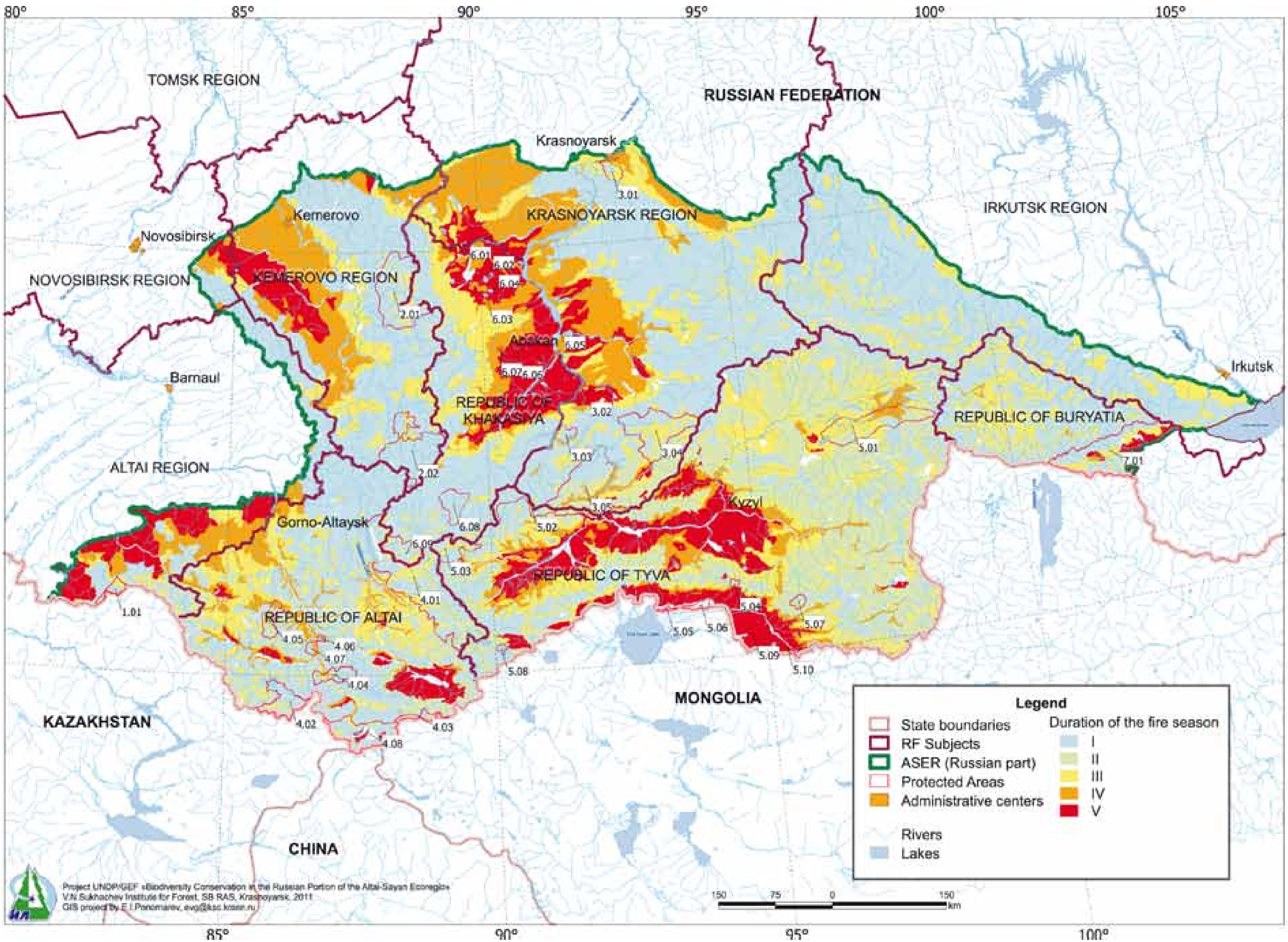


Fig. 1.11. Grading the duration of the wildfire season on the territory of ASER (description of zones given in text)

Information on the timing of fire detection in protected areas was obtained from the database of the Federal Forest Service for the period 1996-2009 and from satellite monitoring of forest fires, conducted in 2000-2009. On the basis of data from these combined sources long-term average beginning and end fire season dates were identified in relation to the designated areas. The resulting table contains data on first and last fire detection times of fire occurrence over fire seasons (Table 1.2).

Table 1.2

Duration of fire seasons in protected areas

Protected Area	Actual fire season		Durations in days
	Beginning	End	
Azas	II ten day period of June	II ten day period of August	60
Altaisky	II ten day period of May	I ten day period of October	150
Ergaki	II ten day period of April	III ten day period of September	160
Katunsky	III ten day period of May	I ten day period of June	20
Kuznetsky Alatau	II ten day period of April	II ten day period of August	120
Sayano-Shushensky	II ten day period of April	II ten day period of September	150
Stolby	III ten day period of April	I ten day period of September	140
Tigireksky	—	—	—
Ubsunurskaya Kotlovina	II ten day period of April	II ten day period of September	150
Khakassky	III ten day period of March	II ten day period of May	60
Shorskiy	II ten day period of May	II ten day period of June	30
Shushensky Bor	II ten day period of April	II ten day period of July	90

No detailed information on fire occurrence in "Tigireksky" Reserve was obtained. However, geographically, the reserve is located in the ASER zone characterized by average fire season durations.

All fires occurring in "Azas" Reserve are recorded in the summer period and in its west and central areas. "Azas" Reserve borders regions that are marked by longer fire seasons and in which cases of fire have been documented in the late spring (Fig. 1.11, polygon 5.01). Thus, in the case of "Azas" Reserve there is a risk of developing a trend of earlier fires (late May) which spread from these neighboring regions. The eastern part of the Reserve is attributed to a short fire season zone. No fires have been recorded in this area.

The territory of "Altaisky" Nature Reserve (Fig. 1.11, polygon 4.01) is located in an area characterized by fire seasons of average duration. However, another significant feature of the reserve is that it includes other areas with extended fire seasons. This defines a longer actual fire season with fire occurrences in May and isolated cases in October. In "Altaisky" Nature Reserve, the effect of the lightning-caused fire season is considerable, with lightning discharges causing up to 50% of all fires.

"Ergaki" Nature Park (Fig. 1.11, polygon 3.04) is characterized by a prolonged fire season. However, fires occurring late summer and early autumn dominate only in the southern part of Park.

The greatest difference between the calendar and actual fire season can be seen on the territory of the steppe clusters of "Khakassky" Nature Reserve (Fig. 1.11, polygons 6.01-6.07). Here spring fires are most frequent with fires occurring somewhat less frequently in dry autumnal conditions.

1.3.2. Analysis of climate factors

According to the 50 weather stations situated in the ASER, a schematic map has been created showing the distribution of interpolated values of mean annual precipitation (Fig. 1.12).

An analysis was conducted of the distribution of precipitation during the fire season based on data provided by weather stations located in areas adjacent to protected areas. The results of the analysis indicate periods most prone to fire in periods of minimum precipitation. In the majority of protected areas lowest precipitation levels are recorded in April, May and the first half of June. The most humid period occurs in July and August.

Leading environmental factors that determine patterns of fire occurrence and development can be summarized as follows: a) the moisture content of fuels and their load, b) wind speed, c) topography, d) relative humidity and air temperature, e) condition of the atmosphere, e) phenological phases of plant development, and f) cloudness and solar radiation (Шешуков, 1982).

The entirety of these characteristics is reflected in an integrated fire dander indicator based on weather conditions, which determine the capacity of combustible material for ignition (moisture content). One of the most significant characteristics of forest fires in the region is the distribution of quantitative fire occurrence according to weather fire danger classes (Fig. 1.10).

It is evident, that on the territory of the Altai-Sayan ecoregion most fires (up to 40%) occur when the integrated fire danger indicator based on weather conditions corresponds to class IV. A significant number of fires occur when classes III and V are indicated (from 20% to 30%). When the highest weather fire danger class V is indicated fewer fires occur than, for example, when class IV is indicated because the total number of days over a given territory with the same characteristic is fewer.

The five class scale of weather conditions fire danger is based on the value of the integrated indicator: in class I fire danger is absent, in class V fire danger is extremely high (Нестеров, 1949).

1.3.3. Analysis of prevailing causes of wildfires

According to statistics, human activity constitutes the main cause of fire whereas lightning discharges are among the most significant natural fire causes. Figure 1.13 shows a diagram illustrating the statistics of forest fire causes in the Altai-Sayan ecoregion for the period 1969 to 2006.

An analysis of data included in a Federal Forest Service report reveals that major causes of wildfires in the Altai-Sayan ecoregion are: careless use of fire (campfire, smoking, debris burning etc.) for 60-90% and thunderstorm's lightning (1.8-36 %). These values are applicable to the entire territory of Russia.
Particularly of note is the large number of fires whose cause was not established (up to 15%) given that the relative value of corresponding category in Russia is less than 3% (Щетинский, 2001). Distribution of the number of fires that occur through the fault of the local population in the Altai-Sayan ecoregion is uneven, mosaic in nature and determined by factors of topography, forest types and population density.

In the Altai-Sayan ecoregion, in April and May, i.e., the onset of the fire season, fires mainly occur at the fault of the local population, and account for 49.6% of the total number of fires per fire season. Typically, these fires are confined to areas of human activity, as well as to transportation routes (rivers, roads, power lines). The number of fires caused by agricultural burning amounts to 3.6%, and fires caused by lightning amount to 0.9%. Other causes account for less than 4%.

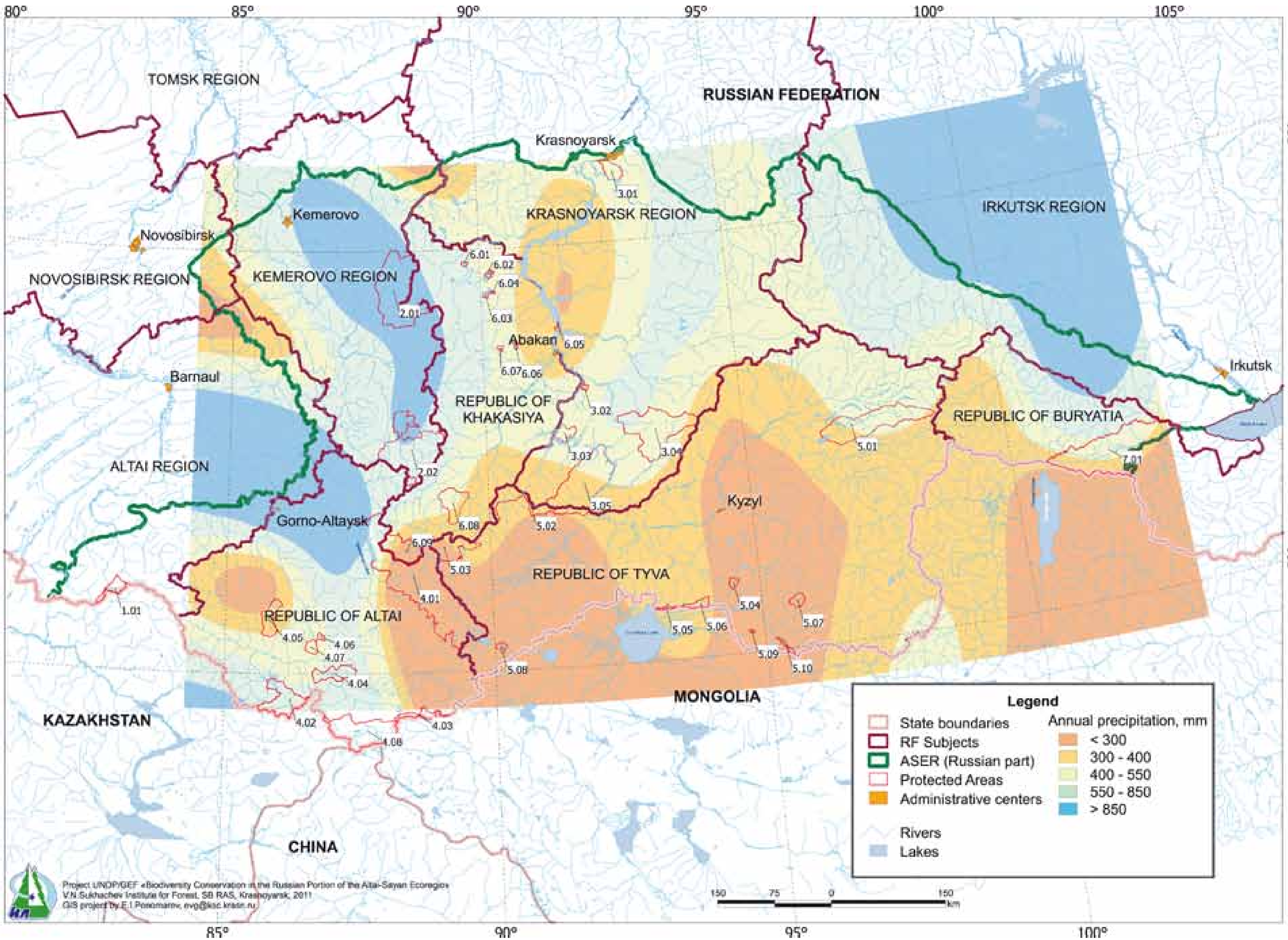


Fig. 1.12. Mean annual precipitation across the ASER

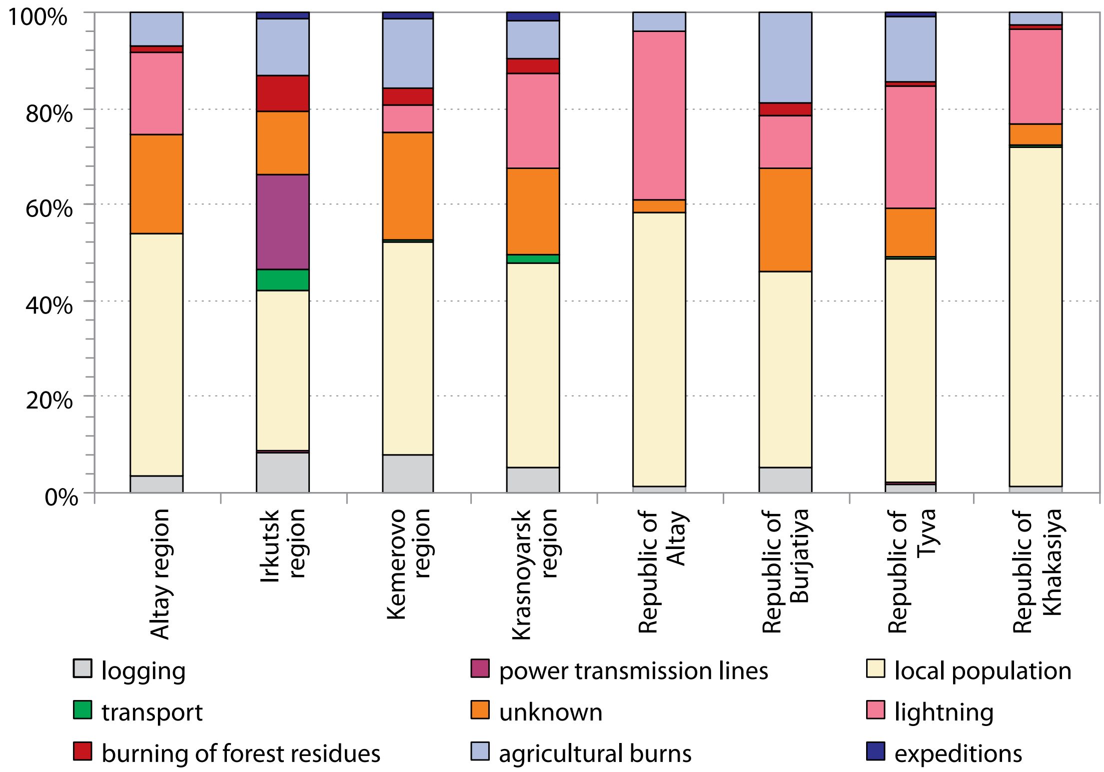


Fig. 1.13. Main causes of fires in forest areas of regions of Russian Federation encompassed by the Altai-Sayan ecoregion

In June, one sees a reduction in the number of fires caused by local populations to 13%, while fires caused by lightning increase to 3.7%. Over the statistical period in question, the number of fires occurring over the summer months that are caused by the local population constitutes 35.2% of the total per season.

The distribution of fires caused by lightning differs considerably from the spatial distribution of fires caused by local populations. At the same time a fairly close relationship can be traced between fire frequency, the number of days on which storms occur and their duration. The rank correlation coefficient is 0.72. This correlation is due to the homogenous impact of weather conditions and lightnings activity on forest fuels ignition in the study area.

Based on data acquired for fires occurring in protected areas (quantitative characteristics are given in Table 1.1) the ratio of various causes of forest fires was calculated (Table 1.3). The protected areas included in the study are accessible to the local population, which assures a high proportion of fires resulting from carelessness in the handling of fire. In the majority of protected areas the number of fires caused by human activity prevails over those caused by natural factors (lightning).

Data on the causes of fires in "Azas" State Reserve and "Ergaki" Nature Park were not provided by protected area administrations neither is corresponding data included in the Federal Forest Service database. As a result, no analysis of the cause of fire in these protected areas was performed. The main causes of forest fires in protected areas located in mountainous areas are local populations and lightning (58%), whereas in the steppe regions there is an increase in the number of fires resulting from agricultural burns (35%).

The proportion of lightning-induced fires is significant in protected areas "Altaisky", "Sayano-Shushensky" and "Khakassky" (clusters of the forest-steppe zone). Fires caused by lightning were recorded in protected areas "Stolby", "Shorskiy", "Tigireksky" and "Shushensky Bor" (3-16% of total fires).

Table 1.3

Causes of fires in protected areas, % of total fires recorded

Protected Area	Local population	Lightning	Agricultural burns	Others
Azas	—	—	—	—
Altaisky	45	36	0	19
Ergaki	—	—	—	—
Katunsky	100	0	0	0
Kuznetsky Alatau	75	0	4	21
Sayano-Shushensky	39	58	0	3
Stolby	95	3	0	2
Tigireksky	60	13	0	27
Ubsunurskaya Kotlovina	100	0	0	0
Khakassky	15	50	35	0
Shorskiy	88	5	1	6
Shushensky Bor	70	16	0	14

On the basis of summary Table 1.4, obtained from a Federal Forest Service data analysis spanning 38 years, one may evaluate the causes of fires in forest areas bordering protected areas. In addition to the main causes of fires typical of protected areas, border areas are marked by fires occurring in logging areas (in the vicinity of PA "Azas", "Ergaki", "Kuznetsky Alatau", "Sayano-Shushensky", "Shorskiy" and an isolated incident in the vicinity of PA "Stolby", and "Ubsunurskaya Kotlovina"). Isolated cases of fire have also been recorded in the vicinity of PA "Kuznetsky Alatau", "Stolby", and "Shorskiy") as a result of slash burning.

In territories situated adjacent to protected areas, the majority of fires are likewise caused by the local population or lightning. Agricultural burning however, represents the most frequent cause of fire in the border areas of protected areas, "Ergaki", "Kuznetsky Alatau", "Ubsunurskaya Kotlovina" and "Shushensky Bor".

1.4. Analysis of fire trends and frequency in protected areas

Particular patterns can be traced in protected areas where forest fires occur on specific days of the week. For example, on the territories of "Sayano-Shushensky" Reserve and "Kuznetsky Alatau" Reserve fire detection occurs on a Monday and Tuesday. In "Shushensky Bor" National Park the number of recorded fires increases on a Friday. One must assume that this is due to mass outdoor Sunday recreation. This indicates that a possible 2-3 day latent burning period exists prior to detection.

A dendroclimatic and fire dating analysis (Валендик и др., 1993, 2001) shows the chronology of forest fires in pine forests of the south of Krasnoyarsk region and Republic of Tyva. These areas are prone to annual periods of drought creating the conditions for wildfires. The average fire return interval depending on the type of forest varies from 11 to 27.5 years. Recently, pine stands have been facing additional human-induced pressures. Similar data for other regions and formations is not available.

Table 1.4

Causes of fire in forest areas adjacent to protected areas

Protected Area	Adjacent forestry	Total fires	Cause of fire					
			Logging	Local Population	Undefined	Lightning-caused	Slash burning	Agricultural burns
Azas	Todjhinskoe	1403	2	889	21	489	0	1
Altaisky	Barun-Khemchinskoe	506	0	476	0	29	0	1
	Ulaganskoe	142	0	87	0	55	0	0
	Teletskoe	37	0	14	0	23	0	0
	Baigolskoe	17	0	12	0	4	0	1
Ergaki	Usinskoe	958	4	274	196	469	0	15
	Karatzuskoe	186	0	122	17	38	0	9
	Yermakovskoe	480	0	281	38	128	0	33
Katunsky	Ust-Koksinskoe	146	0	125	1	18	0	2
Kuznetsky Alatau	Tisulskoe	116	2	70	32	1	1	8
	Kemerovskoe	675	2	614	29	0	2	28
	Mejhdurechenskoe	83	6	67	1	5	1	2
	Kopevskoe	18	0	70	0	0	0	0
Sayano-Shushensky	Usinskoe	958	4	274	196	469	0	15
	Sayano-Shushenskoe	609	0	204	58	326	0	16
Stolby	Krasnoyarskoe	196	1	172	9	9	3	2
	Maganskoe	198	0	153	7	31	0	5
Tigireksky	Gorno-Kolyvanskoe	15	0	11	1	0	1	2
Ubsunurskaya Kotlovina	Tes-Khemskoe	431	0	340	8	73	0	6
	Chadanskoe	1211	1	1056	0	124	1	30
	Barun-Khemchinskoe	506	0	476	0	29	0	1
Khakassky	Abazinskoe	141	0	140	0	0	0	1
	Tashtypskoe	435	0	364	5	64	1	1
	Tuimskoe	444	0	442	0	1	0	0
	Bogradskoe	540	0	539	1	0	0	0
Shorskiy	Tashtypskoe	435	0	364	5	64	1	1
	Baigolskoe	17	0	12	0	4	0	1
	Tashtagolskoe	190	8	134	30	2	2	13
Shushensky Bor	Sayano-Shushenskoe	609	0	204	58	326	0	16

Chapter 2. FIRE IMPACT ON FLORA AND VEGETATION IN PROTECTED AREAS

2.1. Fire impact on forest ecosystems

2.1.1. Fire effect on stand

Post-fire stand mortality is determined by fire type, fire severity, litter thickness, tree species, trunk diameter and structure of the root system. Taking these factors into account, it is possible to predict post-fire stand mortality in fresh burned areas. The prediction is based on dependencies, nomograms, and tables specially developed for this purpose.

Fires of low or in part, moderate severity have a positive impact on phytocenosis. Running surface fires cause only very slight changes in mature, maturing and middle-aged pine, deciduous and larch stands, and often do not lead to the settlement of secondary pests. Spruce, fir and young stands of other species, are, on the contrary, occupied by secondary pests. Steady surface fires weaken the growth of most tree species, creating favorable conditions for the development of secondary pests. Running crown fires weaken the growth of stands and also lead to colonization by secondary pests. Steady crown fires usually totally destroy the stand and so do not create conditions for the proliferation of secondary pests with the exception of burned areas with total tree mortality. Ground fires result in the loss of trees, partly creating conditions for the development of secondary pests. Spring burned areas of pine stand are colonized by insect pests (longhorn beetles, bark beetles, long-horned beetles) in the spring, summer and autumn of the burn year. Spruce burned areas are affected by longhorn and bark beetles. Summer burned areas are colonized in the same year by bark beetles, longhorn beetles, borers, etc. Autumn burned areas are colonized only in spring of the following year. Intense colonization of burned areas by secondary pests occurs in cases where the breeding ground is situated in the vicinity (500-2,000 m).

2.1.2. Fire effect on lower vegetation layers

Based on levels of fire-resistance plants are divided into the following groups:

• Plants avoiding fire impact. These include: a) species represented in the plant community during fire such as dormant populations (viable seeds, dormant underground parts), sheltered in the soil from high temperatures. Burns favors the germination of seeds and the taking root of their shoots; b) diaspora, that enter the area from external sources: moss spores, lichen soredia, seeds of pyrogenic anemochores (*Chamerion angustifolium*).

• Plants, the above ground parts of which are sufficiently resistant to fire. Only a few plants of these species die out during fires. This group includes several species of woody plants, for example, Scots pine and larch. Among herbaceous plants, resistant species forming dense tussocks, especially mounds, of which only peripheral tuft shoots (hare's-tail cottongrass) are damaged by fire.

• Plants whose above ground shoots are destroyed during fire, but underground organs are preserved, generating new shoots (blueberry, cowberry). For these species a sharp reduction in the intensity of competition with other species and improved provision of warmth and mineral elements creates conditions favorable for rapid growth.

• Plants, the above ground parts of which perish during fire (horsetail, marsh labrador tea, common cow-wheat). Such plants are only gradually restored in the plant community with the germination of surviving underground parts and viable seeds present in the soil.

• Plants that are destroyed during fires, and only gradually recover in the plant community as a consequence of the external arrival of diaspores (sidebells wintergreen, *Dicranella, Orthodicranum montanum*, common haircap moss).

• Plants that reproduce via seed and which spread seeds only after exposure to fire and can perish during fire.

The combination of these types of postfire strategies creates a great variety of pyrogenic response in plant communities. Size can represent an obstacle to the active colonization of burned areas (seeds and sprouts find it difficult to reach areas of burned forest at distances from the edge), but a more common obstacle is the waterlogging process. The disappearance of woody plants in whose layer active transpiration has occurred, leads to disruption of water balance in the area and raising ground-water levels.

2.1.3. The influence of fire on rare plants

According to increase in fire resistance the biomorphs of rare and vulnerable plant species can be arranged as follows: above ground-creepers, above ground-stolons, dense shrubs, underground-stolons, long-rhizomes, bedding-rhizome, raceme-rhizome, short-rhizomes, rhizome-bunch grass, long rhizomes, bulbous, root-tuberous, cormerous and tap root (Безделева, Безделев 2006; Чижов, 2000).

One of the very significant effects of fire irrespective of its severity is the almost complete disappearance of mosses and lichens which in terms of pyrology represent the least stable vegetation layer. Lichens are generally highly susceptible to fire, recovering extremely slowly, over a period of decades (Иванов, 1950).

Fires also cause significant damage to communities xylotrophic fungi, especially in dry habitats, where large quantities of snags and downed dead wood accumulate. In most cases, fires occuring in these conditions lead to the destruction of the mycocoenosis (Сафонов, 2006). Saprotrophic fungi settling on litter are even more vulnerable to the effects of the pyrogenic factor as they are exposed to high temperatures. Humus saprotrophs whose mycelium develops much deeper in the humus soil layer are more protected from the fire.

It has been established that the majority of rare and vulnerable species listed in the Red Book of Russia, vascular plant species (Биоразнообразие Алтае-Саянского экорегиона; Красная книга России; Красная книга РСФСР, 1988), are in fact fire resistant (45%), i.e., plants of this group are retained at levels of more than 50% even after intense surface fires accompanied by litter burn of up to 80-90%. Reduction in the abundance of vascular plant species post-fire may be caused simply by the adverse indirect effects of fire on certain environmental factors. 11% of species respond to fire impartially. After intensive surface fires the abundance of these species may be reduced by 2-5 times due to the death of individuals whose roots are concentrated in the litter. However, qualitative changes in the cenotic role of these species has not been observed, as they quickly recover lost ground via vegetative and seed reproduction. The safety of these species depends to a large extent on the degree of litter combustion. 25% of species are not fire resistant. After intensive burns the abundance of these species is reduced by more than 10 times. Populations return to their original state very slowly, hence frequently repeated fires may cause their complete elimination. In 18% of species the response to fire is difficult to determine unambiguously. The safety of these populations depends on fire severity.

2.2. Pyrogenic succession

Forest fires are a significant external influence not only in relation to the stand and lower vegetation layers but also in relation to forest ecosystems as a whole. In the case of post-fire habitat formation the forest formation process in burned areas is interrupted. A new succession cycle begins which depending on the combination of original forest forming conditions can develop according to several patterns including digression which leads to qualitative change in the ecosystem.

Any assessment of the impact of fire on the subsequent forest formation process requires a description of the possible development pattern of succession cycles (Корчагин, 1954; Работнов, 1978). The structure of the forest community is revealed through a systematization, which takes account of the peculiarities of forest regeneration processes (Типы лесов гор южной Сибири, 1980; Власенко и др., 1999; Власенко, 2003). Discovery of the spatial-temporal structure of post-fire forest ecosystems can be reduced to a description of classification units, i.e. marking the beginning and end of cycles, the characteristics of their phases, stages and the probability of their formation.

Tables describing the possible patterns of pyrogenic succession illustrate the rationale from the point of view of forestry for recommending specific local regulations for fire management in specific areas including protected areas. Recommendations are differentiated according to plant formations, groups of forest type and moisture levels.

Sequential change in vegetation takes places across the earth's entire surface. At any moment in time all plants are located in a particular phase or stage of one or another succession cycle. Successions are cyclical and probabilistic in nature, i.e. when the original conditions change there may be a temporal shift in that it occurs sooner, later, or does not occur at all. Two types of temporal rhythm should be distinguished:

• age-related changes during the life of the ecosystem;
• sequence of shifts in plant communities.

When external influences are stable one may assume that the types of succession do not replace each other, each being expressed on an individual territory. However, changing external conditions lead to changes which to one degree or another alter the environmental circumstances and habitat mosaic. To a large degree, change in succession types is characteristic of boundary areas, for example, between dark (shade-tolerant) coniferous and light (light-demanding) coniferous forests or between the taiga and forest-steppe. The reason for this is that in these areas the environment is responding to different types of succession simultaneously and therefore the slightest change in external factors alters the scenario of forest regeneration processes. As a result, transitions are made to qualitatively different types of succession. At the current time in which one witnesses vast forest fires and random felling, shifts in succession types, even in border landscapes are difficult to predict.

To date, no generally accepted classification scheme for forest formation processes exists. A great number of different versions exist which can be explained by the diversity of succession types, originality in methodological approaches and inconsistent use of terminology and approaches to typology when selecting an object for observation. The succession classification scheme applied for the purposes of this paper was developed under the auspices of the International Institute for Applied Systems Analysis as part of the international project "Forest Resources, Issues of Natural Environment and Socio-economic Development in Siberia" by A.Z. Shvidenko and subsequently approved by the heads of various research groups. The classifier relating to pyrogenic succession types is presented in Table 2.1.

The classifier includes all subtypes of pyrogenic succession, describing the complete destruction of the stand: recovery with no change in species (01, 02), recovery with change in species (03); and to a lesser degree, digressional patterns of succession processes: waterlogging (04), erosion (05), steppification (06), and shrubification (07). Regards the development of the stand reference number 01 in the code is to a large degree consistent with the description of pyrogenic succession in coniferous species. Siberian pine stands in the upper-mountain-taiga zone are characterized by the direction indicated by reference number 02, when Siberian pine cannot be replaced by short-lived deciduous species and fir. In this case, 'climax' is an appropriate term for the final stage (Фарбер, 2000).

For all other formations, in which development is relatively swift and the duration of the final stage is comparable with other stages, the term 'decay' is used.

Table 2.1

Classifier of pyrogenic succession types

Pattern of stand development	Development Phase (stage)
Complete destruction of the stand	
01	1. Pioneer
	2. Recovery with no change in species
	3. Young growth, polewood
	4. Middle-age, semi-mature, mature
	5. Overmature, decay
02	1. Pioneer
	2. Recovery with no change in species
	3. Young growth, polewood
	4. Middle-age, semi-mature, mature
	5. Overmature, climax
03	1. Pioneer
	2. Regeneration of deciduous types
	3. Saplings, polewood, establishment of native tree type
	4. Middle-age, formation of native tree type layer
	5. Maturity and decay of deciduous trees, formation of coniferous canopy
	6. Overmature, coniferous decay
04	1. Pioneer without regeneration
	2. Waterlogging
05	1. Pioneer without regeneration
	2. Erosion - destructive
06	1. Pioneer without regeneration
	2. Sodding
07	1. Pioneer without regeneration
	2. Shrubification
Partial destruction of the stand	
08	1. Destructive phase
	2. Open forest
	3. Pseudo-climax (deterioration)
09	1. Destructive phase
	2. Increase in density
	3. Pseudo-climax (stabilisation)

Pioneer stage - the period of time from the moment of fire to the appearance of undergrowth. This stage is characterised by greatest development of herbaceous vegetation.

The process of post-fire recovery is possible in: 1) surviving elements of pre-fire plant communities (eg, shrubs: common bilberry, cowberry, labrador tea, bearberry, bog bilberry), 2) sprouts or individual organs of plants laying dormant in the soil (e.g., reed, wood-rush, false brome and others), 3) introduction of propagule from neighbouring areas (e.g., fireweed, northern hawkweed, cottonweed timber, goldenrod, siwiec meadow).

The sequence of colonization in burned areas is determined by the life strategies of specific species (pyrophytes, explerents, patients, violents). Dominant annual species are replaced by perennials. There is an increase in the duration of each subsequent stage and there the woody component of the ecosystem is particularly slow to recover.

Moist habitats may see the growth of "post-fire mosses", *Funaria hydromorfica* and *Marshantia polymorfa*. In some habitats one sees active postfire settling of cladonia (*Cladonia glacilis, C. deformis, C. Careosa*). These belong to the "post-burned suite" and are gradually replaced by "bushy cladinas" (*Cladina amaurocraea, C. uncinalis, C. sylvatica*), and then *C. rangiferina* and *C. Apestris*.

<u>Recovery stages</u> are well developed in forest science and are consistent with the stages of stand formation. The sapling growth stage lasts up to and beyond the closing of the undergrowth canopy. The polewood stage is marked by thinning of light coniferous species and the appearance of dark coniferous types under the canopy of deciduous saplings, inhibition of herbaceous vegetation and the beginning of the formation of moss and lichen. In the middle-age stage the main characteristics of the forest are formed with its particular range of biodiversity. Within light coniferous formations it is at this stage that the first surface fires occur. In dark coniferous areas a subcanopy layer of these species is formed under the canopy of deciduous trees, which determines future stand composition and its longevity. There is no fundamental difference between semi-mature and mature stands. The complexity of species diversity and cenotical structure gradually increases on the background of the dominant stand.

In the final stage a complete replacement of the canopy takes places as a result of fire, insects and windthrow or there is partial reduction in canopy density due to change in tree species. This overmature stage largely corresponds to the term decay.

2.2.1. Features of pyrogenic succession in the Altai-Sayan ecoregion

The possibility of a fire spreading depends on natural features of the mountain landscape: climate, composition and structure of vegetation cover, terrain and geographical layout of forest communities (Растительный покров Алтая, 1960; Крылов, 1963; Назимова, 1963; Куминова, 1965; Растительный покров Хакасии, 1976; Седельников, 1979, 1988; Типы лесов гор Южной Сибири, 1980; Огуреева, 1980, 1983; Куминова и др., 1985; Семечкин и др., 1985; 2002; Зоны и типы поясности растительности России и сопредельных территорий, 1999; Ермаков, 2003). The correlation between forest areas with different levels of fire activity and their specific landscape features determines the likelihood of various types of natural succession in forest vegetation. This is determined by the "fire turnover". In areas with low fire occurrence the replacement of pine forest by spruce is complete, and the spruce reaches the climax state (with a completely mixed-age composition). With more frequent exposure to fires endodynamic processes are periodically interrupted, pine forests are restored in burned areas or are cleared of undergrowth and spruce subcanopy. These types of forest area are dominated by relatively mixed-age spruce that fail to reach the climax phase before the next fire onset.

Mountain relief creates a great variety of settings for forest fires. The position of mountain ranges in relation to wet winds, altitudinal belts, the differences in exposure, slope gradients and landforms are all factors which play a role in determining the diversity of overall climatic conditions (Поликарпов и др., 1986; Назимова, 1998). As a consequence they also have a bearing on the following: differences in periods of fuels readiness to burn in forest areas, duration of fire season, opportunities for the occurence and spread of fire, specific pattern of restorative succession.

In accordance with the scheme of bioclimatic units (climatic facies) given below the territory of the Altai-Sayan ecoregion can be divided into four climatic regions (climatic facies): perhumid cyclonic, humid cyclonic, semihumid anticyclonic, semiarid (subarid) anticyclonic (Поликарпов и др., 1986).

Perhumid cyclonic *climate facies* – chern mixed fir-aspen forests dominated by fir (*Abies sibirica*), aspen (*Populus tremula*) and dark coniferous mountain taiga dominated by fir and Siberian pine at an altitude range of 350-500 to 1,300-1,600 m. Geographically these regions are located on the most humid windward slopes of the front mountain ranges and ridges (north-eastern Altai, Kuznetsky Alatau mountains, north-eastern part of the Western Sayan region, south-western part of Eastern Sayan

region). In these areas the average annual rainfall is 950 mm or more. High cyclonic activity in winter prevents onset of the Asian anticyclone. As a result, highest temperatures are observed in January and low average temperatures are observed in July. Lowest indicators of continentality occur in this group.

In the spectrum of altitudinal belts present these are sequentially replaced by: mountain chern forests dominated by aspen and fir, perhumid cyclonic mountain-taiga dominated by fir and fir-Siberian pine, subalpine open forest dominated by *Pinus sibirica* and *Abies sibirica*. In comparison to other groups this group is marked by the lowest altitude of tree line: from 1,100 m in the north of the Altai-Sayan region and up to 1,300 (1,600) m in the south of the region. In forests with perhumid cyclonic facies, especially in the chern belt, successful regeneration of conifers is mostly limited to a period of 2-3 years due to the rapid and powerful growth of herbaceous plants in all deforested areas. Deciduous species (aspen and birch) differ in vegetative regeneration, being more abundant and frequent seed bearers and producing rapid growth in the first years of life, all of which contributes to the successful colonization of the cleared territory.

As a result, regeneration of conifers in the chern belt is often delayed for a period of 20-40 years, the time necessary for the leaf canopy to form and the displacement of herbaceous plants. In burned areas fir and Siberian pine display a satisfactory regeneration rate in the chern belt of 30%, and in the mountain-taiga, 40-60%.

<u>Forest-steppe</u>. The forest layer of typical plant communities is characterized by a 0.5-0.6 density with a predominance of silver birch, which can represent the sole dominant. An admixture of aspen and pine can often be observed in the stand composition. Density of the shrub layer reaches a maximum 10% and mostly consists of rosehip, caragana, spiraea and hawthorn. The average cover extent of the herb shrub layer is 80%; species richness 50-80 species over 200 m^2. The greatest phytocenotic role is played by typical mesophytes: tor-grass, rough small reed, stone bramble, lung lichen. A specific feature of the floristic composition is the increased role of meadow-steppe mesoxerophytes. The moss layer in most cases does not develop. There are 8 rare and vulnerable plant species.

The territory is dominated by birch, birch-aspen and pine-larch (in the eastern habitat range) stands of herbaceous groups of forest types.

<u>Subtaiga forest.</u> Dominated by pine small leafed stands and mesophyte grass associations, often with a predominance of aspen. Productivity of pine and larch is evaluated at II-III, and in best conditions to I-Ia quality of stands. The widespread series of forest types include mixed herbaceous with bracken (*Pteridium aquilinum*), *Carex macroura, Calamagrostis arundinacea and* large herbs (*Crepis sibirica, Thalictrum minus, Cimicifuga foetida*). On contact with chern forests in the subtaiga one may observe pine, aspen and birch forest types with bracken and nemoral species (*Brunnera sibirica, Anemone baicalensis, Galium odoratum*).

Subtaiga forest is characterized by a considerable number of nemoral adaptants: violet palmate (*Viola dactyloides*), health speedwell (*Veronica officinalis*), rattlesnake fern (*Botrychium virginianum*), spring vetchling (*Lathyrus vernus*), woodland geranium (*Geranium sylvaticum*), granulate gagea (*Gagea granulosa*) and large-cupped primrose (*Primula macrocalyx*). The undergrowth is sparse and consists of bird cherry, rowan and elder. The herb layer is generally strongly developed (80-100% cover extent, average height 140 cm, species richness 70-80 species over 200 m^2), and divided into sub-layers. There are 19 rare and vulnerable plant species.

In most forest types natural regeneration beneath the canopy is poor. Slow shifts to aspen and meadow cenoses may occur subsequent to logging or fire.

Chern forest. Dark coniferous and deciduous/fir forest types (*Pinus sibirica, Abies sibirica, Populus tremula*) are most widespread and have a highly developed undergrowth and well developed herb cover. The tree layer has a density extent of 0.6-0.7 and consists of mixed aged Siberian fir with an admixture of Siberian pine and aspen. The undergrowth has a cover of 5-15% and predominantly consists of Bird cherry (*Padusavium),* rowan *(Sorbussibirica)* and currants *(Ribeshispidulum, Ribesatropurpureum).*The herbaceous layer has a density extent of 70-75% and an average height of 130 cm. The herb synusiae are dominated by ecobiomorphs of large forest ferns, forest and meadow tall herbs, taiga species, boreal-forest and meadow cereal grasses, nemoral broadleaf herbs and grasses. The latter are represented by relict broadleaf flora. The development of spring ephemeroids is common. Species richness in the herbaceous layer is 45-60 species over 200 m^2. The moss synusiae is poorly developed. There are 18 rare and vulnerable plant species.

Dominant types are Siberian pine forest of I-II class stand quality and fir of II-III class stand quality of the large herb-fern series.

Mountain taiga forests. Closed taiga (*Pinus sibirica, Abies sibirica*) with green moss cover, mesophilous boreal herbs, taiga dwarf shrubs and small-taiga herbs is most typical of this forest group. The herbaceous layer is dominated by *Calamagrostis obtusata*, sedges, bilberry, bergenia, labrador tea and cowberry, etc. One may also observe a predominance of mesotrophs and oligotrophs, with some participation of psychrophytes and petrophytes. Average species richness ranges from 10 to 40 species over 200 m^2. The moss layer is well developed consisting of common boreal mosses. The herb-green moss group represents the most widespread group of forest types. There are 11 rare and vulnerable plant species.

Subalpine Pinus sibirica and Abies sibirica dominated open woodland. Characterized by a spatial combination of different phytocoenomorphs: subalpine dark coniferous forest, dark coniferous subgolets, dark coniferous subalpine and subgolets open woodland, subalpine meadows and subalpine shrub communities. The distribution of subalpine and subgolets phytoxenomorphs is largely determined by the level of the snow cover. Species richness is high, ranging from 50 to 70 species per 200 m^2. There are 8 rare and vulnerable plant species.

Mountain tundra, golets. Mountain tundra occupies the higher mountain ranges. Marked by the lower part of the altitudinal vegetation complex dwarf birch-lichen tundra and the upper slope ranges (dryad, festuce, lichen, crowberry tundras). The higher ranges are occupied by golets which represent rocky formations, in places covered with lichen. There are 6 rare and vulnerable plant species.

In the perhumid regions of deforested areas, particularly in low-mountain vegetation altitudinal belts (chern forest) one may observe rapid herb growth which prevents the successful regeneration of coniferous trees. As a result, stand regeneration occurs via long-secondary or stable-secondary shifts. The deciduous stand phase can last up to 150-160 years. Aspen stands generally predominate. Conifers are mainly represented by fir and Siberian pine with fir dominating in the initial stages. The age formation of the Siberian pine stand is characterised by undulating alternation of mixed-age generations, while the fir stand is replenished much more evenly and is totally mixed-age. In the high-mountain zone, due to weakened seed bearing, increased skeletal soils and the development of cryogenic soil processes, the regeneration of coniferous trees species is poor. In the subgolets-subalpine belt postfire Siberian pine, Siberian pine-fir forests and open forest are often marked by dense meadow grass growth.

Humid cyclonic climate facies (mountain taiga-foreststeppe regions dominated by larch and Siberian pine (1,200-2,000 m) located in the low mountain ranges of the Northern Altai region, the northern part of Central Altai, axial parts of West and East Sayan and north-eastern Tyva. Cyclonic activity in these areas is relatively insignificant but nonetheless, contributes to the formation of mesoclimate

conditions marked by high levels of heat and moisture, and relatively low continentality (average 44). Vegetation in this group of regions is dominated by dark coniferous (Siberian pine) forests. Light-coniferous subtaiga or taiga are pervasive in the lower part of the altitudinal belt up to an altitude of 600-800 m.

Higher areas are dominated by Siberian pine forests of dwarf shrub-green moss series with spruce of blue-joint-green moss series in valleys, and on warmer slopes with richer soils, fir of small herbs-green moss series. Siberian pine forms the upper tree line (1,600-1,800 m) and upper subgolets-taiga belt with participation of dwarf birch, alder, rhododendron and *Rhododendron aureum*. The subalpine meadow and open forest zone is represented only in fragments. In humid climates, fires can have disastrous consequences despite their low frequency due to the dominance of dark coniferous forests which contribute to crown fires, and also due to the intensive colonization of burned areas by grasses and shrubs.

Forest steppe-subtaiga forest. In contrast to the perhumid subtaiga, the composition of the humid subtaiga, is significantly enriched by elements of xeromesophilous forest-steppe mixed herbs, including species characteristic of poor pine forest habitats. At the same time, a large group of meadow-forest mesophilous mixed herbs and tall herb species retains its physionomic similarity to perhumid subtaiga areas. The tree layer of native communities consists of a mix of pine (*Pinus sylvestris*) and birch (sometimes with the isolated participation of aspen). Density of canopy 0.5-0.7. The shrub layer cover extent reaches as much as 20% and is dominated by *Spiraea chamaedrifolia*, subdominants *Caragana arborescens*, *Spiraea media*, *Rosa acicularis and Cotoneaster melanocarpus*. The herb layer with 70-80-100% cover extent, 60-70 species richness (sometimes up to 110 species) over 200 m^2, average height 80 cm, is divided into sublayers. Typical mesophites play a significant role (*Lathyrus, Cacalia hastata, Geranium albiflorum, Senecio nemerensis*), against a background of predominant mesoxerophytes. The moss layer is poorly represented consisting of separate individuals of *Rodobrium roseum, Pleurozium schreberi* and *Rhitidiadelphus triquetres*. There are 17 rare and vulnerable plant species.

In the western spurs of the East Sayan mountains, in the Yenisei district one may observe widespread distribution of pine-birch, with aspen stands in some places, with few or no dark coniferous species or with a small admixture of fir on shady slopes and with a predominance of spruce in ravines and valleys. These areas are characterized by high forest productivity and an abundance of grassy, herbaceous, tall herbs groups of forest types (*Carex macroura, Calamagrostis arundinacea, Pteridium aquilinum*) forming on grey forest soils and soddy litozems. The presence of steep southern steppified slopes foresees the presence of steppe and poor pine forest-steppe species. The regeneration of coniferous species under the stand canopy is estimated to be satisfactory (from 1 to 6 thousand per hectare.) Dark-coniferous regrowth occurs mainly at the boundary of the overlying dark coniferous belt. In the central part of the Eastern-Sayan province on the northern East-Sayan macroslope in the Biryusinsk-Kitoisk district one sees a predominance of forest types with a cowberries (lingonberry) (*Vaccinium vitis-idaea)* and mixed herbs serie (pine, larch, secondary birch forests), widely distributed pine forest (*Pinus sylvestris*) with rhododendron in loamy soddy-forest or light textured podzolic soil types.

Mountain taiga Scots pine/Siberian larch forests. These forests are of a typically boreal nature being characterized by pine and larch stands of average productivity. The subordinate layers are dominated by boreal dwarf shrub, taiga small herbs and mosses. The shrub layer is poorly developed and consists of: Altai honeysuckle (*Lonicera altaica*) and spined briar (*Rosa acicularis*). The herb-dwarf shrub cover is dominated by typical taiga and boreal-forest species: lingonberry (*Vaccinium vitis-idea*), common bilberry (*Vaccinium myrtillus*), twin-flower (*Linnaea borealis*), round-leaved wintergreen (*Pyrola rothundifolia*), sidebells wintergreen (*Orthilia secunda*) and creeping lady's tresses (*Goodyera repens*). The cover extent of the moss-lichen layer averages 60-70%, and is represented by: *Pleurozium schreberi, Dicranum polysetum, Hylocomium splendens* and *Ptilium crista-castrensis*. Average species richness 20-45 over 200 m^2. There are 4 rare and vulnerable plant species.

Mountain taiga Siberian pine forest. In the mountain taiga altitudinal belt of middle-mountain regions, Siberian pine with green moss cover is the native forest type. The tree layer is mix-aged or conventionally even-aged, density of 0.6-0.8. The shrub layer has a cover extent of 5-30%. It consists of elm-leaf spirea (*Spirea chamaedrifolia*), rowan (*Sorbus sibirica*) etc. The herb-dwarf shrub layer is characterized by a cover extent of 30-60% and species richness of 15 - 30 (up to 45) over 200 m^2. Taiga species of dwarf shrub and fern have the greatest consistency: cowberries (lingonberry) (*Vaccinium vitis-idaea*), common bilberry (*Vaccinium myrtillis*), twin-flower (*Linnaea borealis*), round-leafed wintergreen (*Pyrola rotundifolia*) and common oakfern (*Gymnocarpium dryopteris).* In places marked by outcrops of bedrock the most abundant species in the herb layer is Siberian tea (*Bergenia crassifolia*). The moss layer is well developed and has a cover extent of 40-90%, formed typically by boreal moss species: *Pleurozium schreberi, Dicranum polysetum, Hylocomium splendens and Ptilium crista-castrensis*. There are 6 rare and vulnerable plant species.

Dark coniferous spruce/Siberian pine stands situated on the floodplains of rivers and streams develop according to coenogenetic succession type. No fire protection is required.

Subgolets-taiga Siberian pine forests and open forest. Species richness 20-40 species over 200 m^2. There are 9 rare and vulnerable plant species.

Mountan tundra. Mountain tundra is classified as lichen-moss, lichen, dwarf shrub, herb- dwarf shrub types. Species richness is 5-16 species over 200 m^2. There are 9 rare and vulnerable plant species.
In humid areas, the rate of regeneration in forest-steppe and subtaiga altitudinal belts often depends on fire severity. In cases of low fire severity species may be preserved which were present in the original plant community. Short-lived shifts may also occur. Conditions created by partial burning are more advantageous to species capable of rapid vegetative reproduction (e.g., rhizomatous grasses). In this case, long-term secondary succession is possible, or sods are formed, which completely inhibit the regeneration of coniferous trees. The formation of dark-coniferous forest takes place in combination with birch, larch, some spruce and Scots pine. The deciduous growth phase is often absent, especially at altitudes above 1,000-1,100 m. At these altitudes, Siberian pine may form pioneer stands over extensive burned sites.

Semi-humid anticyclonic climate facies (mountain taiga-forest steppe regions dominated by larch and Siberian pine (1,200-2,000 m) forests) are found in areas which come under the barrier effect of the shadow of the front range of the mountain system (low mountains of the "Kuznetsky Alatau" eastern macroslope, the main part of the intermontane basins of the Republic of Khakasiya, middle-mountain Central Altai and the lower slopes of the East Sayan region). The mesoclimate in these areas has pronounced features of aridity and continentality. In this group of semihumid taiga-forest steppe regions the exposure asymmetry in the altitudinal belt structure is clearly evident. The lower part contains steppe belt formations and their surrounding forest steppe complexes. The higher mountain ranges contain predominantly larch subtaiga and taiga belts. The northern slopes contain Siberian pine massifs at altitudes of 1,000-1,400 m. The upper tree line runs at an altitude of 1,600-1,900 m and is formed by Siberian pine and sometimes larch. Spruce and fir are absent at the upper tree line. Spruce is common in valleys and the lower ranges of slopes with a moisture inflow. In this group of regions, all geographically linked to the lee slopes of the Southern Siberian mountain ridges, the development of cryogenic processes and extended seasons of frozen soils are observed. These processes intensify in an eastward direction. Permafrost in the lower vegetation belts forms in 'islands', which leads to the spread of ledum-moss and dwarf shrub-sphagnum forest types. The lingonberry-green moss series should be considered zonal, as it corresponds to an automorphic (transit-automorphic) soil moisture regime. The southern slopes contain steppe formations on gravelly chestnut soils and montane black earth. To the west, the altitudinal spectrum mainly contains steppe and forest steppe belts. In conditions of severe moisture limits, frequent, running surface fires are typical. As a result, seed banks are preserved and soil mineralization is increased ensuring high regeneration potential for key forest forming tree types (Scots pine and larch).

All high mountain forest fires can cause irreversible loss of forested areas together with their sheltering function, and initiate shifts to dwarf birch thicket, subalpine meadows and stony areas devoid of vegetation.

Only restorative shifts move into this group of regions. Pure Siberian pine forests are commonly formed in the dark coniferous belt. Shifts to birch are extremely rare and short-lived in all vegetation altitudinal belts. In the contact zone between light and dark coniferous zones, the deciduous phase of Siberian pine forest growth may be replaced by a more prolonged larch phase. The pyrogenic series of Siberian pine regrowth from beneath the Scots pine canopy is rare due to insufficient heat in the soil.

Steppe. Widespread steppe vegetation consists of true steppes belonging to two formation groups: low bunchgrass (low herb) steppe and tall bunchgrass steppes. Low bunchgrass steppes are dominated by low bunchgrass polydominant steppe in chestnut soils or light textured southern chernozems. The most abundant community forming plants (edificators) include: Fescue (*Festuca valesiáca* and *Festuca rubra*), *Koeleria cristata*, *Cleistogenes squarrosa*, *Stipa Krylov, Poa botrioide* and *Agropyron cristatum*. Tall bunchgrass steppes in southern and typical chernozems cover a smaller area and are confined to wetter habitats than low bunchgrass steppe. Widespread steppe types are: feather grass steppe dominated by *Stipa capillata*; fescue steppe with an oat grass (*Helictotrichon desertorum*) edificator; and feather grass–fescue steppe in which both species dominate. In all tall bunchgrass steppes mixed herbs and grasses play a significant role. In steppe communities average species richness is 10-50, sometimes as much as 75 species per 200 m^2. There are 10 rare and vulnerable plant species.

Forest-steppe, subtaiga forests. Larch and pine forests with steppe and mixed herbaceous groups are widespread in mountain-forest soddy and rendzina soils. On light textured soils one finds pine with rhododendron, lingonberry and mixed herbs. The stand is formed from Siberian larch, with an admixture of silver birch. Crown density reaches 0.4-0.6. In warmer river valley habitats the community composition also includes Scots pine. The shrub layer with density 3-30% is represented by *Spiraea chamaedryfolia, Spirea media*, *Cotoneaster melanocarpus*, *Lonicera caerulia var. Altaica* and *Rhododendron dauricum*. The herb layer has a cover extent of 50-70%, average height - 30-45 cm and species richness 45-55 per 200 m^2. Common characteristic forest features: predominance of mesophytes and xeromesophytes in the floristic composition: *Carex macroura, Carex amicta*, *Láthyrus vérnus,* turks's cap lily *(Lilium martagon),* Canada hawkweed *(Hieracium umbellatum), Agrimonia pilosa, Plurospermum urolense, Cimicifuga foetida, Thalistrum minus,* Siberian meadow-grass *(Poa sibirica Roshev),Viola uniflora, Aqilegia sibirica, Zigandenus sibiricus,* snow lotus *(Saussurea controversa),* northern bedstraw *(Galium boreale), Galium krylovii,* May lily *(Maianthemum bifolium),* Siberian geranium *(Geranium sibiricum),* Asian globe-flower *(Trollius asiaticus), Heracleum dissectum, Aconitum volubile* and stone bramble *(Rubus saxatilis).* The moss layer is always expressed, but is nonetheless thin and sparse (3-15%); consists of taiga mesophytic mosses, with *Rhytidium rugosum*. This subgroup community forms a specific microcombination within the subtaiga/forest steppe vegetation altitudinal belt, illustrating a unity of adaptation to topographical elements such as specific slope exposure and absolute elevation. There are 15 rare and vulnerable plant species.

Mountain taiga larch forest. The determinant group contained in this altitudinal belt is larch with mixed herbaceous species and lingonberry. This group is marked by a low stand quality (IV), a simple phytocenotic community structure and extremely poor floristic composition. The stand consists of Siberian larch with an admixture of Siberian pine and silver birch; extent of crown density 0.5-0.7. The undergrowth is commonly made up of: *Delphinium altaica* and *Rhododendron dauricum*. The herb-dwarf shrub layer has a 40-60% cover density; average species richness 20-40 species per 200 m^2. Species occuring with high consistency include hygromesophytes and cold-loving shrubs: bog bilberry (*Vaccinium uliginosum)*, northern labrador tea (*Ledum palustre)* and crowberry (*Empetrum)* which, together with lingonberry (*Vaccinium vitis-idaea)* are the main dominant and subdominant species. The specific features of these habitat conditions also indicate a well-developed (90-100% cover extent, 15-30 cm height)

lichen-moss layer of *Hylocomium splendens, Pleurozium schreberi, Sphagnum, Aulaconmium palustre, A. turgidum, Flavocetraria cucullata, Cetraria islandica, Cladina stellaris* and *C. rangiferina, C. arbuscula*.

<u>*Mountain taiga Siberian pine forests.*</u> Siberian pine forests with a class IV-V stand quality with lingonberry-green moss, common bilberry-green moss, sedge-moss, rhododendron aureum-moss series in combination with larch with lingonberry- woodreed-green-moss on a graded, concave topography with sedge-moss. A sparse undergrowth consists of honeysuckle, rose hip and Siberian juniper. A mosaic herbaceous cover is composed of lingonberry, *Calamagrostis Pavlovi*, red wintergreen (*Pyrola incarnata)*, twinflower (*Linnaea borealis),* small taiga herbs and boreal-forest mixed herbs and grasses. Species richness just 13-43 species per 200 m^2. Extent of moss synusiae cover 30-50%. There are 4 rare and vulnerable plant species.

<u>*Subgolets subalpine forest and open woodlands.*</u> This group consists of typical coniferous forest (larch and Siberian pine-larch) open woodland with a well-developed shrub layer of alpine shrub species as well as open woodlands with a predominance of subalpine tall herbs. The unity of this group of coenoflora on the main axis of ordination can be accounted for by the leading phytocenotic role of arctic-alpine and alpine species of shrubs and herbs: *Rhododendron aureum, Rhododendron adamsii, Spiraea arcuata, Bistorta vivipara, Juniperis sibirica, Saxifraga nelsoniana, Luzula sibirica*, *Swertia obtusa*, as well as lichens such as *Flavocetraria cucullata* and *Cetraria islandica* in associations. Rare and vulnerable species: Coccocarpia lichen (*Coccocarpia erythroxyli),* Altai onion *(Allium altaicum), Aconitum paskoi, Aconitum sajanense*, *Fritillaria dagana*, *Oxytropis alpestris*, *Bupleurum martjanovii.* There are 7 rare and vulnerable plant species.

Subalpine forests consisting of Siberian pine, fir and larch as well as natural subalpine Siberian pine, fir and larch forests with sparse tree growth, located in the upper tree line belong to subalpine, green mosses-mixed herbs, tall herbs, moss (*Sphagnum, Polytrichum, Pleurozium*) and bergenia groups of forest types. Fires do not occur in these areas. The vertical migration of forest with sparse tree growth occurs as a result of changes in climate trends. Successional climatogenic replacement takes place in meadows, alder stands with gold rosebay (*Rhododendron aureum)* and rocky talus. Fire protection is not required.

<u>*Subgolets-taiga Siberian pine forests and open forest.*</u> Subgolets Siberian pine forests and sparse (thin) forests situated in the upper tree line belong to subgolets lichen, mossy (*Sphagnum, Polytrichum, Pleurozium)*, and ledum-moss forest type groups. There are 4 rare and vulnerable plant species.
Fires do not occur in these areas. The vertical migration of forests and woodlands with sparse tree growth occurs as a result of changes in climate trends. Successional climatogenic shift takes place into tundra, dwarf birch, rocky talus, shrub thickets and heathland.

In high mountain Siberian pine-larch open woodlands of semi-humid areas, post-fire regeneration of the stand is slow and may continue indefinitely. Digression is likely in post-fire development leading to an increase in heathland. Post-fire, dwarf birch communities are capable of restoration by vegetative means over a ten year period. They may also form mixed herbaceous, meadow-type communities. In the dark coniferous belt the formation of pure Siberian pine forests is more common. Shifts to birch in all zones are rare and short-lived.

The predominance of Siberian pine in the post-fire stand usually occurs after 100-120 years. The deciduous phase of Siberian pine forest development in the contact zone between light and dark coniferous forests can be supplanted by a more long-term larch phase. Forest-steppe/subtaiga forests are characterized by repetitive running surface fires with preservation of seed trees and increased soil mineralisation. In these circumstances, pine and larch regenerate without species change. The main dominants of the herb-shrub layer are also adapted to regular fire impact. The pattern of pyrogenic succession in steppe zones depends on the burned plant association, time of fire, and subsequent

weather pattern. Spring fires in feather grass and fescue steppes destroy litter and provide conditions for more rapid plant growth. Summer fires on the contrary lead to a decrease in the abundance of grass species.

Semiarid anticyclonic climate facies (mountain taiga-steppe areas larch (*Larix sibirica*) forests and steppe (1,400-2,300 m)) is spatially confined to leeward slopes and mountain areas located in the wind shadow, with minimum cyclonic activity (plateau Alash, Oka Plateau in the Sayan Mountains, south-eastern Altai, part of the Tannu-Ola, the steppes of central Tyva and lake Uvs Nuur). In these areas one observes special ultra-continental mesoclimate patterns with low precipitation levels and high temperature ranges throughout the cold and summer seasons. Basins are characterized by dry areas from arid steppe to semi-desert. The valley systems of both geomorphological forms have similar phytocenotic structures but play a different role in the landscape structure. Mountain steppes rise high up on the southern slopes dominating the middle mountain landscapes. Forest masses are isolated and only occupy the northern slopes at an absolute elevation of 1,400-2,300 m above sea level. The mesoclimate and topographic conditions of these forest areas define them as extrazonal. The dark coniferous vegetation altitudinal belt is partly to completely reduced, usually represented by larch/Siberian pine stands with an abundance of ledum-cowberry-moss, bergenia-cowberry and dwarf birch-lichen series of forest types. Larch and birch-larch forests are formed in close vicinity to steppe areas and are grassy-taiga in nature.

High mountain forests are dominated by larch. Widespread replacement of tree species is not characteristic, hence the deciduous phase of forest growth is omitted. Siberian pine forests occupy the upper flat part of the northern slopes, where local conditions include high atmospheric humidity.

<u>Steppe.</u> Classified by type: (low bunchgrass (fescue), semidesertic (nanophyton-feathergrass), secondary semidesertic (cold sagebrush, bistort). Average species richness ranges from 20 to 40 species per 200 m^2. 7 rare and vulnerable plant species.

Fires in real steppes lead to decreased abundance of annuals and reduced productivity in the first 1-2 years. Due to rapid recovery and locality of fires creating firelines is a sufficient for fire protection. In semidesertic steppe conditions the spreading of fire is unlikely due to low grass cover, hence fire protection is not required.

<u>*Valley forests*</u> are poplar (*Populus laurifolia*) with a well-developed, diverse shrub layer. The ground cover is characterized by high species diversity and productivity. These stands are exposed to fire impact with a short pyrogenic series of vegetative renewal without species change. The banks of lakes are characterized by rush thicket with a high fire risk and rapid subsequent regeneration.

<u>*Birch and larch subtaiga.*</u> On northern slope mountains plumes one observes the fragmentary distribution of class III-IV stand quality larch forests with herbs, sedges and grasses. The shrub layer is sparse and marked by the presence of Altai honeysuckle (*Lonicera altaica*) and *Spiraea media*. This subtaiga type has a thick, three-storeyed herb layer dominated by *Carex pediformis*, *Carex macroura, Heracleum dissectum*, Urals edgepistil (*Pleurospermum uralense*), lillyleaf ladybell (*Adenophora lilifolia*) and *Artemisia tanacetifolia*. Species richness is approximately 40 species. Moss layer absent. There is 1 rare and vulnerable plant species.

After fire, larch may be replaced by birch. On terraces and valleys, complex, mixed stands are formed with a high proportion of spruce.

<u>*Larch peristeppe altitudinal belt*</u>. Larch class V stand quality, with cereal-iris-sedge, *Rhytidium rugosum* -artemisia-sedge, cowberry -sedge-reed, cowberry-mixed grass-festuce, *Rhytidium rugosum -Rhododendron* with festuce tuft grasses or cowberry and caragana-sedge series. The larch peristeppe belt contains a sparse shrub layer made up of: Siberian peashrub (*Caragana arborescens*), *Caragana pygmaea*,

Altai cotoneaster (*Cotoneaster uniflorus*), *Spiraea hypericifolia* and *Spiraea media*. The herb layer is of a mosaic nature situated under a canopy of forest-steppe species: *Carex pediformis*, *Iris ruthenica*, *Helictotrichon pubescens*, *Poa sibirica*, Boehmer's catstail (*Phleum phleoides*), Hungarian brome (*Bromopsis inermis*), *Artemisia tanacetifolia* and meadow-steppe grasses. In openings one sees festuce and steppe species. The moss-lichen cover in larch forests with rhytidium and rhododendron is composed of *Rhytidium rugosum*, *Tuidium philibertii* and *Tomenthypnum nitens*. There are no rare and vulnerable plant species.

After fire, long-term woodlands with scattered clusters of larch occur with meadow-steppe glades and some steppification.

<u>*Mountain taiga larch forest.*</u> Dominated by larch forest with dwarf shrub-green moss and dwarf shrub mixed herbs, with a predominance in the cover of: marsh labrador tea (*Ledum palustre*), *Calamagrostis obtusata*, round-leafed wintergreen (*Pyrola rotundifolia*), cowberries (*Vaccinium vitis-idaea*) and arctic starflower (*Trientalis europaea*). In warmer habitats the undergrowth is dominated by dahurian rhododendron (*Rododendron dauricum*). Shady well-drained slopes and plumes also consist of *Duchekia fruticosa*. The cover extent of the moss-lichen layer can reach 100%, but on average, remains approximately 50-60%. The cover is dominated by common boreal mosses. Average species richness 20-40 species over 200 m^2. There are 4 rare and vulnerable plant species.

<u>*Subgolets-taiga forest.*</u> Open larch-Siberian pine forest, located in the upper tree line belonging to the dwarf birch-lichen, festuce and ledum-moss forest type groups. Most common are lichen-dwarf birch, larch woodlands with sparse tree growth. The density of the stand does not exceed 0.2. The shrub layer is composed of almost pure roundleaf birch (*Betula rotundifola*) thicket, with a cover extent of 30 to 90%. The lower layer is represented by synusiae bushy lichens. Average species richness 5-31 over 200 m^2. There are 2 rare and vulnerable plant species.

Successional climatogenic shift occurs into the mountain tundra. Larch and pine share a pyrogenic succession pattern characteristically leading to the formation of sparse tree growth, whereas the formation of sods is only characteristic of larch forest. A pyrogenic succession pattern in which one observes uncovering of rocky talus is characteristic of the lichen group. Regeneration of the pre-fire forest stand proceeds indefinitely. Without fire control burned areas can reach considerable sizes.

<u>*Mountain steppe, tundra.*</u> Steppes in the alpine zone represent a cereal dominated complex consisting of fescues, hierochloe, as well as sedges, alpine mixed grasses, mosses and lichens. Tundra is represented by lichen-moss-dwarf birch, dryad, stony-gravelly lichen and mixed herbs communities. The cover is dominated by alpine summer-green shrubs, foliose lichens, and high-altitude vascular plant species. Average species richness 12-17. There are 4 rare and vulnerable plant species.

Dwarf birch may be lost in fire with the short-term formation of alpine vegetation types.

In forests situated in ***semiarid areas*** mutual replacement among different tree species are not generally characteristic. Larch is pervasively dominant. The deciduous phase is often surpassed with the exception of purely local floodplain and valley successional shifts involving poplar, birch, spruce and larch. In post-fire conditions peristeppe larch is often replaced by steppe communities. In open high mountain wildfires can lead to the forest being replaced by dwarf birch, stony placers or meadow-steppe communities.

The peculiarities and rates of the regeneration-age dynamics are unique to each climatic facies and to the conditions of each altitudinal vegetation belt.

In deforested areas of perhumid regions, and particularly in the chern belt, one may observe rapid herb growth which prevents the successful regeneration of coniferous species. As a result, stand

regeneration predominantly takes place via long-term secondary or stable secondary shifts. The deciduous phase can be extended over 150-160 years. Aspen stands predominate. Coniferous species are mostly represented by fir and Siberian pine, with fir dominant in the initial stages. In the Siberian pine stand the age structure is characterized by undulating alternation of conditionally mixed-age generations, while the fir portion is replenished much more evenly with a totally mixed age group. In the high mountain zone one observes poor regeneration of coniferous species due to the elevational weakening of seeding, increasing skeletal soils and development of cryogenic soil processes. In post-fire succession Siberian pine and Siberian pine-fir forests and open woodlands in the subgolets-subalpine zone often become overgrown with meadow grasses.

In humid areas, the rate of regeneration in the forest steppe–subtaiga often depends on the severity of fire. In cases of low fire severity species present in the original community may survive. In this case, one may observe short-secondary shifts. In cases of partial burning, species capable of rapid vegetative propagation are at an advantage, especially rhizomatous grasses. In such cases, one sees long derivative shifts, or sods formed at the complete exclusion of coniferous species. The formation of dark coniferous forest takes place with a mixture of birch, larch, partly with spruce and pine. Often the deciduous phase of development is omitted, especially at altitudes above 1000-1100 m. At these same altitudes pioneer settlements of Siberian pine have been noted in expansive burned areas.

In high mountains, semihumid areas post-fire stand regeneration in Siberian pine/larch open woodlands is slow and may continue indefinitely. Therefore, a digression scenario is likely to emerge resulting in the development of heathland. Dwarf birch communities are capable of postfire regeneration over a ten year period by vegetative means. Meadow type forb communities may also be formed. In the dark coniferous belt the formation of pure Siberian pine forests is common. In all vegetation belts, shifts to birch are rare and short-lived. In the postfire stand Siberian pine generally predominates after 100-120 years. The deciduous phase of Siberian pine forest development in the contact zone between light and dark coniferous belts can be replaced by larch which is much longer-lived. Forests in the subtaiga–forest-steppe zone are characterized by frequent running surface fires. In these fires seed trees are preserved and soil mineralization occurs. In such circumstances, pine and larch are at an advantage, recovering without species change. The main dominants in the grass-shrub layer are also adapted to regular fire exposure.

Forests in semiarid areas are not generally characterised by mutual replacement among different tree species. Larch is pervasively dominant. The deciduous phase is often omitted from stand growth with the exception of purely local floodplain and valley successional shifts involving poplar, birch, spruce and larch. In high mountain open woodlands fires may initiate shifts to dwarf birch, stony placers and meadow-steppe communities.

Chapter 3. FIRE IMPACT ON ANIMAL POPULATIONS

Terrestrial vertebrates are constantly engaged in the search for optimal living conditions. The degree to which an area is suitable for populations of particular animals depends on specific biotype sets and their spatial distribution. Harsh climates often force animals to relocate in search of more suitable habitat, which involves high energy expenditure. Habitat use by vertebrate animals depends on a number of factors such as time spent in exploration, settlement processes and the size of individual and family habitat areas. Fire plays a key role in maintaining the internal habitat mosaic of the landscape structure which significantly influences the spatial distribution of animal populations.

The effect of wildfires on animal populations is specific to each individual fire and depends on fire return intervals, burned area and burn pattern as well as cause of fire. Post-fire successional changes overlap with population dynamics caused by long-term weather fluctuations. Therefore, any assessment of wildfire impact on species composition of animal communties and population density should involve both an analysis of the ecological requirements of a species as well as monitoring its populations.

The dramatic post-fire changes that take place in the vegetation have an ongoing effect on animal populations. Like in plant communities, the extent to which fire impacts animal populations depends on fire severity, rate of fire spread and area burned. In their entirety, these factors lead either to the decline of the animal population or determine the nature of post-fire settlement of the burned area. Unlike plants, animals lead a mobile existence and require a combination of seasonal habitat areas with different types of forage and cover. The suitability of a habitat area for an individual species is determined, above all, by the accessibility of a combination of life-supporting resources. A burn area covering less than one third of an individual species' habitat area will not significantly affect the quality of that habitat area. When the burn encompasses larger areas, the post-fire settlement of small mammals is hindered. Despite their high reproduction potential, the rate of spatial redistribution among small mammals is limited, especially in colonial species. For larger-sized animals the appearance of extensive habitat areas with uniform ecological characteristics leads only to change in their patterns of habitat use by individuals. In this regard, the edges of the burned area, which usually repeat the natural boundaries of certain landscape elements are highly influential in the formation of the post-fire fauna habitat mosaic.

In the post-fire vegetation dynamics the following stages stand out as being most significant in the formation of the biocenosis including zoological complexes:
1) Fresh burned area - the territory burned in the current year. Characterized by minimum surface fuels load and higher surface air temperature (due to its dark background because the root cause being solar radiation). These conditions attract insects, and where deadwood is available after intense fire, xylophagous insects are attracted, which in turn attract insect-eating animals. Seeds accumulated in the litter become more accessible making this stage a favorable one for granivores.
2) Herbaceous stage – characterized by rapid development of herbaceous vegetation (fireweed, cereals, forbs) and characteristic of herbaceous forest types. Light coniferous forest with poor soils pass this stage very quickly and with a poorly developed grassy layer. At the herbaceous stage either fireweed or grasses (reed grass) develop. The former is short term (3-5 years) and provides habitat poorly suited to small rodents and insectivores, but better suited to ground-feeding insectivorous birds. The latter stage is more prolonged, and in the absence of the resumption of deciduous species can last for more than 10-15 years. This habitat is most suitable for herbivorous rodents (voles), insectivorous shrews and small insectivorous passerine birds.
3) Shrub and young growth (woody-twig) stage for stand age class I. At this stage a relatively large supply of fodder and herbaceous plants is preserved and a large volume of accessible vegetative

forage (annual shoots of woody plants) is formed with a mass potentially exceeding 150 kg / ha. This stage is favourable for shrub insectivores (warblers, bluethroat, crickets) and carnivorous bird species (true thrushes, hazel grouse), and continues to support a high density of herbivorous rodents and insectivores. At the same time, forest voles begin to settle. Maximum capacity for ungulates and white hare habitat.
4) Pole stage (stand age class II) - this stage begins with canopy closure and ends with its natural thinning, before the onset of mass seed production. The pole stage is characterized by a scanty supply of all types of forage and a lack of developed grasses. In addition, the high sheltering provided by the canopy exclude the possibility of year-round habitation for most vertebrate species. This stage is marked by reduction in population number and species diversity. In dark coniferous forests this stage may not manifest in its pure form due to the patch distribution of regeneration which results in a less pronounced decrease in population numbers.
5) Middle-aged and mature stage (stand age classes III-IV) begins at the point of abundant seed production of the stand and thinning of the canopy, which leads to the formation of grass, underbrush and undergrowth. At the beginning of this period the fauna complex characteristic of each formation is initiated. In light coniferous forests surface fires occur at 40-50 year intervals. (This fact should be considered within the light of the previous sections where the frequency indicated is somewhat different.) Surface fires briefly alter the ground cover by destroying the undergrowth and underbrush, which quickly recover either vegetatively or via the seeds. At this stage, stability of fauna species diversity is characteristic of all formation types and changes in population size are attributable to fluctuations in climate conditions.
6) The complex stage (stand age class VI and above) – is marked by the most sophisticated and feature-rich habitat, including undergrowth, subcanopy, large-sized downed dead wood (fallen trunks), high defectiveness in trees. This stage represents the condition of forests before decay caused by crown fires, pest and disease outbreaks or windfalls, and their natural climax community (of middle-aged and mature stages). At this stage, one sees maximum biodiversity in the formational series of plants and animals. As a rule, high population density is characteristic only of a small number of dominant species.

The edge effect of most types of closed (forest) habitat does not exceed 100-150 m in the directions of an open area from the interior and considerably less (30-50 m) in the opposite direction. Under certain conditions it is possible to gather specific data on edge colonization for individual species in order to assess the impact of burned area on animal populations.

Assuming a conventional square of a burned area, area covering less than 0.25 ha (25 m from the centre to the forest wall) would not be expected change vertebrate habitat conditions. A burned area of 1 hectare initiates weak change, an area of ten hectares initiates average change, an area of 100 hectares initiates strong change and a burned area of 1,000 hectares initiates catastrophic change to local populations. The configuration of the burned area must be taken into account and a proper evaluation made of the impact on the biotopic structure of habitat areas in correlation to the perimeter and area of its outline. Depending on the body size of the animal and the area affected by fire the impact level of the burn will differ (Table 3.1). For large animals (elk, bear) a plot of 0.25 hectares is insufficient to provide a single foraging session. For medium-sized animals (sable, squirrel) a plot of the same size can sustain a day's food requirements, whereas small animals (gray voles) can be sustained as a family group on such an area for a whole year. Invertebrates, such as xylophagous insects (long-horned beetles, bark beetles) can form a phenotypic group, reaching population densities on the same tree of more than 100 individuals and completing the entire development cycle. A habitat area of more than 1,000 hectares can provide large vertebrates with necessary resources over the period of a year. Vegetation changes in burn areas can also generate seasonal trophic diversity, phenotypic diversity in average sized vertebrates and population diversity in small vertebrates. Accordingly, alterations in the diversity of different animal groups can be evaluated according to the size and particularly the configuration of a specific burned area.

Different types of fire effect on animal populations in different ways, and therefore, forest fires that occur for example after pest outbreaks (e.g. Dendrolimus sibiricus) and felling should be considered separately. The same goes for high and low severity surface and crown fires. At low severity just the surface cover is burned whereas at high severity the undergrowth and underbrush are totally destroyed, fire scars form on trunks, and where there are surface root systems the stand dries out.

Table 3.1

Temporal and functional use of areas of different sizes animals

Size of burn area in hectares	Use of territory by different groups of vertebrates		
	Large-bodied	Average-sized	Small-bodied
0.25	once	daily, individual	decade, family
1	daily, individual	decade, family	seasonal, clan
10	decade, family	seasonal, clan	annual, population
100	seasonal, clan	annual, population	several years, population
1,000	annual, population	several years, population	habitat area

Low-severity fires result in the incomplete burning of litter and surface cover with isolated cases of damage to trees and shrubs. This leads to a minor increase in insect numbers. The population of xylophagous insects in downed dead wood and their species composition depend on the tree species composition and age of the stand, time of fire and specific microclimatic conditions of the site itself.

Partial burning of ground cover, mostly accompanied by the destruction of grassy litter, leads to short-term changes in trophic conditions and damages the protective habitat conditions of small mammals and ground-nesting birds. The seeds of tree species become more accessible, and weak soil mineralization prohibits a shift in ground cover. These changes increase the attractiveness of the fire-damaged forest fodder for insectivores and seed-eating animals. Herbivorous animals suffer a reduction in volume of available forage.

After running fires, the grass cover is almost completely restored and increases in biomass over a period of 1-3 years. Population dynamics and species diversity in animals approach those of non-burned habitat areas.

High intensity surface fires cause severe soil mineralization associated with the almost complete burning of surface cover, more intense undergrowth mortality and the emergence group of new regeneration. The result is a mixed third stage of young shrub growth and a fourth stage of mature forest, combining species of crown and shrub of at lower density.

Stand mortality resulting from crown or creeping surface fire does not significantly change trajectories of pyrogenic succession in animal biotopes. A burned area will shift successively through all six formation stages of the animal community over a period of 120-220 years, beginning with the fresh burned area with its predominance of open living species to overmature stands with a comprehensive forest animal communities. In the initial stages (herbaceous, shrub) zoocomplexes are formed with high biodiversity and population number indicators. Later, in the pole stage, one observes a sharp decrease in both indicators. Species preferring grass and bushes leave the species composition being replaced by forest species whose diversity is maintained until the next fire.

The impact on animals immediately after fire can be illustrated using three categories of gradation: 1 – change in population density with preservation of species composition; 2 – change in species composition or partial replacement; 3 – complete turnover in species composition. The first category

is observed in cases of running or creeping fire in forest areas and clearings that have shaped the population of species adapted to open habitats. The second category is characteristic of creeping surface fires which alters the ground cover and thins the tree canopy. As a result edge-seeking are added to forest species and the trophic structure of animal groups is altered. Regular fires conjunction with forest pests occur at 10-15 year intervals and lead to a partial shift in populations. The third category leads to significant changes in species composition. The formation of a new animal community occurs as a result of crown fire, where the majority of forest species lose suitable habitat conditions.

In accordance with the successional series of developments in forest ecosystems, consisting of six different stages, the animal community undergoes the same post-fire stages as individual botanical formations, experiencing a similar set of constraints. The number of stages, their duration and animal species diversity depends on the strength of the pyrogenic effect and the formation itself. A summary of data on changes in forage supply and shelter of vertebrate habitat according to successional stage is given here in tabular form.

In the initial stages of the post-fire successional dynamics non-forest herbivores make the greatest contribution to the formation of the small mammal complex. The shift towards dominant forest species occurs only after the complex pole stage (mature and overmature). Maximum species diversity is observed in the initial stages as a result of the superposition of two sets of open and forest habitats; maximum population density is observed in the final two stages.

Depending on their food and shelter requirements hunter animals respond differently to the post-fire stage. Moose and hare can even use fresh burn areas thereby escaping from gnats and ticks while badger and wild boar search for insects in the soil. The majority of species show little interest in pole stage forest. Greatest species diversity and most suitable habitats are characteristic of the final stage.

Thus, forest fires cause shifts in the animal community and, accordingly, increase landscape biodiversity creating habitat conditions for non-forest (ruderal) and edge-seeking species. The pyrogenic mosaic leads to stable high levels of diversity in animals. Homogeneous old-growth forests also have relatively high levels of diversity, but are dominated by a small number of species.

A high fire frequency is typical in steppe zones. Fire intensity is determined however by the load of combustible material available. Desertified steppes therefore rarely burn because the lack of a solid ground cover does not support the spread of fire. The true dry steppes of the Republic of Tyva usually burn in fine contours, and form broadcast burned area only under certain wind conditions. Sustained burns occur in meadow steppes with a continuous grassy cover and high load of debris. One of the main causes of contemporary fires and spreading of fires in forest-steppe and steppe zones is a 12-13 x reduction of domestic livestock. High grazing pressure in forest and steppe areas leads to the formation of track networks and consumption of most of the ground litter, which in its entirety increases resistance to fire in steppe territories and dramatically reduces fire intensity.

In steppe zones fires are largely regulated by man. Spring fires (accidental and deliberate) are aimed at combating ticks and increasing the biomass of the grass cover, whereas summer fires more often lead to the degradation of pasturelands. The positive effect of fires lasts for 3-5 years. Almost no natural steppes remain and so their protection from spontaneous arson fires is an urgent task for fire protection systems in nature reserves. In order to prevent disastrous fires in steppe ecological communities measures must be designed for surface fuels reduction via controlled burning or cutting rather than via unauthorized burns and arson fires which lead to a reduction in biological diversity in steppe zones.

In the case of low-severity fires, post-fire visible alterations in the vegetation of steppe zones are short-lived. The impact of a running fire is not sufficient to cause total combustion of grass debris and so growth points are preserved. Due to grazing and steppe aridity rhizomatous plants dominate that

do not suffer from damage to the above ground part of the plant. Therefore, the fresh burn stage can last for a period of 1-3 weeks, after which the original condition is restored. Time of fire may be critical to ground-nesting birds whereas small rodents are easily able to survive a running fire in the shelter of their burrows.

By comparison, fires of high intensity in steppe communities lead to significant changes in the species structure of plant communities. In the first year after fire, the surface cover is dominated by rhizomatous grasses and succulents, which form phytomass in the same year. The ground cover remains open. In addition, shrub vegetation begins its recovery by sending out root suckers. Seed plants are most affected by fire, hence two pyrogenic stages are identified: rhizomatous and grassy. These stages pass relatively swiftly and so changes in the animal community are mainly associated with small rodents, ground-nesting birds and insects. In the second year after fire the species composition is fully restored, and in the third year becomes richer than the original composition. No significant, long-term shifts in fauna species composition are observed although population density is altered.

In mountain tundra ecosystems pyrogenic succession is typical of shrub or bush formations. Grasslands located in humid areas do not burn. Dryad tundra does not usually have a continuous ground cover, and so the dead surface fuel fails to ignite and sustain a fire. Subgolets dwarfs develop two stages, as has been described in Chapter 2. These are post-fire grassy and shrubby. The first stage exists up until the point when the regenerated young shrub growth closes. This stage lasts for quite a long time (3-5 years) and is characterized by the growth of alpine grasses and herbs the composition of which contains many forage and seed plants. As a result of shrubland burning the shrub bird community (e.g., bluethroat) is replaced by ground birds (e.g., thrush). Studies of these habitats have not yet been conducted, hence one can only provide an expert assessment. There is clearly a marked improvement in the summer pastures of large herbivores and the year-round habitat of small herbivorous mammals (grey voles). This in turn increases the feeding capacity of predator habitat.

The analysis shows that wildfires do not affect the species diversity of birds in steppe habitat, and that the impact on bird species diversity in the tundra is minimal. However, wildfires create short-term change in population density. This is particularly evident in cases where fires occur during the nesting period, when, the post-fire ground surface takes on a biologically inert aspect (up to 10 days). According to research data, a spring fire in a grassy steppe area results in a decrease of nesting bird species of up to three times and a decrease in biomass of up to seven times. This is explained due to the destruction of conditions essential for nesting: dead plant matter used for building nests and shelters and high stalks for roosting.

For approximately half the species inscribed in the Red Book wildfire will traverse a significant portion of the individual habitat area and have a negative effect on population size. In this connection, it is important to strive towards reducing the burned area which in turn will minimize the negative effects of fire on rare and endangered species.

For birds the main negative factor of pyrogenic impact is the resulting absence of conditions essential to nesting and rearing offspring as well as the possible destruction of nests and chicks. In steppe zones these conditions last for the current fire year only. In the following season, changes are apparent only if accompanied by a shift in plant communities. In forests, a shift in bird population will correspond to post-fire stages of stand formation. Grass and shrub stages are most favorable for herbivores, insectivores and dead-wood associated species with their corresponding range of predators. The lowest levels of diversity and productivity among animal complexes are observed in the dead-ground cover associated with the pole stage.

In assessing the impact of fire on animals key factors are the size and configuration of the burned area. A burned area of less than one third of a species' habitat or radius of a species' home range will

have no effect on faunal distribution. A burned area of more than 100 hectares will have a short-term negative impact on small vertebrates, which given favorable conditions are capable of assimilating biotopes at a distance of 1 km over a period of 2 years. Large fires leaving a burned area of more than 1,000 hectares alter almost the full range of fauna for a considerable period of time. Moreover, the delay in settlement during pyrogenic stages and the formation of favorable conditions will to a large degree be observed clearly in mammals.

Fine contoured burn areas, elongated in shape, lead to an increase in the mosaic quality of habitat conditions, improving a territory's overall ecological capacity, supporting the wealth of edge-seeking species and increasing productivity in the fauna range. In this regard, fire protection should be aimed at reducing and fragmenting burned areas. For most rare and endangered terrestrial vertebrate species the effects of fire will be either neutral or positive.

Thus, with regard to developing fire management strategies for protected areas it is clear that a biotope classification system should be used which takes account of heterogeneous fire impact on flora and fauna. Key pyrogenic successional series should be identified specific to each ecosystem type and variety of vegetation present. On this basis, temporal-spatial models of pyrogenic biodiversity change can be designed to develop effective fire management strategy and tactics in individual protected areas.

Chapter 4. ASSESSMENT OF CARBON STOCK, BALANCE AND FIRE EMISSIONS IN ECOSYSTEMS OF THE ALTAI-SAYAN ECOREGION

4.1. Methods of assessing of carbon stock, balance and fire emissions

Carbon stocks in stands are determined by a series of climate-forming factors, the geographical position, growth conditions, age, density and stand productivity. Carbon stocks in the Altai-Sayan ecoregion were considered and analyzed by differentiating the contributions of various ecosystem components (stand, undergrowth/underbrush, down woody debris, living ground cover, litter, and duff) owing to their varying roles in the process of combustion and in the carbon balance. Carbon stocks in non-forest areas were determined separately. Carbon balance was calculated on the basis of data on input (the entry of carbon into the ecosystem - NPP), and output (release of carbon from the ecosystem via the decomposition of organic matter).

Carbon stocks in the Altai-Sayan ecoregion were evaluated using data from the 2003 Government Report of Russian Forests (GRRF) (Фомченков и др., 2003) and by applying models designed under the Forest Program implemented by the International Institute for Applied Systems Analysis (IIASA, Austria) (Швиденко и др., 2007). In order to determine reserves of carbon sequestered in protected areas the recent forest management data of Government Reports on Russian Forests (GRRF) on the distribution of forest areas according to dominant species and age groups and published materials on biological productivity were used. An assessment of the quantity of biomass in tree trunks was conducted using data on wood density as stated in reference materials for different tree species according to their location (Боровиков, Уголев, 1989). Biomass quantities in separate components of the stand were defined using data on the biological productivity of modal stands taking account of tree species, stand productivity and location (Швиденко и др., 2008).

The biomass of living ground cover (grasses, herbs, shrubs, mosses, lichens), litter and duff in forests of the ecoregion was estimated according to data on Siberian forests provided by G.A. Ivanova (Иванова, 2005) depending on tree species, stand conditions, and forest types. Dominant forest types were defined according to data from the GRRF as well as other published sources (Заповедники Сибири, 1999). Carbon stocks in coarse woody debris were estimated on the basis of D.G. Zamolodchikov (Замолодчиков, 2009) data. The non-forest vegetation biomass was defined according to existing published data on the regions under study (Кыргыс, 2004; Ефремов и др., 2005; Belelli Marchesini et al., 2007).

A coefficient of 0.5 was used to convert biomass to carbon (Алексеев, Бердси, 1994). The carbon budget was estimated using the biometric method with regard to published data on the speed of decomposition in organic matter and annual increment. The ecosystem was considered as the following set of blocks representing accumulators of organic matter: 1) live above- and below-ground biomass of woody and herbaceous vegetation; 2) dead plant residue on and in soil; and 3) soil. The carbon cycle is determined by the exchange between the blocks themselves and each individual block and the atmosphere. The cycle is controlled by the balance produced between carbon sequestration in vegetation and carbon release via the decomposition of organic matter. The difference between these two parameters characterizes the quantitative change in ecosystem carbon pools and determines the role of the ecosystem in the biosphere (Ведрова, 1997).

Carbon emissions from fires were calculated using data on burned biomass. The data was determined by estimating pre- and post-fire fuel biomass using experimental data obtained in the course of large-scale experiments on fire behaviour modeling in various types of Siberian forest (Иванова и др., 2007; Кукавская, Иванова, 2006; McRae et al., 2006, 2009). Calculations were made taking account of fire type which determines the contribution of different fuel types to the overall carbon emission, and the

fire severity. Fire severity depends primarily on weather conditions which affect the moisture content of fuels and their consumption (Вонский, 1957; Курбатский, 1962; Конев, 1977). In order to determine the ground cover consumption, data on the distribution of fires during the fire season was used. In determining consumption during a crown fire it was assumed that needles and small twigs with a diameter up to 5-7 mm would burn in the stand canopy (Курбатский, 1970).

4.2. Carbon stocks and balance in the Altai-Sayan ecoregion

In the Altai-Sayan ecoregion forests represent the main accumulator of carbon in above-ground organic matter (2,614.6 Mt). The carbon accumulated in coniferous forest, accounts for as much as 80% of the total carbon stock, and in deciduous forest – up to 18%. Steppe and forest steppe which occupy 24% of the total area of the Altai-Sayan ecoregion accumulate 78.1 MtC, whilst valley systems and wetlands – 37.8 MtC. The overall carbon stock in above-ground organic matter in the Altai-Sayan ecoregion amounts to 2,735.9 Mt (Table 4.1).

Table 4.1

Carbon reserves in above-ground organic matter in ASER by land category

Land Category	Carbon Stock	
	Mt	%
Mountain Tundra and Alpine Meadow	5.4	0.2
Valley Systems and Wetlands	37.8	1.4
Forest	2,614.6	95.6
Forest steppe	67.8	2.5
Steppe	10.3	0.4
Total	**2,735.9**	**100.0**

The majority of carbon accumulated in live vegetation is found in trees (59%). Undergrowth and underbrush account for up to 1.9% of the total carbon stock in the study region. The biomass of the stand and undergrowth is attributed to the category of crown fuels. The presence of coniferous undergrowth results in increase of the probability of fire spreading to crowns (Курбатский, 1962; Исаков, 1985). In cases where surface fires spread to the tree canopy, it is mainly needles, dead and live twigs up to 5-7 mm in diameter that take part in the combustion process. These needles and small branches account for 2 to 7% of the total biomass in the stand. The carbon stock of the ground cover exceeds that of the undergrowth and underbrush by 1.8 times. Down woody debris represents 15 to 34% of the total stock of above-ground organic matter. Quantitative analysis of carbon pools and fluxes based on specialists' assessments has shown that in the Altai-Sayan ecoregion, forest ecosystems act as a carbon sink of the atmospheric CO_2 (0.43 tC ha^{-1} $year^{-1}$). Ground vegetation accumulates up to 35% of the net primary production carbon. The remaining carbon is accumulated in the stand and undergrowth with current needle and leaf growth accounting for up to 19%.

The whole forested area of the Altai-Sayan ecoregion accumulates 20.69 MtC per year in the above-ground biomass. Steppe areas represent carbon sinks in the summer period only. For example, the southern steppes of Krasnoyarsk region in the period May to September accumulate 1.50 tC ha^{-1}.

4.3. Carbon emissions from biomass burning in the Altai-Sayan ecoregion

Fire emissions contribute substantially to the overall carbon budget. Although in forests the biggest amount of carbon is accumulated in the stand, during surface fires the quantity of carbon emissions is determined by the ground cover loading, which, in the cases of steady fires can burn completely. Carbon emissions resulting from surface fires in pine forests range from 4.8 to 15.4 tha^{-1} depending

on the fire severity (McRae et al., 2006; Иванова и др., 2007). Carbon emissions from a surface fire in a pine forest exceed annual carbon release via the decomposition of organic matter by 4.5, 5.4, and 12.6 times at a low-, moderate, and high severity fires, respectively (Кукавская, 2009).

According to official statistic data the majority of forest fires in the Altai-Sayan ecoregion are surface fires ranging from low to moderate intensity. The area burned by crown fires consists on average of 16% of the total burned forest area, and varies by year from 0 to 50%.

Annual amount of carbon emitted to the atmosphere due to forest fires at the Altai-Sayan region was found to be 2,64.9 x 10^3tC (according to data on area burned from 1969 to 2006 provided by Federal Forest Service). The quantity of carbon released during the combustion of litter and duff consists of up to 63% of the overall carbon emissions. The quantity of carbon released during combustion of living ground cover consists of 24 to 31% (Table 4.2).

Table 4.2

Contribution of different fuel types to carbon emissions (tC x 10^3) from surface forest fires in regions of the Russian Federation encompassed by the Altai-Sayan ecoregion*

Regions of the Russian Federation	Fuel type			
	living ground cover	litter, duff	down woody debris	total
Altai region	0.03	0.06	0.03	0.12
Irkutsk region	22.03	49.96	8.97	80.95
Kemerovo region	0.49	1.03	0.18	1.70
Krasnoyarsk region	19.33	44.01	2.99	66.32
Altai republic	2.46	5.02	0.49	7.96
Republic of Buryatiya	2.54	5.55	0.33	8.42
Republic of Tyva	27.85	57.11	7.77	92.73
Republic of Khakasiya	1.96	4.34	0.35	6.65

*according to Federal Forest Service data on area burned.

In the Altai-Sayan ecoregion the maximum emissions from surface fires are observed in May (162.1 × 10^3tC), that corresponds to the month with the largest area burned (fig. 4.1). At this time of year surface running fires predominate, during which mainly upper layer of fuels (grasses, shrubs, and litter) is consumed.

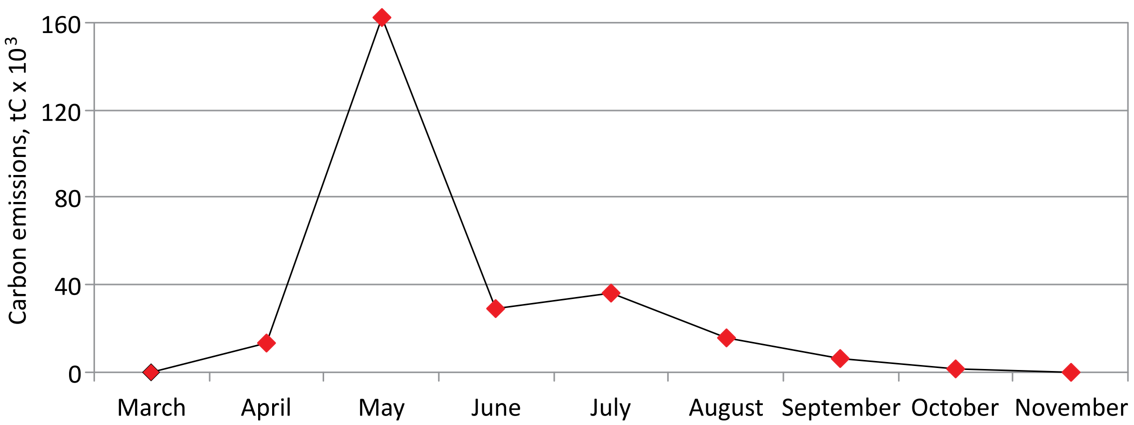


Fig. 4.1. Seasonal dynamic of annual carbon emissions due to surface fires at the Altai-Sayan ecoregion (according to Federal Forest Service 1969-2006 data on area burned)

Satellite data and data provided by Federal Forest Service give significantly different values for total burned areas. This may be accounted for by the low resolution of satellite images used which indicate an apparent increase in the burned area. By contrast, data provided by Forest Service tends to underestimate area burned. According to satellite data gathered over a ten year period (2000-2009) carbon emissions from fires in the forest territory of the Altai-Sayan ecoregion amount to 2,735.8 x 10^3 tC per year. This figure is more than ten times greater than the value of carbon emissions from area burned based on Federal Forest Service data. Among the territories of the Russian Federation included in the Altai-Sayan ecoregion Krasnoyarsk region and the Republics of Tyva and Khakasiya represent the main sources of carbon emissions (these territories account for 85% of annual carbon emissions from fire). Fires occurring on non-forest areas add another 214.0 x 10^3 tC per year to overall carbon emissions.

The distribution of carbon emitted from fires in forest and non-forest areas obtained on the basis of satellite data on area burned is illustrated in figure 4.2. Three years (2002, 2007 and 2008) are responsible for 64% of total carbon emissions for the ten year period (2000-2009). In the remaining seven years carbon emissions generally do not exceed 2 Mt.

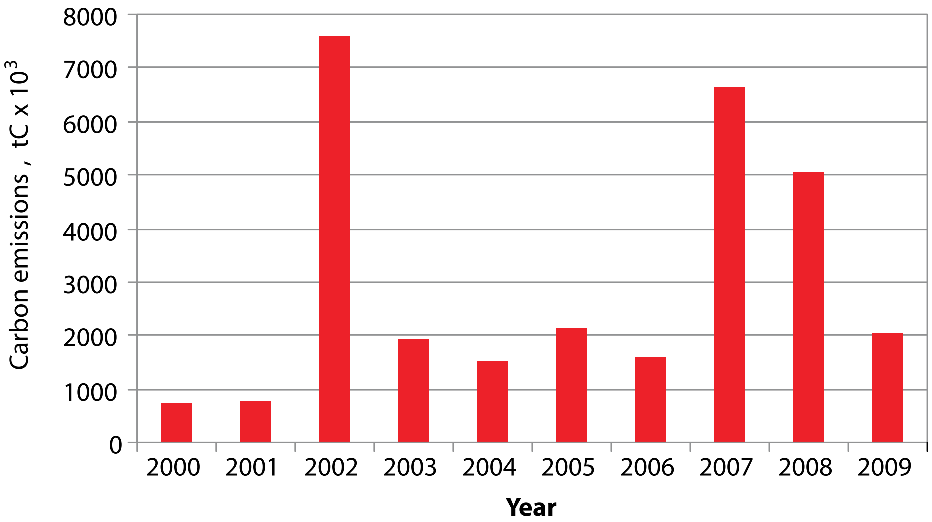


Fig. 4.2. Carbon emissions at the Altai-Sayan ecoregion (according to satellite data on area burned)

According to V.N. Kudeyarov etc. data (Кудеяров и др., 2007) forest fire carbon emissions from 1996 to 2002 make up 4.2% of the total anthropogenic emissions in Russia. At the same time many authors estimate carbon emissions from fires in Russia's boreal forests to be 200 MtC per year and above and, therefore, as equivalent to industrial emissions (Conard, Ivanova, 1997; Isaev et al., 2002; Soja et al. 2004; Shvidenko et al. 2011).

Over the past 10 years, in the Altai-Sayan ecoregion carbon emissions from surface fires in forest areas by Federal Forest Service data amount to 9.80 MtC. In the spreading of crown fires an additional 0.95 MtC was released from the combustion of needles and small branches in the tree canopy. The release of carbon into the atmosphere from the combustion of biomass for this period amounted to 11% of the total stock fixed in above-ground organic matter in the burned area. During the same period, in the case of fires occurring in non-forest areas, most of which were recorded in the south of the Altai-Sayan ecoregion (up to 24% of the total burned area), carbon emissions amounted to 0.16 Mt.

According to satellite data on the area burned in the Altai-Sayan ecoregion carbon emissions from fires in forest areas amount to 27.4 MtC over the ten year period. The combustion of crown fuels accounts for an additional emission of 2.9 MtC. In non-forest areas carbon emissions for the period in question amounts to 0.5 MtC.

4.4. Carbon storage and emissions from fires in protected areas of Altai-Sayan ecoregion

Carbon stocks in above-ground organic matter in forests located in protected areas of the Altai-Sayan ecoregion range from 1.77 to 33.40 Mt C (Fig. 4.3). The bulk of the carbon stock is comprised by the forest stand with the contribution of stemwood consisting of up to 85% of the total. The value of annually deposited carbon in stemwood varies from 0.22 to 0.47 tC ha^{-1}.

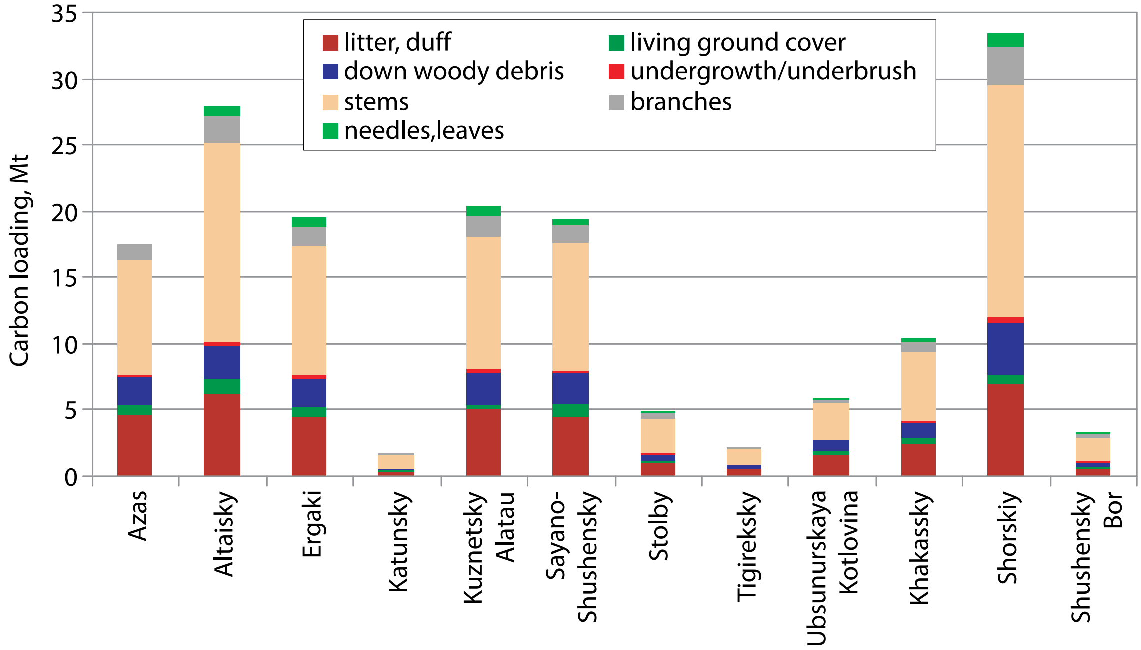


Fig. 4.3. Above-ground carbon stocks in forest stands of the Altai-Sayan ecoregion protected areas

During fire, the living ground cover (herbs, shrubs, mosses and lichens) burns almost completely accounting for the greatest volume of carbon released by burning, on average 4.4 tC ha^{-1}. Duff whose contribution to carbon emissions is largely determined by its moisture content varies from 13 to 23% of the total above-ground organic matter.

The carbon stock in above-ground organic matter in non-forest and non-covered by forest lands of protected areas constitutes up to 2.32 MtC, the key proportion of which (up to 97%) is constituted in natural open woodlands and burned areas (Fig. 4.4).

Average annual carbon emissions from fires in protected areas range from 10 tC in "Kuznetsky Alatau" Nature Reserve to 30,002 tC in "Ubsunurskaya Kotlovina" Nature Reserve (Fig. 4.5). The wide variability in emissions is due both to differences in the size of protected areas and to annual burned areas (1.6 and 3,367.8 ha per year, respectively).

The greatest amount of carbon is released during combustion of the live ground cover (26-48%). Because fires occur mainly in spring and spread as running fires, the contribution of duff in carbon emissions is less - from 15 to 23%. Crown fires occurring in protected areas increase carbon emissions by 4-9% due to the combustion of needles and small branches in the tree canopy.

Above-ground organic matter in the Altai-Sayan ecoregion is estimated as 2,735.9 MtC the bulk of which (95%) is constituted by forest areas. The forest area of the ecoregion accumulates 20.69 MtC per year.

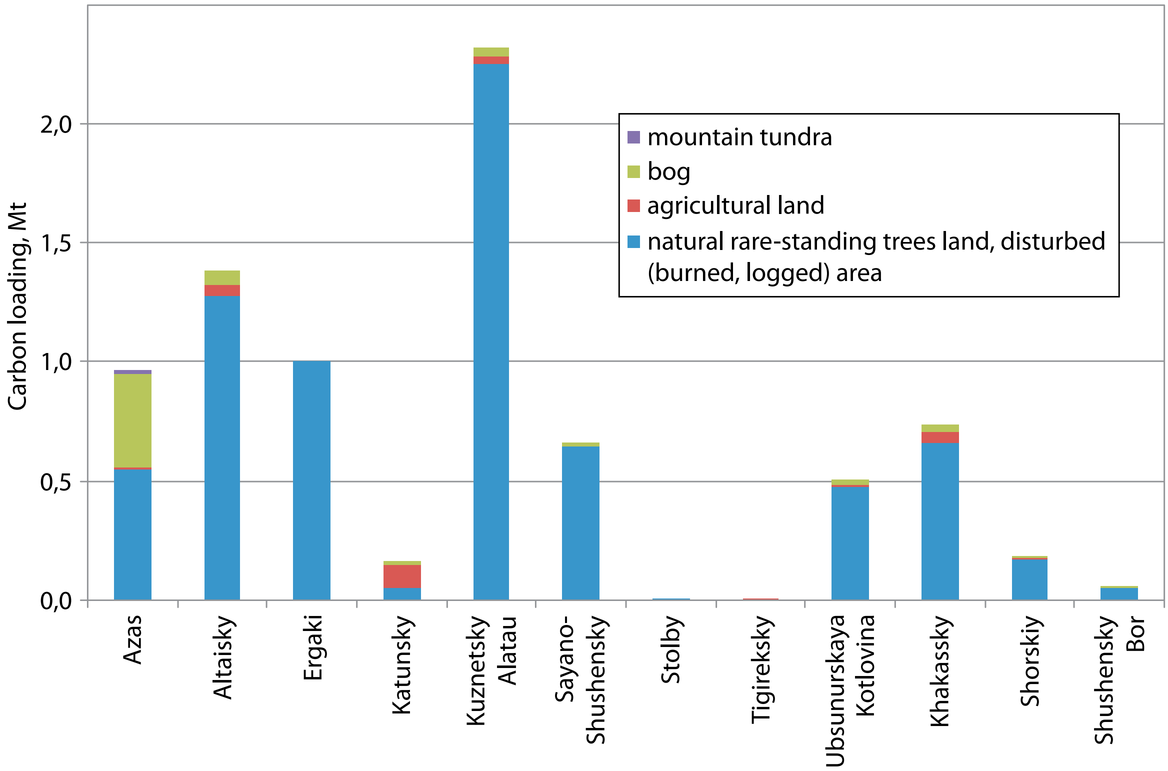


Fig. 4.4. Carbon reserves in non-forest and non-covered by forest lands of Altai-Sayan ecoregion protected areas

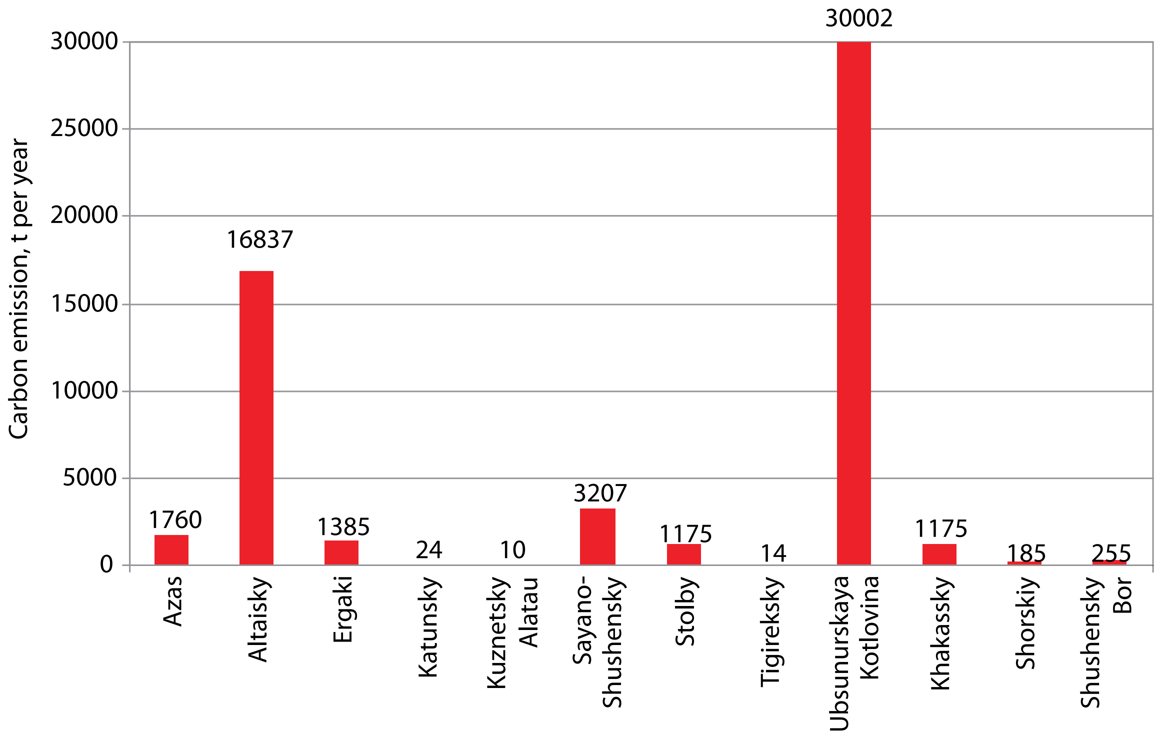


Fig. 4.5. Average annual carbon emissions from wildfires in protected areas

Fire is a main disturbance factor impacting on carbon reserves, emissions and balance. Uncertainties in burned area remain an important source of inaccuracy in estimates of fire emissions. The discrepancy between methods of assessment gives variability in annual carbon emissions by tens of times, from 264.9 x 10^3 (according to the Federal Forest Service for the period from 1969 to 2006) to 4,397.7 x 10^3 tC per year (based on satellite data from 2000 to 2009). Release of carbon into the atmosphere from the combustion of biomass constitutes 11% of the total stock of above-ground organic matter in the burned area.

CONCLUSION

Fire is a natural ecological factor which has influenced the formation of vegetation in the natural zones across the globe throughout the whole period of the development of the biosphere. Fires posed one of the most serious threats to humans living in forest and forest-steppe zones. The greatest damage was caused by widespread and catastrophic fires raging through areas of hundreds of thousands of hectares, with smoke spreading out over even larger areas.

However, over the millennia wildfires have not lead to catastrophic consequences for the biosphere. On the contrary, fires can have a positive impact on natural systems, the distribution and replacement of tree species and plant communities. Fire can serve as an essential condition for the existence of individual species. Post-fire successions are often associated with improved habitat, increased species and ecosystem diversity as well as ecosystem productivity.

It is impossible to completely exclude fires from boreal forests where they arise naturally be it in the cultivated forests of Europe or the Siberian taiga. The exclusion of forest fires leads to the formation of dark coniferous forests, which under certain conditions, will nonetheless burn with catastrophic consequences for large areas. The complete prevention of fires and grazing leads to an accumulation of grassy litter, alters natural processes in the formation of steppe vegetation, and most importantly, disrupts the natural process of the decomposition of accumulated organic matter. Protected areas and reserves in particular represent natural laboratories which should reflect the natural cycles inherent in vegetation.

According to the satellite monitoring system for the year 2,000 onwards, 17,928 fires were recorded in the Altai-Sayan ecoregion with a total area of 8.3 million hectares. Each year, the area is exposed to 1,700 fires, 1,100 of which occur in forest areas damaging 50-70 thousand hectares, each fire having an average burned area of 45 hectares. In general, the fire return intervals of extreme fire seasons in the Altai-Sayan ecoregion has been 2-3 years for the past 10 years. Number of non-forest fires has remained stably high over the past five years (2005 onwards). At the same time, a trend showing increase in numbers of fire can be observed against a general background of unchanging cyclicity in fire occurrence.

According to current Russian Federation regulations all fires occurring in an area of the forest fund must be extinguished simultaneously, irrespective of the pyrological features of a given ecosystem. The mandatory requirement to simultaneously extinguish all existing and newly emerging forest fires is unjustified both from an economic and an environmental point of view. Often this approach is neither feasible nor it is guaranteed to produce the desired results. Such strategy inevitably leads to the premature exhaustion of economic resources applied in detecting and extinguishing fires. At the present time a strategy for selective fire control is being developed and tested for use in the Russian forest fund based on the economic and social feasibility of fire fighting costs. The same approach should be implemented in protected areas taking into account the ecological role of fires in the functioning of protected biocenoses as an additional factor.

In developing a fire management strategy for protected areas, the following issues should be taken into account: habitat classification according to typical natural systems; the homogeneity of fire impact on habitats; subsequent successional patterns. On this basis spatial-temporal models of change in pyrogenic biodiversity can be developed and effective fire management strategies and tactics designed for each individual protected area.

Proposed fire management activities (including measures for prevention, monitoring and fire control) should be incorporated into the overall coordinated system of protected area activities. Observation

points, roads, patrol stations and technical support should all be used for the purposes of monitoring natural objects, and not only for the purposes of fire detection and suppression. Maintaining and servicing specialized and particularly heavy forest fire equipment is not economically feasible, and its use in reserve territories should be limited. The creation of a common infrastructure designed for maximum territory accessibility and coverage with a common transport facility equipped with special forest fire-fighting equipment, however, can provide for a consistently mobile system of fire management.

Therefore, within the context of the goals and objectives of protected areas, as well as their level of fire activity it is proposed that a dedicated fire management strategy be based on the following principles:

1. Coordinate fire management measures and other protected area activities such as monitoring etc. Integrating a series of fire protection measures with other activities enables more efficient use of financial and technical resources in protected areas.

2. Determine acceptable burn levels for the area based on landscape classification and vegetation types. It is not possible to completely prevent fires in protected area forests, because to do so would disrupt natural restorative and dynamic processes and cause the extinction of pyrogenic species of plants and animals. The absence of fire hinders the succession at its final stages which are usually the least productive and diverse. At the same time, many plant and animal species characteristic of other succession stages are deprived of opportunities for growth. Conservation regimes for vegetation in protected areas should be sensitive to natural and acceptable levels of fire activity according to landscape type and plant formation. Pyrogenic cycles should be taken into account which are not critical in the destruction of the ecosystem in question. The greatest damage from fire is suffered by climax communities (dark coniferous species, mosses, lichens), the recovery period of which falls in the final stage of succession.

It is however desireable to completely exclude fire from spruce-fir and Siberian pine forests confined to depressions and valleys. Fire return intervals in these stands should not exceed 70 years, and the acceptable average long-term area burned, should not exceed 0.01% of the total area of the stands. In larch and pine forests fire return interval is 20-40 years with an acceptable burned area of up to 0.1% and in small-leaved herbaceous areas of forest-steppe, 2-5 years and up to 0.15% respectively. Pyrogenic cyclicity in bare areas (waste lands, burned forest, old felled areas, areas of pest-outbreak (e.g. *Dendrolimus sibiricus*) and steppe can be even shorter (1-2 year) with an acceptable burn area of up to 10%.

3. Establish maximum burned area of a single fire. The most significant value in assessing fire impact on animals is the size and configuration of the burned area. For seed plants sources of seed are equally as important. A burned area of less than 1/3 of a species' habitat area or radius of feed and shelter points is not considered to inhibit the distribution of animals. Fine-contoured, elongated burned areas enhance the 'edge effect' creating favorable habitat mosaics which improve the overall ecological capacity of the area, support the wealth of edge-seeking species and increase productivity in animal communities. In this regard, fire protection should be aimed at reducing and fragmenting burned areas. In semination of arboreal species in felled and burned areas regeneration is observed at a distance of 200 m from the forest wall. In the case of grassy steppes the size of the burned area appears to have no effect on the vegetative recovery of plant communities.

4. Establish priority sequence for suppression in wildfire response strategy based on landscape class, vegetation types and their distribution in accordance with the main aims of protected areas. In a complex fire situation in a protected area several fires may occur simultaneously with new hot spots arising, whereas firefighting equipment and resources are limited. Theory and long-term practice shows that it is essential to suppress of fires occurring in small areas. When choosing which fire should be considered first priority two working principles should be taken into account based on an assessment of the probable effects of fire and fire risk to other biocenoses: the pyrogenic status of the landscape

unit and the possibility of fire spread to other vegetation types. It is also important to carry out an economic and administrative evaluation of the feasibility of suppression of each fire spot.

Given limited firefighting capacity and resources priority in suppression tactics should be given to fires which threaten protected area infrastructure (patrol stations, visitor centers, power lines, etc.), and populated areas located within the vicinity of reserve and national park boundaries.

5. Reduce the number and density of anthropogenic fire sources. In protected areas located in montane regions, the main causes of forest fires are local populations and thunderstorms activity, while in steppe regions the number of fires increases as a result of ongoing agricultural burns. High grazing loads reduce fire risk both in steppe zones and in the 'edges' of forest burned areas. To ensure the safety of existing adjacent buildings and infrastructure, legal fire protection activity should be carried out including grass cutting, clearing strips to mineral soil, organizing targeted concentration of firefighting equipment etc.

6. Optimize systems for the detection and suppression of forecasted fires (routes for delivery of manpower and equipment, storage for firefighting equipment, training, etc.). Protected areas should be classified according to fire risk based on natural fire hazard and fire occurrence using data provided by aviation patrol and satellite tracking. Routes should be designed for the delivery of manpower and equipment to fire areas taking account of actual terrain and accessibility for required transport and equipment both for the purposes of fire suppression and the implementation of other activities. Firefighting patrol units should be coordinated with units in adjacent territories. Likewise, joint observation points should be established (including automated systems) along protected area boundaries.

7. Organize mobile firefighting brigades during the fire season and their deployment to high risk zones. It is advisable to involve the local population (familiar with the area under protection) during the fire season to create mobile firefighting units on a contractual basis. Contracts should be drawn up for fire detection and suppression services with specialized units such as the Russian Aerial Forest Protection Service 'Avialesookhrana', the Ministry of Emergency Situations, forestry and agricultural employees, as well as other enterprises engaged in economic activities in protected area buffer zones.

8. Use compact all-terrain vehicles and firefighting equipment in common use. Preference should be given to small-scale mechanization. Currently, the most promising forms are considered to be ATVs and tractors with attachable equipment. The main advantage of these types of transport is their mobility, ease of delivery to places of fire and all-terrain performance.

9. Use of control burning to create fire barriers and prescribed burns. Prescribed fires are required to create fire barriers and gaps in steppe zones and light coniferous forest. It is recommended that prescribed burns be carried out along areas with particularly high fire risk and frequent fire occurrence (roads, fields, etc.), as well as on the perimeter of areas that have reached high fire flammability. Prescribed burns should only be performed in suitable weather conditions by specially trained teams with sufficient equipment to control the burn and carefully prepared and documented prescribed burn plan.

Based on the established basic principles of fire management strategy the above recommendations represent a system of measures developed for implementation in protected areas to facilitate fire control and protection in the context of current Russian legislation.

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Institute of Forest SB RAS is the first forest academic institution in Russia. It was founded in 1944 in Moscow by an outstanding biologist and academician Vladimir Nikolayevich Sukachev. The Institute of Forest was subsequently named after him in 1967. Back in 1959 the Institute joined the Siberian Branch of the Academy of Sciences of the USSR and was transferred to Krasnoyarsk.

Institute of Forest SB RAS is the largest forest research institution in the Russian Academy of Sciences. Over 160 people are employed at the Institute, including 1 academician, 40 doctors of sciences and 98 candidates of sciences (Ph. D.), 3 Honored Scientists of the RF and 4 Honored Foresters of the RF. More than 30 people are taking a Ph.D. course in a number of forest research areas: forest science, forestry, forest management, forest taxation, sylviculture, forest pyrology, genetics and selection, ecology, botany, forest soil science, entomology, microbiology, etc.

The Institute comprises 4 departments, 13 laboratories and a branch in Novosibirsk, ensuring development of fundamental and applied research in a wide range of areas: from biospherical role, ecologic functions, and biodiversity of forest ecosystems to monitoring forest condition and sustainable use of forest resources.

The following research laboratories have been established at the Institute: forest science, GIS, taxation and forest use, forest genetics and selection, forest pyrology (laboratory of forest fires research), zoology, biogeochemical cycles in forest ecosystems, physiology and biochemistry of wood plants, tree ring structure, etc.

The library of the Institute holds a wide range of scientific literature on forests for the regions of Siberia and the Far East. The Institute has two arboretums, in which it investigates about 450 species, subspecies, and various forms of trees and bushes from different botanical and geographical regions for over 40 years.

Since 1947 the Institute has been a collective member of the International Union of Forest Research Organizations (IUFRO), and since 1991 – the member of the International Boreal Forest Research Association (IBFRA).

http://forest.akadem.ru

On behalf of

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

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Since the beginning of 2008, additional funding from the auction of emission allowances has been available to the BMU for the implementation of the International Climate Initiative. The Climate Initiative aims to cost-effectively tap existing potential for emission reductions and advance innovative model projects for climate protection. It focuses on the following areas:

- Promoting a climate-friendly economy;
- Promoting measures for adaptation to the impacts of climate change;
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International Climate Initiative

The Federal Environment Ministry supports model climate protection projects in developing, newly industrialising and transition countries through the International Climate Initiative. The projects are geared towards the needs of the partner countries and support climate protection measures, in particular reducing greenhouse gases, improving adaptability to the consequences of climate change and conserving and using climate-relevant areas which merit protection. The International Climate Initiative therefore also supports the implementation of the Copenhagen Accord and facilitates consensus-building regarding an ambitious post-2012 climate protection agreement. It is part of the German contribution to fast-start financing, the commitment of industrialised countries in the Copenhagen Accord to financing immediate climate protection measures in developing countries until 2012.

www.bmu-klimaschutzinitiative.de

ALTAI-SAYAN ECOREGION

UNDP
Russian Federation

Altai-Sayan Ecoregion: Action on Climate Change

UNDP-ICI Project "Extension of Protected Areas Network for Conservation of the Altai-Sayan Ecoregion"

The Altai-Sayan Ecoregion is the heart of Asia and occupies an area of more than one million square kilometers. Russia, Mongolia, China, and Kazakhstan share its unique mountain landscapes. The Russian portion of the Ecoregion stretches over fifteen hundred kilometers from the Kazakh steppe in the west to Baikal Lake in the east.

The Russian Federation has acknowledged uniqueness of the ecoregion. There are 9 state nature reserves, including 3 biosphere reserves, and 4 national parks. Also there are tens of other protected areas, such as nature parks, wildlife refuges, and Nature Monuments.

Project "Expansion of the Protected Areas Network for the Conservation of the Altai-Sayan Ecoregion" implemented jointly by United Nations Development Programme and International Climate Initiative and supported by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) focuses on expanding the protected areas network in the Russian Altai-Sayan so as to build resilience to climate change induced threats and protect carbon sinks.

This component is an independent programme planned over a three year period. The main tasks are (1) to create new protected areas on the territory of the Altai-Sayan region as a means of supporting natural ecosystem climate change adaptation and (2) to secure carbon stocks of these ecosystems. Other tasks, no less ambitious, includedeveloping and implementing a fire protection strategy and creating a complex system for monitoring climate change in newly created protected areas. The programme is aimed at strengthening climate change resilience in Siberian forests of the Altai-Sayan ecoregion.

www.altai-sayan.com – UNDP-ICI Project "Extension of Protected Areas Network for Conservation of the Altai-Sayan Ecoregion"

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FIRE DANGER MITIGATION: A STRATEGY FOR PROTECTED AREAS OF THE ALTAI-SAYAN ECOREGION

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