Low Carbon, Green Growth

PROCEEDINGS

International Symposium

Regional / National Impact of Climate Change on Fire Regimes

Date

February 2~6, 2009

Place

Haeundae Grand Hotel(Busan)

Sponsors

Korea Forest Service
GFMC

Organizers

Korea Forest Research Institute
Inje University

산림청
KOREA FOREST SERVICE

국립산림과학원
KOREA FOREST RESEARCH INSTITUTE

인제대학교
INJE UNIVERSITY

Opening Address

Distinguished Guests,
Ladies and Gentlemen,

Good morning.

Due to the exceptionally dry winter, the public awareness of forest fire has been raised early on. I express my wholehearted appreciation to the Minister of the Korea Forest Service, staff members and guests for attending the "International Symposium on Climate Change and Forest Fire Control for Low-carbon Green Growth," despite your tight schedule in this busy season in dealing with forest fire.

On behalf of the Korean government and Korea Forest Research Institute, I would like to welcome participants from overseas who will present today's topic. Also, I would like to express my gratitude to Dr. Johann G. Goldammer, chair of the Global Fire Monitoring Center (GFMC) under the UN International Strategy for Disaster Reduction (ISDR) for your efforts in making this symposium happen.

Today, the global community is faced with a major challenge of climate change induced by global warming. In order to address this crisis, all countries in the world are aiming at realizing a carbon zero society and exerting themselves to curb the emissions of carbon dioxide (CO_2), which is the main culprit of global warming. Because of the acceleration of global warming, the forest areas all over the world, including Asia, are becoming more arid. As a result, more forest fires are occurring than in the past, bringing about more property damages.

While biomass is burned due to forest fire, the amount of carbon dioxide equivalent to the use of fossil fuel is released and subsequently global warming is facilitated. Moreover, this negatively affects the sustainability of the ecosystems, biological diversity and forest productivity, as well as local communities that make their living out of forests.

Therefore, the value of forests, which serve as carbon sinks, is becoming greater. Although the forest fire is considered one of the natural ecological processes, it is also targeted to be controlled.
Now it is evident that forest fires go beyond the borders. In this regard, this challenge requires international cooperation to cope with.

At this critical juncture, we believe, holding the symposium on forest fire is timely and significant. We are also confident that, through this symposium, we will be able to lessen the impact of the forest fire caused by climate change and come up with global measures to wisely address the problem.

Lastly, my sincere thanks go to President LEE, Kyung Ho of Inje University who spared no effort to arrange this meeting, Prof. Bambang Hero Saharjo from Bogor Agricultural University of Indonesia who attended this meeting to present many topics, Dr. Ahmad Ainuddin Nuruddin of University Putra Malaysia, Dr. Shu lifu from Chinese Academy of Forestry, Dr. Sundar Sharma from the Ministry of water Resources of Nepal, Dr. Leonid Kondrashov from Pacific Forest Forum of Russia, Dr. Colonel Ganbaatar Jamiyansuren from Fire Department Agency of Mongolia and Dr. Siri Akaakara from Thailand National Park.

Moreover, I would like to express my appreciation to Dr. SUH, Ae Sook from the Korea Meteorological Administration, Prof. LEE, Sang Woo from Kunkuk University, Prof. LEE, Woo Kyun from Korea University, Prof. LEE, Si Young from Kangwon National University and Prof. PARK, Pil Sun from Seoul National University who will be in charge of presentation, panel and the discussion sessions.

Besides, I would like thank all the staff members for your endeavors in preparing for this symposium.

In closing, I wish all of you good luck and good health.

Choi Wan Yong

Director General
Korea Forest Research Institute

Congratulatory Address

Honorable Dr. Johann G. Goldammer, Chairman of the Global Fire Monitoring Center (GFMC) under the UN International Strategy for Disaster Reduction (ISDR),

Dr. Bambang Hero Saharjo from Bogor Agricultural University of Indonesia,
Dr. Shu Lifu from Chinese Academy of Forestry,
Dr. Sundar Sharma from the Ministry of Water Resources of Nepal,
Dr. Leonid Kondrashov from Pacific Forest Forum of Russia,
Dr. Colonel Ganaatar Jmiyansuren from Fire Department Agency of Mongolia,
Dr. Siri Akaakara from Thai National Park,

Distinguished guests and delegates from NGO's and related organizations,
Ladies and gentlemen,

I believe that it is significant to hold today's international symposium on climate change and forest fire control strategy at this distinguished port city of Busan. It gives me great pleasure to extend my sincere congratulations on such a significant event.

Both the number of incidents and the extent of forest fires have been growing globally due to the increase in the number arid days caused by the climate change.

These forest fires not only cause damages to the forest but also lead to loss of life and property. Moreover, they release tremendous amount of carbon dioxide, accelerating the global warming phenomenon.

Particularly, the forests in Asia, from the tropical to the boreal forests, are vulnerable to forest fire. Also, due to the difficult access, it is hard to manage the forest fire.

In case of Korea, we went through a devastating disaster in the year of 2000 caused by huge forest fire which occurred in the east coast, losing about 23 thousands ha. Currently, huge forest fires have occurred globally, in countries such as the United States, Australia and Portugal. These incidents were a matter of concern in Korea as well.

The negative impacts of forest fire influence the neighboring countries as well. Smoke and fog from the fire causes adverse effects cross the border and loss of biodiversity eventually affects the global environment.

Accordingly, I believe that, in order to minimize the damage from the forest fire, it is necessary for many countries to collaborate and to develop a cooperative system. In addition, through the establishment of an international forest fire network and cooperation, we will be able to effectively cope with forest fires.

Therefore, I hope that this symposium will be an opportunity for an international discussion in search for better fire control strategies by establishing matters of common interest, and sharing forest fire policies and experiences.

I am looking forward to the success of this symposium with open-minded presentations and discussions.

Once again, I would like to extend my appreciation to President LEE, Kyung Ho of Inje University, for his full support in holding this symposium. Many thanks to all those concerned for the excellent preparation, and I wish good health and fortune to all of you.

Thank you.

CHUNG, Kwang Soo

Minister
Korea Forest Service

Congratulatory Address

Ecosystems throughout the Asian region are undergoing changes in wildland fire regimes. These changes are primarily induced by humans and aggravated by climate extremes. In equatorial Asia the use of fire in converting native primary or secondary vegetation is highest in the region. Main current burning activities are related to still practiced conversion of peatlands to plantations, notably biofuel plantations. Wildfires spreading from land-use fires are favored by dry spells or extended droughts during El Nino-Southern Oscillation (ENSO) events. Increasing severity and frequency of ENSO events are a consequence of global climate change. In the seasonal forests of mainland South and Southeast Asia regular seasonal smoke pollution caused by wildland fires are aggravated by industrial pollution and other burning activities such as trash burning. The so-called Asian Brown Cloud or the seasonal smoke pollution in Northern Thailand are a consequence of multiple sources of fire. In the mountain regions of the Himalayas regional warming linked to climate change is predicted to alter the snow and ice regimes in high-altitude ecosystems. Rapidly melting glaciers will not only impact the drinking water supply of around one billion people but also may effect regional vegetation dryness and fire regimes. In Central Asia a trend of regional desiccation as a consequence of climate change is observed. Non-sustainable forestry practices, often illegal, are influencing fire hazard and increase wildfire risk and severity. Besides regional drying wildfires are becoming a major force of steppization of Central Asia. In the current regions of continuous or discontinuous permafrost of Northern Asia regional warming will affect permafrost, forest cover and fire regimes. In Northeast Asia, notably in the Far East of Russia, mixed forest ecosystems are becoming increasingly vulnerable to fire as a consequence of regional climate change, careless fire use and reduced institutional capacities to manage fires.

These examples of climate change and society impacts on fire regimes in Asia will be highlighted by authors and representatives from the region who are contributing to this Pan-Asia Forest Fire Consultation. During this day we will have ample opportunities to discuss these issues in detail.

I would like to congratulate the Korean Forest Research Institute, the convener and host of this symposium, to invite international and national contributors and audience to address the very critical theme of climate change and fires in the greater Asian space. The Korean Forest Research Institute through the Division of Forest Fire and its Director, Dr. Myung Bo Lee, and Dr. Dong Hyun, Kim. in 2004 assumed responsibility to establish and coordinate the Regional North East Asia Wildland Fire Network. This network is one of the thirteen regional network of the Global Wildland Fire Network – an international programme operating under the United Nations International Strategy for Disaster Reduction. Korea's active participation in the network was one of the high-level measures in implementation and follow-up of the Global Wildland Fire Summit 2003. After the inauguration meeting in Seoul in 2004 a number of regional meetings were held, most of them prepared and hosted by the Pacific Forest Forum of Russia, represented here today by Dr. Leonid Kondrashov. A remarkable set of publications has been elaborated jointly in the region.

This symposium and consultation is in line with the explicit recommendation of the 4th International Wildland Fire Conference, which was held in Sevilla, Spain, May 2007. The conference conclusions that were directed to the regional networks included this statement:

> *A series of Regional Consultations tentatively addressing "Global Change and Wildland Fire: Regional Solutions for Fire Management" – (to...) be held globally, within the next 1-2 years, to progress the global issues that are impacting people, resources and livelihoods.*

This seminar and consultation is taking the challenge set by the international community. Representatives of the regional networks of Central Asia, South Asia, Southeast Asia / ASEAN and Northeast Asia are participating at this consultation, which for the first time is a full-scale Pan-Asian fire consultation. The outcomes of our discussion will encourage Governments and international organizations to increase the efforts in addressing the problem of wildfires and excessive application of land-use fires in the future. At national levels priority should be given to develop responsive and responsible national fire management policies and implementation strategies to address these challenges. Cooperative solutions by governments, the science community and civil society is needed to solve the fire problems, many of the having a border-crossing dimension such as transboundary fire smoke pollution and border-crossing fires.

I wish all of the symposium and consultation contributors and attendees to exchange their views and experiences, and to come up with fresh thoughts and initiatives to follow up this important event.

Johann Georg Goldammer

The Coordinator of UN ISDR Global Wildland Fire Network/GFMC

Welcome Address

On behalf of Inje University, I extend our most cordial welcome to the International Symposium.

My special thanks must go to the chief director of Prof. Johann G. Goldammer at GFMC, Pieter van Lierop at FAO including a number of foreign forest fire inspectors and prevention specialists, Korea Forest Service, Korea Meteorological Administration, Korea Forest Research Institute, Korea University, Gangwon National University and other forest fire officials.

Globally, it has been problematic to the solution for handling the recent problem, 'dramatic climate change'. Given this situation, it could be assumed that protecting forests that are carbon storage is very significant. Therefore, the presentations and active discussion sessions would be solid foundation to develop forest fire management strategies.

It has been 30 years since Inje University was first founded. A number of domestic and East Asian specialists and international organizations such as FAO and GFMC will lead this symposium to focus on Forest Fire Management Strategies According to Climate Change. Additionally, I am very pleased to co-host the international symposium with Korea Forest Research Institute and Korea Forest Service.

Moreover, I hope that the symposium will make a critical stepping-stone of exchanging the information with regard to forest fire management to minimize fire damages.

LEE, Kyeong Ho

The president of Inje University

Program

2 February (Mon)

- Sponsored by Korea Forest Service, Global Fire Monitoring Center
- Organized by Korea Forest Research Institute, Inje University

Date	Session	Time	Title	Speakers/Chairs	Affiliation
		08:30-09:00	**Registration**		
Feb. 2	**Opening**	09:00-09:05	Opening Address	Dr. Choi WanYong Director General of KFRI	
		09:05-09:15	Congratulatory Address	Dr. Kwang Soo CHUNG, Minister of Korea Forest Service Dr. Johann G. Goldammer, the Coordinator of the UN_ISDR/GFMC	
		09:15-09:20	Welcome Address	Dr. Kyeong Ho LEE, the President of Inje University	
		09:20-09:40	Photo time & Coffee Break		
	1	**09:40-11:50**		**Dr. Leonid Kondrashov**	**Pacific Forest Forum, Russia**
		09:40-10:10	Impact of Climate Change, Socio-economic and Land-use Changes on Fire Regimes in the Asian Region	Dr. Johann G. Goldammer	the Coordinator of the UN_ISDR /GFMC
		10:10-10:35	Climate Change Monitoring in Korean Peninsula Using Satellite Images	Dr. Ae Sook SUH	Korea Meteorological Administration, Korea
		10:35-11:00	National Impact of Climate Change on Fire Regimes, Indonesian Report	Dr. Bambang Hero Saharjo	Bogor Agricultural University, Indonesia
		11:00-11:25	Climate Change Impacts on Forest Ecosystems in Korea and Needs of Proactive Adaptation Measures	Dr. Jong Hwan LIM	Korea Forest Research Institute, Korea

Date	Session	Time	Title	Speakers/Chairs	Affiliation
		11:25-11:50	Fluctuation of Forest Fire in Spatial Space and Their Regional Behavior	Dr. Shu lifu	Chinese Academy of Forestry, China
		11:50-13:20	**Lunch**		
	2	**13:20 - 15:00**		**Dr. Bambang**	**Bogor Agricultural University, Indonesia**
		13:20-13:45	Climate Change and Forest Fire	Dr. Joon Hwan SHIN	Korea Forest Research Institute, Korea
		13:45-14:10	Climate Change and Wildland Fire Regimes : South Asia Regional Perspectives	Mr. Sundar P. Sharma	Ministry of Water Resources, Nepal
		14:10-14:35	Climate Change Impacts on Fire Regimes in the Mongolia	Dr. Ganbaatar Jamiyansuren	Fire Department Agency(NEMA), Mongolia
		14:35-15:00	The Space and Time Evaluation of Forest Fire Occurrence Hazards Using Climate Data of Ten-day Intervals 30 years in Spring, Korea	Dr. Myoung Soo WON	Korea Forest Research Institute, Korea
		15:00 - 15:50	**Coffee Break & Poster Session**		
	3	**15:50 - 17:30**		**Prof. Sang Woo LEE**	**Konkuk University, Korea**
		15:50-16:15	Reginal/National Impact of Climate Change on Fire Regimes in Central Asia	Dr. Leonid Kondrashov	Pacific Forest Forum, Russia
		16:15-16:40	Change in Land Cover and Carbon Dioxide Sequestration by Forest Fire	Prof. Woo Kyun LEE	Korea University, Korea
		16:40-17:05	National Impact of Climate Change on Fire Regimes, Thailand Report	Mr. Siri Akaakara	Wildlife and Plant Conservation Department, Thailand
		17:05 - 18:00	**Discussion and Closing Ceremony**		
		18:00 -	**Dinner**		

Table of contents

Session 1 .... **1**

Impact of Climate Change, Socio-economic and Land-use Changes on Fire Regimes in the Asian Region
Johann G. Goldammer 3

Climate Change Monitoring in Korean Peninsula Using Satellite Images
Ae Sook SUH 23

National Impact of Climate Change on Fire Regimes, Indonesian Report
Bambang Hero Saharjo 36

Climate Change Impacts on Forest Ecosystems in Korea and Needs of Proactive Adaptation Measures
Jong Hwan LIM 53

Session 2 .... **67**

Climate Change and Forest Fire
Joon Hwan SHIN 69

Fluctuation of Forest Fire in Spatial Space and Their Regional Behavior
Shu Lifu 91

Climate Change and Wildland Fire Regimes : South Asia Regional Perspectives
Sunder P. Sharma 104

Climate Change Impacts on Fire Regimes in the Mongolia
Ganbaatar Jamiyansuren 116

The Space and Time Evaluation of Forest Fire Occurrence Hazards Using Climate Data of Ten-day Intervals 30 years in Spring, Korea
Myoung Soo WON 127

Session 3 143

Regional/National Impact of Climate Change on Fire Regimes in Central Asia
Leonid Kondrashov 145

Change in Land Cover and Carbon Dioxide Sequestration by Forest Fire
Woo Kyun LEE 157

National Impact of Climate Change on Fire Regimes, Thailand Report
Siri Akaakara 171

Poster Session 185

Participants 328

Session 1

Impact of Climate Change, Socio-economic and Land-use Changes on Fire Regimes in the Asian Region

기후 변화, 사회경제, 토지 이용 변화가 아시아 지역 산불형에 미치는 영향

Johann Georg Goldammer

Abstract

Ecosystems throughout the Asian region are undergoing changes in wildland fire regimes. These changes are primarily induced by humans and aggravated by climate extremes. In equatorial Asia the use of fire in converting native primary or secondary vegetation is highest in the region. Main current burning activities are related to conversion of peatlands to plantations, notably biofuel plantations. Wildfires spreading from land-use fires are favored by dry spells or extended droughts during El Nino-Southern Oscillation (ENSO) events. Increasing severity and frequency of ENSO events are a consequence of global climate change. In the seasonal forests of mainland South and Southeast Asia regular seasonal smoke pollution caused by wildland fires are aggravated by industrial pollution and other burning activities such as trash burning. The so-called Asian Brown Cloud or the seasonal smoke pollution in Northern Thailand are a consequence of multiple sources of fire. In the mountain regions of the Himalayas regional warming linked to climate change is predicted to alter the snow and ice regimes in high-altitude ecosystems. Rapidly melting glaciers will not only impact the drinking water supply of around one billion people but also may effect regional vegetation dryness and fire regimes. In Central Asia a trend of regional desiccation as a consequence of climate change is observed. Non-sustainable forestry practices, often illegal, are influencing fire hazard and increase wildfire risk and severity. Besides regional drying wildfires are becoming a major force of steppization of Central Asia. In the current regions of continuous or discontinuous permafrost of Northern Asia regional warming will affect permafrost, forest cover and fire regimes. In Northeast Asia, notably in the Far East of Russia, mixed forest ecosystems are becoming increasingly vulnerable to

fire as a consequence of regional climate, careless fire use and reduced institutional capacities to manage fires.

요 약

아시아 지역 도처의 생태계가 산불형의 변화를 당하고 있다. 이 변화들은 주로 인간활동에 의해 야기되었고 기후 극치에 의해 악화되었다. 적도 부근의 아시아는 원시림과 이차림을 변화시키기 위하여 불을 사용하는 빈도가 가장 높은 지역이다. 현재의 주요 소각 활동은 이탄토지대를 식재지로, 특히 연료림으로 전환시키는 행위와 관련된다. 토지 이용을 위한 불로부터 확산되는 산불은 엘니뇨 남방진동(ENSO) 기간 동안의 건조기 또는 장기간의 가뭄으로 인해 촉진되었다. 극심하고 빈번한 ENSO 현상의 증가는 세계적인 기후 변화의 결과이다. 아시아 대륙 남부 그리고 동남아시아의 계절림 지역에서는 산불에서 비롯된 정기적인 계절 연무 현상이 산업공해나 또 한편 쓰레기 소각 등의 각종 연소 활동으로 인해 악화되었다. 소위 황사 또는 태국 북부 지역의 계절적 스모크 현상은 불의 다원적 결과이다. 히말라야 산맥의 산간지역에 있어서 기후 변화와 관련된 지역의 온난화는 고해발 생태계의 설빙형을 바꿀 것으로 예측되었다. 빠르게 녹아내리는 빙하는 10 억 인구의 식수 공급에 영향을 줄 뿐만 아니라 지역 식생의 건조와 산불형에도 영향을 끼칠 것이다. 중앙아시아에서는 기후 변화로 비롯된 지역적 건조 추세가 관찰되었다. 종종 불법이기도 한 지속불가능한 임업행위는 화재 위험성에 영향을 미치고 있으며 산불 위험도와 심도를 증가시킨다. 게다가 지역을 건조시키는 산불은 중앙아시아의 스텝화에 주요 원동력이 되고 있다. 현재 북부아시아의 연속적이거나 비연속적인 영구 동토 지역들에서는 지역적인 온난화가 영구 동토층과 산림식피율 및 산불형에 영향을 미칠 것이다. 북동아시아, 특히 러시아의 극동지방에서는 혼효림 생태계가 지역적 기후, 부주의한 불의 사용과 화재를 관리하기 위한 공공시설의 용량의 감소 등으로 인하여 화재에 점점 더 취약해져 가고 있다.

Impact of Climate Change, Socio-economic and Land-use Changes on Fire Regimes in the Asian Region

Johann Georg Goldammer
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Abstract

Ecosystems throughout the Asian region are undergoing changes in wildland fire regimes. These changes are primarily induced by humans and aggravated by climate extremes. In equatorial Asia the use of fire in converting native primary or secondary vegetation is highest in the region. Main current burning activities are related to conversion of peatlands to plantations, notably biofuel plantations. Wildfires spreading from land-use fires are favored by dry spells or extended droughts during El Nino-Southern Oscillation (ENSO) events. Increasing severity and frequency of ENSO events are a consequence of global climate change. In the seasonal forests of mainland South and Southeast Asia regular seasonal smoke pollution caused by wildland fires are aggravated by industrial pollution and other burning activities such as trash burning. The so-called Asian Brown Cloud or the seasonal smoke pollution in Northern Thailand are a consequence of multiple sources of fire. In the mountain regions of the Himalayas regional warming linked to climate change is predicted to alter the snow and ice regimes in high-altitude ecosystems. Rapidly melting glaciers will not only impact the drinking water supply of around one billion people but also may effect regional vegetation dryness and fire regimes. In Central Asia a trend of regional desiccation as a consequence of climate change is observed. Non-sustainable forestry practices, often illegal, are influencing fire hazard and increase wildfire risk and severity. Besides regional drying wildfires are becoming a major force of steppization of Central Asia. In the current regions of continuous or discontinuous permafrost of Northern Asia regional warming will affect permafrost, forest cover and fire regimes. In Northeast Asia, notably in the Far East of Russia, mixed forest ecosystems are becoming increasingly vulnerable to

fire as a consequence of regional climate, careless fire use and reduced institutional capacities to manage fires.

1. INTRODUCTION

It is generally accepted conclusion among scientists and a growing percentage of the public that climate change is a reality, and that global impacts will be profound, and largely unavoidable, over the next century. The Intergovernmental Panel on Climate Change has recently concluded that "the global average surface temperature has increased over the 20th Century by 0.6°C, lower atmosphere temperatures are rising, snow cover and sea ice extent have decreased, sea levels are rising, atmospheric greenhouse gas concentrations continue to increase due to human activities, and global temperatures and sea levels will continue to rise under all modeling scenarios". Numerous General Circulation Models project a global mean temperature increase of 1.6 to 5.4°C by 2100 – a change much more rapid than any experienced in the past 10,000 years. The frequency and severity of extreme weather and climate events are also projected to increase and will lead to an alteration of fire regimes. Most importantly more frequent droughts may result in increasing occurrence of high-severity wildfires with consequences for vegetation cover loss, desertification and reduced terrestrial carbon sequestration.

The 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change calls for the "protection and enhancement of sinks and reservoirs of greenhouse gases", and requires all countries to monitor and understand the major factors influencing the exchange of carbon between the biosphere and the atmosphere. Both land-use fires and wildfires in all ecosystems are affecting carbon pools and global carbon cycling. At the same time, climate change impacts the duration and severity of dry seasons, thus having impacts upon the incidence and severity of fires.

2. BOREAL AND TEMPERATE FORESTS OF NORTHERN AND CENTRAL ASIA

Climate change is expected to be most severe at northern latitudes, and boreal zone impacts are projected to be most significant over Siberia, west-central

Canada, and Alaska (Stocks et al. 1998). Research to date indicates that both the incidence and severity of forest fires will increase dramatically (Flannigan et al., 2000). The result will be longer fire seasons (Wotton and Flannigan, 1993), larger areas burned (Flannigan et al. 2005), shorter fire-return intervals, a shift to a lower forest age-class distribution, and a net loss of terrestrial carbon to the atmosphere, likely resulting in a positive feedback loop to climate change wherein more fire leads to greater atmospheric carbon which leads to greater warming and more fire (Kurz et al., 1995). Any trend towards increased fire activity and impacts will put extreme pressure on fire management agencies in the boreal region, and they will be unlikely to maintain their current level of control over fire impacts. Recent studies indicate substantial costs would be required to attempt to keep escaped fires at current levels, and escaped fires increasing significantly using current resource strength under a changing climate. It appears fire suppression as practiced today will not be economically sustainable in the future. This will have direct effects on wood supply, the competitiveness of forest industry, and the future of forest industry-based communities. It will also have a direct effect on carbon sequestration and greenhouse gas emissions, particularly with increased carbon loss through more severe forest fires and the new exposure of carbon-rich peatlands to future fire.

With regard to existing international agreements, a statement of the Russian Academy of Sciences on the role of the Kyoto Protocol mechanisms in forestry and land use development in Russia (Korovin, 2005) is drawing the context between the Kyoto Protocol and the potential of reducing carbon emissions by fire management, by stating:

> *The urgent need to reduce fire-induced emissions of the greenhouse gases is dictated by both increased fire occurrence in the boreal forests and the projected increase in the number and scope of forest fires due to global warming.*

This report and other studies refer to the scenarios that the Eurasia's large terrestrial carbon pool – mainly carbon stored in forests, tundra and peatlands – may become threatened by the combined effects of climate change, human interventions and fire. With more than 300 billion tons, the territory of the Russian Federation is currently holding the largest terrestrial carbon pool (Dixon et al., 1994) and one of the most important terrestrial carbon sinks, especially in the Siberian peatlands (Smith et al., 2004).

Climate-change models (Global Circulation Models - GCMs) have been used since the early 1990s to predict drought severity and consequently fire severity of the boreal zone including Central Asia (Stocks et al., 1998). Selected scenarios are provided in Figures 1 and 2. It is based on the GCM of the Canadian Climate Center (CCC) and compares average monthly fire severity rating across Eurasia and North America under the current climate conditions vs. a projected climate-change (2 x CO_2) scenario for the year 2030 (Stocks, 2004). Increased wildland fire occurrence and severity will be a consequence of increased occurrence of droughts in the extreme continental climate of Central Asia.

Stocks (2004) furthermore summarizes the trends associated with regional climate change:

> *In addition to increased fire activity and severity, climate warming of the magnitude projected can be expected to have major impacts on boreal forest ecosystem structure and function in northern circumpolar countries. Based on GCM projections large-scale shifting of forest vegetation northward is expected, at rates much faster than previously experienced during earlier climate fluctuations. Increased forest fire activity is expected to be an early and significant result of a trend toward warmer and drier conditions, resulting in shorter fire return intervals, a shift in age-class distribution towards younger forests, and a decrease in biospheric carbon storage. This would likely result in a positive feedback loop between fires in boreal ecosystems and climate change, with more carbon being released from boreal ecosystems than is being stored). It has been suggested that fire would be the likely agent for future vegetation shifting in response to climate change.* [1]

[1] For detailed references of cited trends, see Stocks (2004)

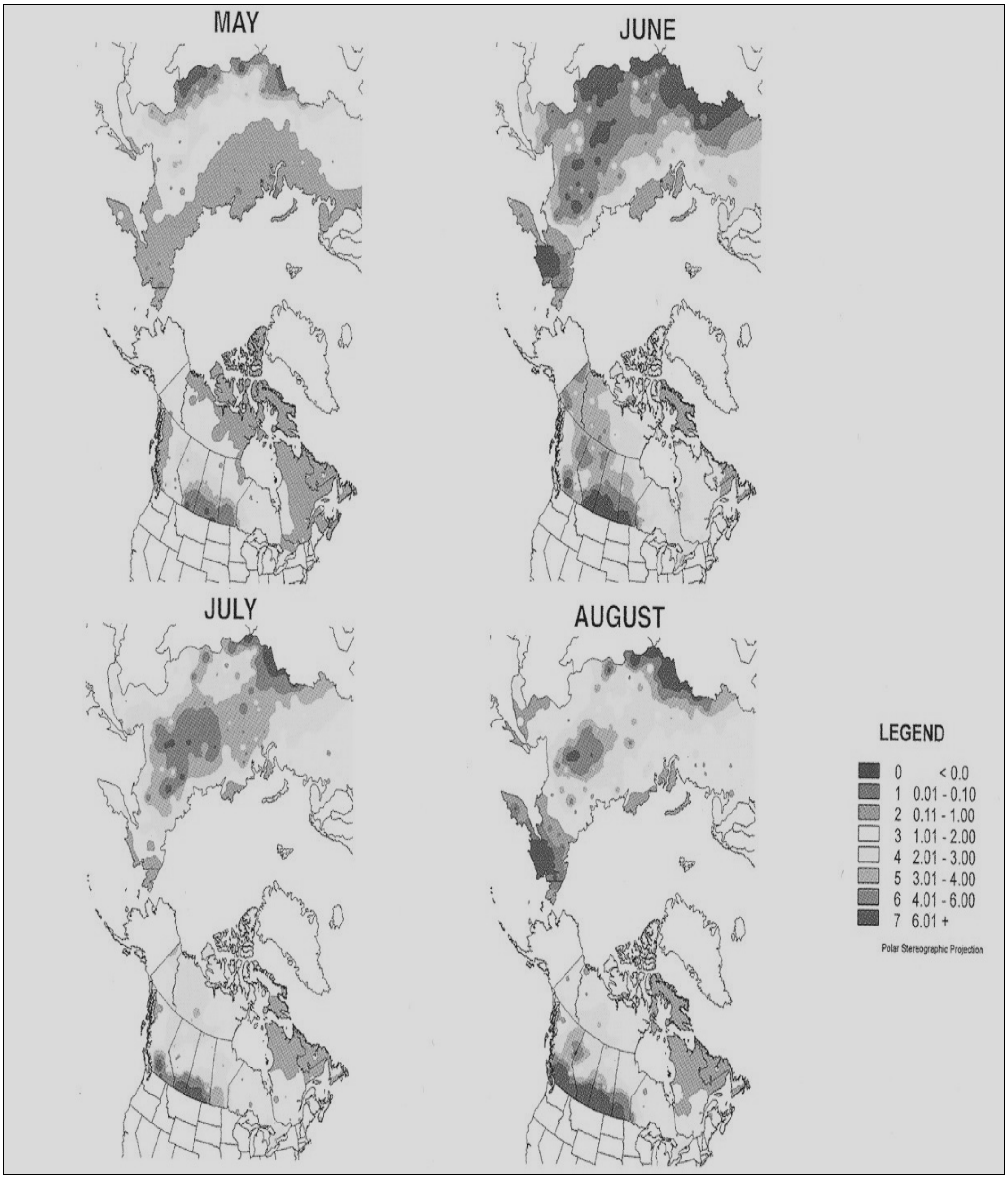

Figure 1 Average Monthly Severity Rating (MSR) maps for Canada and Russia, based on measured 1980-1989 daily weather [2]

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[2] Average Monthly Severity Rating (MSR): see Alexander and Stocks (1987) and additionally http://www.fire.uni-freiburg.de/programmes/un/idndr/idndr_ha.htm

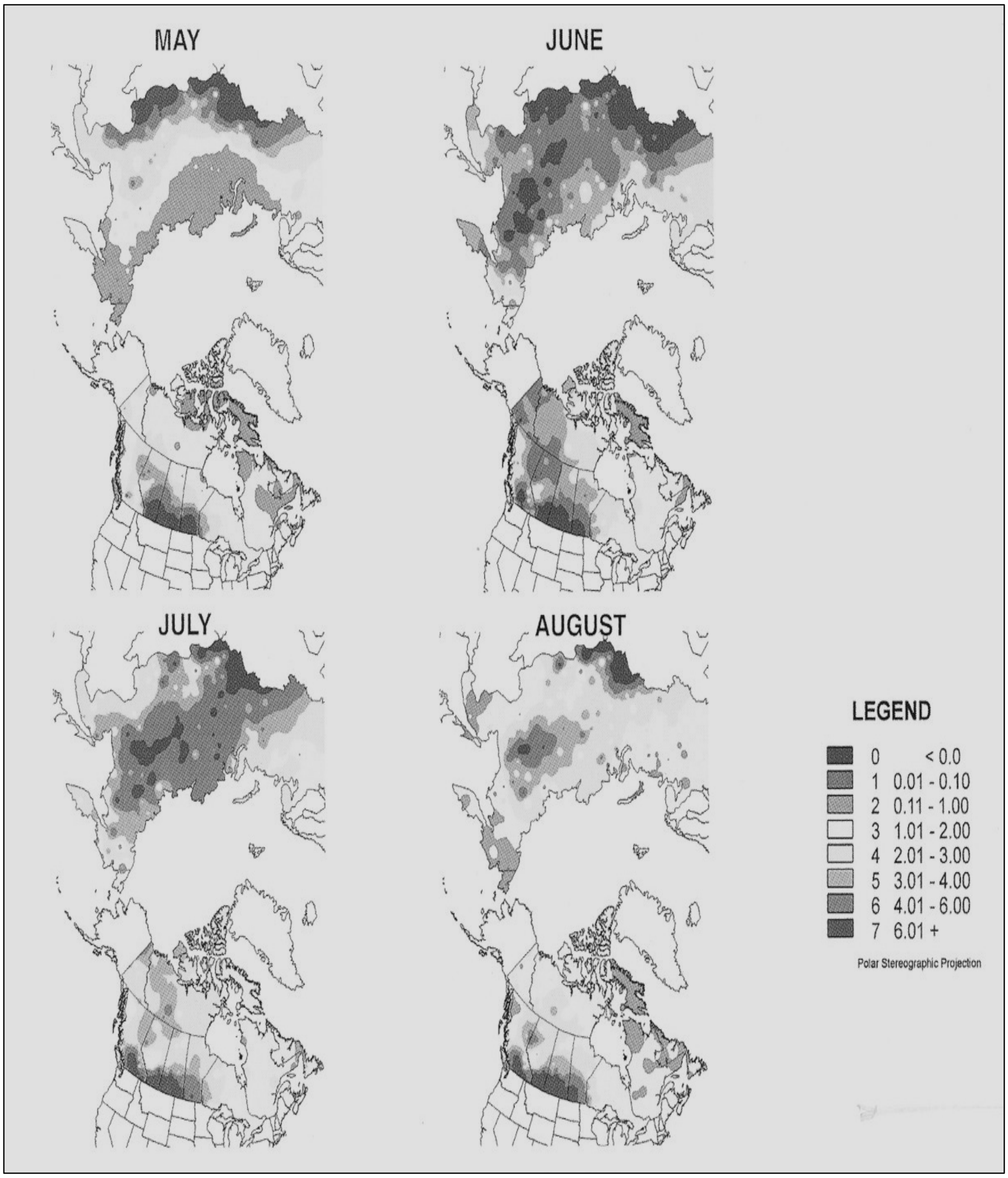

Figure 2 Average Monthly Severity Rating (MSR) maps for Canada and Russia under a 2xCO_2 climate using the Canadian General Circulation Model (see footnote).

The FRA 2005 report from Russia states that, over the past 10 years, up to 72% of the forest fires were caused by humans, about 7% result from agricultural burnings, 7% originate from lightning and 14% of fires are due to other causes (Goldammer, 2006). However, in some regions – especially in the Northern areas of European Russia, Siberia and Far East, particularly in sparsely inhabited territories where forest fires are not suppressed – the share of lightning-caused ignitions is considerably higher (up to 50-70 %) (Davidenko and Kovalev, 2004).

These statistical data, however, do not reflect the complex interaction of factors that may lead to extreme fire situations. The fire season of 2003 is in Russia an example of an extreme fire year in which the combined effects of

- extreme drought
- reduced capabilities of the fire management establishment
- inappropriate forest management involving extended clearcuts, and
- economically motivated arson and carelessness

resulted in an extreme fire situation in the regions Northwest and Southeast of Lake Baikal. This region was mostly affected by extreme drought in 2002/2003 (Goldammer *et al.*, 2004a). Extremely low precipitation was recorded in the 10-month period between August 2002 and May 2003 in Buryatia Republic (total rainfall: 36.0 mm) and Chita Oblast (45.7 mm). Besides these precipitation data a vegetation health map generated by NOAA AVHRR satellite data shows a dramatic picture of vegetation stress and drought on 1 June 2003 – a situation much more extreme as compared to 1987, the last extreme drought and fire year in the Transbaikal Region (Figure 3).

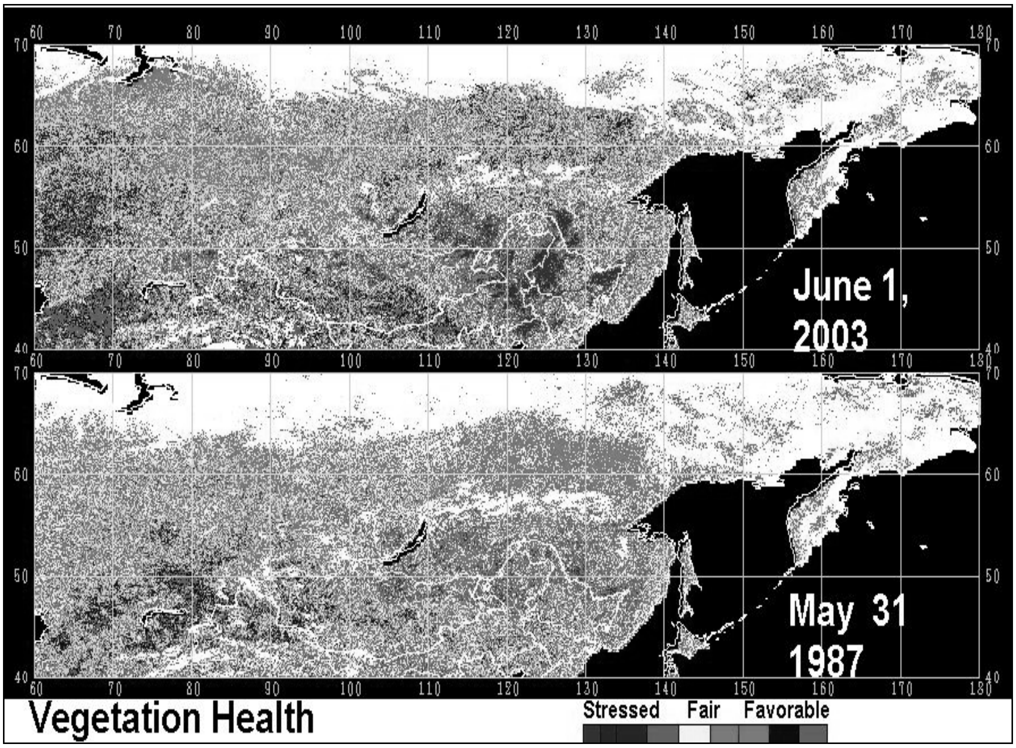

Figure 3 Vegetation health maps of Southern Siberia, Mongolia and Northern China on 1 June 2003 and 31 May 1987. The images is a color-coded map of vegetation condition (health) estimated by the Vegetation and Temperature Condition Index (VT). The VT is a numerical index, which changes from 0 to 100 characterizing change in vegetation conditions from extremely poor (0) to excellent (100). Fair conditions are coded by green color (50), which changes to brown and red when conditions deteriorate and to blue when they improve. The VT reflects indirectly a combination of chlorophyll and moisture content in the vegetation and also changes in thermal conditions at the surface. This new approach combines the visible, near infrared, and thermal radiances in a numerical index characterizing vegetation health. This approach is extremely useful in detecting and monitoring such complex and difficult-to-identify phenomenon as drought. The VT values below 35 are used for identifying vegetation stress which is an indirect drought indicator. The VT is very useful for early drought detection, assessing drought area coverage, duration, and intensity, and for monitoring drought impacts on vegetation and agricultural crops. For technical details for the background of the tool see Kogan (1997) and: http://orbit-net.nesdis.noaa.gov/crad/sat/surf/vci/index.html. Map courtesy F. Kogan, NOAA. Source: Goldammer et al. (2005).

In the same year 2003 the Aerial Forest Fire Service *Avialesookhrana* continued to be faced with insufficient budgets for operations. Thus, the organization had to reduce aerial observation flights that are crucial for early detection of wildfires and rapid response. Aerial surveys are also important for mapping of fire effects. Thus, with the reduced budgets it was not possible to suppress wildfires in an early stage. Consequently the wildfires grew large in size and became uncontrollable in most cases.

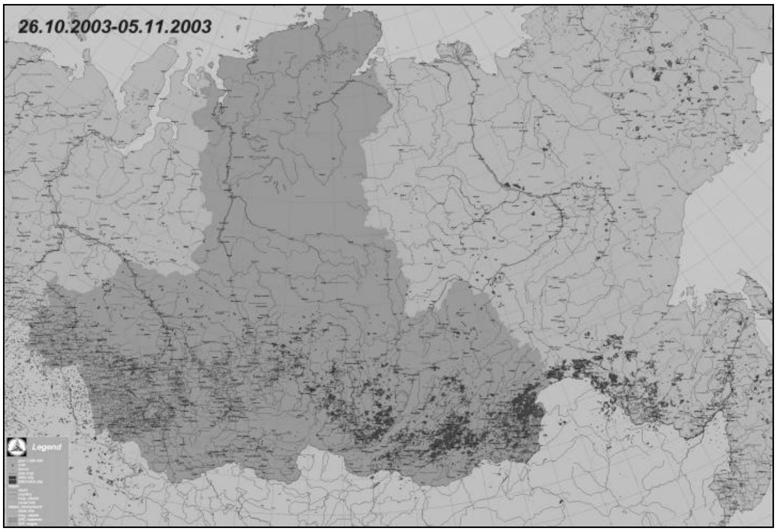

Figure 4 NOAA-AVHRR-derived burn scar map of the fire season of 2003. Source: Sukachev Institute for Forest.

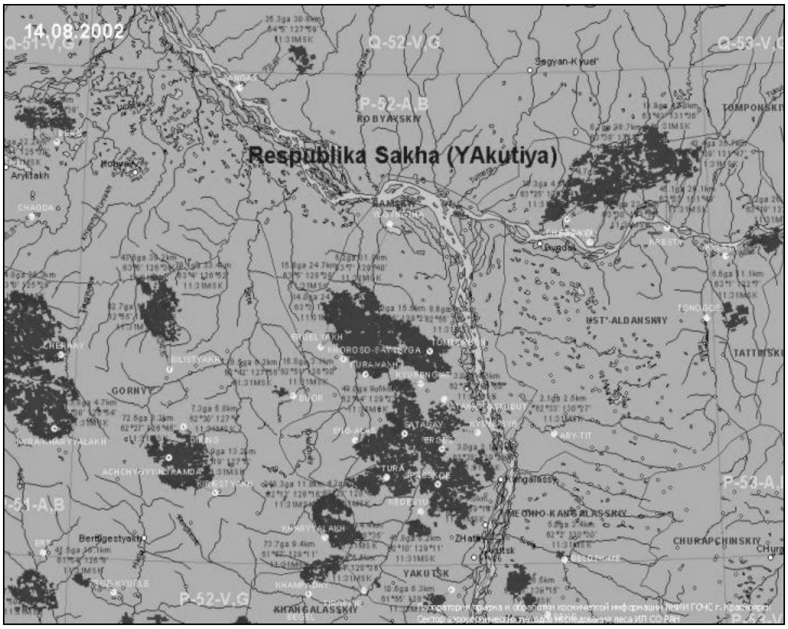

Figure 5 Example of a daily NOAA-AVHRR-derived burn scar map (Yakutia, 14 August 2002) generated by he Fire Laboratory of Sukachev Institute for Forest and displayed daily on the GFMC website.[3]

[3] http://gfmc.org

Another aggravating factor of the wildland fire theatre in the region around Lake Baikal, especially in Buryatia and Chita, is the increasing occurrence of arson fires. The underlying causes for arson fires are deeply rooted in the economic development of Southeast Russia and its neighboring countries. The depletion of China's forest resources and the increasing demand for timber products on the market in China have created an enormous pressure on the forest resources of Mongolia and the Russian Federation. Observations in the Russian Federation and in Mongolia indicate that timber dealers have encouraged or bribed local people to set fires to forests in order to increase the permissible salvage logging areas. Fire-damaged timber is presently allowed to be harvested for sanitary reasons at low stumpage prices, and can be a lucrative source of income. In addition extended illegal logging and timber export has been observed during two on-site inspection missions by the GFMC in Mongolia and the Russian Federation by the first author during 2003.[4]

A fourth factor contributing to the overall degradation of forest sites are the consequences of large clearcuts. In the dark coniferous taiga forests in northern part of Siberia, large-scale clearcuts of the 1990s nowadays show no natural regeneration of forest. This is also observed in some southern light taiga forests where the combination of removal of seed trees, clearcut sizes extending the aerial seed transport distance for pines (ca. 500 m) and recurrent fires have resulted in large non-forested areas dominated by pure grass stands. These "green desert grasslands" are maintained by regular fires – a phenomenon that has been observed at large scale in Mongolia and China.

Another problem is related to the relationship between climate change, fire and permafrost thawing. The immediate consequences of a fire through the removal of heat-insulating raw humus layers and accumulated debris is resulting in higher temperatures of the surface and the soil, thus resulting in the deepening of the active layer and thawing of permafrost in the upper layers, affecting soil drainage, creation of wet meadows, ponds, and even small lakes. With vegetation recovery this effect is lost over time. Predicted increase of fire frequency and fire severities in a changed climate, however, implies that permafrost collapse will be possible at large scale, with implications on the release of additional greenhouse gases currently trapped in the ice, notably methane (e.g., Liang et al., 2006; Myers-Smith et al., 2008).

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[4] The view of the GFMC is supported by this article "Fiddling while Siberia burns: 'lungs of Europe' under threat from forest fires. Russia's pristine forests are the lungs of Europe. But vast swathes are being destroyed by global warming and loggers' greed - and ill-equipped firefighters are powerless to act", in which a number of scientists from Russia and the USA were interviewed, published by The Independent, 31 May 2005: http://www.fire.uni-freiburg.de/media/2005/news_20050601_ru.htm

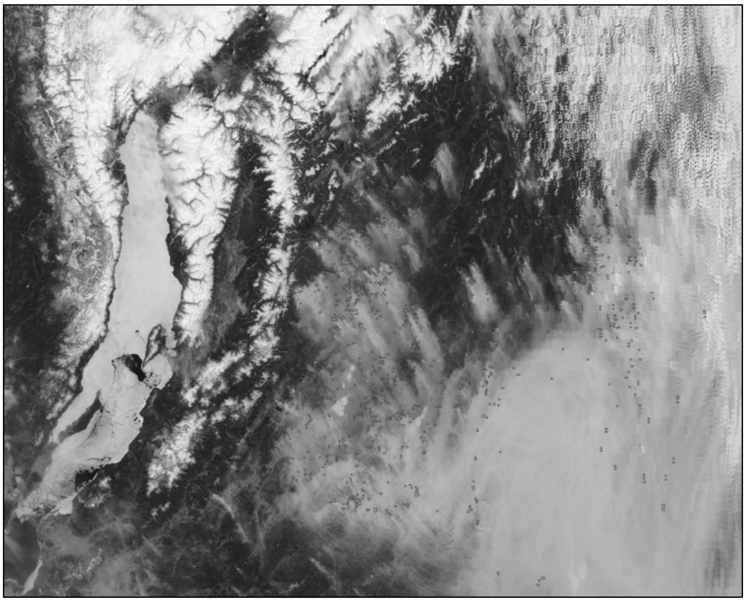

Figure 6 Fire activities on 8 May 2003 at 0400 UTC (11:00 local time) Southeast of Baikal Lake. Source: Moderate-Resolution Imaging Spectroradiometer (MODIS).

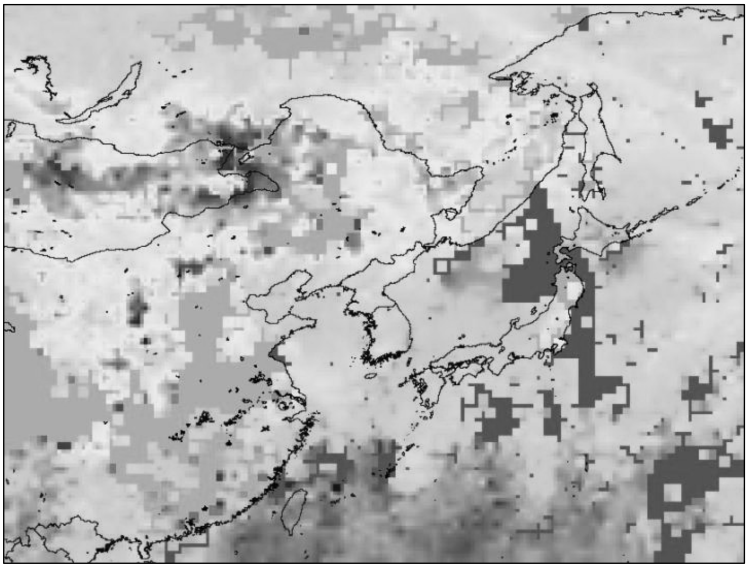

Figure 7 Accumulated carbon monoxide concentration for the period 3-8 May 2003 originated by smoke from wildland fires in the Transbaikal Region. The image shows measurements of carbon monoxide captured by the Measurements of Pollution in the Troposphere (MOPITT) sensor on the Terra satellite, with values ranging from zero (dark blue) to 360 parts per billion (red). Source: NASA Earth Observatory (http://earthobservatory.nasa.gov/)

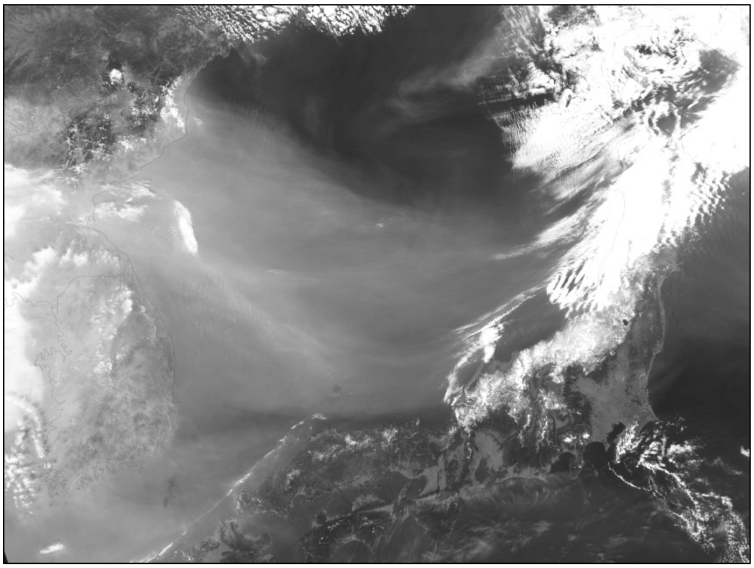

Figure 8 This MODIS Aqua satellite scene of 11 March 2008 captured the fire smoke drifting from Russia's Far East to Japan.. See also Figure 9 below. Source: NASA, displayed at GFMC on 11 March 2008:http://www.fire.uni-freiburg.de/GFMCnew/2008/03/0311/20080311_ru.htm

Figure 9 Smoke pollution in Khabarovsk City, Far East of Russia, resulting from extended fires burning in organic terrain. This kind of situation has occurred increasingly during the last years and is expected to continue in future as more fires in the Far East region are expected. Source: Pacific Forest Forum (PFF), Krasnoyarsk.

Already during the past decade the increasing fire activities in Central Siberia and the Far East of Russia, as well as in Mongolia and China have resulted in severe regional air pollution.

3. TROPICAL FORESTS OF SOUTH AND SOUTHEAST ASIA: REGIONAL WARMING, EL NIÑO AND FIRES

Climate variability and precursors of climate change in tropical Asia are most prominently represented by the El Niño-Southern Oscillation (ENSO) phenomenon. The ENSO phenomenon has been comprehensively described since almost half a century (Troup 1965; Julian and Chervin 1978; Philander 1983; Harger 1995) and is regarded as one of the most striking examples of inter-annual climate variability on a global scale. It is caused by complicated atmospheric-oceanic coupling. The event is initiated by the Southern Oscillation, which is the variation of pressure difference between the Indonesian low and the South Pacific tropical high. During a low pressure gradient, the westward trade winds are weakened, resulting in the development of positive sea surface temperature anomalies along the coast of Peru and most of the tropical Pacific Ocean. The inter-tropical convergence zone and the South Pacific convergence zone then merge in the vicinity of the dateline, causing the Indonesian low to shift its position into that area. Subsequently, during a typical ENSO event, the higher pressure over Malesia leads to a decrease in rainfall. The severity of the dry spells depends on the amplitude and persistence of the climate oscillations.

During the past ENSO episodes the increasing fire activities in SE Asia have been widely attributed to the ENSO droughts. A comparison of ENSO severity and fire activities, notably land-use fires, seem to confirm this at first glance as can be seen in Figure 4 – an example of Sumatra / Indonesia. It has also been thoroughly investigated that ENSO-triggered droughts are resulting to increased flammability and vulnerability of tropical equatorial forests in SE Asia (Goldammer and Seibert, 1990). However, the causes of wildfires and the underlying causes of land-use fires and smoke pollution are exclusively of human-made origin and increasingly originating from the application of fire to convert native vegetation, including peat-swamp ecosystems. These burning activities are favored but not caused by drought. Since there is some evidence that global warming could increase the frequency and duration of ENSO events, resulting longer and more severe periods of drought (Trenberth and Hoar, 1996) it may be expected that the overall future burning regimes in insular SE Asia will aggravate in the future.

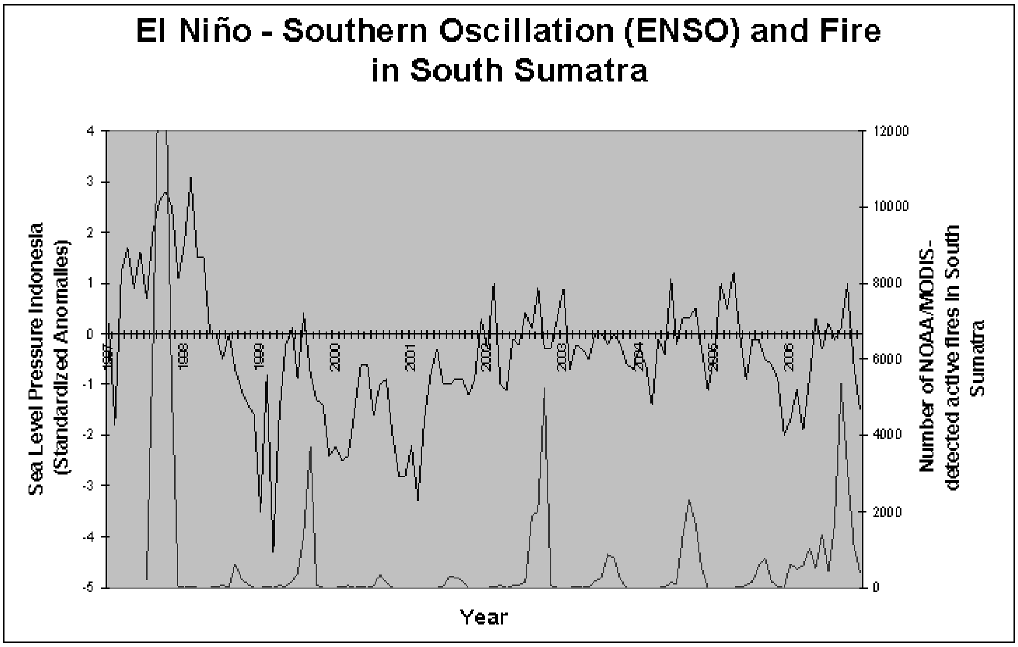

Figure 9 Relationship between ENSO and fire activities by comparing anomalies of seal level pressure in Indonesia and active fires detected by NOAA AAVHRR and MODIS on Sumatra between 1997 and 2007. Source: South Sumatra Forest Fire Management Project (SSFMP).

In mainland South Asia the environmental effects of land-use fires and wildfires are increasing human activities are aggravated by the emissions of industrial burning, including fossil-fuel and waste burning. S. Sharma (this volume) is further exploring the origin and impact of the “Asian Brown Cloud” and its possible effect on rainfall reduction over the Indo-Gangetic plain, which has decreased by about 20 per cent since the 1980s. He is also exploring the implications of regional warming on changes of snowfall, ice cover regional desiccation and water regimes.

Figure 10 Annual surface fire in a dry dipterocarp forest in Thailand – a phenomenon typically in seasonally dry forests throughout mainland South Asia. Photo: GFMC archive by Kobsak Wanthongchai.

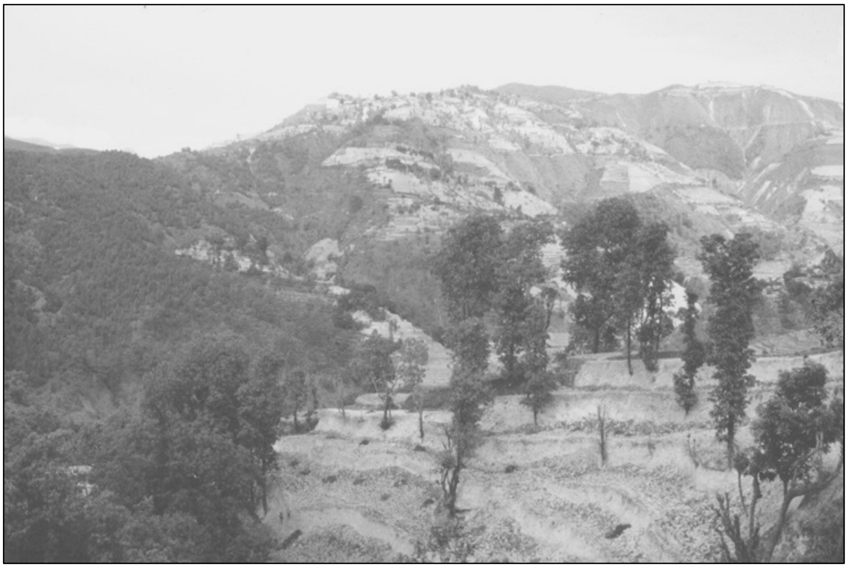

Figure 11 In the high altitudes of the Hindu Kush - Himalayas increasing conversion of natural vegetation to land-use systems is affecting water-holding capacity of the mountain ecosystems and increasing susceptibility to wildfires. This process will be aggravated by the changed snowfall and ice cover regimes due to regional warming. Source: GFMC archive.

4. CONCLUSIONS

The examples of climate change and society impacts of fire regimes in Asia given in this paper do not intend to be complete and detailed as authors from the region are contributing to this Pan-Asia Forest Fire Consultation (this volume) are providing focused insight on regions and countries of the greater Asian space. However, it is intended to show the variety of climate extremes and socio-economic developments, which are interacting and reinforcing each other and changing fire regimes in some parts of Asia. One of the main roles of the UNISDR Global Wildland Fire Network – and particularly the networks of Central Asia, South Asia, Southeast Asia / ASEAN and Northeast Asia represented at this consultation – is to encourage Governments and international organizations to address the problem of wildfires and excessive application of land-use fires. At national levels priority should be given to develop responsive and responsible national fire management policies and implementation strategies to address these challenges. Cooperation of governments, the science community and civil society is needed to address the border-crossing problems such as transboundary fire smoke pollution and border-crossing fires.

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Climate Change Monitoring in Korean Peninsula Using Satellite Images

위성영상을 통해서 본 한반도의 기후변화

Ae-Sook Suh, Jong-Seo Park, and Nam-Jae Jeong

Abstract

Satelliteimages are widely applied for earth environmental change such as Asianyellow dust, Typhoon, drought, forest fire, vegetation, and Ozone change. The data demands will be increased by monitoring climate change from now on. The precision, scientific technique and revitalization of satellite data related to climate change are expected to find a clue for solving global problems threatening human being.

After launch of COMS (Communication, Oceanic and Meteorological Satellite), weather forecasting will be improved by using higher space-temporal data derived from COMS.

In this presentation, effects of Korean peninsula climate change related to factors of climate change, tendency of global temperature increment and change of Korean peninsula temperature has been discussed, and examples of applied satellite images for climate change in KMA(Korea Meteorological Administration) has been shown.

We showed that the intensity of dust storm and typhoon have been increased comparing with past years due to climate change. Especially, these deepening of dust storm intensity and increasing of the number of its occurrence day may affect to the economic and society issue. Through this study, we identified that a clear satellite picture in next coming season can make people or industries prepare unstable weather pattern such as dust storm and fire detection.

요 약

위성영상의 변화탐지를 이용한 황사, 태풍, 가뭄, 산불, 식생변화, 오존변화 등 지구환경변화와 관련된 연구를 할 수 있는 것은 다양하다.

일찍이 기상관측의 중요성에 눈뜬 선진국들은 날로 심해지는 기상재해와 기후변화에 대처하기 위해 차세대 기상위성을 개발하고 있다. 앞으로 기후변화감시를 위한 위성자료의 수요는 늘어날 전망이며, 따라서 위성자료를 지역적으로 이용하고자 하는 시도 또한 증가할 것으로 예상된다. 이에 대비하여 위성자료 검증·보정 등을 통한 정확도 확보와 활용기술 개발 및 기후변화 대처에 활용 활성화를 통하여 인류의 생존을 위협하는 전지구적 문제의 해결 실마리를 찾을 수 있을 것으로 기대된다. 그러나 보다 심도 높은 연구를 위해서는 다양한 위성관측자료의 수집과 보관, 그리고 다년간의 방대한 위성자료의 축적이 전제되어야 가능할 것이다. 지구온난화의 경제적인 파급효과에 대한 Stern Review(2006년, 스턴 보고서)에 의하면 기후변화에 따른 홍수·가뭄·해수면 상승·빙하 축소·식량생산 감소·생물종 멸종 등으로 인한 경제적 피해가 증가할 것으로 보고 있다.

2009년 하반기에 통신해양기상위성이 발사되면 우리나라는 기상위성 보유국이 되며, 한반도 기상관측에 새로운 지평을 열게 되어, 우리 기상위성이 관측한 시공간적으로 고해상도 위성자료를 이용하여 돌발 위험기상 탐지 능력을 향상시키고 기상예측 능력을 향상시킬 것이다. 나아가 세계 국가들과 위성자료를 공유하여 전지구 기후감시에 기여하고 기상재해로부터 인류를 보호하기 위한 국제 프로그램에 적극 동참하게 될 것이다.

지금까지 알려진 기후변화의 원인과 지구평균기온 변화 추세, 한반도 평균기온변화 등 한반도 기후변화 영향에 대하여 다시 짚어보고, 현재 기상청에서 활용하는 위성영상으로 감시 가능한 대표적 사례 영상에 대하여 다시 살펴보고자 한다.

Climate Change Monitoring in Korean Peninsula Using Satellite Images

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위성영상의 변화탐지를 이용한 황사, 태풍, 가뭄, 산불, 식생변화, 오존변화 등 지구환경변화와 관련된 연구를 할 수 있는 것은 다양하다.

일찍이 기상관측의 중요성에 눈뜬 선진국들은 날로 심해지는 기상재해와 기후변화에 대처하기 위해 차세대 기상위성을 개발하고 있다. 앞으로 기후변화감시를 위한 위성자료의 수요는 늘어날 전망이며, 따라서 위성자료를 지

역적으로 이용하고자 하는 시도 또한 증가할 것으로 예상된다. 이에 대비하여 위성자료 검증·보정 등을 통한 정확도 확보와 활용기술 개발 및 기후변화 대처에 활용 활성화를 통하여 인류의 생존을 위협하는 전지구적 문제의 해결 실마리를 찾을 수 있을 것으로 기대된다. 그러나 보다 심도 높은 연구를 위해서는 다양한 위성관측자료의 수집과 보관, 그리고 다년간의 방대한 위성자료의 축적이 전제되어야 가능할 것이다. 지구온난화의 경제적인 파급효과에 대한 Stern Review(2006년, 스턴 보고서)에 의하면 기후변화에 따른 홍수·가뭄·해수면 상승·빙하 축소·식량생산 감소·생물종 멸종 등으로 인한 경제적 피해가 증가할 것으로 보고 있다.

2009년 하반기에 통신해양기상위성이 발사되면 우리나라는 기상위성 보유국이 되며, 한반도 기상관측에 새로운 지평을 열게 되어, 우리 기상위성이 관측한 시공간적으로 고해상도 위성자료를 이용하여 돌발 위험기상 탐지 능력을 향상시키고 기상예측 능력을 향상시킬 것이다. 나아가 세계 국가들과 위성자료를 공유하여 전지구 기후감시에 기여하고 기상재해로부터 인류를 보호하기 위한 국제 프로그램에 적극 동참하게 될 것이다.

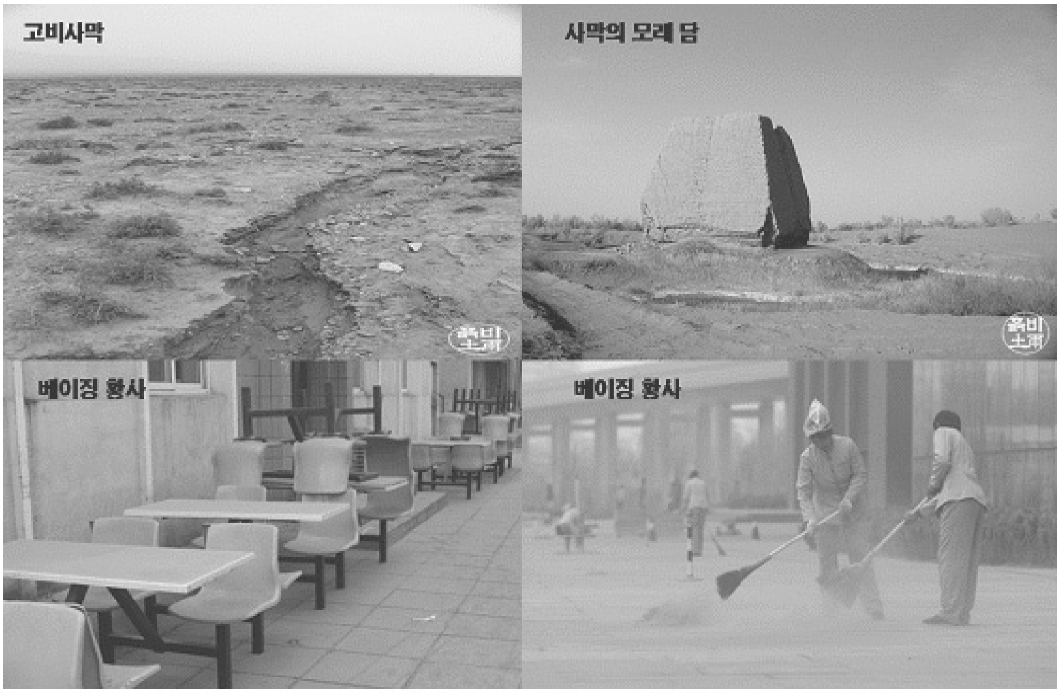
지금까지 알려진 기후변화의 원인과 지구평균기온 변화 추세, 한반도 평균기온변화 등 한반도 기후변화 영향에 대하여 다시 짚어보고, 현재 기상청에서 활용하는 위성영상으로 감시 가능한 대표적 사례 영상에 대하여 다시 살펴보고자 한다.

2. 위성영상 사례

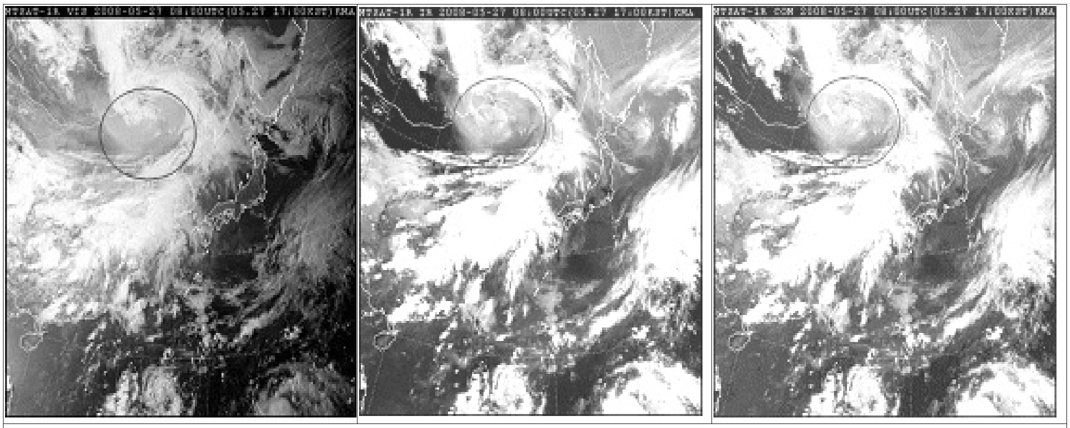
2.1. 황사

황사 발원지

황사 이동 경로

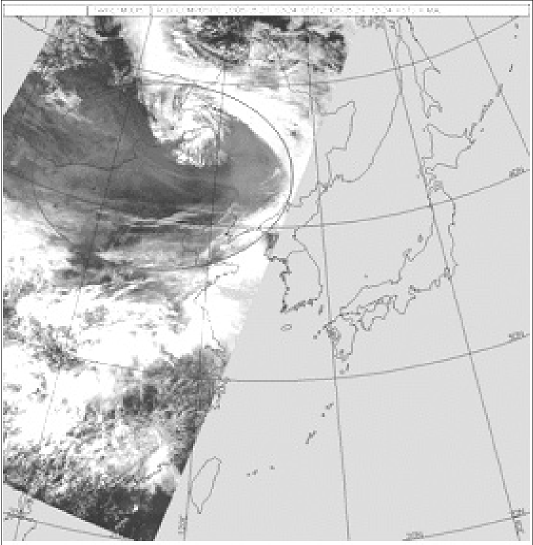


사진으로 본 발원지

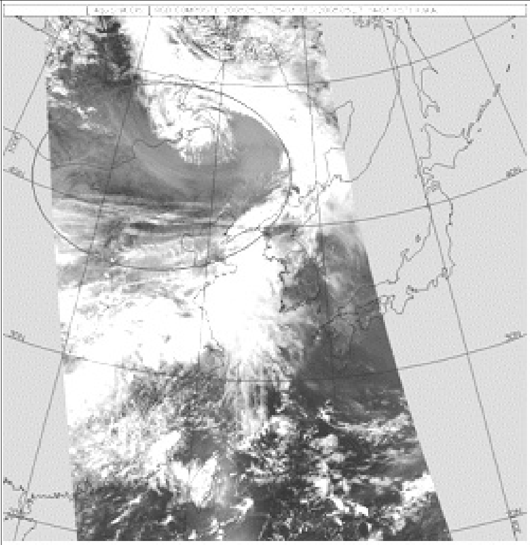


2008. 5. 27. 08:00UTC

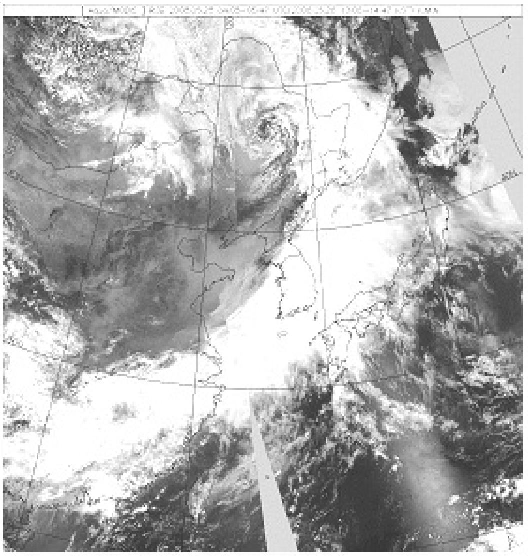
영상별 특성		
가시영상	적외영상	합성영상
밝은 회색 영역(milky gray area or band)으로 나타나며, 뿌옇게 보임(반사도)	적외휘도온도가 지표면보다 낮아 더 밝게 보임	옅은 회색에서 옅은 붉은색으로 나타남



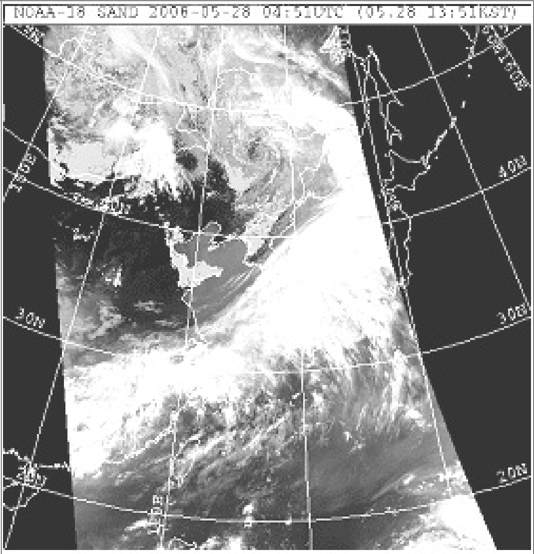
2008. 5.27. 03:24UTC



2008. 5.27. 05:03UTC



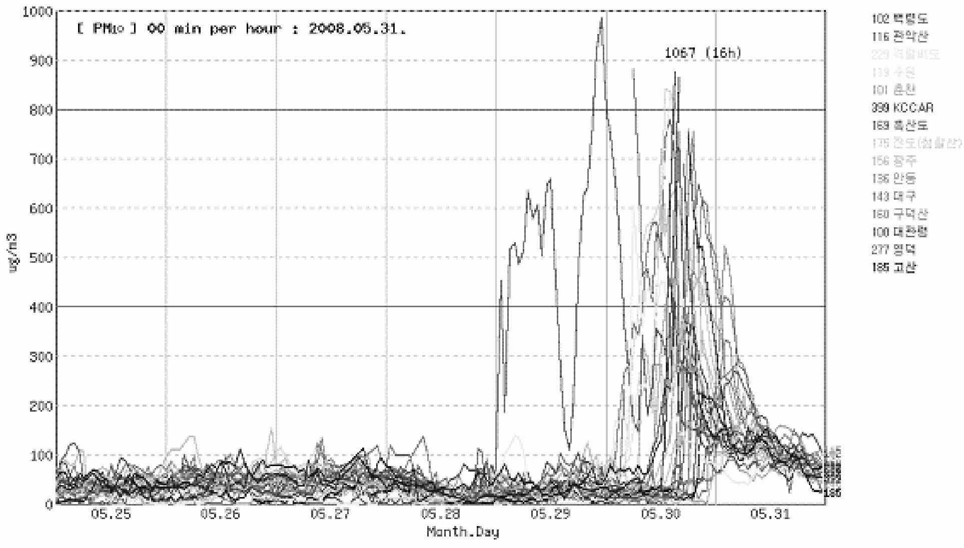
2008. 5.28. 04:08-05:47UTC



2008. 5.28. 04:51UTC

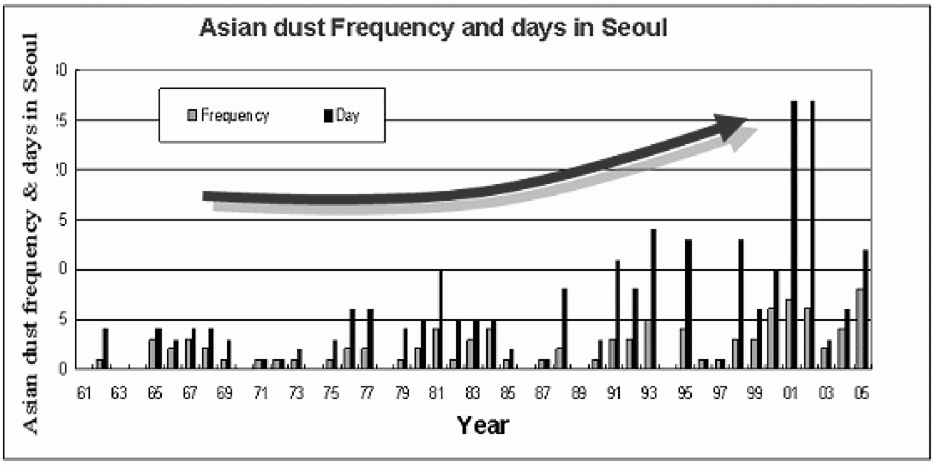
황사감시를 위한 분석에 위성영상을 이용하면 황사 발원 상황 파악, 황사 이동의 연속적 탐지 가능, 황사의 공간분포 파악이 용이한 장점이 있다.

아래 시계열 그래프는 2008 년 5 월 25 일부터 31 일까지 전국의 PM10 관측값을 나타낸 것이다.



PM10 농도 2008. 5. 25~2008. 5. 31

* 우리나라의 황사발생 현황



황사 등 미세 먼지로 인해 피해 : 연간 11 조 8000 억 원 규모
√ 조선업체(100%), 전자업체(70%), 반도체업체(60%) 등
전체의 56.6% 업체가 황사로 인하여 생산활동에 영향과 피해.
(한국환경정책평가원)

황사는 최근 점차 증가 추세에 있으며, 앞으로도 산업화, 자동차 배기가스 증가, 화석연료 사용 증가 등으로 이러한 피해는 점차 증가될 것으로 예측된다. 따라서 발원지의 사막화 확대 등 기후변화감시에 위성 관측자료의 축적이 필요하다.

2.2. 태풍

태풍의 관측은 전세계적으로 아직은 위성에 의존적인 것이 현황이다. 해상에서 주로 발생하는 태풍은 직접 관측이 어렵고, 종관 관측값은 해상 기압경도력에 비해 관측오차가 크다.

위성은 해양을 포함한 전지구를 고루 매시 관측 가능하다는 장점이 있어 태풍을 포함한 넓은 범위를 동영상으로 지속적 감시가 가능하여 매우 유용하다. 현재 기상청에서는 위성을 이용한 선진 태풍분석기법(AODT)을 현업에 적용, 태풍의 종합적인 분석이 가능하여 한번의 중심 결정으로 강도와 중심기압, 중심풍속을 자동 생산하고 있다.

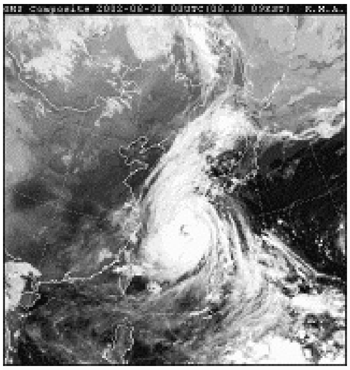
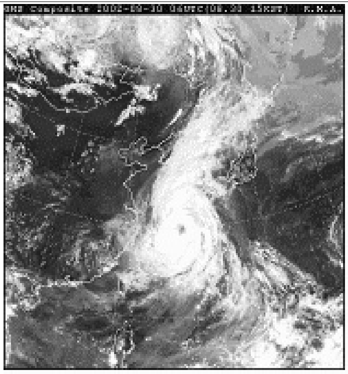
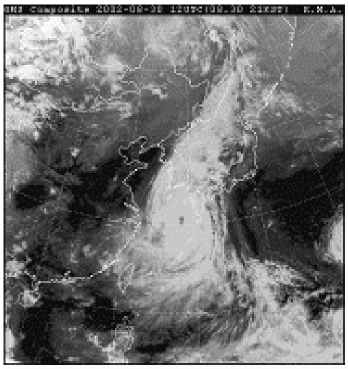
1904년 3월 근대적 기상관측을 시작한 이후 통계에 의하면 한 해에 평균 3개 정도의 태풍이 우리나라에 영향을 미치며, 태풍내습의 최다 월은 8월, 7월, 9월의 순이고, 7월, 8월, 9월 석달 동안에 내습한 태풍 수는 전체의 91%이며, 아주 드물게 6월, 10월에도 내습하는 경우가 있다. 그러나 최근 들어 우리나라에 영향을 주는 태풍의 수는 점차 증가하는 추세이다.

기간	105 년 평균 1904~2008 년	30 년 평균 1971~2000	10 년 평균 1991~2000
우리나라에 영향을 미친 태풍 수	3.1	3.5	3.9

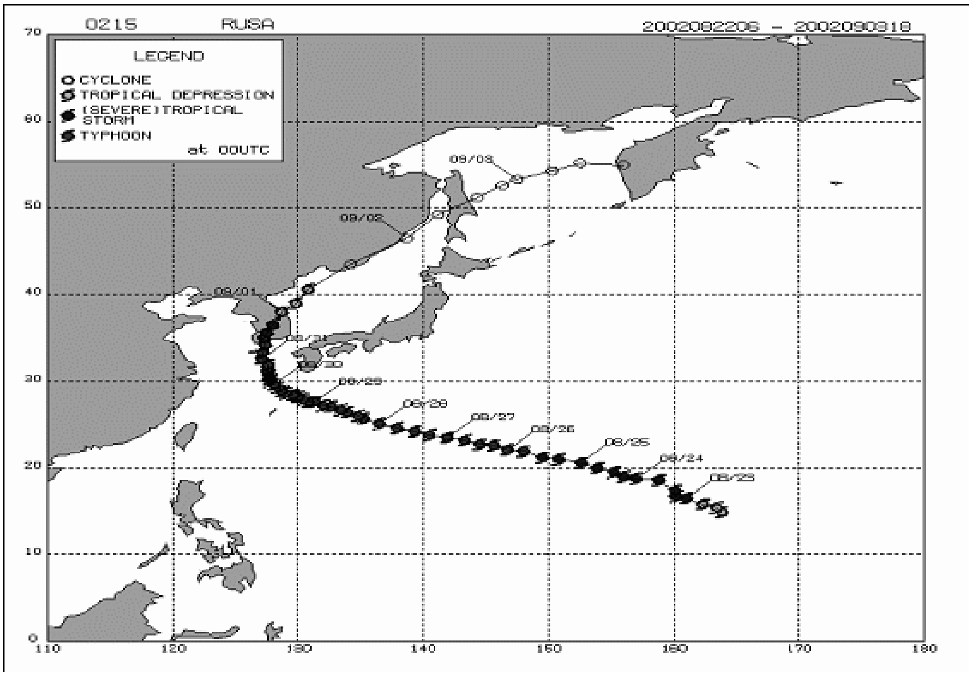
또한 지난 105년(1904~2008) 동안 태풍통과 시 일최다강수량 순위를 살펴보면 5순위까지는 1981년 이후에 모두 나타나 최근 들어 태풍의 영향이 증가하는 추세임을 알 수 있다.

* 태풍통과 시 일최다강수량 순위 (1904~2008)

순위	태풍 번호	태풍 이름	지명	일 최다강수량(mm)	나타난 일자
1	215	RUSA	강릉	870.5	2002. 8.31
2	8118	AGNES	장흥	547.4	1981. 9. 2
3	9809	YANNI	포항	516.4	1998. 9.30
4	9112	GLADYS	부산	439	1991. 8.23
5	711	NARI	제주	420	2007. 9.16.
6	314	MAEMI	남해	410	2003. 9.12
7	7214	BETTY	해남	407.5	1972. 8.20
8	7119	OLIVE	삼척	390.8	1971. 8. 5
9	9907	OLGA	동두천	377.5	1999. 8. 1
10	9507	JANIS	보령	361.5	1995. 8.25

		
2002. 8. 30. 00:00UTC	2002. 8. 30. 06:00UTC	2002. 8. 30. 12:00UTC

* 태풍 RUSA(0215) 2002.08.31~2002.09.01



○ 강릉

- 일 강수량 년강수량(1401.9mm)의 62%
- 가장많인 내린 달(8 월 평년값 288.2mm)의 3.3 배
- 누적 강수량 : 898.0mm ,
- 일강수량(8/31) : 870.5mm
- 1 시간 최다강수량 : 100.5mm

○ 인명피해(전국) : 246

○ 재산피해(전국, 2006 년 환산가격 기준) : 5,832,922 백만원

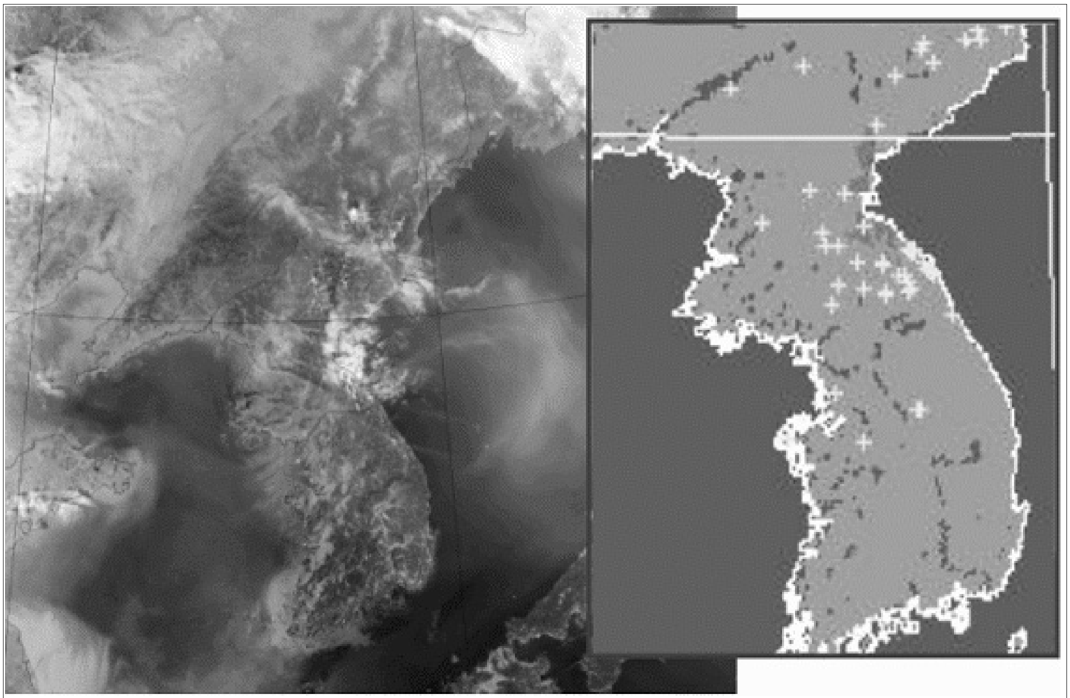
* 근대적 기상관측 시작 이후 우리나라에 영향을 미친 태풍 중 최대 재산피해

2.3. 산불

산불 피해를 최대한 줄이기 위해서는 산불이 발생하면 발원지 위치 및 현재 산불 피해 규모, 진행 방향 및 속도 등의 주요 정보들을 빠르고 정확하게 탐지하여 신속하게 대처하는 것이 중요하다.

일반적으로 산불피해지역의 경우 조사자의 접근이 어려운 험한 산지에서 확산되는 경우가 많고 경제적, 시간적인 면에서 볼 때, 원격탐사에 의한 분석이 효과적인 것으로 평가되고 있다. 국외에서는 위성 영상을 이용한 원격탐사기술을 산불 탐지에 적용하여 많은 효과를 보고 있으며, 산불 지점 분석뿐만 아니라 산불 피해 및 강도 분석을 통한 상세 정보를 실시간으로 제공하고 있다. 기상청에서는 지구관측위성(Terra/Aqua) MODIS(MODerate resolution Imaging Spectro radiometer) 열적외선 채널을 이용한 산불분석영상을 이용하고 있다.

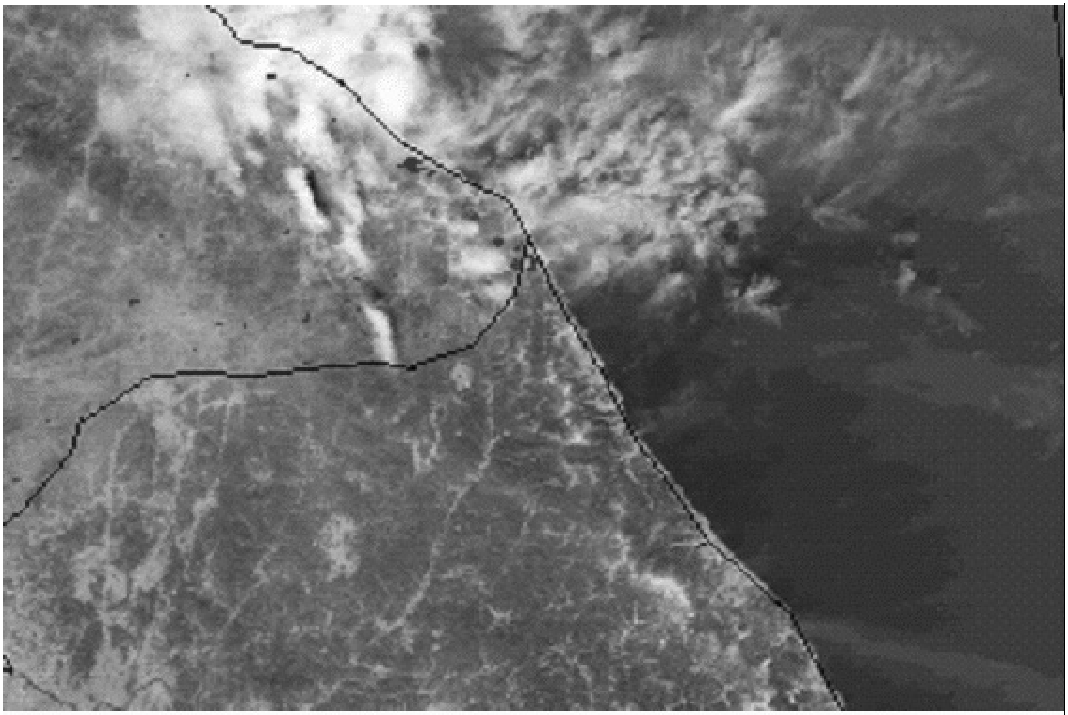
* 기상청에서 수신 처리하여 활용중인 산불분석영상



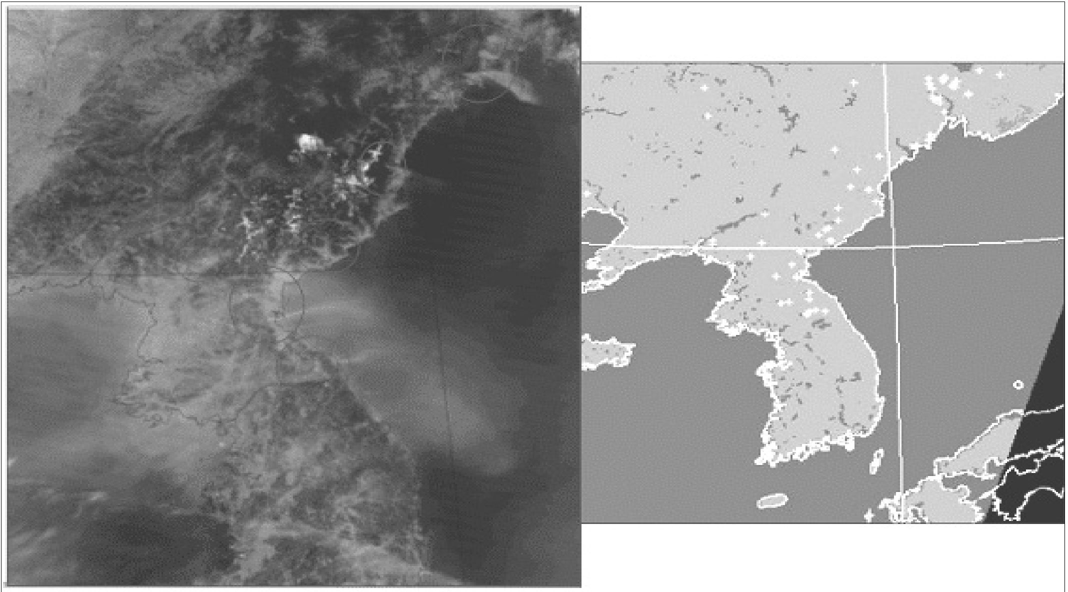
산불분석 주간영상과 산불지점분석 영상
강원 영동 산불 탐지 사례 (MODIS Aqua) - 2005. 04. 05(04:34 UTC)

○ 사용위성자료 : 지구관측위성(Terra/Aqua) MODIS(MODerate resolution Imaging Spectro radiometer) 열적외선 채널 이용
- 36 개 채널중 21, 22, 31 채널 이용함. 수평해상도 1km

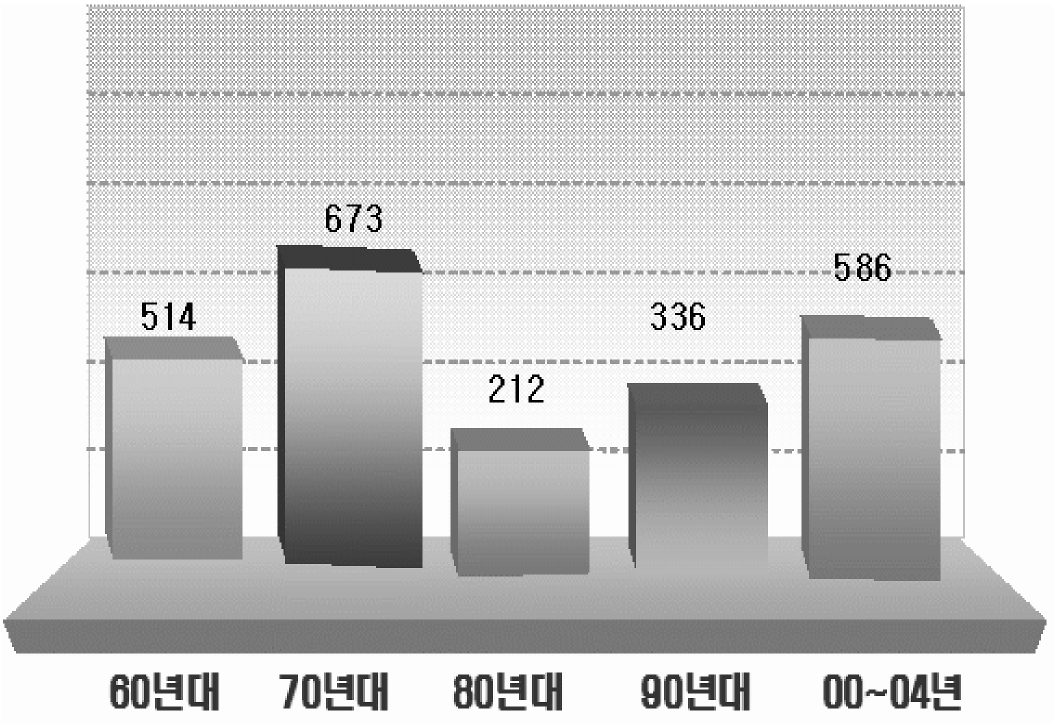
○ 산불탐지 방법 : 열적외선 채널 영상에서 주위화소보다 상대적으로 온도가 높게 올라가는 화소들을 산불 화소로 판단



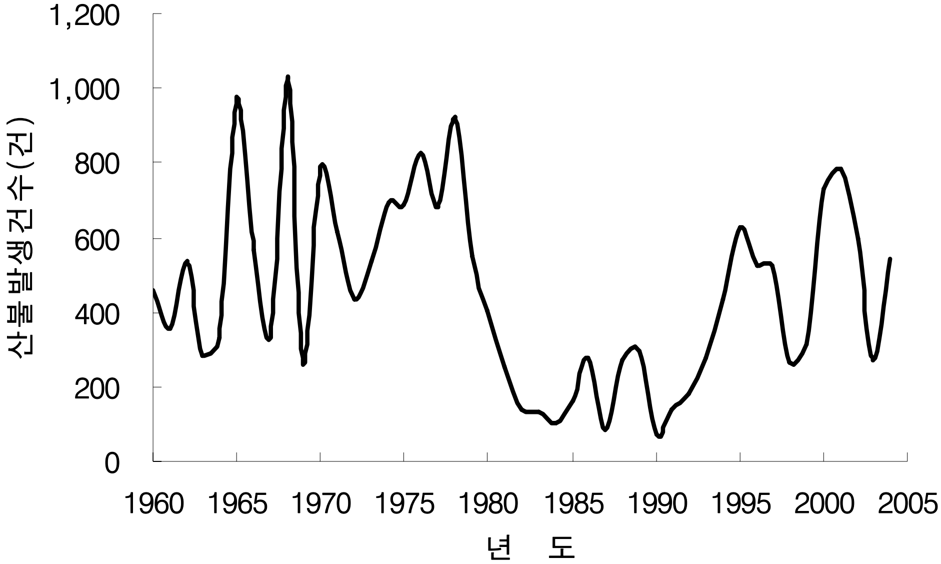
강원 영동 산불 탐지 사례 (MODIS Aqua) - 2005. 04. 05(04:34 UTC)



북한지역 산불 탐지 (MODIS Terra) - 2007. 04. 29(02:46 UTC)


673
514
586
336
212
60년대
70년대
80년대
90년대
00~04년

산불 발생 건수


1,200
1,000
800
600
400
200
0
산불발생건수(건)
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
년 도

우리나라 산불 발생 건수는 1980~1990년 감소되었으나, 1990년 이후 다시 증가되는 추세를 보이고 있다. 앞으로도 향후 10년간 봄철의 기상조건은 더 건조하고, 지구온난화로 온도가 상승할 것으로 전망된다. 산불 피해를 최대한 줄이기 위해서는 대중적인 홍보를 통해 철저한 예방활동을 전개하는 한편, 근원적인 산불발생 요인을 최대한 줄이고 고해상도 위성자료를 활용하는 산불 탐지 및 산불 예보기술에 적극적인 활용이 필요하다.

3. 결론

위성영상을 활용하여 한반도에서 감시 가능한 몇가지 사례를 살펴보았다. 현재 인류에게 닥친 기후변화 영향에 대응하기 위해서 기후변화 감시를 위한 위성관측 자료의 중요성이 강조되어 진다. 또한 다양한 위성자료를 확보하여 축적하고 제대로 활용할 수 있는 고도의 기술력이 요구되며 이 분야에 대한 투자와 연구개발이 매우 중요하다 하겠다.

National Impact of Climate Change on Fire Regimes, Indonesian Report

기후변화가 인도네시아 산불형에 미치는 영향

Bambang Hero Saharjo

Abstract

Forest fire is not new phenomenon for Indonesia as it had been well known since 18 century. Fire frequency tend to increase significantly at 19 and 20 century that finally reach the biggest area burned in 1997/1998 where 10 million ha of forest and land destroyed and predicted release 2.6 Gt. carbon to the atmosphere which put Indonesia as the third rank of Greenhouse Gas producer in the world, where 75 % due to deforestation and land conversion. Forest fire was the significance contributor for deforestation and land conversion which cover 57 % of total deforestation and land conversion. Unfortunately the fire is still moving forward until today which recently dominated in peat land area which actually should be protected even though the frequency was quite decrease during 2007 and 2008 fire seasons.

The newest release report made by Indonesian Ministry for Environment shown that due to global warming there was an increasing of sea water level varies from 1.3 mm/year to 9.37 mm/year. The increasing of sea water level predicted behind of 24 small islands which disappeared during 2004-2007.

Beside that it had been known there was also an increasing of daily temperature that varies from 0.2 °– 1° C. The role of global warming believed is behind of the extremely dry condition and less rainfall during dry seasons which supported by El-Nino. This worse condition finally will create big disaster as it occurred before.

During 2003-2005 about 1,429 disasters occurred, where 53% related to hydro-meteorology. These facts had shown how sensitive Indonesia to the global climate change which supported by one significance contributor that usually occurs every year that is forest fire.

요 약

인도네시아에서 산불은 18세기 이래로 잘 알려져 있는 것처럼 더 이상 새로운 현상이 아니다. 화재 빈도는 19세기와 20세기에 두드러지게 증가하였다. 이것은 결국 1997/1998년에 숲의 1천만 ha 라는 대규모 지역을 태워 토지를 파괴시키고 2.6 Gt. 탄소가 대기 중에 방출되는 결과를 가져왔다. 이로써 산림 벌채와 토지 전환의 75%를 차지하는 인도네시아는 온난화가스 발생량 세계 3위에 올랐다. 산불이 산림벌채와 토지전환의 주요 원인으로써 총 산림 벌채량 및 토지전환량의 57%를 차지한다. 2007/200년의 화재 계절 동안 빈도가 꽤 줄어들긴 했지만, 불행히도 산불은 현재에도 여전히 그치지 않고 빈번하게 발생하여 최근에는 적극적으로 보호해야할 이탄토 지역을 위협하고 있다.

인도네시아 환경부에서 나온 최근의 보고서에 의하면, 바다 수위가 지구온난화 때문에 원래 1.3mm/year 에서 9.37mm/year 으로 높아졌다고 한다. 2004년에서 2007년 사이 24개의 작은 섬들이 사라진 배경은 이 해수면 수위의 증가였다.

한편 온도 또한 0.2℃ 에서 1℃ 정도 높아졌다고 한다. 엘니뇨에 의해 지속되는 건기 동안의 극도로 건조한 상황과 적은 강우량 역시 지구온난화 현상에 의해 생긴 일이라고 할 수 있다. 이 최악의 상황은 결국 예전에 일어났던 것과 같은 대재앙을 불러일으키는 결과를 가져올 것이다.

2003년에서 2005년 사이 총 1429개의 재앙이 발생하였다. 그 중 53%는 수문기상학과 관련이 있다고 한다. 이러한 사실들은 인도네시아가 세계 기후의 변화에 얼마나 민감한지를 보여주었다. 이러한 변화의 주된 원인은 주로 매년 발생하는 산불이다.

National Impact of Climate Change on Fire Regimes, Indonesian Report

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Abstract

Forest fire is not new phenomenon for Indonesia as it had been well known since 18 century. Fire frequency tend to increase significantly at 19 and 20 century that finally reach the biggest area burned in 1997/1998 where 10 million ha of forest and land destroyed and predicted release 2.6 Gt. carbon to the atmosphere which put Indonesia as the third rank of Greenhouse Gas producer in the world, where 75 % due to deforestation and land conversion. Forest fire was the significance contributor for deforestation and land conversion which cover 57 % of total deforestation and land conversion. Unfortunately the fire is still moving forward until today which recently dominated in peat land area which actually should be protected even though the frequency was quite decrease during 2007 and 2008 fire seasons.

The newest release report made by Indonesian Ministry for Environment shown that due to global warming there was an increasing of sea water level varies from 1.3 mm/year to 9.37 mm/year. The increasing of sea water level predicted behind of 24 small islands which disappeared during 2004-2007.

Beside that it had been known there was also an increasing of daily temperature that varies from 0.2 °– 1° C. The role of global warming believed is behind of the extremely dry condition and less rainfall during dry seasons which supported by El-Nino. This worse condition finally will create big disaster as it occurred before.

During 2003-2005 about 1,429 disasters occurred, where 53% related to hydro-meteorology. These facts had shown how sensitive Indonesia to the global climate change which supported by one significance contributor that usually occurs every year that is forest fire.

INTRODUCTION

Scientific evidence show that forest fire in Indonesia is not new because it had been found that repeated fire had been occurred between 15510 BC and 1650 AD, especially in lowland tropical rain forest in East Kalimantan. Big forest fire for the first time occurred in East Kalimantan in the year 1982/1983 where 3.6 million ha of forest and land burnt, then very year fire blow up with different size and impact. The biggest fire at the 20th century in Indonesia occurred in the year 1997/1998 where 10 million ha of forest and land burnt which caused cost damaged of US$ 10 Billion and environmental impact faced to about 20 million peoples and most of the fires blow up in Sumatra and Kalimantan Island. It was very surprised that most of the fire rooted from arson during dry seasons and it had been investigated that it was come from land preparation of using fire for oil palm and forestry plantation done by companies and local peoples.It has been scientifically demonstrated beyond reasonable doubt that fire has been part of the natural ecosystem in Indonesia for many thousands of years, and burning coal seams have been part of the landscape in that time.

The vulnerability of Indonesian forest is also linked to more fundamental issues of forest management and the role of communities and local governments. There is very little attention given to the existence of local communities living close to the forests, including those that are vulnerable to fire (UNCHS, 1999). Burning for land preparation is banned by law for companies, but since it is cheap and quick, and companies need to achieve planting targets, it is still widely practiced. Although burning increases the amount of nutrients in the soil, which temporarily enhances growth performance, it also has negative effects. It has been found that the smoke of fire rooted from land preparation using fire mostly (60-80%) from an oil palm and industrial forest plantation illegally where rest of it to be believed made by shifting cultivation which unfortunately usually blaming for the smokes occurred. Zero burning policy had been used as a promising solution for reducing smoke which has an implication to reduce greenhouse gasses; unfortunately it was not work because the smoke increased due to high increasing of land conversion activity done for oil palm and industrial forest plantation.

Smoke and "haze" from forest fires produce some of the most visible costs to society. People suffer respiratory problems, which puts pressure on meager medical facilities in many tropical countries. Estimates suggest that between 20 million and 70 million people were adversely affected by smoke from the

Indonesian fires and at least 40,000 people were hospitalized both in Indonesia and neighboring countries (Asian Development Bank, 1999 and Glover and Jessup, 1999). Smoke reduces visibility, provoking transportation accidents and airport shutdowns. This often leads to transboundary smoke pollution, which provokes international indignation (ADB, 1999). It had been found also the flooding area emerges in several districts and regions mostly believed have directly due to the fire done before.

CAUSES OF FOREST FIRES

Land Conversion

It is a common misconception that most land conversion in the ASEAN region involves the clearing of pristine forest (Qadri, 2001). While this may be true in the case of peat swamp forestland, much land conversion in the region simply continues the process of human intervention that began with timber extraction from virgin forestland. According to a recent report, of the total area of about 4.8 million ha consumed by fire during 1994, 88 percent comprised logged-over forests, some of which were under cultivation by traditional dry land agricultural techniques. By contrast, shifting cultivation areas accounted for only 5.3 percent, transmigration farmland 4.5 percent, areas occupied by previously-established plantations only 0.8 percent, and natural protected forests a scant 0.2 percent. The corresponding figures for 1997 (which exclude information for calendar year 1998) tell a similar story. Of the total land area consumed by large-scale fires during that year, logged-over production forest accounted for 62 percent. The reminder comprised the following: national parks, 20.6 percent; protection forests, 8.4 percent; nature reserve, 6.5 percent; and recreation parks, 0.6 percent (MOE/UNDP, 1998).

Observation made during the fires and haze of 1997-1998 and previous cases have indicated that the intensity of the fire in logged areas was directly related to the intensity of logging. Even severe fires did not completely destroy moderately logged stands where, after fire, a few trees with green foliage could still be observed, although spaced and scattered. In heavily logged forest areas, which remaining trees were widely spaced, shrubs had formed a thick ground cover, providing an efficient biomass source for the fires after the extensive drought. Here, the fuel consumption was more complete (BAPPENAS, 1999).The main factors causing increased combustibility are wasteful logging and forest clearance for agricultural crops, estate crops, and forest plantations leading to build up of dry materials. The changing composition of vegetation due to mono-cropping, draining of peat swamps, and mining practices that expose coal deposits also contribute to altering the fuel characteristic (Qadri, 2001). The land clearance and preparation activities influence the volume and condition of the fuel load, serve as the ignition source, and often cause the spread of fire. These activities, in the effect, take advantage of drought conditions created by weather disturbances such as ENSO.

Drought Condition

Indonesia's climate is shaped by the annual cycle of east and west monsoons, which affect rainfall and winds across the archipelago (Qadri, 2001). The major islands and smaller island groups are dominated by a humid tropical climate and rain forest vegetation, although the Lesser Sunda Islands, eastern Java, and small parts of other islands have mild to pronounced rainfall seasons. There are two weather phenomenon considered to be crucial to the spread of forest fires and haze (Qadri, 2001). The first is recurrent ENSO conditions, bringing extraordinarily dry weather to the region (and in the process, creating conditions ideals for disposing of biomass residue by open burning). Prolonged drought in Indonesia occurs at least once every 10 years. Data on rainfall in Bali, Java, Kalimantan, Sulawesi, and Sumatra, since the early 1900s show that prolonged drought occurred 17 times during the century, of which 11 corresponded with an *El Nino.* When the dry season in Indonesia occurs at the same time as an *El Nino ,*the result is a prolonged drought, which extends from June to November and can continue until May of the following year. The second weather factor is that in geographic areas that lie close to the equator, there is relatively little wind. This means that in the ASEAN areas where land conversion is in progress, the weather forces that mix (and dilute) the particulate matter from land conversion fires with unpolluted air are weak (Qadri, 2001).

In Indonesia, a prolonged drought as a consequence of an *El Nino* has occurred fire times over the last 20 years. This had varying effects in different parts of the country, depending on the strength of the El Nino and the monsoon winds sweeping past Indonesia. Compared with the previous El Nino years, the once in 1997 had the highest impact on drought and fires in Indonesia. Forest and land fires in 1997 occurred in nearly all provinces.

SOURCES OF FIRES

Illegal Shifting Cultivators

Usually when fire broke up in many provinces in Indonesia, many people's blames shifting cultivator as source of it, because they used fire for land preparation for agricultural purposes. It was proved by jailing three of them in East Kalimantan in 1997 and also in Riau in 1999 and another's six persons in the year 2005. Of course shifting cultivators used a fire for they land preparation, because it was cheap, and easy to do, and it was done for thousands years ago (Goldammer, 1993) without any environmental problems like it happens now. Shifting agriculture systems in their early practice and extends use largely determined by low human population pressure on the forest resources. They provided a sustainable base of subsistence for indigenous forest inhabitants, and their patch impacts had little effects on overall forest ecosystem stability (Nye and Greenland, 1960). By burning they will got a free mineral from ash that rich of organic-carbon, phosphorus, magnesium, potassium, and sodium. The nutritional value increase temporarily after burning, however, because when rainy comes, it will be leached and decline (Garren, 1943; Jordan, 1985 and Saharjo, 1995).The origin of the 1982-83 fire has not been definitely identified, but swidden agriculture has been considered as one of the most plausible sources (Wirawan 1993). Swidden, slash-and-burn or shifting agriculture has been traditionally practiced by rural people in Borneo, as in many other parts of the tropics. With the intention of planting crops at the onset of the rainy season in November and December, they usually start clearing and then burning their fields during the second half of the dry or less rainy period, usually in September and October, while in Sumatra on August to September. The timing of their slash-and-burn practice is well established and is primarily based on the annual variation of the Monsoon.By the way one of the reasons why shifting cultivators activity become environmental problem is because of illegal shifting cultivator did it (Saharjo and Husaeni, 1998). They are not the real shifting cultivators but they are a new comer from other cities or region who never did shifting cultivation and without any experienced. For the real shifting cultivator they are know how to burn and prevent fire jump to other place, for instance using fire breaks and they know also when fire should be put down and stop. This knowledge is not a simple and easy thing to be done quickly by the new comer. Some time they never think about this, then, burn it directly and we can imagine what would happen, burned are become larger and spread everywhere. Some time it takes several days, with black smoke in the sky.

Forest and Oil palm plantation

It was proved that the sources of fires in 1997 forest fires were mostly from land preparation using fire for forest plantation and estate crops. It was shown that 65 % (Anonymous 1998) until 80 % (WWF 1998) of the forest area burned in East Kalimantan was done in the forest concessions and estate crops. This was also supported by the Ministry of Forestry statement which announced the list of 176 companies that suspected burn they land for forestry and estate crops planting. By the way, none of those companies being subject for punishment by the government due to not enough evidence. In the year 1999 it has been known that more than 40 companies in Riau province doing the same things like in 1997/1998 but no punishment. After the year 2000 then forest plantation and oil palm (un or intentionally) and the community with business perspective become the most significant activities produce smoke within the country. Fortunately in the year 2001 an oil palm company finally had been punished, and until the year 2005 at least around 25 companies being investigated for court.The use of fire is officially forbidden although every company uses it, because this is the only viable and economic method of reducing the huge biomass. The underlying cause is, hence, the policy that plans to convert 500,000 ha of forest into plantations every year (Schindler, 1998). The government (CIFOR, 1998) has licensed and stimulated many companies to develop new industrial plantations of rubber, oil palm and pulpwood, as well as transmigration sites. These activities require the clearing of hundreds of thousands of hectares of land, and fires are their cheapest option. The traditional method of claiming forested land as in many parts of the world has been to burn and then plant. It seems likely that migrants, particularly in areas near cites, as well as large government-sponsored agricultural or forestry development programs, are clearing forest to establish land claims.

Logging

Logging activities have greatly increased both fire risk and hazards (Mackie, 1984). Access roads opened up the forests to both immigrant and local people for making field (Wirawan, 1993). By opening up the forest canopy, logging activities have greatly stimulated the growth and accumulation of plant biomass near the ground. Additional dead biomass is also provided by deformed logs and branches left behind by loggers. The failure of the rainy season to arrive on time, as was the case in late 1982, prolonged dry season, dried this plant biomass and then helped the fires started by shifting cultivators in September or October to spread wildly unchecked for several months until heavy rain fall in May 1983. As a result, 70 % of the burned forest in East Kalimantan, occurred in the logged-over forest areas (Wirawan, 1993). When logging companies enter into a new area, they automatically bring with them the fire problem. They are opening up the forests and making them more susceptible to forest fires through road, logging waste, bulldozing through the stands and opening up the canopy and finally bringing in people as the source of fire (Schindler, 1998). Fire risk is increased dramatically by the conversion of material forests to rubber and oil palm plantations, and by the logging of natural forests, which opens the canopy and dries out the ground cover. Plantations are drier and trees are move evenly spaced than natural tropical moist forests, thus increasing the opportunities for fire to spread. Evidence also suggests that fires burned mostly easily in secondary forests that had already been disturbed through (frequently illegal) timber operations. Selective logging destroys much of the most undergrowth and the closed canopy that reduces the likelihood and impact of forest fires in natural forests (Dudley, 1998). Fire was used to exploit the natural rain forest especially in Kalimantan by the name of salvage logging. It was realized when fire come to their area and they do not have ability to fight it, resulted in the cleaning of the natural forest from shrubs and grass create a condition which easily entered. Unfortunately the do not cut down the trees burned but also fresh tress which is the main target.

RECENTLY FIRE SITUATION

Based on data made by Department of Forestry (2007), it had been known that until 2006 the increasing of hotspot was very significant as it can be seen that from 8 (eight) fire risk provinces in Indonesia only North Sumatra which produce less hotspot (-6.50%), meanwhile other provinces produce more hotspot that varies from 56.54 % until 1,738.75 % (Table 1). The total forest and land burned during 2006 predicted about 6 million ha.

Table 1. Number of detected hotspot in the period 2005-2006 monitored by Department of Forestry

No.	Province	Number of hotspot detected		
		2005	2006	%
1	North Sumatra	3,380	3,581	-6.50
2	Riau	22,630	35,426	56.54
3	Jambi	1,208	6,948	475.17
4	South Sumatra	1,182	21,734	1,738.75
5	West Kalimantan	3,022	29,266	864.43
6	Central Kalimantan	3,147	40,897	1,199.56
7	South Kalimantan	758	6,469	753.43
8	South Sulawesi	133	1,201	803.01

Fire incident in the year 2006 seems anti climax of fire occurred following 1997/1998 fires which burnt more than 10 million ha of forest and land. To fight forest and land fire during 2006 incident, two BE-200 from Russian help us for suppression activities in Sumatra and Kalimantan and it takes around 100 days, beside that helicopters and other heavy equipment provided by Manggala Agni fire brigade which separated in 30 station at fire risk provinces (under controlled by Department of Forestry) and companies (oil palm and forestry plantation) also involved. Suppression activities during 2006 fire incident led by Coordinator Ministry for Welfare because the fire effects worsen and out of control and transboundary haze pollution occurred. This command system was also based on the standard procedure regarding the fire out of control and trandsboundary haze pollution occurred then the suppression activities take over by National Disaster Management Agency. Department of forestry take responsibility for suppression equipment, human resource, technique and connecting with international community on fire, while Ministry for Environment takes responsibility for advocating and environmental evaluation.

Number of hotspot during 2006-2007 according to the data taken by Department of Forestry (KNLH, 2008) shown that hotspot detected decreased significantly compared to hotspot detected in 2007 at average of 71.39 % (Table 2), while according to the data made by ASMC Singapore the decreasing of hotspot detected was only 49.76 % (Table 3).

Table 2. Number of hotspot detected during 2006 – 2007 taken by Department of Forestry (KNLH, 2008)

No.	**Province**	**Number of hotspot detected**		
		2006	**2007**	**%**
1	North Sumatra	3,581	936	-73.86
2	Riau	11,526	4,169	-63.83
3	Jambi	6,948	3,120	-55.09
4	South Sumatra	21,734	5,182	-76.16
5	West Kalimantan	29,266	7,561	-74.16
6	Central Kalimantan	40,897	4,800	-88.26
7	South Kalimantan	6,469	928	-85.65
8	South Sulawesi	1,201	551	-54.21
	Average			-71.39

Table3. Number of hotspot detected during 2006 – 2007 taken by ASMC Singapore (KNLH, 2008)

No.	**Province**	**Number of hotspot detected**		
		2006	2007	%
A	**Sumatra Island**			
1	Bangka Belitung	953	477	-49.95
2	Bengkulu	233	118	-49.36
3	Nanggroe Aceh Darussalam	336	172	-48.81
4	Jambi	2,617	1,310	-49.94
5	Riau Island	67	34	-49.25
6	Lampung	947	474	-49.95
7	Riau	4,654	2,361	-49.27
8	West Sumatra	361	181	-49.86
9	South Sumatra	5,057	2,532	-49.93
10	North Sumatra	1,015	512	-49.56
	Total Sumatra	**16,240**	**8,171**	**-49.69**
B	**Kalimantan**			
1	West Kalimantan	6,197	3,103	-49.93
2	South Kalimantan	1,079	540	-49.95
3	Central Kalimantan	5,580	2,801	-49.80
4	East Kalimantan	2,842	1,430	-49.68
	Total Kalimantan	**15,698**	**7,874**	**-49.76**
	Total A+B	**31,938**	**16,045**	

Most of hotspot detected in the period of January-December 2007 (Table 4) totally about 10,280 or about 64.07 % was in the community (KNLH, 2008), followed by hotspot detected in the estate crops was 2,644 (16.48%) in the estate crop, in the forest concession was 1,691 (10.54 %) and in the forest plantation was 1,430 (8.91 %).

Table 4. Number of hotspot detected during January-December 2007 according to land use (KNLH, 2008)

No.	Province	Forest concession	Forest plantation	Estate crop	Community	Total
A	**Sumatra Island**					
1	Bangka Belitung	0	0	0	477	477
2	Bengkulu	2	0	13	103	118
3	Nanggroe Aceh Darussalam	7	15	23	127	172
4	Jambi	72	172	119	947	1,310
5	Riau Island	0	0	2	32	34
6	Lampung	0	99	35	340	474
7	Riau	323	422	698	918	2,361
8	West Sumatra	8	1	32	140	181
9	South Sumatra	12	172	136	2,212	2,512
10	North Sumatra	6	23	34	439	512
	Total Sumatra	**440**	**904**	**1,092**	**5,735**	**8,171**
B	**Kalimantan**					
1	West Kalimantan	350	271	675	1,807	3,103
2	South Kalimantan	74	51	36	379	540
3	Central Kalimantan	598	91	430	1,682	2,801
4	East Kalimantan	229	113	411	677	1,430
	Total Kalimantan	**1,251**	**526**	**1,552**	**4,545**	**7,874**
	Total A+B	**1,691**	**1,430**	**2,644**	**10,280**	**16,045**
	%	**10.54**	**8.91**	**16.48**	**64.07**	**100**

Hotspot detected in peat land during January-December 2007 totally about 3,127 both in Sumatra (2,036) and Kalimantan (912) or about 20.05 % compared to the all hotspot detected, 16,045 (KNLH, 2008) . Hotspot detected in mineral soil totally about 12,828 both in Sumatra (5,866) and Kalimantan (6,962) or about 79.95 % compared to the all hotspot detected (Table 5).

Table 5. Number of hotspot detected in peatland during January-December 2007(KNLH, 2008)

No.	Province	Peat land	Mineral soil	Number	%
A	**Sumatra Island**				
1	Bangka Belitung	31	446	477	5.84
2	Bengkulu	3	115	118	1.44
3	Nanggroe Aceh Darussalam	44	128	172	2.11
4	Jambi	109	1,201	1,310	16.03
5	Riau Island	6	28	34	0.42
6	Lampung	73	401	474	5.80
7	Riau	1,242	1,119	2,361	28.89
8	West Sumatra	41	140	181	2.22
9	South Sumatra	580	1,952	2,532	30.99
10	North Sumatra	176	336	512	6.27
	Total Sumatra	**2,036**	**5,866**	**8,171**	
B	**Kalimantan**				
1	West Kalimantan	420	2,683	3,103	39.41
2	South Kalimantan	75	465	540	6.86
3	Central Kalimantan	293	2,008	2,801	35.57
4	East Kalimantan	124	1,306	1,430	18.16
	Total Kalimantan	**912**	**6,962**	**7,874**	
	Total A+B	**3,127**	**12,828**	**16,045**	
	%	**20.05**	**79.95**	**100**	

EFFORTS TO REDUCE THE FIRES

It was found that Indonesian forest fire management lacked useful data rooted through forest fire research, making effective action against forest fires very weak. There was also a weakness in the interest of the people who working in the forest plantations and agricultural activities such as rubber and oil palm plantations that use fire in land preparation without any clear guidelines. There is no alternative solution for shifting cultivators who have been using fire for land clearing for thousand of years. There is also a loss of control from the government side which causes rules and laws become absurd. This situation has remained for a long time, even there were a large forest fires in 1982/1983 which destroyed 3.6 million ha. Unfortunately forest fires have occurred every year from small to large scales as happened in 1994, destroying 5.4 million ha of forest and land. Shifting cultivation and El-Nino would be blamed for those fires, without any clear solution on how to solve the problem. To solve this problem through law enforcement, education and technique then Indonesian government fight the fires.

Law

Through law enforcement, land and forest fires tried to be reduced. Beside Indonesian Law No.23 regarding Environmental Management announced in the year 1997, Law No.41 about Forestry that announced in the year 1999 there was also another Government regulation and Law that produced until the year 2005. It was such Government Regulation No. 4 regarding Destruction and Pollution Management Related with Land and Forest Fires that announced in the year 2001, Indonesian Law No.18 regarding Estate Crops and Government Regulation No.45 regarding Forest Protection that both announced in the year 2004. The results of those regulation give a significant results when for the first time an oil palm Estate Manager found guilty of using fire for the land preparation that proved by fire expert witness which then send him to the jail and finalty for US$ 1.1 Million. Following this case now at least 50 cases not only from oil palm but also from forest concession and forestry plantation being processes to go to the court.

Technical

Through those regulations also now the companies and ministry of forestry fight the fires based on their own responsibility using simple and high technology with the main purpose to protect their asset from fire invasion rooted from un or intentionally. In July 2002 the forest fire control brigade named ‘Manggala Agni’ was established under Ministry of Forestry. This Manggala Agni is an institution facilitated with personnel, equipment and budget to perform the function and tasks of prevention, suppression and post-suppression of forest fire. The fire brigade is attached to the MoF with a single command line under the Director General of Forest Protection and Nature Conservation down to its Technical Executing Unit at Natural Resource Management Unit. Until today 30 fire brigades had been established at eight fire prone provinces including North Sumatra, Riau, Jambi, South Sumatra, South Kalimantan, West Kalimantan, Central Kalimantan and South Sulawesi. This fire brigade is supplied with forest fire equipment including hand tools, water pumps, mechanical tools, communication and transportation facilities, logistic and medical.

Education

Fighting fires are not only through law enforcement and equipment but also through human education. Most of the fires in Indonesia rooted from human intervention with certain purpose some time not. For the local people nowadays Community Development (CD) program become very important on how to facilitate the community for not using fire through productive activity. The program directly focused on how to reduce fuel load that usually burned but getting benefit from it without burning.Another important aspect also regarding the role of human in preventing fire is through training. The training could be given to the company staff, local peoples and to the decision makers with different purpose and responsibility.

CONCLUSION

Most of the hotspot detected during January-December 2007 trend to decreased significantly (71.39 %) and it was located in the area belongs to the community that was about 64.07 % which means that the sources of the fire significantly different compared to the forest and fire incidents before. This situation means that the community base fire management should be put in the first priority and without any clear command during fire incident will increase the hotspot as it occurred before.

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CLIMATE CHANGE IMPACTS ON FOREST ECOSYSTEMS IN KOREA AND NEEDS OF PROACTIVE ADAPTATION MEASURES

우리나라 산림생태계의 기후변화 영향과 전진적 적응대책의 필요성

Lim, Jong-Hwan

Abstract

Recent global warming seems to be dramatic and has influenced forest ecosystems. Obvious changes in phenology of biota, species distribution range shift, and catastrophic climatic disasters due to recent global warming have been observed during the last century. Korean forests located mainly in the temperate forest zone have also experienced climatic change impacts including shifting of leafing and flowering phenology, changes in natural disasters and forest productivity. However little research has been conducted on the impact of climate change and basic long-term and integrative data are rare for the forest ecosystems in Korea to assess the impact and to establish practical adaptation measures. Even though these uncertainties remained we need to prepare proactive adaptation measures to the anticipated climate change because of the long life-time characteristics of trees and forests. According to the projected climate change scenarios, Korean climate will be warmer rapidly and more rainfall with seasonal differences and rise of atmospheric CO2 concentration. When we recognize that Korea is a peninsula with complex topography, monsoon climate with heavy rainfall and typhoons in summer, and age classes of forests are concentrated on 20-40 years, climate change will affect on biodiversity, forest health and disasters including landslides by heavy rainfall and big forest fires due to the accumulated fuels on site by forest growth and occasional drought events. I reviewed global warming effects on Korean forest ecosystems, and suggested several adaptation measures including restoration activities to conserve biodiversity, to maintain forest health and productivity.

요 약

최근의 지구온난화 현상은 급진전하고 있으며 산림생태계에도 많은 영향을 미쳐 온 것으로 보인다. 지난 세기에 지구온난화와 함께 생물들의 생물계절, 종 분포범위 이동 및 급작스런 기상재해 등에 있어 분명한 변화가 있었다. 우리나라 산림은 주로 온대림지역에 위치하고 있으면서 잎과 꽃이 피는 시기의 변화, 자연재해 및 산림생산성의 변화 등을 포함하여 기후변화의 영향을 받아왔다. 그러나 우리나라에서는 기후변화의 영향을 가늠하고 적응전략 수립에 필수적이라 할 수 있는 산림생태계의 영향에 관한 연구와 장기적인 자료축적이 미흡하였다. 비록 이러한 불확실성들이 있다고 하더라도 수목과 산림의 장기적인 특성을 감안한다면 향후 예상되는 기후변화에 대응한 전진적 적응조치를 마련하여야 한다. 기후변화시나리오에 따르면 우리나라는 대기 중 이산화탄소농도 및 강수량 증가와 더불어 빠른 기온상승 그리고 계절적인 차이도 예상된다. 우리나라가 지형이 복잡한 반도이며 여름철 많은 강수와 태풍이 있는 몬순기후라는 특성, 그리고 산림 영급이 20-40년생에 집중되어 있다는 점 등을 고려하였을 때, 기후변화가 생물다양성, 산림건강 그리고 여름철 강수증가에 따른 산사태, 그리고 산림발달에 따른 임내 연료량 증가와 간헐적인 가뭄현상 등에 따른 대형산불피해 등과 같은 재해에 많은 영향을 미칠 것으로 예상된다. 여기에서 기후변화가 우리나라 산림생태계에 미치는 영향에 대하여 고찰하였고 생물다양성 보전을 위한 복원사업, 산림건강성과 생산성 유지증진 등 전진적인 적응대책을 제시하였다. 특히 온실가스 저감과 기후변화 적응의 2가지를 모두 달성하는 산림복원사업에 대하여 논의하였다.

CLIMATE CHANGE IMPACTS ON FOREST ECOSYSTEMS IN KOREA AND NEEDS OF PROACTIVE ADAPTATION MEASURES

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Abstract

Recent global warming seems to be dramatic and has influenced forest ecosystems. Obvious changes in phenology of biota, species distribution range shift, and catastrophic climatic disasters due to recent global warming have been observed during the last century. Korean forests located mainly in the temperate forest zone have also experienced climatic change impacts including shifting of leafing and flowering phenology, changes in natural disasters and forest productivity. However little research has been conducted on the impact of climate change and basic long-term and integrative data are rare for the forest ecosystems in Korea to assess the impact and to establish practical adaptation measures. Even though these uncertainties remained we need to prepare proactive adaptation measures to the anticipated climate change because of the long life-time characteristics of trees and forests. According to the projected climate change scenarios, Korean climate will be warmer rapidly and more rainfall with seasonal differences and rise of atmospheric CO2 concentration. When we recognize that Korea is a peninsula with complex topography, monsoon climate with heavy rainfall and typhoons in summer, and age classes of forests are concentrated on 20-40 years, climate change will affect on biodiversity, forest health and disasters including landslides by heavy rainfall and big forest fires due to the accumulated fuels on site by forest growth and occasional drought events. I reviewed global warming effects on Korean forest ecosystems, and suggested several adaptation measures including restoration activities to conserve biodiversity, to maintain forest health and productivity.

1. INTRODUCTION

According to the IPCC 4th assessment report, the earth's climate has warmed by 0.74℃ over the past 100 years with about a 10-25cm rise of sea level, compared with that of the pre-industrial era (IPCC, 2007). Besides many recent worldwide natural disasters due to catastrophic weather events, Korea has also experienced frequent disasters; i.e., a big forest fire in the east-coastal region in 2000, severe drought in spring of 2001, heavy rainfall accompanying landslides by typhoon Rusa in 2002, a warm winter in 1988, etc. By mid-year 2006, two extreme weather events were recorded; the heaviest snowfall in Busan on March, and the hottest air temperature in April at 40 cities since the beginning of Korean meteorological measurements in 1904. The annual mean temperature of Korea has risen about 1.5℃ since 1912, and the Korean climate has warmed about 0.9℃ when we assume that the urbanization effect is about 30% and offset it. In particular, low temperatures in winter increased more than summer highs, and the intensity of precipitation (the amount per event) increased while precipitation frequency decreased (Kwon, 2003).

IPCC (2007) predicted that global averaged surface temperature will rise by 1.1-6.4℃. These projected changes are considered to be very rapid and to be non-uniform in time and space. The IPCC models projected spatially different patterns of mean temperature increase and annual precipitation change by regions, a decrease in diurnal temperature range in many areas (with nighttime lows increasing more than daytime highs), a general decrease of daily variability of air temperature in winter, and increased daily variability in summer for Northern Hemisphere land areas. Moreover, the amplitude and frequency of extreme precipitation events is very likely to increase, leading to more frequent floods, landslides with loss of life, property damage, loss of infrastructure and settlements, human health impacts, etc. (IPCC, 2001).

The impacts of global warming on forests can, in turn, influence the global climate system by feedback mechanisms involving changes in albedo, evapotranspiration, concentration of greenhouse gases, etc. Furthermore, forests directly affect climate on local, regional and continental scales by influencing ground temperature, surface roughness, cloud formation and precipitation. Thus adaptation activities in forest sector are much more important due to the linkage with mitigation of warming and reduction of CO_2 emission at the same time.

2. LONG-TERM MONITORING AND INTEGRATIVE FOREST ECOSYSTEM STUDY

Korea Forest Research Institute has established three long-term ecological research sites; Gwangnung Experiment Forest (GEF) in the central subzone of the cool temperate forest zone, Mt. Gyebangsan Forest (GBF) in the northern subzone of the cool temperate forest zone, Mt. Geumsan Forest (GSF) in the warm temperate forest zone and Mt. Hallasan in Jeju island. At the sites, we aimed to monitor long-term changes of the forest ecosystem processes including energy flux, water and nutrient cycling, forest stand structure and biological diversity including plants, vertebrate (birds, mammals), invertebrate (in soil, on forest floor, on air, in canopy, in stream water) and microbes (plant disease, mushrooms, lichens). We are developing forest dynamics models to quantify carbon/nutrient budgets and fluxes among forest ecosystem compartments and to integrate ecological data using GIS-assisted system.

Interdisciplinary forest ecosystem research by the union of long-term ecological research program of KFRI and flux research programs at the same site of Gwangneung forest resumed in 2004. This included the construction of one more flux tower (the second tower, ST) to better capture the heterogeneities of the site of complex terrain and to supplement the measurement at the main tower (MT). Researchers with widely varying expertise joined the projects including GIS/RS, soil sciences, forest hydrology, forest ecology and dynamics, stable isotopes, and ecosystem modeling.

3. CLIMATE CHANGE EFFECTS ON FOREST ECOSYSTEMS

Many studies showed ecological responses to changes of regional climate, particularly increases in temperature. Such observed changes include:

1) Changes in timing of biological events (phenology)
2) Changes in species distribution ranges
3) Increased frequency and intensity of outbreaks of pests and diseases
4) Changes in species composition of communities
5) Changes in the ecosystem services including clean water, resources provision and tourism.

As a result of many long-term phenological data sets, especially in Europe and North America, it is evident that phenological trends respond to climate change. Common changes in the timing of spring activities include plant leaf unfolding, flowering, breeding or arrival of birds, spawning of amphibians, appearance of butterflies, etc. In Mt. Gyebangsan, the degree of leafing for 3 tree species including *Quercus mongolica* was observed and compared with the spring temperature (Lim and Shin, 2004). The relationship of leafing and spring temperature was very close. Leafing time of several tree species became 5-7 days earlier by 1℃ increase in United Kingdom (Sparks and Carey, 1995). Root et al (2003) using more than 10 years of data, analyzed observations on species and global warming, and estimated means of phenological shifts separately for invertebrates, amphibians and birds, and for trees and other plants. Means, except for trees, clustered around an earlier shift of 5 days per decade, but trees were 3.0±0.1 days per decade. Mean shifts at latitudes from 50 to 72° were 5.5±0.1 days/decade earlier while at latitudes from 32 to 49.9° were 4.2±0.2 days/decade. Menzel and Fabian (1999) reported that the growing season expanded 3.6 days/decade during the past 50 years. These results indicate that many species have some capacity to respond rapidly to climate changes by altering the timing of life-history events. However, timing of life-history events depends on factors besides temperature, and a shift in phenology may disrupt important correlations with other ecological factors. Plant-animal interactions such as pollination and seed dispersal depend on synchrony between species. For many systems, species will respond to climate change at similar rates and maintain synchrony (Buse and Good, 1996), whereas for other species the loss of synchrony may have detrimental effects. In the Netherlands, warmer springs have resulted in a mismatch between the time of peak availability of insects and the peak food demands of nestling Great tits (Visser et al. 1998).

Climate is an important determinant of geographic range for many species. Recent northward movements of species' range boundaries consistent with warming have been observed in birds (Thomas and Lennon, 1999), mammals (Payette, 1987), and butterflies (Dennis, 1993; Parmesan et al., 1999). Parmesan et al. (1999) examined changes in the northern range boundaries of 52 species of European butterflies over the past 30-100 years, and found that 34 species shifted northward, 1 species southward and 17 species unchanged.

Air temperature in mountain regions changes with elevation at about 1℃ per 160 m and changes with latitude at about 1℃ per 150 km (IPCC, 1996).

Grabherr et al. (1994) surveyed montane plants on 26 mountain communities in the Swiss Alps and compared species distributions to historical records. The rate of upward shift was estimated to be 1-4 m per decade. These movements were slower than the 8-9 m per decade expected based solely on the change in mean temperature over the last 90 years. In Korea, using the scenario of climatic warming 2℃ by 2100, the shifts of the potential ranges of the several native trees including *Camellia japonica* which is an evergreen broadleaved tree, *Q. mongolica* and *Abies nephrolepis* were predicted based on the thermal ranges of the species (Lim and Shin, 2005). The predicted changes of distribution ranges were dramatically toward northward in latitude, and toward the top of the mountains. Distribution ranges of the trees in the warm temperate forest zone, such as *C. japonica* were predicted to expand about 2 times, and extend 100m higher in elevation (Lim and Shin, 2005). Trees of the cool-temperate forest and sub-alpine forest zones were predicted to become confined to half of the current potential ranges. Since forests in Korea are located mainly on the mountainous area, altitudinal shifts of the distribution ranges are also important factor. Thus the vegetation in the sub-alpine zone will be mostly vulnerable. Priority should be given to the conservation of the high mountains vegetation and species of the habitat ranges in anticipation of significant global warming. Recent Korean fir forest decline in Mt. Halla, has been accelerated by water stress due to the imbalance between water requirement and supply from roots in winter and spring which was primarily caused by climatic warming in Jeju Island (Lim et al 2006, Woo et al 2008). Kong (2005) suggested some plant species vulnerable to global warming using a climatic indicator of high summer temperature in Korea. The author mentioned the further research on bioclimatic ranges and adaptation abilities of plant species would be required to assess the possible impacts of climatic warming.

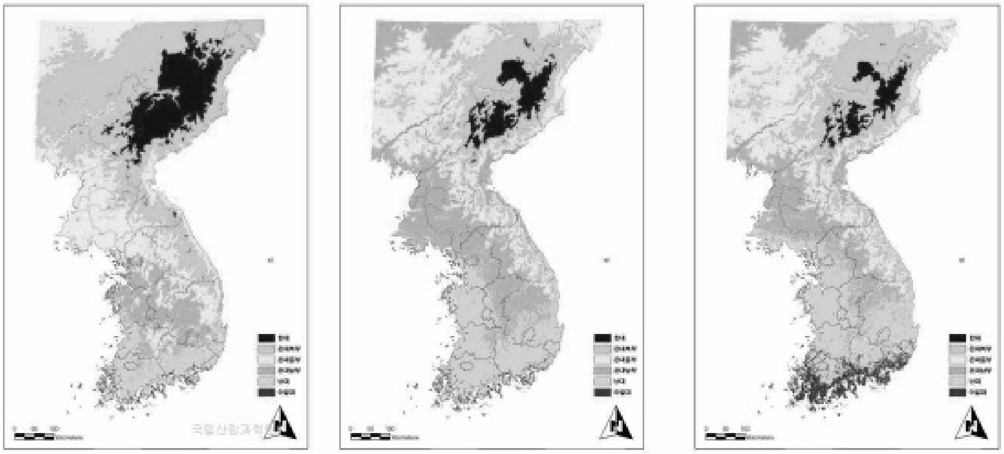

Figure 1. Projected changes of potential forest vegetation zones in Korea by increases of mean air temperature (left: present climate, center: 2℃ increase, right: 4℃. Increase).

Other montane habitats may also be showing the effects of climatic change. Dieback of montane trees (Hamburg and Cogbill, 1988; Fisher, 1997) is consistent with the effects of warmer climate. We feel that the alpine and sub-alpine forests are vulnerable to global warming and that communities should be monitored and conserved.

Figure 2 shows a recent increase of forest area disturbed by forest fire and landslide in Korea. It is possible that these extreme climate-related events were driven by erratic conditions associated with early stages of ongoing global warming. The recent tendency of frequent climate-related disturbances is worldwide (IPCC, 2001). I plotted landslide area in Korea against annual precipitation, and we can find the high limitation line in Figure 3. However, the plotted landslide area in 2002 was out of the trend line due to destruction by heavy rainfall that accompanied typhoon Rusa. The typhoon impacted the same area previously burned by a big forest fire in 2000, and showed an amplified effect.

The changes in disturbances would be important in sense of adapting to anticipated climate change and maintaining the forest as a carbon reservoir. Carbon stored in forest ecosystems could be lost as forests transit from one type to another under a changing climatic condition. Moreover, the raised air temperature accelerates soil respiration rate and may contribute to enhancing the greenhouse effect. Using a process-based simulation model, changes of species composition and biomass were simulated for central cool-temperate forest zone in Korea. It was predicted that biomass production would be increased and *Pinus koraiensis* and *Q. mongolica* would be replaced with *Q. serrata, Carpinus laxiflora and C. tchonoskii* in a 1℃ warmer climate. However, biomass production would be decreased in a 2℃ warmer climate (J-H Lim, unpublished data).

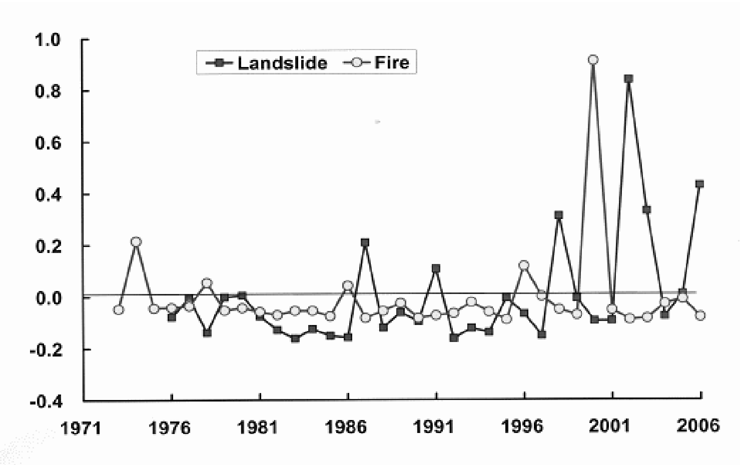

Figure 2. Changes of forest area disturbed by landslide and forest fire in Korea. Y axis is anomaly standardized as (Xi –Xmean)/(Xmax-Xmin). Forest fire areas were from Korea Forest Service (2008) and landslide area from internal data of Korea Forest Service.

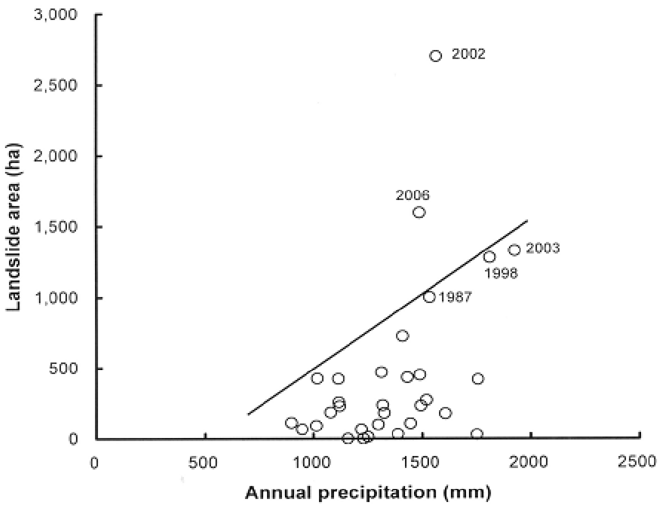

Figure 3. Relationship between annual precipitation and landslide area in Korea. In 2002, typhoon Rusa with heavy rainfall destroyed the previously damaged area by a big forest fire in 2000 and multiple heavy rainfalls in 2006.

4. ADAPTING TO CLIMAE CHANGE BY PROACTIVE FOREST MANAGEMENT

Korean Peninsula is located on the north eastern side of the Asian continent, stretching down from the northern continent to the south. The main mountain ridge, so-called the BDMS, also stretches from north to south with mountain ridges branched to it. As the land stretches from north to south along with its complex topographical features and adjoins the ocean, Korea shows wide variations in temperature and precipitation. Even though the population density is very high, about 64% of the national territory is covered with forests due to the characteristic complex topography. According to the projected climate change scenarios, Korean climate will be warmer rapidly and more rainfall with seasonal differences and rise of atmospheric CO_2 concentration. When we recognize that Korea is a peninsula with complex topography, monsoon climate with heavy rainfall and typhoons in summer, and age classes of forests are concentrated on 20-40 years, climate change will affect on biodiversity, forest health and disasters including landslides by heavy rainfall and big forest fires due to the accumulated fuels on site by forest growth and occasional drought events as reviewed above. Thus I would like to suggest some adaptation measures as follows:

- Enhancement of ecological networks by effective designation and management of Forest Protected Areas
- Conservation of rare and endangered plant species and ex-situ conservation of useful genetic resources including alpine and sub-alpine plants
- Establishment of effective control system and mapping of forest hazards
- Forest practices to reduce the risks of big fire and outbreaks of pest and disease
- Enhancement forest health by increase of forest types and age-class diversity in forested landscapes
- Appropriate species selection for the success of regeneration and maintain productivity considering fast changing climate through the rotation period
- Ecological restoration of degraded forest ecosystems

Among them, I would like to emphasize on the forest restoration activities especially major two forest ecosystem networks, Baekdudaegan Mountains

System (BDMS) and the De-militarized Zone (DMZ) which have synergistic effects of adaptation and mitigation to climate change as well as providing various ecosystem services.

Up until the mid-20th century, undergoing the Japanese colonial period and the Korean War, it's economy was poor condition while the population had been soared leading to a highly populated country, 485 people per km^2 as of 2006. Deforestations and heavy extractions of forest resources were followed. Consequently, the average forest stock volume reached only 10 to 30 m^3/ha leading to the status of open forest and the severe soil erosion had been occurred. Since then, top predators such as tigers (*Panthera tigris altaica*), Amur leopards (*P. pardus orientalis*), and wolves (*Canis lupus coreanus*) have been extinct. Since the 1970s, the growing stock volume has reached as high as 79 m^3/ha due to successful forest restoration and rehabilitation along with poverty reduction and fuel substitution, fire woods to fossil fuels. Throughout the course, the dominant tree species in forests has been changed. As a pioneer species, single pine species *Pinus densiflora* covered over 60% of forest area in the mid-20th century. Afterwards, the coverage shrunk down to 25% in the late 20th century yielding its place to oaks according to natural succession and outbreaks of pests and diseases including pine caterpillar (*Dendrolimus spectabilis*), pine gall-midge (*Thecodiplosis japonensis*), black pine bast scale (*Matsucoccus thunbergianae*).

With rehabilitation and restoration, forest biodiversity is being recovered. According to the annual reports on "Wildlife Population Census in Korea" (National Institute of Environmental Research, 2005), the population of the Japanese pygmy woodpecker (*Dendrocopos kizuki*), pale thrush (*Turdus pallidus*), brown-eared bulbul (*Hypsipetes amaurotis*) and other indicator species has been increased. In a comprehensive manner, a favourable environment for biodiversity recovery has been created according to forest restoration, enlarged Forest Protected Areas, intensified management, spread of ecological management as well as public awareness in natural conservation and the economic growth. However, at the same time, through urbanization and industrialization, some forests have been converted into agricultural land, residential areas, industrial complexes and roads, significantly fragmentizing forests. Agricultural ecosystems face the loss of biodiversity due to broken relationship between human and nature and utilization of pesticides and fertilizers on farm lands. In addition, current forest fires, the torrential rain showers, forest disasters, outbreaks of pests and diseases, and occurrence of invasive species are becoming major threats to the biodiversity and forest health along with upcoming climatic change.

As the "Act on Protection of the BDMS" was enacted in December 2003, and designated the core zones of 1,699 ㎢ and buffer zones of 935 ㎢, totalling 2,634 ㎢ in September 2005. The BDMS Protected Area is designed to connect whole BDMS which is fragmented as islands of mountain-type national parks. For the conservation of biodiversity actively, preventing degradation and ecological restoration on damaged forests are underway along with environmentally friend agricultural practices.

The DMZ between South and North Korea is a 4 km width strip. The region 10 to 20 km south to the DMZ is designated as Civilian Control Zone (CCZ). Since 1953 these areas have been kept intact without people's interference. Therefore, lowland wetlands and rivers that would have been developed into cultivating or housing lands in other regions remain in their natural states in this area. The DMZ and CCZ is serving as habitats and refuges for wildlife animals and plants including rare birds, insects. Recently, active discussions and researches are conducted to protect the DMZ even after reunification.

5. CONCLUSION

According to the projected climate change scenarios, Korean climate will be warmer rapidly and more rainfall with seasonal differences and rise of atmospheric CO2 concentration. When we recognize that Korea is a peninsula with complex topography, monsoon climate with heavy rainfall and typhoons in summer, and age classes of forests are concentrated on 20-40 years, climate change will affect on biodiversity, forest health and disasters including landslides by heavy rainfall and big forest fires due to the accumulated fuels on site by forest growth and occasional drought events. Thus we need to prepare proactive adaptation strategies to minimize the adverse effects of climate change for the conservation of biodiversity, maintaining ecosystem services and forest health. As well as reducing the risks of forest hazards and maintaining forest health, I emphasize on the forest restoration activities especially major forest ecosystem networks, BDMS and the DMZ which have synergistic effects of adaptation and mitigation to climate change as well as providing various ecosystem services.

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Session 2

Climate Change and Forest Fire

기후변화와 산불

Joon Hwan SHIN

Abstract

Climate change that results from increasing levels of greenhouse gases in the atmosphere has the potential to increase temperature and alters rainfall patterns all over the world. Climate change also affects forests both directly and indirectly through disturbance including forest fire. I review the physical science basis, impacts, adaptation and vulnerability of climate change from "the Fourth Assessment Report of the Intergovernmental Panel on Climate Change". The Foundation for Deep Ecology published a very interesting book, "Wild Fire : A Century of Failed Forest Policy" and I summarise ten myths about fire policy and fire ecology from the book. Nowadays many articles on forest fire affected climate change have been published. It is time to sum up the versatile results about the subject. I introduce the interesting research results related this topic from all over the world, inter alia mountain Kilimanjaro, Alps, Sierra Nevada, Australia, savanna and boreal forest including even microbial community.

요 약

대기 중의 온실가스 증가로 인해 초래되는 기후변화는 전 세계의 기온 상승과 강우 패턴을 변화시킬 수 있다. 또한 기후변화는 산불을 포함한 교란을 통해 직·간접적으로 산림에 영향을 미친다. 여기서는 “제4차 정부간 기후변화 패널 평가서”로부터 기후변화의 물리적 기초, 영향, 적응 및 취약성에 대하여 재고코자 한다. Deep Ecolog의 기초서로서 “산불 : 실패한 산림정책의 세기”라고 할 매우 흥미로운 책이 발간되었다. 이 책에서 특히 산불 정책과 산불 생태에 관한 10가지 신화를 요약한다. 요즈음 기후변화에 따른 산불의 영향에 관한 많은 논문들이 발표되었다. 이제 이 주제와 관련한 다양한 결과들을 요약할 때이다. 전세계 그 중에서도 킬리만자로 산맥, 알프스 산맥, 시에라네바다 산맥, 호주, 사바나와 타이가(극지림) 그리고 미생물의 세계에 이르기까지 이 주제와 관련한 흥미로운 연구 결과들을 소개한다.

Climate Change and Forest Fire

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Abstract

Climate change that results from increasing levels of greenhouse gases in the atmosphere has the potential to increase temperature and alters rainfall patterns all over the world. Climate change also affects forests both directly and indirectly through disturbance including forest fire. I review the physical science basis, impacts, adaptation and vulnerability of climate change from "the Fourth Assessment Report of the Intergovernmental Panel on Climate Change". The Foundation for Deep Ecology published a very interesting book, "Wild Fire : A Century of Failed Forest Policy" and I summarise ten myths about fire policy and fire ecology from the book. Nowadays many articles on forest fire affected climate change have been published. It is time to sum up the versatile results about the subject. I introduce the interesting research results related this topic from all over the world, inter alia mountain Kilimanjaro, Alps, Sierra Nevada, Australia, savanna and boreal forest including even microbial community.

1. Climate Change; The Physical Science Basis(IPCC 2007a)

Human and Natural Drivers of Climate Change

Changes in the atmospheric abundance of greenhouse gases and aerosols, in solar radiation and in land surface properties alter the energy balance of the climate system. These changes are expressed in terms of radiative forcing, which are used to compare how a range of human and natural factors drive warming or cooling influences on global climate. Since the TAR(Third Assessment Report), new observations and related modelling of greenhouse gases, solar activity, land surface properties and some aspects of aerosols have led to improvements in the quantitative estimates of radiative forcing.

Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years(Figure 1). The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture.

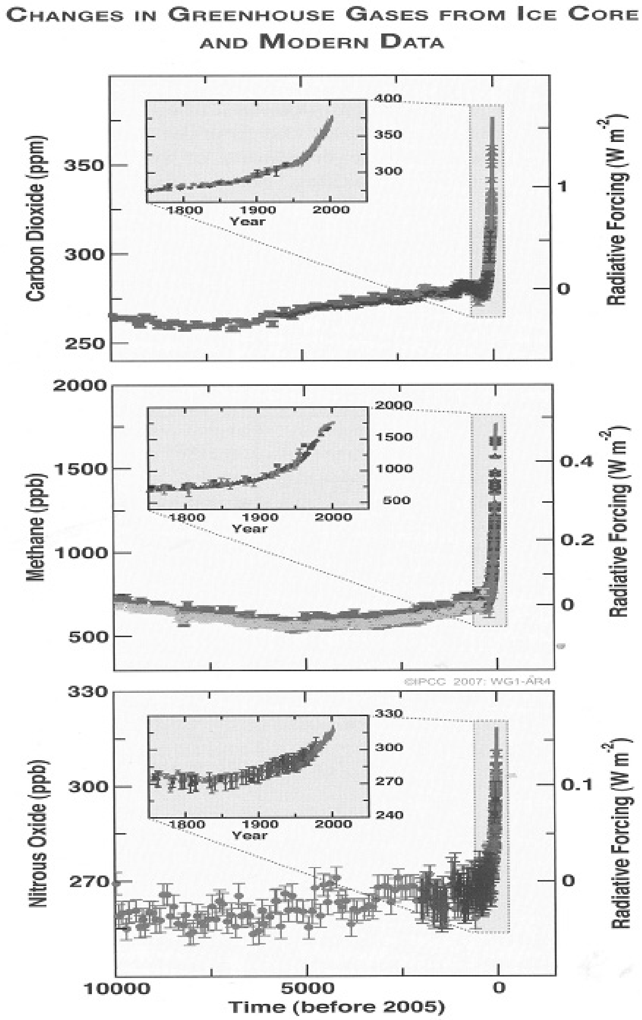

Figure 1. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panels.

The understanding of anthropogenic warming and cooling influences on climate has improved since the TAR, leading to very high confidence that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6(0.6 to 2.4) Wm^{-2}(Figure 2).

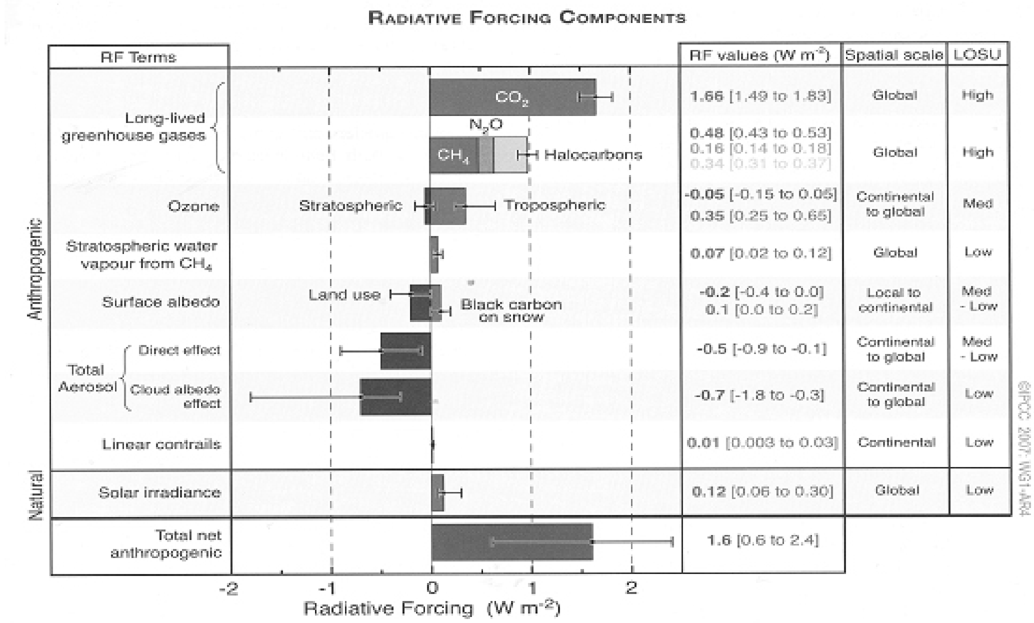

Figure 2. Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane(CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. The range for linear contrails does not include other possible effects of aviation on cloudiness.

Robust findings related to this subject are,

Current atmospheric concentrations of CO_2 and CH_4, and their associated positive radiative forcing, far exceed those determined from ice core measurements spanning the last 650,000years.

Fossil fuel use, agriculture and land use have been the dominant cause of increases in greenhouse gases over the last 250 years.

Annual emissions of CO_2 from fossil fuel burning, cement production and gas flaring increased from a mean of 6.4±0.4 $GtCyr^{-1}$ in the 1990s to 7.2±0.3 $GtCyr^{-1}$ for 2000 to 2005.

The sustained rate of increase in radiative forcing from CO_2, CH_4 and N_2O over the past 40 years is larger than at any time during at least the past 2000 years.
Natural processes of CO2 uptake by the oceans and terrestrial biosphere remove about 50 to 60% of anthropogenic emissions (i.e., fossil CO2 emissions and land use change flux). Uptake by the oceans and the terrestrial biosphere are similar in magnitude over recent decades but that by the terrestrial biosphere is more variable.

It is virtually certain that anthropogenic aerosols produce a net negative forcing (cooling influence) with a greater magnitude in the NH than in the SH.

From new estimates of the combined anthropogenic forcing due to greenhouse gases, aerosols and land surface changes, it is extremely likely that human activities have exerted a substantial net warming influence on climate since 1750.

Solar irradiance contributions to global average radiative forcing are considerably smaller than the contribution of increases in greenhouse gases over the industrial period.

Direct Observations of Recent Climate Change

Since the TAR, progress in understanding how climate is changing in space and in time has been gained through improvements and extensions of numerous datasets and data analysis, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements. Increasingly comprehensive observations are available for glaciers and snow cover since the 1960s, and for sea level and ice sheets since about the past decade. However, data coverage remains limited in some regions.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.

At continental, regional and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones like typhoons and hurricanes.

Robust findings related to this subject are,

Global mean surface temperatures continue to rise. Eleven of the last 12 years rank among the 12 warmest years on record since 1850.
Rates of surface warming increased in the mid-1970s and the global land surface has been warming at about double the rate of ocean surface warming since then.

Changes in surface temperature extremes are consistent with warming of the climate.

Estimates of mid- and lower-tropospheric temperature trends have substantially improved. Lower-tropospheric temperatures have slightly greater warming rate than the surface from 1958 to 2005.

Long-term trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Increases have occurred in the number of heavy precipitation events. Droughts have become more common, especially in the tropics and subtropics, since the 1970s. Tropospheric water vapour has increased, at least since the 1980s.

Palaeoclimatic information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1,300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6m of sea level rise.

Robust findings related to this subject are,

During the last interglacial, about 125,000 years ago, global sea level was likely 4 to 6 m higher than present, due primarily to retreat of polar ice.

A number of past abrupt climate changes were very likely linked to changes in Atlantic Ocean circulation and affected the climate broadly across the NH.

It is very unlikely that the Earth would naturally enter another ice age for at least 30,000 years.

Biogeochemical and biogeophysical feedbacks have amplified climatic changes in the past.

It is very likely that average NH temperatures during the second half of the 20th century were warmer than in any other 50-year period in the last 500 years and likely that this was also the warmest 50-year period in the past 1300 years.
Palaeoclimate records indicate with high confidence that droughts lasting decades or longer were a recurrent feature of climate in several regions over the last 2000 years.

Understanding and Attributing Climate Change

Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years in likely to have been due to the increase in greenhouse gas concentrations". Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.

Analysis of climate models together with constraints from observations enables an assessed likely range to be given for climate sensitivity for the first time and provides increased confidence in the understanding of the climate system response to radiative forcing.

Robust findings related to this subject are,

Greenhouse gas forcing has very likely caused most of the observed global warming over the last 50 years. Greenhouse gas forcing alone during the past half century would likely have resulted in greater than the observed warming if there had not been an offsetting cooling effect from aerosol and other forcings.

It is extremely unlikely (<5%) that the global pattern of warming during the past half century can be explained without external forcing, and very unlikely that it is due to known natural external causes alone. The warming occurred in both the ocean and the atmosphere and took place at a time when natural external forcing factors would likely have produced cooling.

It is likely that anthropogenic forcing has contributed to the general warming observed in the upper several hundred meters of the ocean during the latter half of the 20th century. Anthropogenic forcing, resulting in thermal expansion from ocean warming and glacier mass loss, has very likely contributed to sea level rise during the latter half of the 20th century.

A substantial fraction of the reconstructed NH inter-decadal temperature variability of the past seven centuries is very likely attributable to natural external forcing (volcanic eruptions and solar variability).

Projections of Future Changes in Climate

For the next two decades, a warming of about 0.2℃ per decade is projected for a range of SRES(Special Report on Emissions Scenarios) emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1℃ per decade would be expected.

Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and of ice.

Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized.

Robust findings related to this subject are, Climate models are based on well-established physical principles and have been demonstrated to reproduce observed features of recent climate and past climate changes. There is considerable confidence that AOGCMs provide credible quantitative estimates of future climate change, particularly at continental scales and above. Confidence in these estimates is higher for some climate variables (e.g., temperature) than for others (e.g., precipitation).

Confidence in models has increased due to:
- improvements in the simulation of many aspects of present climate, including important mode of climate variability and extreme hot and cold spells;
- improved model resolution, computational methods and parametrizations and inclusion of additional process;
- more comprehensive diagnostic tests, including tests of model ability to forecast on time scales from days to a year when initialized with observed conditions; and
- enhanced scrutiny of models and expanded diagnostic analysis of model behaviour facilitated by internationally coordinated efforts to collect and disseminate output from model experiments performed under common conditions.

Even if concentrations of radiative forcing agents were to be stabilized, further committed warming and related climate changes would be expected to occur, largely because of time lags associated with processes in the oceans.

Near-term warming projections are little affected by different scenario assumptions or different model sensitivities, and are consistent with that observed for the past few decades. The multi-model mean warming, averaged over 2011 to 2030 relative to 1980 to 1999 for all AOGCMs considered here, lies in a narrow range of 0.64℃to 0.69℃ for the three different SRES emission scenarios B1, A1B and A2.

Geographic patterns of projected warming show the greatest temperature increases at high northern latitudes and over land, with less warming over the southern oceans and North Atlantic.

Changes in precipitation show robust large-scale patterns: precipitation generally increases in the tropical precipitation maxima, decreases in the subtropics and increases at high latitudes as a consequence of a general intensification of the global hydrological cycle.

As the climate warms, snow cover and sea ice extent decrease; glaciers and ice caps lose mass and contribute to sea level rise. Sea ice extent decreases in the 21st century in both the Arctic and Antarctic. Snow cover reduction is accelerated in the Arctic by positive feedbacks and widespread increases in thaw depth occur over much of the permafrost regions.

Heat waves become more frequent and longer lasting in a future warmer climate. Decreases in frost days are projected to occur almost everywhere in the mid- and high latitudes, with an increase in growing season length. There is a tendency for summer drying of the mid-continental areas during summer, indicating a greater risk of droughts in those regions.

Future warming would tend to reduce the capacity of the Earth system (land and ocean) to absorb anthropogenic CO_2. As a result, an increasingly large fraction of anthropogenic CO_2 would stay in the atmosphere under a warmer climate. This feedback requires reductions in the cumulative emissions consistent with stabilization at a given atmospheric CO_2 level compared to the hypothetical case of no such feedback. The higher the stabilization scenario, the larger the amount of climate change and the larger the required reductions.

Temperatures averaged over all habitable continents and over many sub-continental land regions will very likely rise at greater than the global average rate in the next 50 years and by an amount substantially in excess of natural variability.

Precipitation is likely to increase in most subpolar and polar regions. The increase is considered especially robust, and very likely to occur, in annual precipitation in most of northern Europe, Canada, the northeast USA and the Arctic, and in winter precipitation in northern Asia and the Tibetan Plateau.

Precipitation is likely to decrease in many subtropical regions, especially at the poleward margins of the subtropics. The decrease is considered especially robust, and very likely to occur, in annual precipitation in European and African regions bordering the Mediterranean and in winter rainfall in south-western Australia.

Extremes of daily precipitation are likely to increase in many regions. The increase is considered as very likely in northern Europe, south Asia, East Asia, Australia and New Zealand - this list in part reflecting uneven geographic coverage in existing published research.

2. Climate Change; Impacts, Adaption and Vulnerability (IPCC 2007b)

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.

A global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems. Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers.

Magnitudes of impact can now be estimated more systematically for a range of possible increases in global average temperature(Figure 3).

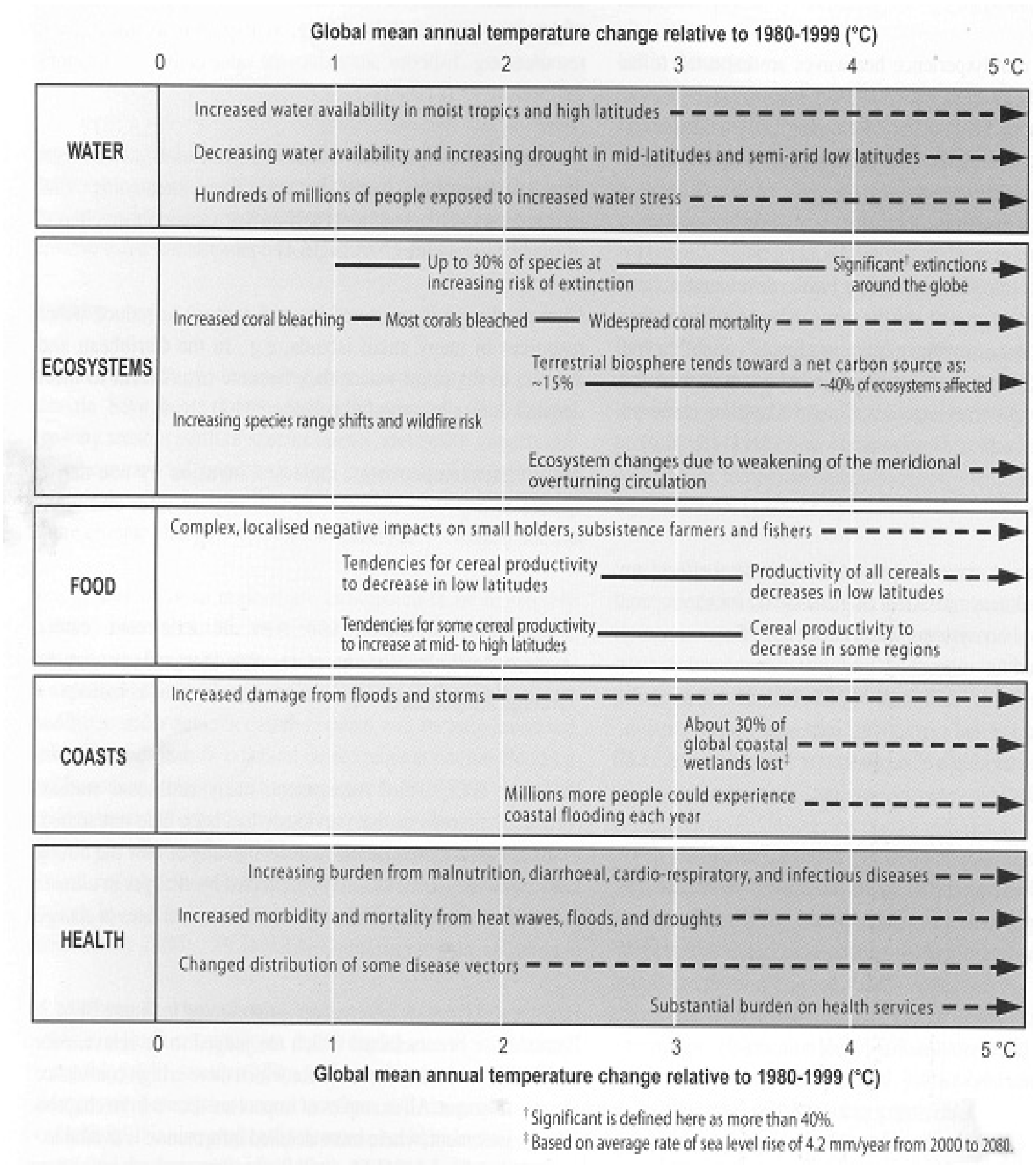

Figure 3. IIlustrative examples of global impacts projected for climate changes (and sea level and atmospheric carbon dioxide where relevant) associated with different amounts of increase in global average surface temperature in the 21st century [T20.8]. The black lines link impacts, dotted arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of the text indicates the approximate onset of a given impact. Quantitative entries for water stress and flooding represent the additional impacts of climate change relative to the conditions projected across the range of Special Report on Emissions Scenarios (SRES) scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. All entries are from published studies recorded in the chapters of the Assessment. Sources are given in the right-hand column of the Table. Confidence levels for all statements are high.

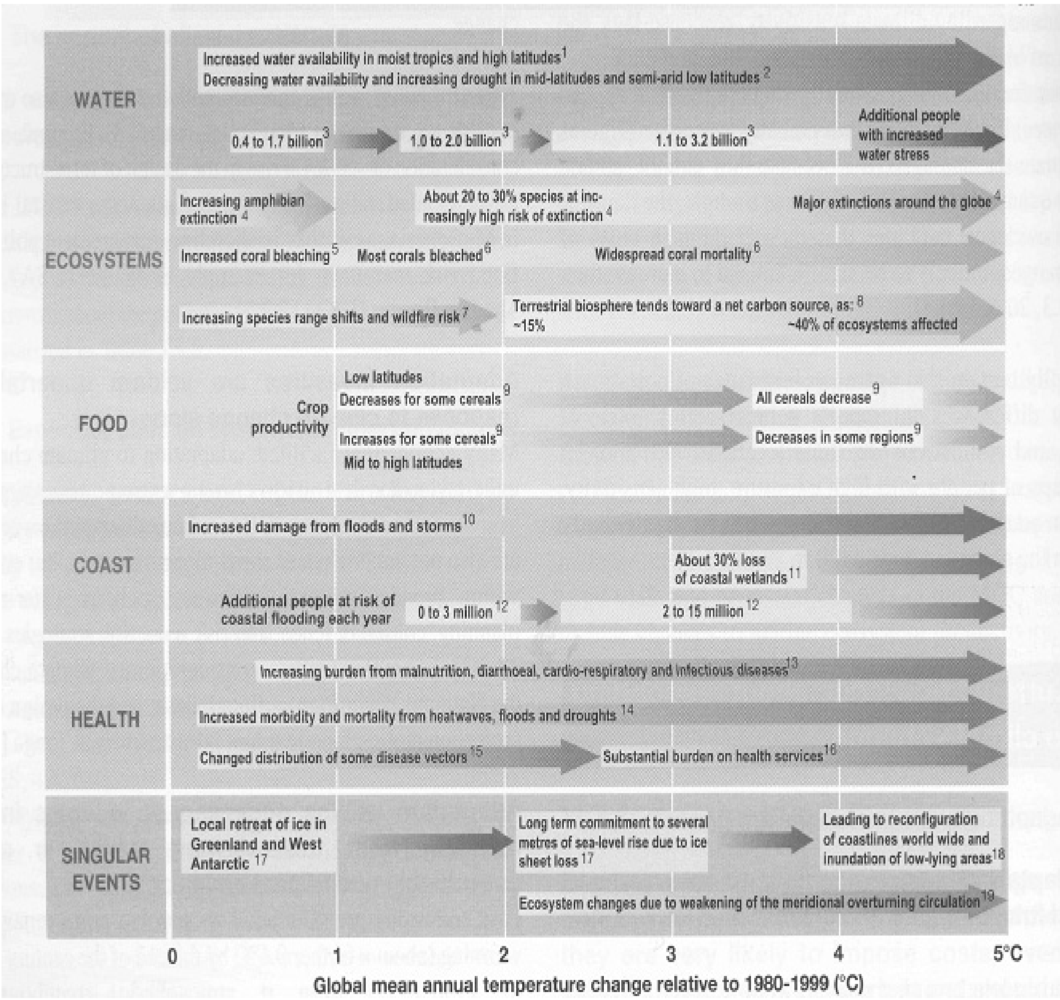

Figure 4. Examples of global impacts projected for changes in climate (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century [T20.8]. This is a selection of some estimates currently available. All entries are from published studies in the chapters of the Assessment.

Impact due to altered frequencies and intensities of extreme weather, climate and sea-level events are very likely to change. Since the IPCC Third Assessment, confidence has increased that some weather events and extremes will become more frequent, more widespread and/or more intense during the 21st century; and more is known about the potential effects of such changes. A selection of these is presented in Table 1.

Table 1. Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid-to late 21st century.

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector		
		Agriculture, forestry And ecosystems [4.4, 5.4]	Water resources[3.4]	Industry, settlement and society [7.4]
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snow melt; effects on some water supplies	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g., algal blooms	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	Likely	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migration, loss of property

[a] See Working Group I Fourth Assessment Table 3.7 for further details regarding definitions.
[b] Warming of the most extreme days and nights each year.
[c] Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
[d] In all scenarios, the projected global average sea level at 2100 is higher than in the reference period [Working Group I Fourth Assessment 10.6]. The effect of changes in regional weather systems on sea level extremes has not been assessed.

These possible impacts of climate change do not take into account any changes or developments in adaptive capacity. Examples of all entries are to be found in chapters in the full Assessment (see source at top of columns). The first two columns of the table (shaded yellow) are taken directly from the Working Group I Fourth Assessment (Table SPM-2). The likelihood estimates in Column 2 relate to the phenomena listed in Column 1.

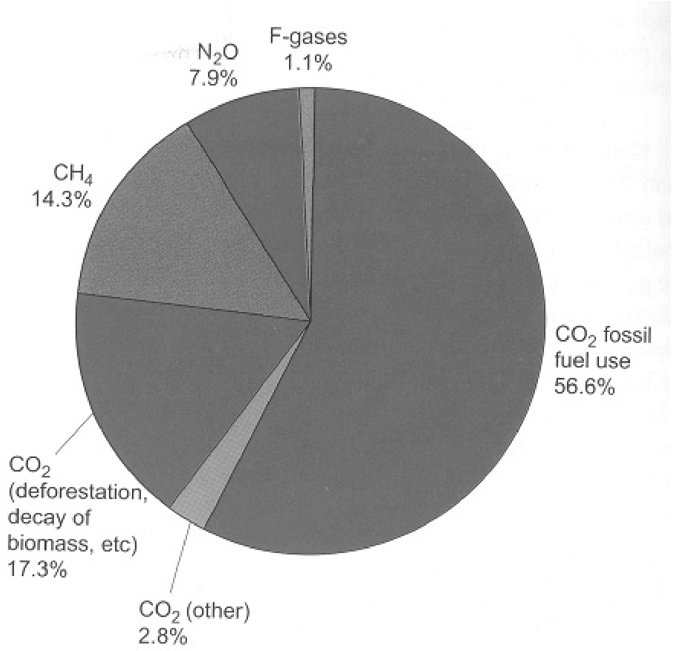

Figure 5. Global anthropogenic greenhousegas emissions in 2004 (IPCC 2007c).

3. Ten myths about fire policy and fire ecology(Wuerthner 2006)

1. Fire is bad and needs to be suppressed.
2. Big fires are the result of too much fuel.
3. Logging mimics fire.
4. Big fires can be stopped.
5. Fire "Destroys" forests and wildfire.
6. Fire "Sterilizes" the land.
7. North american landscapes were widely managed by native american fire use.

8. Livestock Grazing can prevent fires.
9. Salvage logging after a fire is necessary to restore forests.
10. Prescribed burning is an adequate substitute for wildfire.

4. Climate Change and Forest Fire

California's Sierra Nevada mountains are predicted to experience greater variation in annual precipitation according to climate change models, while nitrogen deposition from pollution continues to increase. These changes may significantly affect understory communities and fuels in forests where managers are attempting to restore historic conditions after a century of altered fire regimes. Understory response to treatments significantly differed between sites with herb biomass increasing in shrub-dominated communities when snowpack was reduced. Fire was a more important factor in post-treatment species richness and cover than either snowpack addition or reduction. Nitrogen additions unexpectedly increased herbaceous species richness. These varied findings indicate that modeling future climatic influences on biodiversity may be more difficult than additive prediction based on increasing the ecosystem's two limiting growth resources. Increasing snowpack and nitrogen resulted in increased shrub biomass production at both sites and increased herb production at the southern site. This additional understory biomass has the potential to increase fuel connectivity in patchy Sierran mixed-conifer forests, increasing fire severity and size.(Matthew and Malcolm 2008)

The incidence and severity of forest fire are linked to the interaction between climate, fuel and topography. Increased warming and drying in the future is expected to have a significant impact on the risk of forest fire occurrence. An increase in fire risk is linked to the synchronous relationship between climate and fuel moisture conditions. A warmer, drier climate will lead to drier forest fuels that will in turn increase the chance of successful fire ignition and propagation. This interaction will increase the severity of fire weather, which, in turn, will increase the risk of extreme fire behavior. A warmer climate will also extend fire season length, which will increase the likelihood of fire occurring over a greater proportion of the year. An increase in fire season length, fire weather severity and fire behavior will increase the costs of fire suppression and the risk of property and resource loss while limiting human-use within vulnerable forest landscapes. An increase in fire weather severity and fire behavior over a greater proportion of the season will increase the risks faced by ecosystems and biodiversity to climatic change and increase the costs and difficulty of achieving sustainable forest management. (Nitschke and Innes 2008)

Although the disappearing glaciers of Kilimanjaro are attracting broad interest, less conspicuous but ecologically far more significant is the associated increase of frequency and intensity of fires on the slopes of Kilimanjaro, which leads to a downward shift of the upper forest line by several hundred meters as a result of a drier (warmer) climate since the last century. In contrast to common belief, global warming does not necessarily cause upward migration of plants and animals. The opposite trend was under way on Kilimanjaro, with consequences more harmful than those due to the loss of the showy ice cap of Africa's highest mountain.(Hemp 2005)

Schumacher and Bugmann(2006) assessed the interactions among forest dynamics, climate change and large-scale disturbances such as fire, wind and forest management. They used the LANDCLIM model to investigate the influence, interactions and the relative importance of these different drivers of landscape dynamics in two case study areas of the European Alps. The simulation revealed that projected future climate change would cause extensive forest cover changes, beginning in the coming decades. Fire is likely to become almost as important for shaping the landscape as the direct effects of climate change, even in areas where major wildfire do not occur under current climatic conditions. The effects of variable wind disturbances and harvesting regimes, however, less likely to have a considerable impact on forest development compared with the direct effects of climate change coupled with the indirect effects of increased fire activity. They concluded that the joint direct and indirect effects of climate change are likely to have major consequences for mountain forests in the European Alps, including their ability to provide protection against natural hazards. (Schumacher and Bugmann 2006)

Pitman et al. (2007) explored the impact of future climate change on the risk of forest and grassland fires over Australia in January using a high resolution climate model, driven at the boundaries by data from a transitory coupled climate model. They reported a consistent increase in regional-scale fire risk over Australia driven principally by warming and reductions in relative humidity in all simulations and they concluded that the likelihood of a significant increase in fire risk over Australia resulting from climate change is very high.

Battles et al. (2008) reported that conifer tree growth declined under all climate scenarios and management regimes in the mixed-conifer forest of the Sierra Nevada, California, USA. The most extreme changes in climate decreased productivity, as measured by stem volume increment, in mature stands by 19% by 2100. More severe reductions in yield (25%) were observed for pine plantations. The reductions in growth under each scenario also resulted in moderate increase in susceptibility to non-catastrophic (i.e., non fire) causes of mortality in white fir (*Abies concolor*).

What is the origin of the savanna biome? Beerling and Osborne (2006) showed that fire accelerates forest loss and C4 grassland expansion through multiple positive feedback loops that each promote drought and more fire. A low CO_2 atmosphere amplifies this cycle by limiting tree recruitment, allowing the ingress of C4 grasses to greatly increase ecosystem flammability. Continued intensification o land use could enhance or moderate the network of feedbacks that have initiated, promoted and sustained savannas for millions of years. They suggested these alterations would overprint the effects of anthropogenic atmospheric change in coming decades.

Waldrop and Harden (2008) questioned whether changes in microbial biomass, activity, or community structure induced by fire might also affect decomposition and hetertrophic respiration, which are strongly controlled by temperature and moisture, at the ecosystem scale in boreal forests. They particularly wanted to understand whether postfire reductions in microbial biomass could affect rates of decomposition. Additionally, they compared the short-term effects of wildfire to the long-term effects of climate warming and permafrost decline. They compared soil microbial communities between control and recently burned soils that were located in areas with and without permafrost near Delta Junction, Alaska. In addition to soil physical variables, they quantified changes in microbial biomass, fungal biomass, fungal community composition, and C cycling processes (phenol oxidase enzyme activity, lignin decomposition, and microbial respiration).

Five years following fire, organic surface horizons had lower microbial biomass, fungal biomass, and dissolved organic carbon (DOC) concentrations compared with control soils. Reductions in soil fungi were associated with reductions in phenol oxidase activity and lignin decomposition. Effects of wildfire on microbial biomass and activity in the mineral soil were minor. Microbial community composition was affected by wildfire, but the effect was greater in nonpermafrost soils. Although the presence of permafrost increased soil moisture contents, effect on microbial biomass and activity were limited to mineral soils that showed lower fungal biomass but higher activity compared with soils without permafrost. Fungal abundance and moisture were strong predictors of phenol oxidase enzyme activity in soil. Phenol oxidase enzyme activity, in turn, was linearly related to both ^{13}C lignin decomposition and microbial respiration in incubation studies. Taken together, these results indicate that reductions in fungal biomass in postfire soils and lower soil moisture in nonpermafrost soils reduced the potential of soil heterotrophs to decompose soil carbon. Although in the field increased rates of microbial respiration can be observed in postfire soils due to warmer soil conditions, reductions in fungal biomass and activity may limit rates of decomposition.

5. Discussion and Conclusion

Climate change that results from increasing levels of greenhouse gases in the atmosphere has the potential to increase temperature and alters rainfall patterns all over the world. Climate change also affects forests both directly and indirectly through disturbance including forest fire. We reviewed the physical science basis, impacts, adaptation and vulnerability of climate change. We also took a look for the research results related climate change and forest fire from all over the world. Can we use the past to manage for the future? The most important thing is that we have to take an ecosystem approach because changes in ecosystem structure and function induced by fire also affect other ecosystem structure and function (Waldrop and Harden 2008), and forest fire related to a range of ecological, social and economic phenomena(Shin and Lee 2004).

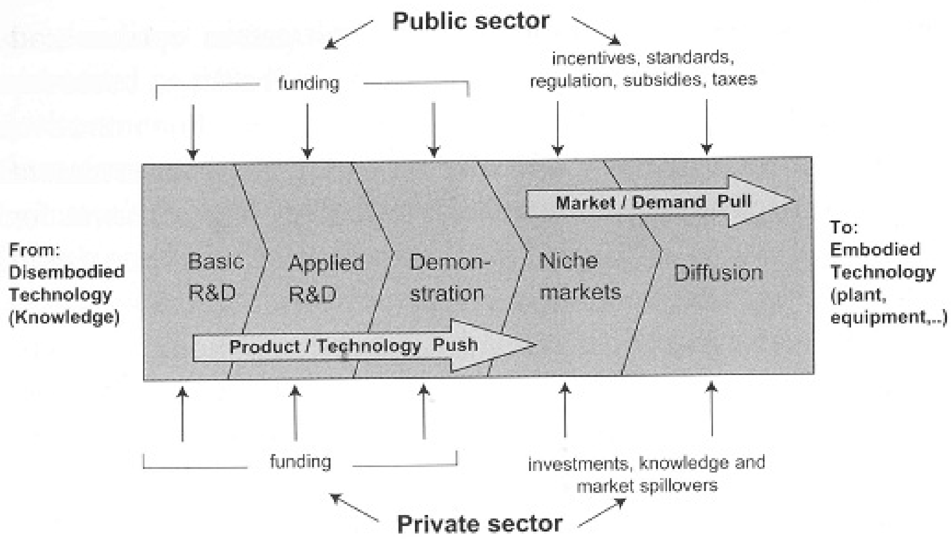

Figure 6. The technology development cycle and its main driving forces (IPCC 2007c)

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Fluctuation of forest fire in spatial space and their regional behavior

특정 지역에서의 산불 발생의 변동과 지역적 형태

Shu Lifu, Wang Mingyu, Tian Xiaorui, Zhao Fengjun

Abstract

Historical forest fires records from Alaska State (1950-2000), California State (1895-2001), USA and Heilongjiang Province (1980-1999), P.R. China were used to calculate the longitude and latitude of annual burned area's centroids of these regions. Fluctuation phenomena by year were analyzed using spectrum analysis. The results shows: Centroids of burned area in these three regions are in fluctuation condition encircling the distribution center. The distribution centers in Alaska State, California State and Heilongjiang Province are 151.11°W Longitude, 64.96°N Latitude, 120.02°W Longitude, 37.11°N Latitude and 127.07°E Longitude, 49.59°N Latitude respectively. Fluctuation of burned area's centroids in Alaska State and California State in longitude has obvious periodicity, and the periodicities are 4.2a，6.25a in Alaska State and 6.24a，106a in California State. Fluctuation of burned area's centroids in Heilongjiang Province has periodicity both in longitude and latitude, and the periodicities are both 3.3a, 6.67a. Fluctuation of burned area's centroids in Alaska State and California State in latitude does not have periodicity, and big forest fires with low frequencies predominate most of fires.

요 약

미국의 알래스카주(1950-2000)와 캘리포니아주(1895-2001), 중국의 흑룡강성(1980-1999)의 역사적인 산불 기록들을 이용하여 이 지역들의 연 소실지역의 중심에 대한 경도와 위도를 계산하였다. 연간 변동 현상은 스팩트럼 분석을 사용해서 분석되었다. 그 결과는 다음과 같다. : 이 세 지역들에 있어서 소실지의 중심은 분포 중심을 선회하며 변동하고 있다. 알래스카주, 캘리포니아주, 그리고 흑룡강성에 있어서의분포중심은 각각 서경 151.11°, 북위 64.96°에 위치한다. 알래스카주와 캘리포니아주에 있어서 소실지역 중심의 경도의 변동은 명백한 주기성이 있고, 이 주기들은 알래스카주에서는 4.2a, 6.25a이고 캘리포니아주에서는 6.24a, 106a이다. 흑룡강성의 소실지역 중심의 변동은 경도와 위도 모두 주기성을 가지고 있으며 둘다 3.3a, 6.67a이다. 알래스카주와 캘리포니아주의 소실지역 중심의 위도의 변동은 주기성이 없고, 대부분의 불들이 발생 빈도가 낮은 큰 산불들이다.

Fluctuation of forest fire in spatial space and their regional behavior

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Abstract

Historical forest fires records from Alaska State (1950-2000), California State (1895-2001), USA and Heilongjiang Province (1980-1999), P.R. China were used to calculate the longitude and latitude of annual burned area's centroids of these regions. Fluctuation phenomena by year were analyzed using spectrum analysis. The results shows: Centroids of burned area in these three regions are in fluctuation condition encircling the distribution center. The distribution centers in Alaska State, California State and Heilongjiang Province are 151.11°W Longitude, 64.96°N Latitude, 120.02°W Longitude, 37.11°N Latitude and 127.07°E Longitude, 49.59°N Latitude respectively. Fluctuation of burned area's centroids in Alaska State and California State in longitude has obvious periodicity, and the periodicities are 4.2a，6.25a in Alaska State and 6.24a，106a in California State. Fluctuation of burned area's centroids in Heilongjiang Province has periodicity both in longitude and latitude, and the periodicities are both 3.3a, 6.67a. Fluctuation of burned area's centroids in Alaska State and California State in latitude does not have periodicity, and big forest fires with low frequencies predominate most of fires.

1. Introduction

Forest fire is a significant disturbance factor that influences the process of forest ecosystem (Agee, 1991; Specht, 1991). The conditions of forest fires occurrence had existed about 350-400 million years ago. Forest fires change the proportion of O_2 and CO_2, the increase of relative proportion of CO_2 enhances the greenhouse effect (Lu et al., 2002). Forest fire is one of the major disturbance agents on the global scale, affects biogeochemical cycling, and plays an important role in atmospheric chemistry and the global carbon cycle (Thonicke et al., 2001). In many situations, forest fire has been one of the import part of ecosystem, dominant species have adapted to fire circle. In the past 100 years, fire frequency and intensity caused by human has increased significantly (Specht, 1991).

In rather long history, human being put out all forest fires actively, whether anthropologic fires or natural fires. The long time putout of forest fires has lead to unnatural accumulation of forest fuel. In this condition, once forest fire outbreak, the fire is likely to develop into big forest fire. Forest fires may profoundly alter structure of landscape and processes of ecosystems (Vázqueza and Moreno, 2001). Disturbance plays an important role in shaping and maintaining land ecosystem, and forest fires are the necessary part for many forest ecosystem. Fire pattern and history is one of the important study aspects of fire regime. In heterogeneous landscape, Fire pattern results from complex interaction among weather, ignition, vegetation, fuel moisture, and topography (Hargrove et al. 2000). The interaction of them influences the shape and progress of landscape in reverse (Li, 2000), and change the component and structure of species.

Human being recognized that global change is a complicated systematic problem gradually, which resulted from greenhouse gas emission. Global change has an impact on precipitation distribution and air temperature change in different region, and then influences the vegetation distribution. Global warming changes the litter amount and decomposition. The rising of air temperature has been changing the vegetation distribution, phonological characteristics and some factors that restrict litter decay, and influencing the function of matter cycling in forest ecosystem.

Global climate change is increasingly recognized as a complicated phenomenon involving multiple shifts in many dimensions of atmospheric function (Peterson et al., 2001). In latest years, more studies focus on the shift of the climate region, relative movement of the vegetation zone, and other responses to the global warming. Such as the change of biodiversity, rising of sea level, movement of vegetation zone, and shrinking of glacier. The impact of global change on forest fires includes of change of burned area, fire frequency, and temporal and spatial fire pattern. In fact, the response of forest fires under the condition of global change is the result of coupling with vegetation, climate, and anthropogenic disturbance. The fluctuation of forest fires distribution along longitude and latitude is the synthetic presentation of the response. Quantity analyzing of the fluctuation of forest fires distribution in spatial dimension may educe the new evidence of global change.

Global change has influenced the distribution of natural and anthropogenic fire sources, influenced the spatial distribution of forest fuel and combustibility. For the continuous accumulation and rapid release of energy of forest fuel (Drossel and Schwabl, 1992; Song et al., 2001), and the impact of other factors, forest fires present the phenomena of fire circle in a defined region and fluctuation in temporal and spatial space. Zhao(2002) study indicated that vegetation zone in east of China will move forward north under the impact of global change, especially deciduous forest area will diminish greatly, so the change of vegetation zone will influence the distribution of forest fires in a certain extent. Wang (2003; 2003a) studied the forest fires in Heilongjiang Province of China, found that centroids of burned area has fluctuation in latitude and longitude dimension. In global scale, the behavior of this fluctuation in different region is still unknown. Study this fluctuation and sensitivity in different region is meaningful and interesting. Whether or not the fluctuation exists in different regions and how much is the amplitude of fluctuation will be studied in this paper.

2. Methods

Three regions are selected in this study in north hemisphere where severe forest fire occurred every year(Fig.1). These regions are Alaska, California, and Heilongjiang Province of China. These three regions represent different latitude and longitude in north hemisphere, and there are detail fire records.

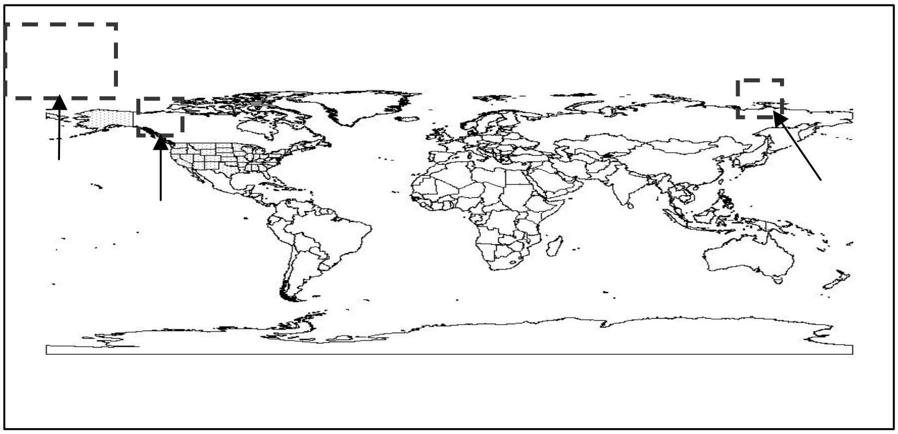

Fig.1 Study Area

Fire historical records of Alaska are from 1950 to 2000. Fire historical records of California are from 1895 to 2001, and records of 1897, 1899, 1904 and 1905 are missing. Fire historical records of Heilongjiang Province are from 1980 to 1999.

Centroids are one of the most useful factors to represent objects spatial distribution. Centroids represent the average location of burned area, they are the balance points of burned area. They can be calculated by following equation.

$$X_C = \frac{\Sigma W_i X_i}{\sum_i W_i} \qquad Y_C = \frac{\Sigma W_i Y_i}{\sum_i W_i}$$

Where, i is discrete fire location, W_i is weigh of fire location, it is the distance from fire location to perimeter of burned area. X_i, Y_i are coordinates of fire locations.

This study calculated all centroids of burned area (Fig.2). By calculating, we can simplify complicated fire pattern effectively, and can present the fluctuation in temporal and spatial dimension synthetically under the background of global change. Then we can study the fluctuation by spectral analysis.

Fig.2 Distribution of burned area's centroids in geographic space

Spectral analysis can be used to analysis repeated spatial character in one dimensional or two dimensional space. Its fundamental thought is to use Fourier transform to decompose a serial of datum into sine wave of different frequency, different amplitude, and different starting point, and then select the best fitting wave equation. Spectral analysis determines the spatial pattern by comparing the centroids data with some known wave equation, and then periodic and random variety can be got from spectral periodogram.

$$Y = a_0 + \sum [a_k \cos(\lambda_k t) + b_k \sin(\lambda_k t)] \quad (k\text{=1 } to\ q)$$

Where, λ_k is wave frequency， a_k , b_k are coefficients.

We analyzed fire historical records of three study area, calculated centroids of burned area in each year with ArcGIS software. We do not have fire perimeter records of Heilongjiang Province, so we buffered the ignition point with circles, and the area of circles is equal to the area recorded, then a serial of approximate fire mapping datum were constructed. Finally, we calculated the centroids of burned area, and analyzed the coordinates of centroids with spectral analysis, and got the period of fluctuation of centroids.

Table 1 Fluctuation amplitude of burned area’s centroids in three regions

Regions	Amplitude/ °	Amplitude/ km
Alaska State, Longitude	17.67	422.2
Alaska State, latitude	5.94	457.2
California State, longitude;	5.48	383.5
California State, Latitude	4.74	608.0
Heilongjiang Province, Longitude	5.60	276.5
Heilongjiang Province, Latitude	5.97	351.7

3. Results

3.1. Spatial movement of fires

The distribution of centroids of burned area has the characteristic of zonal distribution with one distribution center. The distribution center of centroids in Alaska is 151.11° W, 64.96° N. The distribution center in California is 120.02° W, 37.11° N. The distribution centre in Heilongjiang Province is 127.07° E, 49.59° N. The amplitude of fluctuation in three regions is showed in table 1.

We analyzed the coordinates of centroids in three regions respectively, and drew the line graph along with yearly change according to longitude and latitude of burned area's centroids (Fig. 3). In Alaska, the maximal value of fire movement toward west is 160.89° W, and the least value of fire movement toward east is 143.22° W. In latitude direction, the maximal value towards north is 66.59° N, the least value towards south is 60.65°N. In California, the maximal value of fire movement toward west is 121.90° W, and the least value of fire movement toward east is 117.16° W. In latitude direction, the maximal value towards north is 39.61° N, the least value towards south is 34.13° N. In Heilongjiang Province, the maximal value of fire movement toward west is 128.68° E, and the least value of fire movement toward east is 123.07° E. In latitude direction, the maximal value towards north is 52.82° N, the least value towards south is 46.86° N.

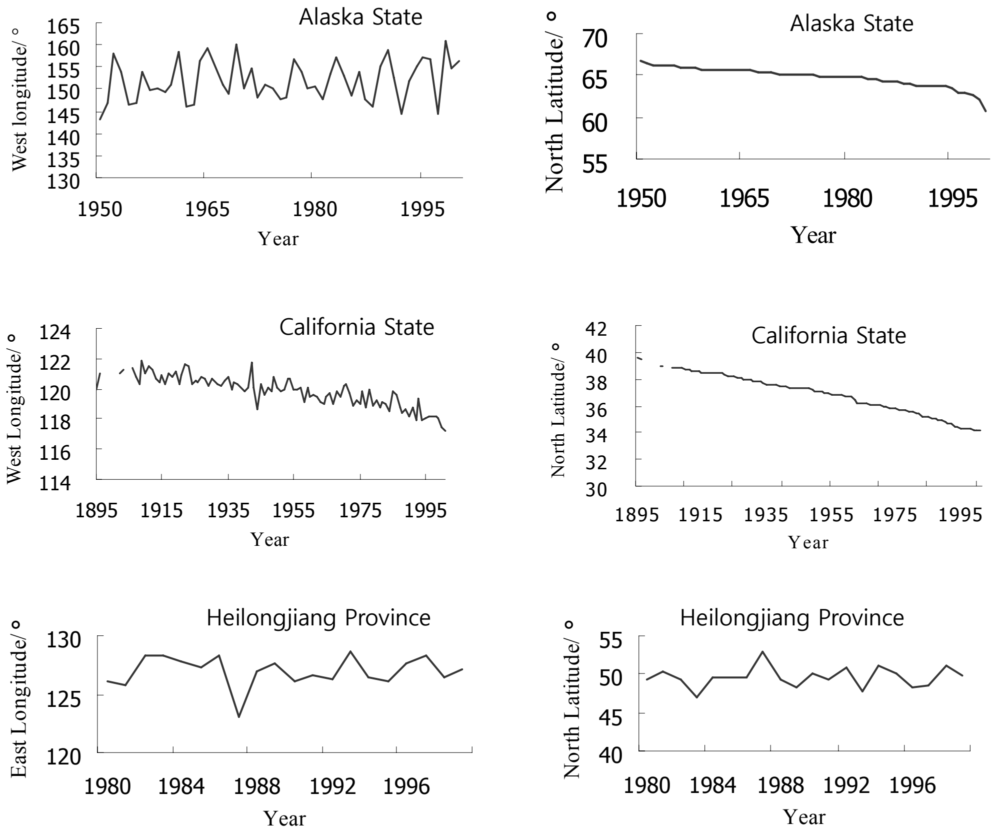

Fig.3 Distribution of burned area's centroids in longitude and latitude space

Plot the trend line of burned area's centroids with longitude as x-axis, and latitude as y-axis. The fitting line of centroids in Alaska is $y = 0.07x + 75.411$, $R^2 = 0.0711$. The fitting line of centroids in California is $y = 1.273x - 115.7$，$R^2 = 0.7607$. The fitting line of centroids in Heilongjiang is $y = -0.842x + 156.54$，$R^2 = 0.6788$. In above equation, x is longitude, unit is °. Y is latitude, unit is °. The above equation exposes that centroids of burned area in Alaska are more disperse. Centroids of burned area in California and Heilongjiang Province are more concentrated, present zonal distribution along the fitting line, and comparatively cluster.

Centroids of burned area in Alaska and California move towards low latitude (Fig.3). Centroids of burned area in Alaska have moved 5.94°towards south from 1950 to 2000, and the distance is 457.2km. Centroids of burned area in California have shifted 4.74°towards south from 1895 to 2001, and the distance is 608.0km.

In California, centroids of burned area move towards east along with fluctuation, besides the impact of regional location, also affected by climate change, fuel management. In Heilongjiang Province, for overmuch human disturbance, the centroids of burned area have obvious fluctuation and with not obvious movement in space.

3.2. Fluctuation of forest fires in spatial dimension

There are two obvious peaks of centroids of burned area in Alaska along longitude direction. The frequency of the peaks is 0.24 and 0.16, and their periodicities are 4.2a and 6.25a accordingly. The periodicity of 6.25a has more intense spectral density. Forest fires in California move towards east along with fluctuation periodically. The change of moving direction results in multiple fluctuation centre. There is multiple periodicities of burned area's centroids in California along longitude, and long periodicity has more intense spectral density. The two intense frequencies are 0.16 and 0.0094, and their periodicities are 6.24a and 106a accordingly (Fig. 4).

There is no periodicity of centroids of burned area in Alaska and California along latitude. We can notice that most of the fires in these two regions concentrate on low frequency; this means that fire intervals are very long, and the intervals are abnormal. These phenomena are related with forest fire management ability. For the high level of fire fighting ability, the burned area is limited under small area level for rapid fighting. Fuel accumulates rapidly for fire exclusion, and fuel energy accumulated is very high. In extreme weather condition, once ignited, the fire is very easy to be out of control, and fighting plays tiny role on fire control. Big fires with different fires interval predominate these two regions. Big fires in California in 2003 are a very typical example of above phenomena.

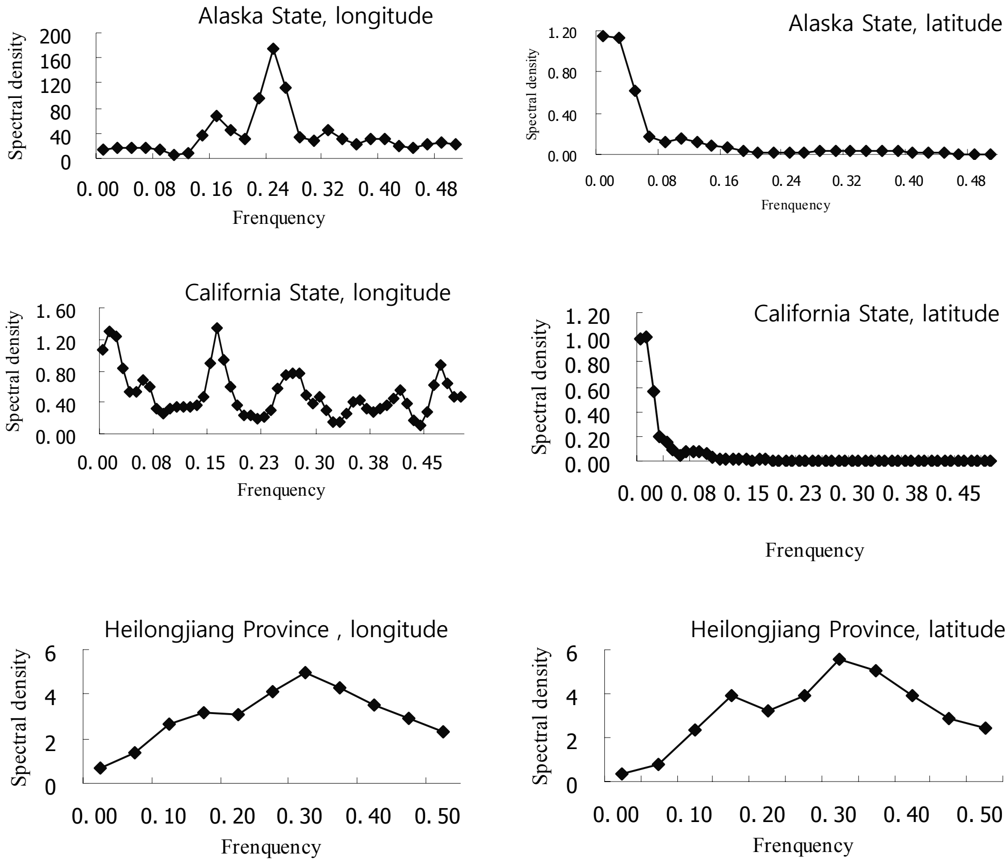

Fig.4 Frequency distribution of burned area's centroids in three regions

There are obvious fluctuations of centroids in Heilongjiang Province both in longitude and latitude direction. From periodogram graph (Fig.4), we can see there are two obvious periodicities, their frequencies are both 0.15 and 0.3 in two directions, and their periodicities are 3.3a and 6.67a respectively.

Periodic fluctuation of forest fires is beneficial to forest health. For those regions with small fluctuation for a long time, forest fires maintain in a low level, these regions are inclined to break up big forest fires. This fact is just consistent with the theory of Self Organized Criticality; periodic fluctuation of forest fires is good for decrease fuel accumulation and fire intensity. Fluctuation is more obvious than movement in longitude direction, but in latitude direction, movement in space is stronger than fluctuation. There are multiple factors that influence forest fires movement in space. Meteorological factors are just some of these influencing factors, other factors, such as forest management, forest fires management, population distribution etc. influence the movement jointly.

Fire sources are the leading factors for forest fires occurrence. Distribution of burned area has strong correlation with distribution of fire sources. Fire sources vary with time and space. Forest fire number is greatly correlated with population distribution, the nearer to resident the more fires occur. Forest fires near the resident, for convenient traffic, the fires can be control in low level. Fire sources are divided into natural fires and anthropologic fires, in northeast of China, lightning fires account for the most proportion of natural fires. The distribution of anthropologic fires is great related to human distribution. Hu and Jin's (2002) study showed that fire number is positive correlated with human distribution in forest region. Burned area has no correlation with human population, natural fires in southeast is more than in northwest in Heilongjiang province. Fire number in the area where developed earlier is more than where developed later. Anthropologic fires are influenced by resident, traffic density, fire sources density, and climate. For fire centroids, the size and distribution of burned area determined the distribution of fire centroids. For the continuous accumulation of fuel and rapid release of energy (Drossel and Schwabl, 1992; Song et al., 2001), and other correlated factors, forest fires have the characteristic of fire circle. The periodical accumulation of fuel and annual fluctuation of weather determine that the fire centroids are influenced by weather in short term and influenced by fuel accumulation in long period. So the fluctuation of fire centroids presents different periodicity in temporal dimension.

4. Discussion

We selected three typical regions to study spatial fluctuation of forest fires. In future we will focus more on larger scale and longer period to study how meteorological factors to influence the fluctuation of forest fires. The factors that influence spatial fluctuation of forest fires are variable and complicated, they relate to a serial of stochastic and periodic variables. Multiple factors acting on together lead to stochastic and periodic fluctuation in spatial dimension, we just studied periodic fluctuation in this paper. For stochastic fluctuation and their related factors, and their meaning under global change background should be studied in the future. Spatial distribution of forest fires is still lack of some quantitative factors to describe it. Meteorological model combined with vegetation distribution, vegetation succession, and vegetation dynamic model, can be used to simulate the regional distribution characteristic of forest fires in the future.

Acknowledgments

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Climate Change and Wildland Fire Regimes: South Asia Regional Perspectives

기후변화와 산불형 : 남부아시아 지역 개관

Sharma, Sundar Prasad

Abstract

Wildfires in high altitude Hindu Kush-Himalayas (HKH) ecosystems are a major driver for destruction of pristine biodiversity, including the habitats of any rare species. During the long and intense dry seasons occurring annually in the region, wildfires are a regular phenomenon, many of them having a potential to cause major damages; e.g., serious degradation of forests, changes of ecosystem properties, and deterioration of social and economic conditions in some land-use systems and natural vegetation types. The ecosystems and society are very vulnerable to wildfires, in general, and to the secondary disasters, such as landslides and flash floods, that follow disastrous wildfires. They are also affecting cultural heritage sites and land-use systems that provide the basis for livelihoods to a population of around 150 million people living in the mountain region. Most importantly, the secondary consequences of wildfires include the destruction of soil protecting vegetation cover, affecting water regimes for a population of 1.4 billion residing downstream of the HKH region. Atmospheric Brown Clouds (ABC) could be the major driver to the regional climate change and pollution though not well understood. Consequently, rainfall over the Indo-Gangetic plain has decreased by about 20 per cent since the 1980s negatively affecting to the agricultural production, changing glacier dynamics and wildfire regimes. It's net positive feedback to the regional climate shape a vicious circle with increasing occurrence of wildfires in the region. Observations indicate that the occurrence of wildfires is increasing as a consequence of regional warming and extended dry spells. Increasing trend of wildfires in the recent past in the southern stretch of the HKH region not only contributing to regional and the overall global climate change but also, if looked at from the point of view of the fragile Himalayan ecology, posing a higher risk to the communities.

요 약

고해발의 힌두쿠시 산맥-히말라야 산맥(HKH) 생태계에서 발생하는 산불은 희귀종의 서식지를 포함하여 본래의 생물다양성을 파괴하는 주요 요인이다. 이 지역에서 매년 계속되는 길고 집중적인 건기 동안에 산불은 정례적인현상이며, 그 중 많은 산불들이 산림의 심각한 훼손, 생태계 속성의 변화, 토지사용체계와 자연식생형과 관련된 사회적 경제적 조건의 악화 등과 같은 주요 손상을 초래하는 잠재적 원인이 되고 있다. 생태계와 사회는 대체로 산불에 매우 취약하며 산불에 뒤따르게 되는 산사태와 갑작스러운 홍수 등과 같은2차적인 재앙에도 그러하다. 산불은 또한 산악지역에 살고 있는 약 1억 5천만 명 인구의 삶의 기반이 되고 있는 문화유적지와 토지사용체계에도 영향을주고 있다. 무엇보다 중요한 것은 산불의 2차적 피해는 HKH 지역의 하류에거주하고 있는 14억의 인구에게 필요한 수자원형에 영향을 끼치면서 토양을보전하는 식피를 파괴한다는 사실이다. 황사는 비록 이해가 되지는 않을지라도 지역적 기후변화와 오염의 주된 요인이 될 수 있다. 결과적으로 인도-갠지스 평원의 강우량은 1980년대 이후 약 20%가 감소되었는데 이는 농업생산에부정적인 영향을 끼쳤으며 빙하의 동태와 산불형에도 변화를 가져왔다. 지역적 기후에 대한 피드백은 산불의 발생이 증가하는 악순환을 형성하게 된다. 관찰결과는 산불의 발생이 지역적 온난화와 건기의 확장으로 인해 증가하고있음을 보여준다. 지난 최근에 HKH지역의 남쪽 일대에서 산불이 증가하고 있는것은 지역적 기후변화와 전반적인 세계기후 변화를 야기하고 있을 뿐만 아니라 취약한 히말라야 산맥의 생태계의 관점에서 본다면 지역사회에도 더 큰 위험요소를 제공하고 있다.

Climate Change and Wildland Fire Regimes: South Asia Regional Perspectives

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Abstract

Wildfires in high altitude Hindu Kush-Himalayas (HKH) ecosystems are a major driver for destruction of pristine biodiversity, including the habitats of any rare species. During the long and intense dry seasons occurring annually in the region, wildfires are a regular phenomenon, many of them having a potential to cause major damages; e.g., serious degradation of forests, changes of ecosystem properties, and deterioration of social and economic conditions in some land-use systems and natural vegetation types. The ecosystems and society are very vulnerable to wildfires, in general, and to the secondary disasters, such as landslides and flash floods, that follow disastrous wildfires. They are also affecting cultural heritage sites and land-use systems that provide the basis for livelihoods to a population of around 150 million people living in the mountain region. Most importantly, the secondary consequences of wildfires include the destruction of soil protecting vegetation cover, affecting water regimes for a population of 1.4 billion residing downstream of the HKH region. Atmospheric Brown Clouds (ABC) could be the major driver to the regional climate change and pollution though not well understood. Consequently, rainfall over the Indo-Gangetic plain has decreased by about 20 per cent since the 1980s negatively affecting to the agricultural production, changing glacier dynamics and wildfire regimes. It's net positive feedback to the regional climate shape a vicious circle with increasing occurrence of wildfires in the region. Observations indicate that the occurrence of wildfires is increasing as a consequence of regional warming and extended dry spells. Increasing trend of wildfires in the recent past in the southern stretch of the HKH region not only contributing to regional and the

overall global climate change but also, if looked at from the point of view of the fragile Himalayan ecology, posing a higher risk to the communities.

1. INTRODUCTION

During the long and intense dry seasons occurring annually in the region, wildfires are a regular phenomenon, many of them having a potential to cause major damages; e.g., serious degradation of forests, changes of ecosystem properties, and deterioration of social and economic conditions in some land-use systems and natural vegetation types. The ecosystems and society are very vulnerable to wildfires, in general, and to the secondary disasters, such as landslides and flash floods, that follow disastrous wildfires.

Fires in high altitude ecosystems are a major driver for destruction of pristine biodiversity, including the habitats of many rare species. They are also affecting cultural heritage sites and land-use systems that provide the basis for livelihoods to a population of around 150 million people living in the mountain region. Most importantly, the secondary consequences of wildfires include the destruction of soil protecting vegetation cover, affecting water regimes for a population of 1.4 billion. These fires are often border crossing in nature.

Fires occurring in the highlands of Tibet, Sikkim, Bhutan and the northern part of Nepal at altitudes from 2,700 to 3,800m above sea level often cross national borders, especially during the dry winter fire season (November to January). Observations indicate that the occurrence of wildfires is increasing as a consequence of regional warming and extended dry spells. The southern slopes of the mountains are primarily affected, since they are generally warmer and drier compared to northern slopes and are therefore exposed to high human pressure. The forest fires in the recent past in the southern stretch of the HKH region not only contributing to regional and the overall global problem but also pose a higher risk to the communities if looked at from the point of view of the fragile Himalayan ecology (SAARC 2009).

One of the key messages of the UNEP report (UNEP 2007) is that the Earth's surface is warming. This is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Other major impacts include changes in water availability, land degradation, food security, and loss of biodiversity.

While in the past century the global average temperature increased by 0.74°C, the best estimate of the Intergovernmental Panel on Climate Change (IPCC) for additional warming over the current century is projected to be from 1.8 to 4.0°C. Climate change may further exacerbate the loss of biodiversity and degradation of land, soil, forest, freshwater and oceans.

The projected increase in frequency and intensity of heat waves, storms, floods and droughts would dramatically affect many millions of people including those living in Hindu-Kush Himalayan region.

2. ATMOSPHERIC BROWN CLOUD (ABC): IMPLICATION TO REGIONAL CLIMATE CHANGE, DWINDLING OF GLACIERS AND GLACIAL LAKES IN THE HIMALAYAS AND FOOD SECURITY

The brown cloud in the atmosphere consists of pollutant particles (primary aerosols) and gases such as nitrogen oxides (NOx), carbon monoxide (CO), sulphur dioxide (SO2), ammonia (NH3), and many organic gases and acids. The brown cloud plumes are formed by the result of the combustion of biofuels in houses and industries, biomass burning, and fossil fuels in densely populated region (Ramanathan et al., 2008).

ABC has been becoming a hot topic among scientists, politicians and scholars in the region in recent years. The atmospheric concentrations of brown clouds are large mainly during the summer season since precipitation removes the aerosols efficiently during other seasons. Satellite data have revealed that ABC plumes, measuring 1 - 3 km thick, surround the Hindu Kush-Himalayan region during November to March (Ramanathan et al., 2008).

Between 1950 and 2002, soot emissions increased three-fold, while sulphur emissions have increased seven-fold in India. Black carbon (BC) in the brown cloud has increased the vertically averaged annual mean solar absorption in the troposphere (from the surface up to 14 km in altitude) by about 15 per cent (about 14 W m^{-2}) and the solar heating at elevated levels (1 - 4 km) over India by as much as 20 - 50 per cent (6 - 20 W m^{-2}) (Ramanathan et al., 2008). BC is formed through the incomplete combustion of fossil fuels, biofuel, and biomass, and is emitted in both anthropogenic and naturally occurring soot. It warms the Earth by absorbing heat in the atmosphere and by reducing albedo, the ability to reflect sunlight, when deposited on snow and ice. Black carbon stays in the atmosphere for only several days to weeks, whereas CO_2 has an atmospheric lifetime of more than 100 years. Black carbon is a potent climate forcing agent, estimated to be the second largest contributor to global warming after carbon dioxide (CO_2) (Ramanathan and Carmichael 2008).

Professor Lonnie Thompson of Ohio State University and a team of researchers found (2006) that high-altitude glaciers, despite residing in colder temperatures, are more sensitive to climate change. As more heat is trapped in the atmosphere, he said, it holds more water vapour. And when the water vapour rises to high altitudes it condenses, releasing the heat into the upper atmosphere, where high mountain landscapes feel the brunt of warming. He further stated that water the Himalayas have is dwindling fast. The glaciers in the Himalayas collect water from the monsoon in the wet season, and release it in the dry season. But how effective they are depends on how much water is in the glaciers (ENN 2008).

If the current rate of retreat continues unabated, these glaciers and snow packs are expected to shrink by as much as 75 percent before the year 2050 (Ramanathan et al., 2008).

2.1. Atmospheric Brown Cloud (ABC) Radiative Forcing

The absorption of solar radiation by the surface and the atmosphere is the fundamental driver for the physical climate system, the biogeochemical cycles, and for all life on the planet. ABCs have significantly altered this radiative forcing over Asia. Brown clouds cause dimming (by at least 6 per cent in south Asia compared with the pre-industrial values) at the surface and soot in it increase solar heating of the atmosphere (absorbed solar radiation at the surface by +15 Watt per square meter compared with the pre-industrial values) (Ramanathan et al., 2008).

Haze, so called ‘brown cloud’ along the Himalaya hover over northern India, Pakistan and Nepal during the beginning of winter season (Figure 1) forming a thick blanket. It is considered that the wildfires or agricultural fires in the region contribute to it, though they are not solely responsible. The haze generally blown from the west probably results from a combination of smoke, urban pollution and dust from neighboring Pakistan might play a role (http://earthobservatory.nasa.gov).

The images (NASA’s Earth Observatory) below clearly shows that this haze, which is boarder crossing in nature, mainly originated from Pakistan and India forming a thick plume of haze along the border between Pakistan, India and Nepal.

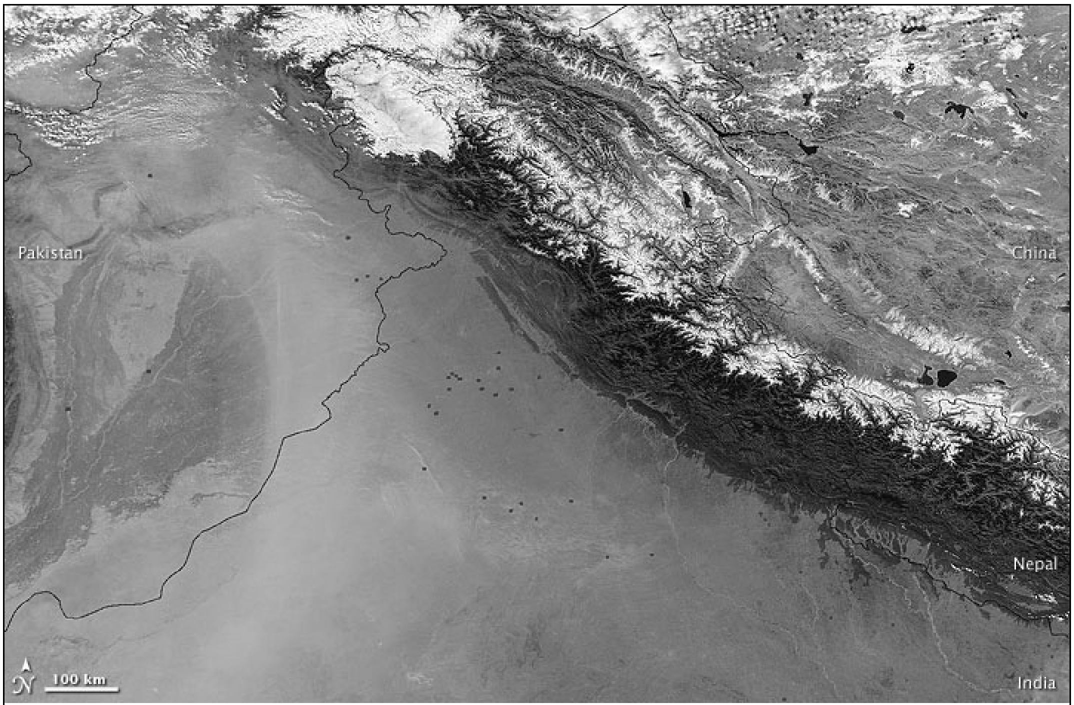

Figure 1: MODIS on NASA's Aqua satellite image, acquired 16 November 2008. Thick smoke hides most of the areas of northern India (Amritsar, New Delhi, Jaipur), east Pakistan (Islamabad, Rawalpindi, Lahore, Okara) and south-west Nepal (Mahendranagar).
(source: http://earthobservatory.nasa.gov)

Not only vehicles and industries are the sources of air pollution and greenhouses gases but also fires contribute to them. Due to the haze, the amount of sunlight falling on the ground has decreased by six per cent in India and that has a direct bearing on the plant growth. In the region, during the dry season, thousands of fires burn each year as people clear cropland and pasture in anticipation of the upcoming wet (growing) season. Intentional fires also escape people's control and burn into adjacent forest. The smoke from these fires crosses border affecting climate far away.

A discourse among politicians and the scientist are going on the topic of the regional climate change. A United Nations Environment Programme (UNEP) study has warned that Asian cities from New Delhi to Beijing are getting darker, glaciers on the Himalayas are melting faster and weather system is getting more extreme because of high pollution levels (UNEP, 2007). However, Sibal (Science and Technology Minister of India) argued that the Asian countries are not responsible for 'brown cloud' formation contending that the per capita emissions of India are 1.2 tonnes as against 23 tonnes in the US and 10 tonnes in European countries (The Economic Times, 2008). But scientists say the effects of climate change are only getting worse.

Climate change and global warming are significant challenges that the world, particularly the developing and least developed countries, face this century. Although LDCs like Bhutan contribute the least to global warming, they will nonetheless be seriously affected by the impacts of climate change. It is important to realize that climate change is not just an environmental problem but a serious challenge to sustainable development and the livelihood of the Bhutanese people (Nado Rinchhen, Deputy Minister, Royal Government of Bhutan, in NAPA 2007).

UNEP 2007 shows Hindu-Kush Himalayan region is critically vulnerable (Figure 2) to poor people in rural and remote areas tend to be the most directly affected by the decline of biodiversity and deterioration or loss of ecosystem services due to the climate change.

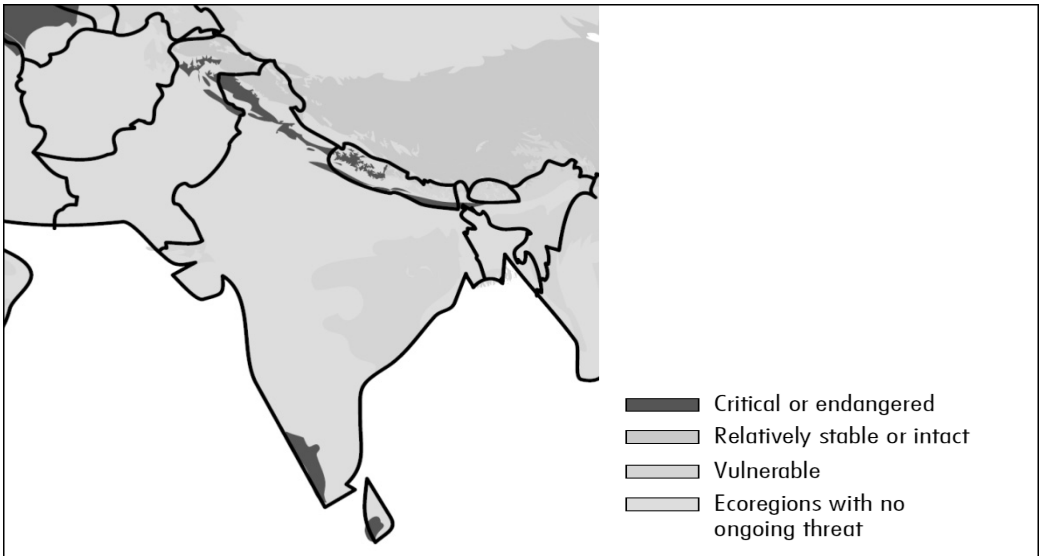

Figure 2: Status of terrestrial ecoregions(source: extracted from UNEP 2007)

Brown cloud is primarily responsible for total cooling effect by 40%. Summer fires could contribute significantly to the melting of glaciers and outburst of the glacier lakes (GLOF) (UNEP 2007).

2.2. *Impact of brown cloud on monsoonal climate, glaciations and socio-economy over south Asia*

The South Asian region is characterized by diverse ecosystems and socio-economic and cultural settings resulting from a wide range of land-use systems and climatic conditions. Consequently these ecosystems have diverse fire regimes and vulnerabilities.

Brown cloud-induced dimming is considered as the major causal factor for the change of monsoonal rainfall pattern (intensity, duration and frequency). For instance, rainfall over the northern half of India has decreased. The number of rainy days for all India is also decreasing, although the frequency of intense rainfall is increasing, leading to more frequent floods in downstream and soil erosions, landslides and debris-flows in upstream areas. The densely populated areas in the region are highly vulnerable from water-induced disasters. Rainfall over the Indo-Gangetic Plain has decreased by about 20 per cent since the 1980s (Ramanathan et al. 2008).

According to the UNEP report, the toxic material could kill 340,000 people in China and India every year. The toxic clouds also threaten the massive Hindu Kush-Himalaya-Tibetan glaciers.

3. CONCLUSION

Occurrences and extents of wildfires in the countries in South Asia are increasingly impacting socio-economy and environment and are contributing to regional and global climate change. Fires affecting sensitive mountain ecosystems have considerable consequences on secondary disasters such as landslides, mudslides, erosion, increased water runoff, and flash floods.

It has been recognized that the involvement of local communities, which are suffering most by the consequences of inappropriate burning practices and wildfires, is crucial to reduce the adverse impacts of fire. But, a lack of fire research and management capability exists in the region, including monitoring, early warning, and ecological and socioeconomic impact assessment.

With much of the high altitude Himalayan region currently in the grip of a long and intense dry seasons occurring annually, the role of under-lying moisture deficits in the fluctuating nature of south Asia’s experience with wildfire is notable, many of them having a potential to cause major damages; e.g., serious degradation of forests, changes of ecosystem properties, and deterioration of social and economic conditions in some land-use systems and natural vegetation types. Equally perhaps, international scientific study has confirmed that significant climate change is under way.

Atmospheric Brown Clouds (ABC) could be the major driver to the regional climate change and pollution though not well understood. Consequently, rainfall over the Indo-Gangetic plain has decreased by about 20 per cent since the 1980s negatively affecting to the agricultural production, changing glacier dynamics and wildfire regimes. Climate change threats mainly to the largely agrarian population that still depends on subsistence agriculture for their daily livelihood in the region.

It's net positive feedback to the regional climate shape a vicious circle with increasing occurrence of wildfires in the region. Observations indicate that the occurrence of wildfires is increasing as a consequence of regional warming and extended dry spells.

Therefore, it has been recommended:

- to enhance and strengthen bilateral/multilateral and international cooperation in wildland fire management for creating synergies and sharing knowledge and technical and human resources among countries in the region by accepting and promoting principles, norms, rules, and decision making procedures within a guiding framework that individual countries agree on;
- to strengthen local communities coping with wildfires and aiding them in addressing the consequences of climate change and fires and the effects on their livelihoods;
- to assist countries in fire management planning, enhancing institutional and technological capabilities and developing synergies through coordinated and collective action both within the region and internationally;
- to emphasize the improvement of participatory/community-based fire management approaches and institutional and technological capabilities at all levels; and
- to promote education and awareness-raising programmes on wildfire prevention.

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CLIMATE CHANGE IMPACTS ON FIRE REGIMES IN THE MONGOLIA

기후 변화가 몽골의 산불형에 미치는 영향

Ganbaatar, Jamiyansuren

Abstract

Territory of Mongolia is located inland, surrounded by high mountains and elevated nearly 1500m above the sea level, where has transition zone between great Siberian taiga and Central Asian desert. Therefore, main climate is continental, harsh and dry. Significant feature of the country climate is long lasting winter, short summer, high fluctuation of temperature, low precipitation and its about 85% falls in summer, and there are great numbers of clear sky day through the year.

There are both negative and positive impact of climate change to the environment and socio economy of the country. However, negative impact is dominated corresponding to recent impact research study, there is high confidence that environment and socio economy is very vulnerable to climate change especially country has continental, semi and arid climate. On the other hand, one of main indicator of climate change is frequency of atmospheric hazardous phenomena such as forest fire, drought, dzud (harsh winter), flus.

According to estimation (liner trend) of temperature and precipitation change using 60 meteorological stations, which are located as homogeneity over Mongolian territory, annual temperature is increased by $1.9^{0}C$, winter is $3.6^{0}C$, spring and fall temperature is $1.3\text{-}1.8^{0}C$ and summer temperature is $0.5^{0}C$, in last 60 years as respectivelyh flood, heat wave, dust storm and heavy snow, forest fire,is increasing in last decade.

It is important to know how climate change effects to forest fire.

요 약

몽골의 영토는 내륙에 있고 높은 산맥들로 둘러싸여 있으며 해발 약 1500m의 높은곳에 위치해 있다. 여기는 거대한 시베리안 침엽수림 지대와 중앙아시아 사막 사이 전이지대이다. 그래서 대륙성 기후이며 날씨가 거칠고 건조하다. 이곳은 겨울이 길고 여름이 짧으며, 기온 변동이 심하고 강수량이 적다.강수량의 85%는 여름에 집중되어 연중 쾌청일수가 큰 것이 주요 기후 특징들이다.

기후 변화는 나라의 환경과 사회경제에 부정적인 영향과 긍정적인 영향을 모두 끼친다. 그러나 최근의 영향 조사연구에 따르면 부정적인 영향이 지배적이다. 특히 대륙성, 반건조 및 건조한 기후를 가져 환경과 사회경제가 기후 변화에 매우 취약하다. 한편 기후 변화의 주요 지표 중 하나는 산불, 가뭄, dzud(혹독한 겨울) 등과 같은 대기 위험 현상의 빈도이다.

몽골의 영토 곳곳에 균질적으로 위치한 60개의 관측소 측정치를 이용한 기온과 강수량의 변화 추정식(선형)에 따르면, 지난 60년간 연평균 기온은 1.9℃ 상승했고, 겨울기온은 3.6℃, 봄과 가을 기온은 1.3-1.8℃, 그리고 여름기온은0.5℃ 각각 상승하였다. 홍수, 열파동, 먼지 폭풍, 폭설, 산불 또한 지난 10년간 증가하였다. 기후 변화가 산불에 어떠한 영향을 끼치는지 아는 것은 중요하다.

CLIMATE CHANGE IMPACTS ON FIRE REGIMES IN THE MONGOLIA

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Abstract

Territory of Mongolia is located inland, surrounded by high mountains and elevated nearly 1500m above the sea level, where has transition zone between great Siberian taiga and Central Asian desert. Therefore, main climate is continental, harsh and dry. Significant feature of the country climate is long lasting winter, short summer, high fluctuation of temperature, low precipitation and its about 85% falls in summer, and there are great numbers of clear sky day through the year.

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It is important to know how climate change effects to forest fire.

Foreword

Fire is the major stand-renewing agent for much of the circumboreal forest zone, greatly influencing forest structure and function. Current estimates are that an average of million hectares burn annually in boreal forests, primarily in Mongolia and there is a growing global awareness of the importance, and vulnerability, of this region with respect to future climate change. Fire activity is strongly influenced by four factors – weather/climate, fuels, ignition agents and human activities (Johnson 1992; Swetnam 1993). Climate and the associated weather are dynamic due to changes in the earth's orbital parameters, solar output and atmospheric composi-tion. Recently, our climate has been warming as a result of increases of radiatively active gases (carbon dioxide, methane etc.) in the atmosphere caused by human activities (IPCC 2001)

It is important to know how climate change effects to forest fire.

Climate of Mongolia 1961-1990

Territory of Mongolia is located inland, surrounded by high mountains and elevated nearly 1500m above the sea level, where has transition zone between great Siberian taiga and Central Asian desert. Therefore, main climate is continental, harsh and dry. Significant feature of the country climate is long lasting winter, short summer, high fluctuation of temperature, low precipitation and its about 85% falls in summer, and there are great numbers of clear sky day through the year.

According to measured observation, annual temperature over Mongolia is within -7.8 to -8.5^{0}C, -7 to -3^{0}C in Altai, Khangai, Khentii and Khuvsgol mountain ranges, and river basin, -3 to 3 ^{0}C in gobi steppe and 3-7^{0}C gobi desert region (Figure 1).

Average temperature of coldest month (January) is within -30 to -34^{0}C in valleys between mountain ranges such as Altai, Khangai, Khentii and Khuvsgol, -25 to -30^{0}C in high mountains, -20 to -25^{0}C in steppe region and -15 to -20^{0}C in gobi desert of Mongolia.

Average temperature of warmest month (July) is less cool than 15^{0}C in, Khangai, Khentii and Khuvsgol mountains, within 15 to 20^{0}C in great lake valley, Orkhon and Seleng basin, region between Altai, Khangai, Khentii and Khuvsgol mountains, and within 20 to 25^{0}C in southern part of Dornod steppe and gobi desert region.

Generally, precipitation amount over the Mongolia is low, within 300 to 400mm in Khangai, Khentii and Khuvsgol mountain ranges, 250 to 300mm in Mongol Altai and forest steppe region, 150 to 250mm in steppe region and 50 to 150mm in gobi desert (Figure 2). The summer rainfall is contributed most percent of the annual precipitation and its intensity high due to convection associated with land surface heating.

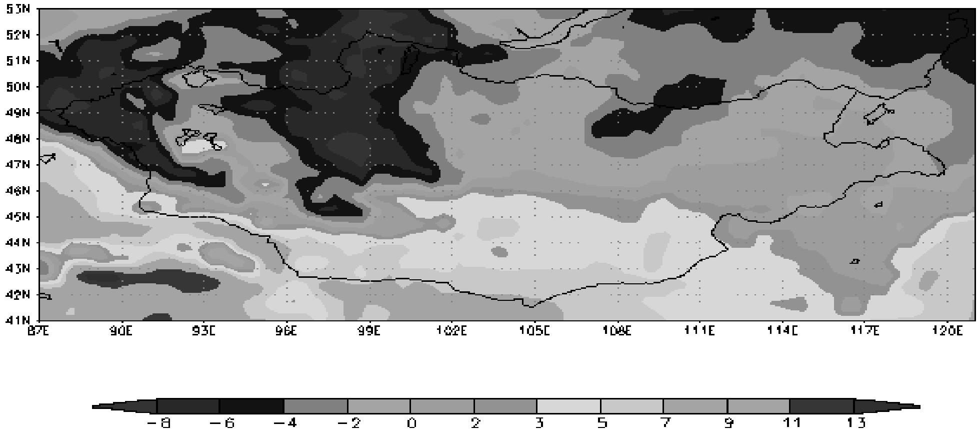

Figure 1. Geographical distribution of annual temperature, ^{0}C

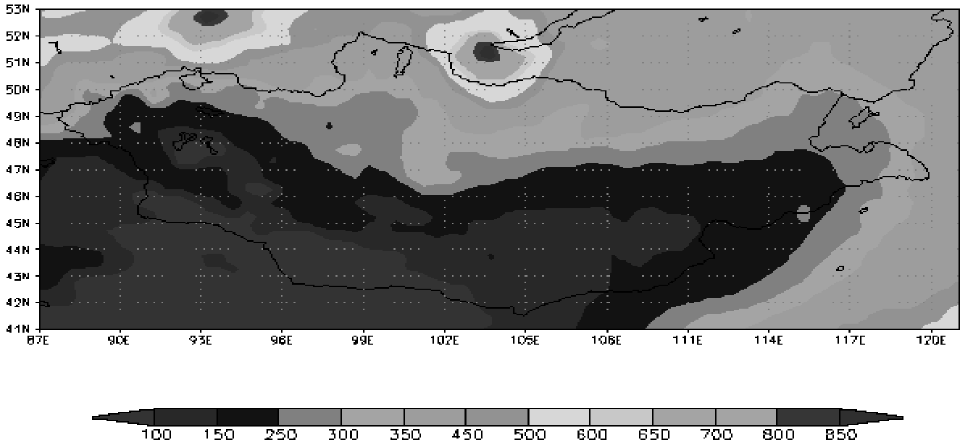

Figure 2. Geographical distribution of annual precipitation, mm

Annual temperature and precipitation of mean climate are determined within climate of 1961-1990 periods. Because World Meteorological Organization

(WMO) has recommended this period depending on global research study, availability of the data and its coverage that could use as a baseline of climate when asses future climate change over word and specific region.

Present climate change of Mongolia

There are both negative and positive impact of climate change to the environment and socio economy of the country. However, negative impact is dominated corresponding to recent impact research study, there is high confidence that environment and socio economy is very vulnerable to climate change especially country has continental, semi and arid climate. On the other hand, one of main indicator of climate change is frequency of atmospheric hazardous phenomena such as forest fire, drought, dzud(harsh winter), flush flood, heat wave, dust storm and heavy snow, is increasing in last decade.

According to estimation (liner trend) of temperature and precipitation change using 60 meteorological stations, which are located as homogeneity over Mongolian territory, annual temperature is increased by 1.9^0C, winter is 3.6^0C, spring and fall temperature is 1.3-1.8^0C and summer temperature is 0.5^0C, in last 60 years as respectively (Figure 3). Warming is observed whole territory of Mongolia, however, there is slight intensity in flat steppe and gobi desert, and high intensity in high mountain and forest steppe region (Figure 5). There was continuously occurred warm year (positive anomaly respect to the climate average) since 1990.

Precipitation is not significantly changed, but it is decreased by 10% in terms of country spatial average (Figure 4). Amount of change rate is different place to place and small increasing of precipitation is observed in east, southeast and Altai mountain region and decreasing in southern part of Khangai mountain and central region of Mongolia as well (Figure 6).

Maximume of spatial average of precipiation amount is obversed in 1994, 1964 and 1959 and minimume is occured in 1942, 1944, 1980 and 2000. Dry period was contiuened in mid of 1940, between 1978-1983 and 1999-2002. At the time many river and lake was dryed.

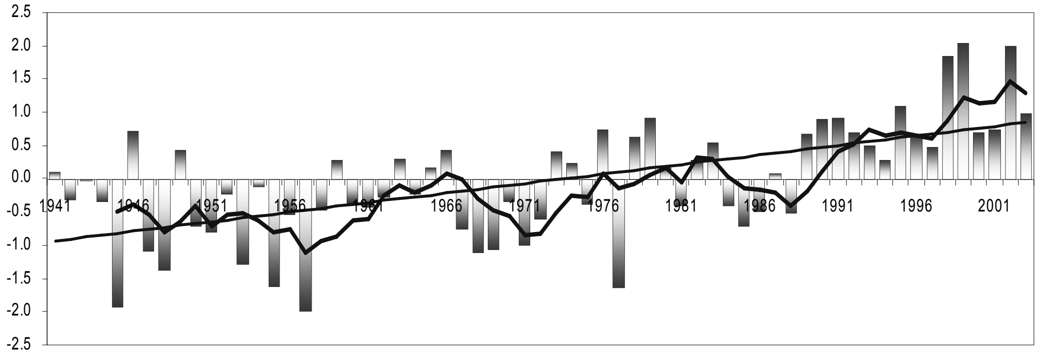

Figure 3. Spatial average of normalized annual

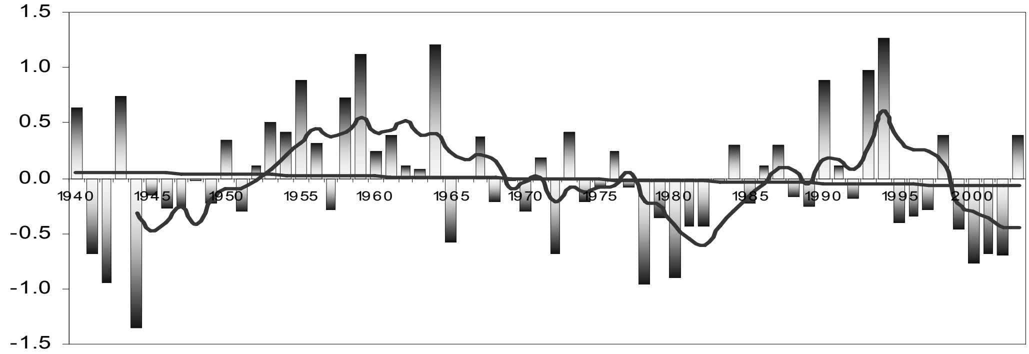

Figure 4. Spatial average of normalized annual temperature over Mongolia precipitation over Mongolia

Source from: P.Gomboluudev, 2005

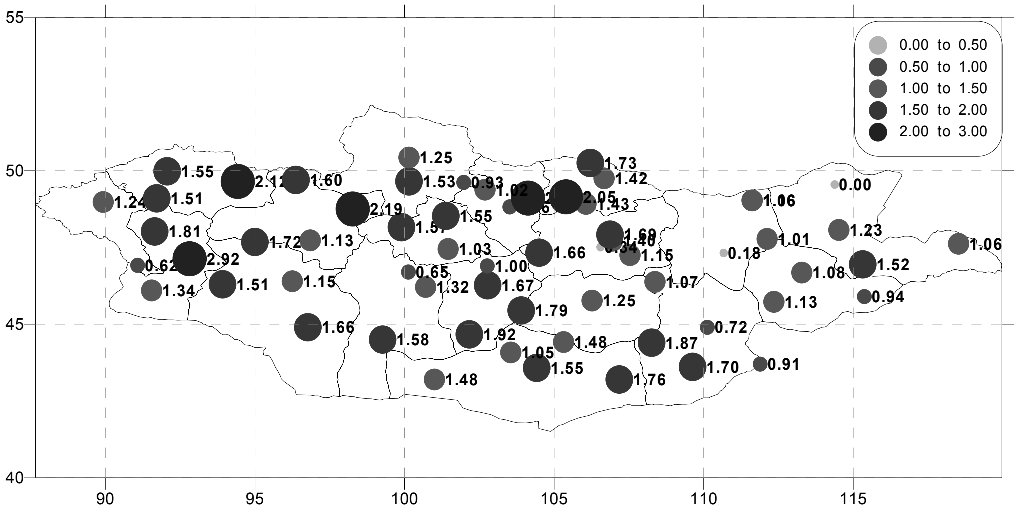

Figure 5. Annual temperature change in last 30years, 0C

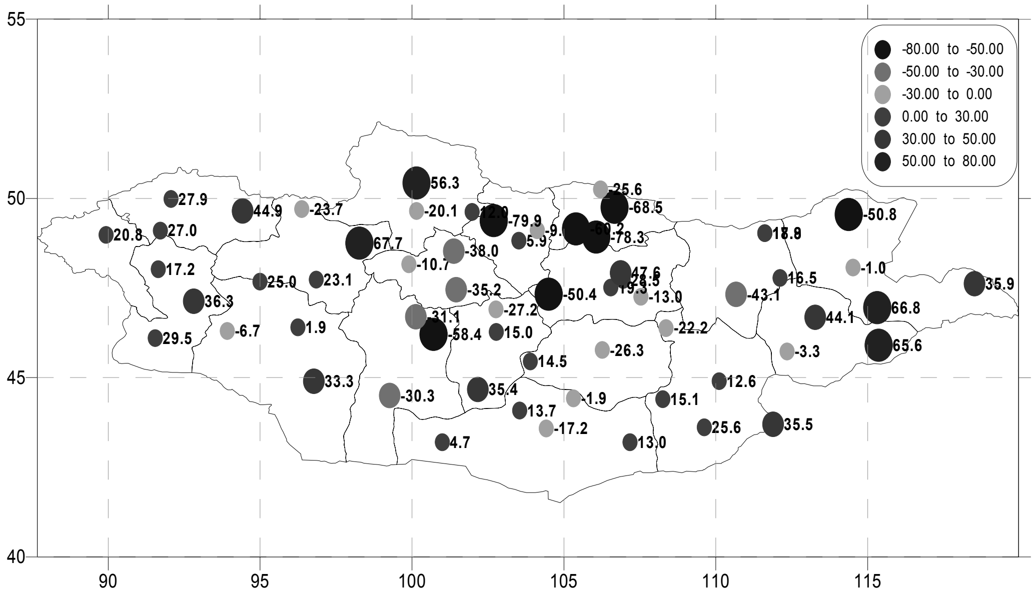

Figure 6. Annual precipitation change in last 30years,mm

Climate change scenarios of Mongolia

It is already known that human activities are influenced climate system. Human induced green house gas (GHG) concentration in atmosphere is dependent on future trends of world population, technology and socio-economic development. These are related to four different sets of assumptions or storylines about key drivers of emissions. Four storyline are refered to by the IPCC as A1, A2, B1, and B2.

Among the global climate models (GCM), Hadley Center, UK, HadCM3 model well represents Mongolian mean climate 1961-1990 in terms of its statistic measure against observation. Mean error of the annual, summer and winter temperature are 1.13^0C, 0.79^0C and 0.92^0C, respectively (Figure 7, 8). Therefore, it is suggested that HadCM3 model output will be close to possible future climate change scenarios and it will be optimal options that we could use in the climate change impact study. Hence, all impact assessment study to be mentioned next section will be based on Hadley Centre model scenarios.

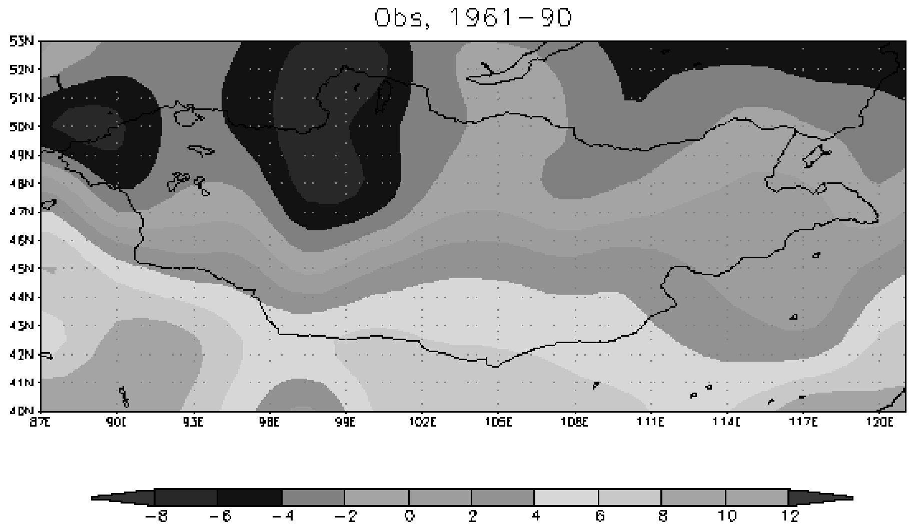

Figure 7. Observed climate of annual temperature 1961-1990, ^{0}C

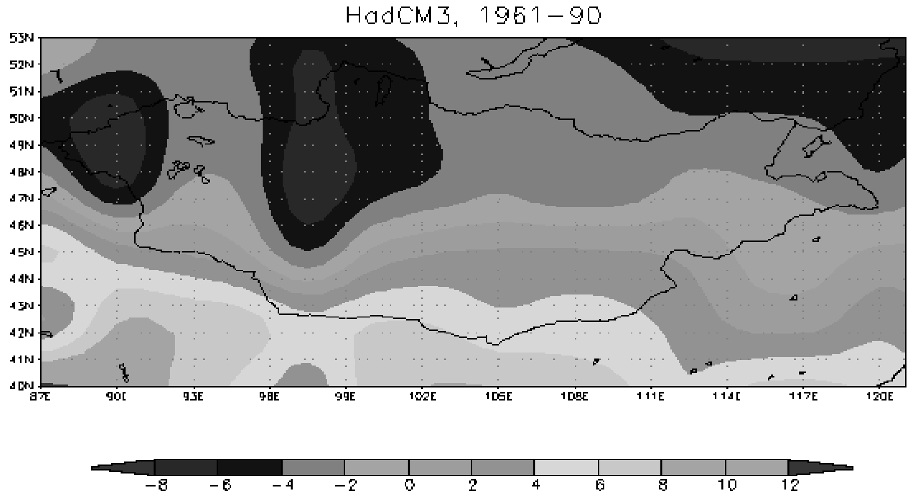

Figure 8. Simulated climate of annual temperature by HadCM3

Climate change scenarios of Mongolia has considered as seasonal aspect in 2020 (2011-2040), 2050 (2041-2070) and 2080 (2071-2100) respect to climate baseline 1961-1990. GHG emission scenarios A2 (mid high), B2 (mid low) is chosen in study.

The annual mean temperature will be increased 1.37-4.88^{0}C, precipitation 2.4-14.3%, winter temperature 0.85-3.89^{0}C, precipitation 23.3-67.0%, spring temperature 1.28-4.37^{0}C, precipitation 7.0-18.7%, summer temperature 1.99-

6.35^{0}C, precipitation will be decreased 2.4% until 2020, then increased 6.4%, autumn temperature 1.37-4.91^{0}C and precipitation 4.4-16.5% as respectively (Table 3).

Above mentioned change, it is indicating that winter is becoming more mild and snowy, and summer is getting hot and dry under A2 GHG scenarios (Figure 9). Under B2 GHG scenarios, general trend is almost same and only difference is that amount of change value is little bit smaller than the A2.

High intensity warming of temperature will be observed in Central and Western region of Mongolia and precipitation decreasing will be observed in Western and increasing will be observed in the Eastern region of Mongolia.

Table 3. Seasonal temperature and precipitation change using HadCM3 model

Seasons	A2						B2					
	2020		2050		2080		2020		2050		2080	
	T, ^{0}C	R,%	T, ^{0}C	R,%	T, ^{0}C	R,%	T, ^{0}C	R,%	T, ^{0}C	R,%	T, ^{0}C	R,%
Annual	1.37	2.4	2.81	11.5	4.88	14.3	1.52	5.2	2.43	11.1	3.49	11.6
Winter	0.85	23.6	2.38	38.7	3.89	67.0	0.96	16.5	1.73	34.4	2.48	54.7
Spring	1.28	7.0	2.61	16.8	4.37	18.7	1.38	6.0	1.97	11.9	3.11	17.6
Summer	1.99	-2.5	3.53	7.1	6.35	6.4	2.23	3.1	3.31	8.7	4.66	4.5
Autumn	1.37	4.4	2.71	8.9	4.91	16.5	1.52	7.5	2.7	10.2	3.71	12.0

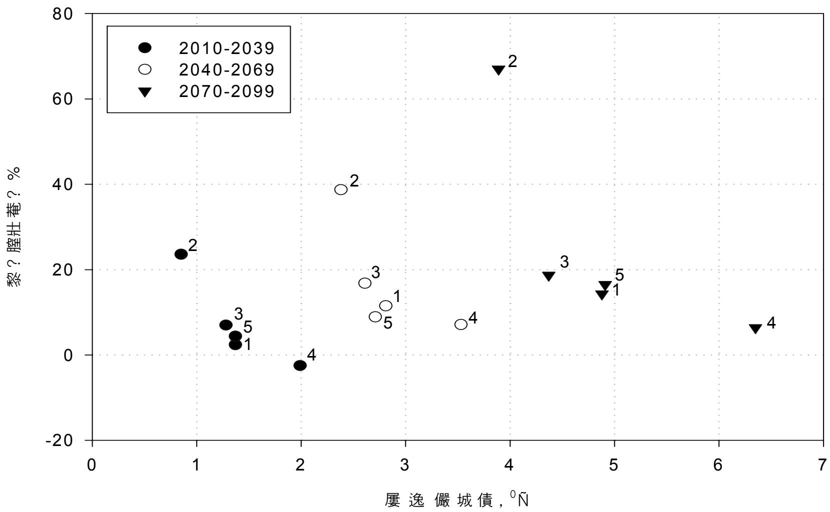

Figure 9. Projected temperature and precipitation change by HadCM3 under A2 GHG
1-Annual; 2-Winter; 3-Spring, 4-Summer, 5-Autumn

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The Space and Time Evaluation of Forest Fire Occurrence Hazards Using Climate Data of Ten-day Intervals 30 Years in Spring, Korea

봄철 순평년 기후자료를 이용한 지역별 산불발생위험성의 시공간적 평가

WON, Myoung Soo, Kyo Sang KOO, Myung Bo LEE, Woo Kyun LEE, Suk Hee YOON

Abstract

This study has an object to look into forest fire occurrence hazards by the change of temperature and humidity for thirty years at intervals of ten days. We used data of the forest fire inventory from 1995 to 2004 and weather data such as average temperature and relative humidity for 30 years from 1971 to 2000. These data were made database at intervals of ten days by 76 weather stations. Forest fire occurrence hazards estimated worked with spring season from the end of March to the middle of April which it have occurred the most forest fires. For the first step, a primitive temperature and humidity surface were interpolated by IDW, which is standard interpolation method. These thematic maps have 1km×1km grid spacing resolution. Next, we execute simple regression analysis after extracting forest fire frequency, temperature and humidity values from 76 points. The result of the simple regression analysis shows coefficient of determination(R^2) ranges from 0.4 to 0.6. Moreover, As a result of estimation of forest fire occurrence hazards during the early in April, it was very high at Gyeongbuk Interior, Chungcheong Interior and the part of Gangwon by region. The range of the temperature and humidity having an influence on forest fire occurrence was as follows; average temperature and relative humidity in the early of April was 9~12℃ and 61-65%. In case of the end of March, temperature was 6-10℃, humidity 62-67% and temperature 11-14℃, humidity 60-67% in the middle of April.

요 약

열흘 간격의 순평년 온·습도 변화에 따른 산불발생위험성을 분석하기 위해 1995년부터 2004년까지 과거 10년 동안의 산불통계자료와 1971년부터 2000년까지 순평년 평균온도 및 습도자료를 이용하였다. 순평년 온·습도 변화에 따른 산불발생위험성 평가를 위해 산불발생빈도가 높고 대형산불 발생이 가장 많은 시기인 3월 하순부터 4월 중순까지를 대상으로 하였다. 분석을 위해 가장 일반적으로사용하는 거리역산가중(IDW) 방법을 이용하여 우리나라 전역의 산불발생빈도 및온·습도 표면을 1km 간격으로 추정하였다. 산불발생빈도가 가장 높은 4월 초순은 중부내륙, 경기 동부, 동해안 지역에서 산불발생 빈도가 높게 나타났으며,순평년 온·습도변화에 따른 산불발생위험 회귀분석 결과 결정계수(R^2)가 0.4-0.6사이에 분포하여 온도와 습도를 독립변수로 하는 다중회귀분석 방법보다 설명력이 향상되는 결과를 보였다. 산불발생에 영향을 미치는 평균온도의 범위는 3월 하순이 6-10℃, 4월 초순은 9-12℃, 4월 중순은 11-14℃ 구간에서 산불발생이많았고, 평균습도의 경우 3월 하순은 62-67%, 4월 초순은 61-65%, 4월 중순은60-67% 구간에서 산불발생빈도가 높았다.

The Space and Time Evaluation of Forest Fire Occurrence Hazards Using Climate Data of Ten-day Intervals 30 Years in Spring, Korea

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Abstract

This study has an object to look into forest fire occurrence hazards by the change of temperature and humidity for thirty years at intervals of ten days. We used data of the forest fire inventory from 1995 to 2004 and weather data such as average temperature and relative humidity for 30 years from 1971 to 2000. These data were made database at intervals of ten days by 76 weather stations. Forest fire occurrence hazards estimated worked with spring season from the end of March to the middle of April which it have occurred the most forest fires. For the first step, a primitive temperature and humidity surface were interpolated by IDW, which is standard interpolation method. These thematic maps have 1km×1km grid spacing resolution. Next, we execute simple regression analysis after extracting forest fire frequency, temperature and humidity values from 76 points. The result of the simple regression analysis shows coefficient of determination(R^2) ranges from 0.4 to 0.6. Moreover, As a result of estimation of forest fire occurrence hazards during the early in April, it was very high at Gyeongbuk Interior, Chungcheong Interior and the part of Gangwon by region. The range of the temperature and humidity having an influence on forest fire occurrence was as follows; average temperature and relative humidity in the early of April was 9~12℃ and 61-65%. In case of the end of March, temperature was 6-10℃, humidity 62-67% and temperature 11-14℃, humidity 60-67% in the middle of April.

1. 서 론

우리나라의 산불은 대부분 사람의 사소한 부주의에 의하여 발생한다. 산불발생의 원인은 등산객, 성묘객, 무속행위자, 산림약초채취자 등 입산자의 부주의에 의한 실화가 가장 많으며 그밖에 논밭두렁 소각, 담뱃불, 군사훈련, 어린이 불장난 등에 의해 발생하고 있다. 한편 산불은 일차적인 원인으로 다양한 인위적 요인에 의하여 시작되지만 이와 같은 실화가 산림에 피해를 줄 정도로 발화·연소·확산되기 위해서는 습도, 풍속, 기온 및 임내 가연성물질의 함수율 등 연소환경을 구성하는 기상적 요인과 깊은 상관관계를 가지고 있다(Lee et al., 2004). 최근 5년간(2001-2005) 발생한 산불 2,715건 중 건조한 봄철(3월-5월)에 발생한 산불이 1,824건으로 전체의 67%를 차지하고 있다(산림청, 2005).이는 봄철이 다른 계절보다 강우량이 적고 맑은 날이 많아 상대습도가 가장낮은 시기이면서 산림내 건조한 낙엽이 많이 쌓여 어느 시기보다도 위험한 상태이기 때문이다(Lee et al., 2004). 따라서 정확한 산불발생위험성을 해석하기위해서는 산불발생 패턴과 시계열적 기상 변화를 함께 고려하는 것이 무엇보다 중요하다.

일반적으로 기상관측소로부터 멀리 떨어진 지점의 기온값을 추정하기 위해 주변 기상관측소의 기온값을 평균하는데 이때 가까이 있는 관측소의 실측값에 가중치를 주는 거리역산가중(Inverse distance weighting) 방법은 지형이 평탄하고 균일한 곳에서는 좋은 추정결과를 보인다(Yun et al., 2000). 그러나 우리나라는 삼면이 바다로 둘러 싸여있고 북쪽은 아시아대륙과 연결되어 해양과대륙의 영향을 동시에 받을 뿐 아니라 국토 대부분을 차지하는 산악지형으로인해 좁은 국토면적에 비해 2,000m에 이르는 표고범위를 보이는 등, 국지기온결정인가가 매우 다양하다(Yun et al., 2000; Chung and Yun, 2002). 지형이 이렇게 복잡한 곳에서는 관측점으로부터의 거리에만 의존한 공간내삽의 경우 현실과 동떨어진 결과를 생성하기 쉽다. 이를 보완하기 위해 중회귀, kriging, spline 등다양한 공간통계학적 기법이 이용되어 왔다(유, 1999).

우리나라에서는 Cheong et al.(1989)이 수종별, 영급별, 지피물량과 임내외기상 및 연료습도 변화를 조사하여 산불위험도를 분석하였으며, Cheong 등(1994)은 지역별, 시기별 산불발생위험도를 전산분석 및 도면화하였다. 또한 Choi andHan(1996)은 기상자료와 산불발생과의 관계를 로짓과 프로빗 확률모형을 적용하여 산불발생확률식을 개발하였으며, Lee et al.(2004)은 전국을 대상으로 지역별 산불발생원인과 기상조건의 관계를 구명하기 위해 통계적 분석을 적용하여 제주도를 제외한 8개 광역지역별 산불발생확률모형을 개발한 바 있다.

우리나라에서는 국립산림과학원의 산불위험예보시스템 개발(과학기술부, 2003)과 더불어 실시간 산불위험상황을 실시간으로 파악할 수 있는 정보체계가 구축되어 있지만 기상변화에 따라 산불발생에 영향을 미칠 수 있는 기상인자별 위험 기준은 마련되어 있지 않다. 따라서 본 연구는 기상적 요인(온도, 습도)과 산불발생 빈도와의 상호관계 구명을 통하여 시간경과에 따른 산불발생위험성과 온·습도 변화에 따른 산불발생위험 구간을 정의하고자 하였다.

2. 재료 및 방법

2.1 사용자료

온·습도 변화에 따른 산불발생위험성 구명을 위해 1995년부터 2004년까지의 10년간 지역별 산불발생 현황자료를 이용하였다. 산불발생 현황자료의 경우 산불이 가장 많이 발생하는 봄철을 포함하여 연간 발생현황을 정리한 것으로, 산불발생위험성을 구명하기 위해 산불발생이 가장 많은 봄철을 중심으로 3·4월만의 발생현황자료를 적용하여 순기별-지역별 산불발생 DB를 구축하였다.

산불발생에 영향을 미치는 기후인자로는 기온, 습도, 풍속 및 강수량 등이 있으며, 본 연구에서는 3월 하순부터 4월 중순까지 순평년 온도와 습도 변화에 따른 순기별 산불발생위험성을 구명하고자 하였다. 산불발생위험성 구명을 위해 사용된 기후자료는 기상청의 1971년부터 2000년까지의 30년 순평년값을 이용하였으며, 기상분석을 위해 기후자료를 산불발생 현황자료와 동일한 시점인 3월과 4월의 순평년값을 대상으로 하였다. 수집된 일별 기상자료를 열흘 간격의 순기별로 분류하여 재작성한 후 기상청의 76개 기상관측소 지점별 속성정보와 결합하여 분석에 이용하였다.

2.2 분석방법

구축된 1995년부터 2004년까지 10년간 지역별 산불발생 현황자료를 이용하여 전국 165개 시·군별 산불발생건수를 순기별로 자료를 구축한 후 행정구역별 폴리곤 및 포인트 정보와 결합하여 전국의 순기별 산불발생 빈도에 대한 공간분석을 실시하였다. 수집한 순평년 기후자료(온도, 습도)는 76개 기상관측소별로 데이터베이스화하여 3월초에서 4월말까지 거리역산가중

(IDW) 보간법을 이용하여 각각의 GIS 주제도를 구축하였다. 순기별 온도 및 습도 분포는 1km×1km 공간해상도로 작성하였다. 전국 76개 기상관측소에서 과거 30년(1971-2000년) 동안 집계된 기상자료로부터 각 지역별 온도와 습도 분포를 산출하기 위해서는 우선 각 기상관측지점의 온도와 습도를 기반으로 우리나라 전역에 걸친 온·습도 표면을 추정해야 한다. 이와 같은 목적으로 GIS에서 일반적으로 사용하는 보간 방법으로는 IDW(inverse distance weighting), spline, polynominal regression과 공간 통계학(spatial statistics, geostatistics)이론에 기반을 둔 보간 방법인 크리깅(kriging) 등이 있다. 이상과 같은 다양한 보간 방법들은 산불발생 특성과 기상해석 등 목적에 따라 선택적으로 적용할 수 있는데 본 논문에서는 가장 일반적으로 사용하는 거리역산가중(IDW)법을 이용하였으며, 온·습도 변화에 의한 산불발생위험성 구명을 위한 일련의 분석과정은 ArcGIS 9.1을 통해 분석하였다. 작성된 주제도를 이용해 기상관측 지점별 발생빈도와 온·습도 값을 추출하여 회귀분석을 실시하여 4월초순의 산불발생위험과 온·습도간의 회귀식을 산출한 후 4월 초순의 산불발생위험 주제도를 구축하였다.

3. 결과 및 고찰

3.1 순기별 산불발생빈도 분석

최근 10년간(1995~2004) 산불발생위험이 가장 높은 봄철(3월~5월)의 순기별-지역별 산불발생 빈도를 분석한 결과 순기별로는 4월초순 > 3월하순 > 4월중순 > 3월중순 > 4월하순 > 3월초순 순으로 산불발생이 높았다. 이 중 산불발생이 가장 높은 4월초순, 3월하순, 4월중순의 지역별 산불발생 빈도를 살펴보면 Fig. 3에서처럼 산불발생위험이 가장 높은 4월 초순경에 충청도를 중심으로 한 중부내륙 지역과 경기도 동부지역, 대구를 비롯한 경상도 동해안 지역, 강원도 영동지역에서 산불발생 빈도가 높게 나타났다. 특히 최근 4월 초순 발생한 산불의 23%가 경기도에서 발생하는 등 전남과 경남 이북지역인 중부내륙 지방을 중심으로 83%의 산불이 집중되고 있다. 지역별로는 대전, 청원, 서울, 인천 등 수도권 지역에서 평균 2건 이상이 발생하여 다른 지역에 비하여 산불발생이 매우 높은 것으로 나타났다. 3월 하순에는 부산, 울산, 포항, 대구지역과 대전을 포함한 충청 내륙 지역, 서울·인천 및 경기·강원 내륙지방을 중심으로 많은 산불이 발생한 것으로 분석되었다. 4월 중순 들어 점차적으로 산불이 초순과 비교하여 소강상태에 들어가지만 서울·인천 등

대도시 일대와 중부 내륙지역 및 강원 동해안 일부 지역은 여전히 산불빈도가 높은 것으로 나타났다<Fig. 1>.

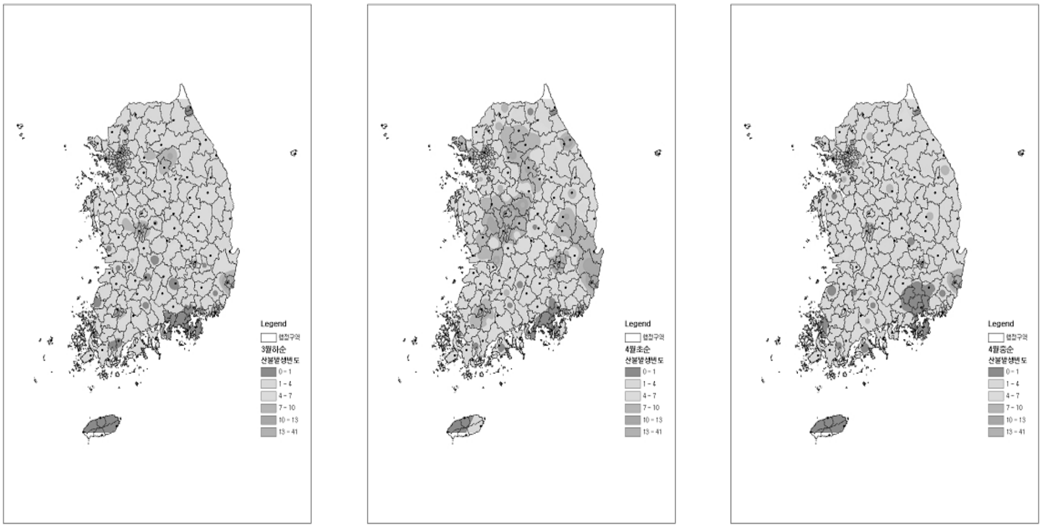

Fig. 1. Forest fire frequency of ten-day intervals(from the left. the end of March, the early of April, the middle of April)

3.2 순평년 온·습도 변화 분석

순평년 온·습도 변화에 따른 산불발생위험을 구명하기 위해 IDW 보간법을 이용하여 3월 하순에서 4월 중순까지의 순기별 평균기온 및 습도분포도를 작성하였다. 분석시 76개 기상관측소 위치정보를 이용하여 공간해상도 1km의 GIS 공간자료를 구축하였다<Fig. 2> <Fig. 3>. 분석 결과 3월 하순에는 전국적으로 평균기온이 0.8-11.3℃, 평균습도는 58.0-74.2%의 분포를 보였으며 4월 초순에는 평균기온 4.1-12.9℃, 평균습도 54.6-73.3%의 분포를 보여 3월 하순과 비교하여 온도는 1.6-3.3℃ 상승하였고 습도는 0.9-3.4% 정도 낮아지는 것으로 분석되었다. 4월 하순의 경우 평균기온 6.4-14.3 ℃, 평균습도는 54.9-74.4%의 분포를 보였다. 온도가 상승함에 따라 중부와 북부지역의 평균습도가 낮아져 건조 정도를 잘 반영하고 있는 것으로 나타났으며, 4월 중순 들어 기온이 상승하면서 중부내륙 이북 지역은 여전히 건조하지만 남부 해안지역은 상대습도가 점차적으로 높아져 산불발생 빈도가 서서히 감소하는 추세였다.

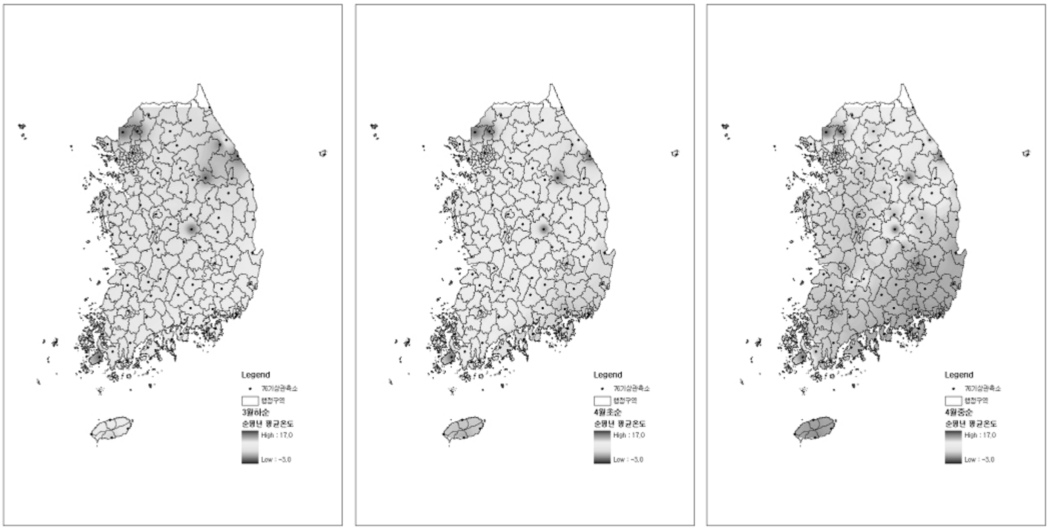

Fig. 2. The average temperature of ten-day intervals for 30 years(from the left. the end of March, the early of April, the middle of April)

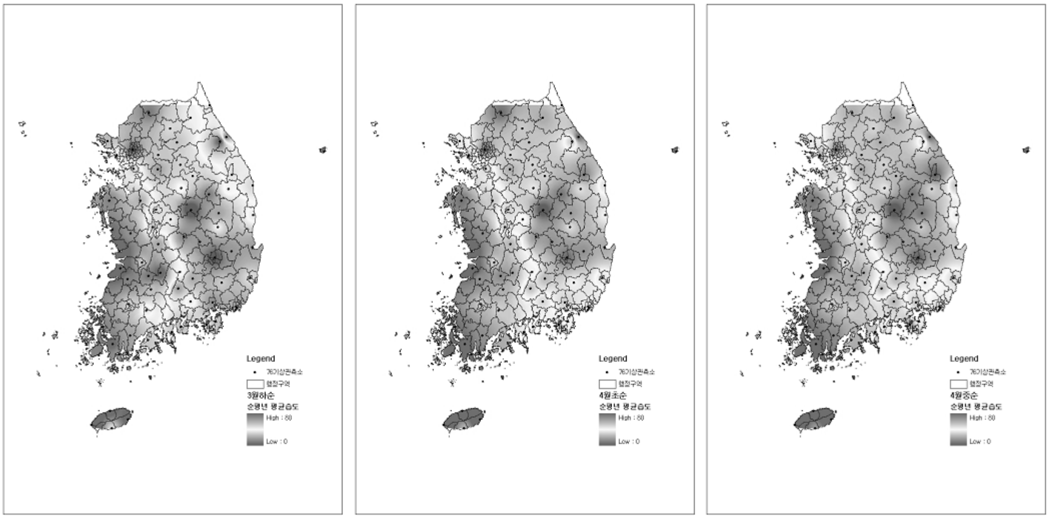

Fig. 3. The average relative humidity of ten-day intervals for 30 years(from the left. the end of March, the early of April, the middle of April)

3.3 온·습도 변화에 따른 산불발생위험성 평가

순기별로 제작한 산불발생 분포도와 온·습도 분포도를 이용하여 온·습도 변화에 따른 지역별 산불발생위험성을 파악하기 위해 순기별로 산불발생

빈도와 온·습도간의 회귀식을 도출하였다. 본 논문에서는 과거부터 산불발생 빈도가 높고 대형산불 발생이 가장 많은 시기인 3월 하순부터 4월 중순을 대상으로 산불발생위험성을 평가하였다. 산불발생위험성 평가를 위한 통계량 산출은 76개 기상관측소 위치정보를 이용하였으며, 이 중 과거 추가 신설되어 평년값 정보가 없는 동해관측소 등 8개소는 분석에서 제외하였다. 추출한 순기별 산불발생빈도와 온·습도 값을 회귀분석에 이용하였다. 분석에 앞서 산불발생빈도, 온도, 습도와의 상관관계를 분석한 결과 온도와 습도의 상관성이 매우 낮아 산불발생빈도를 종속변수로, 온도와 습도를 독립변수로 하는 다중회귀분석을 실시할 경우 설명력이 매우 떨어지는 결과를 보였다 (Won et al., 2006). 다중회귀분석 결과는 Table 1과 같다. Table 1에서 보면 순기별 온도와 습도 요인들이 산불발생과의 관계를 10% 정도만을 설명하고 있어 회귀식이 무의미함을 알 수 있다.

Table 1. The multiple regression equations of forest fire occurrence hazards by the change of average temperature and humidity

	Equations	R^2
March-End	$y = -0.2346*T_{mean}-0.3937*RH_{mean}+31.69$	.1037
April-Early	$y = -0.6623*T_{mean}-0.3947*RH_{mean}+37.88$	.0997
April-Mid	$y = -0.2864*T_{mean}-0.2209*RH_{mean}+21.29$	.0935

따라서 본 논문에서는 순평년 온·습도 변화에 따른 산불발생위험성 분석을 위해 독립변수로 온도와 습도를 분리하는 단순회귀분석 방법을 이용하였다. 3월 하순부터 4월 초순까지의 온·습도 변화에 따른 산불발생위험성 회귀분석 결과는 Fig. 4와 같다. Fig. 4에서처럼 산불발생빈도는 평균온도가 높아짐에 따라 증가하다 감소하는 현상을 보이는데 발생빈도의 정점을 중심으로 우측은 대부분이 남해안과 인접한 지역들이다. 평균습도는 68% 이상에서 산불발생빈도가 급격히 감소하는데 주로 제주도를 비롯한 서해안 인접지역을 중심으로 분포하는 것으로 나타났다. 이러한 결과는 우리나라의 기후특성상 봄철에 온도가 상승하면서 매우 건조해지지만 남부지방부터 초본과 수목의 새싹이 돋아나기 시작함에 따라 수목과 잎 그리고 토양의 함수율이 증가하여 산불발생이 줄어들기 때문인 것으로 사료된다. 그러나 온도변화에 따른 산불발생위험은 시간이 경과함에 따라 결정계수가 높아지나 습도의 경우 시간이 경과됨에 따라 결정계수가 낮아지는 경향을 보이고 있어 이에 대한 보완연구가 필요하다.

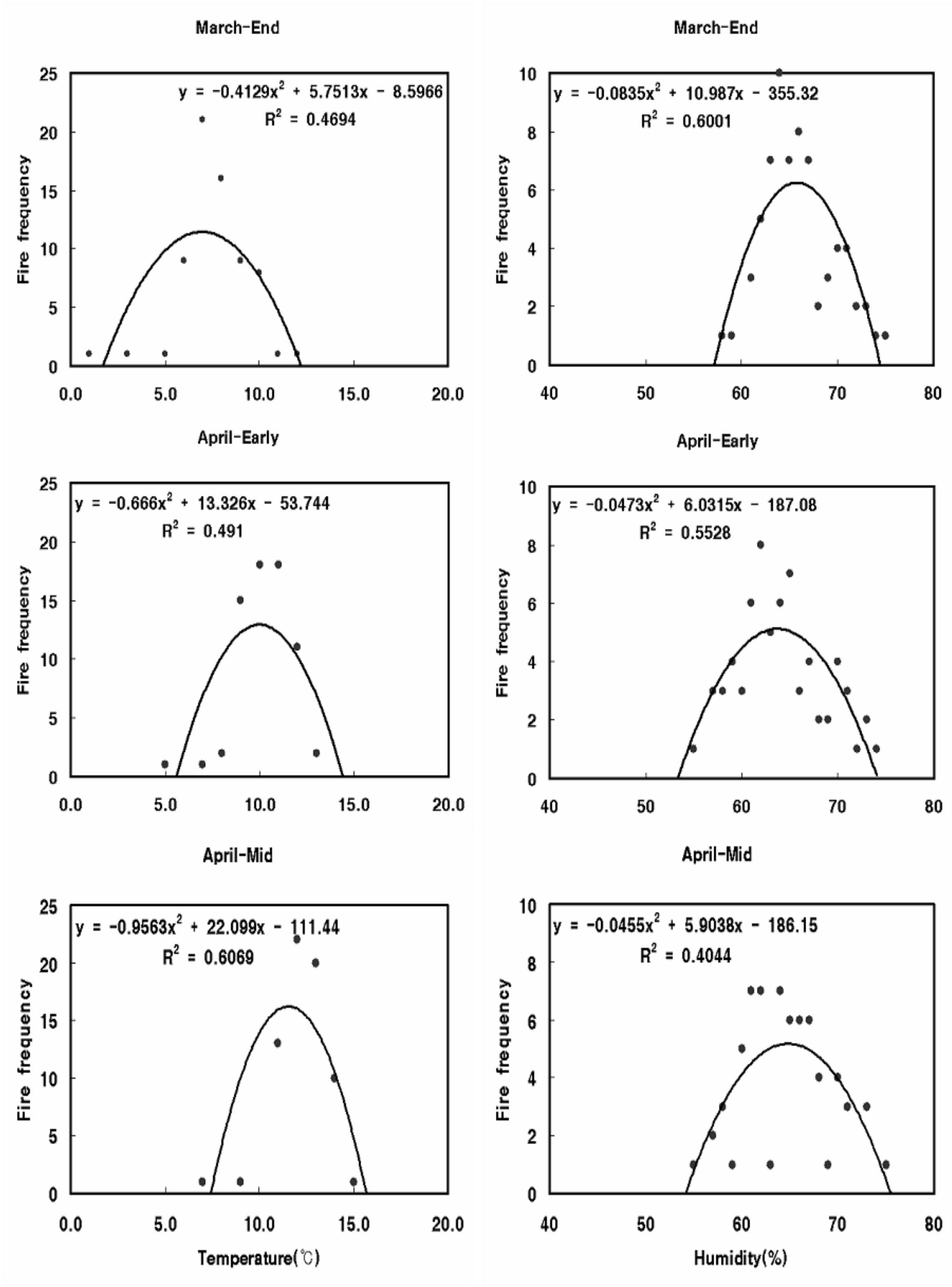

Fig. 4. The simple regression analysis of forest fire occurrence hazards by the change of average temperature and humidity

도출한 단순회귀식을 적용하여 온도와 습도의 변화에 따른 독립적인 산불발생위험도를 작성하였다. 작성된 순기별 위험도를 GIS 공간분석과 레이어 중첩을 통해 3월하순에서 4월중순까지의 순평년 온·습도 변화에 따른 산불발생위험도를 작성하였다. 산불발생위험도 작성을 위해 해당 시기의 온·습도 GIS 공간자료를 식 (1)과 같이 중첩하였다.

$$\text{Forest Fire Occurrence Hazard} = A \cap B \tag{1}$$

여기서, A는 순기별 온도변화에 따른 산불발생위험성, B는 습도변화에 따른 산불발생위험성이다.

Table 2는 온도와 습도변화에 따른 산불발생위험성에 대한 평균과 표준편차이며, 식 (1)을 적용하여 순기별 산불발생위험성 구분을 위한 임계치로 활용하였다. 즉 순기별 산불발생위험도 작성을 위해 3월 하순의 온도에 의한 산불발생위험성은 10.4 이상, 습도에 의한 산불발생위험성은 5.49이상을 적용하여 3월하순 산불발생위험도를 작성하였다. 4월 초순의 경우 온도와 습도를 각각 9.71과 4.61 이상을 적용하였으며, 4월중순은 11.41과 4.73 이상을 적용하여 온도와 습도변화에 따른 순기별 산불발생위험도를 제작하였다.

Table 2). The mean and standard deviation(SD) of forest fire frequency by the change of temperature and humidity

Division		Forest fire frequency by the T_{mean}	Forest fire frequency by the RH_{mean}
March-End	Mean	10.04	5.49
	SD	2.71	0.66
April-Early	Mean	9.71	4.61
	S.D.	8.30	0.57
April-Mid	Mean	11.41	4.73
	S.D.	15.13	0.60

식 (1)을 적용하여 순기별 시간경과에 따른 산불발생위험성을 평가한 결과 3월 하순은 동해안 일부지역과 내륙지방을 중심으로 수직적인 형태로 분포하였으며, 4월 초순 들어서는 남해안 거의 대부분 지역으로 산불발생 위험도가 확대되는 것을 알 수 있었다. 또한 4월 중순의 경우 남해안과

서해안 대부분 지역으로 발생위험도가 확대되며, 특이한 것은 동해안 지역을 따라 산불위험성이 증가하는 것으로 나타났다<Fig. 5>. 그러나 과거 대형 산불이 잦았던 강릉, 삼척 등 강원 동해안 지역은 3월 하순을 제외하고 4월 초순과 중순에 산불발생위험도가 낮게 나타났다. 이것은 위험성 평가 요소 중 풍속이 제외되고 과거 지역별 산불발생빈도만을 대상으로 분석하였기 때문인 것으로 사료된다.

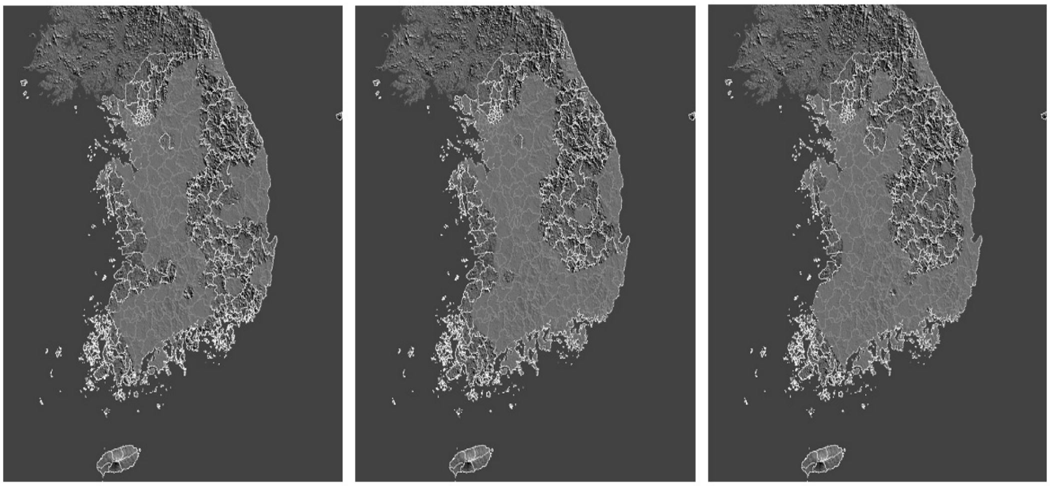

Fig. 5. The forest fire occurrence hazards overlapping change of average temperature and humidity at ten-day intervals in spring (from the left. the end of March, the early of April, the middle of April)

3.4 온·습도 변화에 따른 산불발생위험 조견표 작성

순기별 온·습도 변화에 따른 산불발생위험도 분석 결과 순평년 평균온도가 3월 하순은 6-10℃, 4월 초순은 9-12℃, 4월 중순은 11-14℃에서 산불발생이가장 많았고, 순평년 평균습도의 경우 3월 하순은 62-67%, 4월 초순은 61-65%,4월 중순은 60-67% 범위에서 가장 많은 산불이 발생하였다. 평균온도 변화에따라 산불발생빈도가 뚜렷이 구분됨을 알 수 있으며, 평균습도는 전반적으로고르게 분포하나 순기별 시간경과에 상관없이 대체로 60-67% 구간에서 60% 이상 산불이 발생하는 것으로 분석되었다.

이상의 결과를 종합하여 순기별 시간경과에 따라 온도, 습도 변화에 따른 산불발생위험 구간범위를 비교하였다. Table. 3은 순기별 온·습도 변화에 따른 산불발생위험 조견표이다.

Table 3. A ready reckoner of forest fire hazard by the change of temperature and humidity

Average temp.	Occurrence ratio(%)			Average humidity	Occurrence ratio(%)		
Interval (℃)	March-End	April-Early	April-Mid	Interval (%)	March-End	April-Early	April-Mid
1.0	1.5	0.0	0.0	55.0	0.0	1.5	1.5
2.0	0.0	0.0	0.0	56.0	0.0	0.0	0.0
3.0	1.5	0.0	0.0	57.0	0.0	4.4	2.9
4.0	0.0	0.0	0.0	58.0	1.5	4.4	4.4
5.0	1.5	1.5	0.0	59.0	1.5	5.9	1.5
6.0	13.2	0.0	0.0	60.0	0.0	4.4	7.4
7.0	30.9	1.5	1.5	61.0	4.4	8.8	10.3
8.0	23.5	2.9	0.0	62.0	7.4	11.8	10.3
9.0	13.2	22.1	1.5	63.0	10.3	7.4	1.5
10.0	11.8	26.5	0.0	64.0	14.7	8.8	10.3
11.0	1.5	26.5	19.1	65.0	10.3	10.3	8.8
12.0	1.5	16.2	32.4	66.0	11.8	4.4	8.8
13.0	0.0	2.9	29.4	67.0	10.3	5.9	8.8
14.0	0.0	0.0	14.7	68.0	2.9	2.9	5.9
15.0	0.0	0.0	1.5	69.0	4.4	2.9	1.5
합계	100.0	100.0	100.0	70.0	5.9	5.9	5.9
				71.0	5.9	4.4	4.4
				72.0	2.9	1.5	0.0
				73.0	2.9	2.9	4.4
				74.0	1.5	1.5	0.0
				75.0	1.5	0.0	1.5
				합계	100.0	100.0	100.0

4. 결 론

본 연구에서는 온·습도 변화에 따른 산불발생위험성을 구명하기 위해 순기별 산불발생빈도와 순평년 온·습도 자료를 이용하여 우리나라에서 산불이 가장 많이 발생하는 3월 하순부터 4월 중순까지의 산불발생위험성과 온·습도 변화에 따른 산불발생위험 구간을 정의하고자 하였다. 연구결과를 요약하면 다음과 같다.

1) 1995년부터 2004년까지의 산불통계자료를 분석한 결과 순기별 산불발생빈도는 4월 초순, 3월 하순, 4월 중순 순으로 산불발생이 높았다. 산불발생빈도가가장 높은 4월 초순은 중부내륙 지역과 경기도 동부지역, 대구를 비롯한 경상도 동해안지역, 강원도 영동지역에서 산불발생 빈도가 높게 나타났으며, 3월하순에는 주로 서울·부산 등 광역시도와 경기·강원 내륙지방을 중심으로 많은산불이 발생한 것으로 나타났다. 그리고 4월 중순 들어서는 여전히 광역시도 일대와 중부 내륙 및 동해안 일대에서 산불빈도가 높았다.

2) 순평년 온도와 습도자료를 이용하여 시기별 변화에 따른 산불발생위험성을 평가한 결과 산불발생빈도와 온도·습도간의 상관성이 매우 낮아 온도와 습도를 분리하는 단순회귀분석을 실시하였다. 순평년 온도와 습도변화에 따른 산불발생위험 회귀분석 결과 결정계수(R2)가 0.4-0.6 사이에 분포하여 온도와 습도를 독립변수로 하는 다중회귀분석 방법보다 설명력이 향상되는 결과를 보였다.

3) 산불발생에 영향을 미치는 온도와 습도의 범위는 3월 하순이 6-10℃, 4월초순은 9-12 ℃ , 4월 중순은 11-14 ℃ 구간에서 산불발생이 많았고, 평균습도의 경우 3월 하순은 62-67%, 4월 초순은 61-65%, 4월 중순은 60-67% 구간에서 산불발생빈도가 높았다.

이러한 결과를 토대로 산불발생위험성이 높은 온도와 습도의 구간 범위를 정의하여 온·습도 변화에 따른 산불발생위험 조견표를 작성하였으며, 향후 작성된조견표를 활용하여 손쉽게 산불발생위험성을 판정할 수 있을 것으로 사료된다.

본 연구에서는 3월 하순부터 4월 중순만을 대상으로 하였지만 향후 산불조심기간인 11월부터 5월까지의 순기별 자료를 분석하여 시간경과에 따른 산불발생빈도와 온·습도 변화구간을 추가적으로 구명할 필요가 있다.

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Session 3

REGIONAL/NATIONAL IMPACT OF CLIMATE CHANGE ON FIRE REGIMES IN CENTRAL ASIA

중앙아시아에서의 기후 변화가 산불형에 미치는 지역적/국가적 효과

Leonid Kondrashov

Abstract

In Central Asia climate change can cause a comparatively rapid (comparing to earlier climate fluctuations) northward shift of forest species. The 20th century warming has been observed in tree-ring reconstructions of temperature from widespread regions of Eurasia, including sites in the Polar Urals, Yakutia, and the Taymir Peninsula, Russia. Wildfires threaten tiger habitat in the Far East of Russia. Climate change is one of the causes leading to an increased fire scope and occurrence on vegetated lands, resulting in shorter fire return intervals, with more carbon being released from boreal ecosystems than is being stored. Space observations and monitoring provide evidence of increasing regional aridity and severity of wildland fires. The trend of increasing fire occurrence, however, is being driven by the anthropogenic activities. Sustainable forest management involves the decrease of deforestation, maintaining or improving tree growth, minimizing soil disturbance and residual stand damage during timber harvesting, adopting socially acceptable programs of forest protection or community-based management; ensuring satisfactory natural regeneration of harvested forests and forests damaged by fire, insects, and disease; improving forest fire suppression and management capabilities; adopting reduced-impact logging practices; and minimizing the negative environmental impact of road construction and maintenance.

요 약

중앙아시아의 기후 변화는 이전의 기후 변동에 비해 비교적 빠르게 산림의 종들을 북쪽으로 이동하게 했다. 20 세기의 온난화가 극지의 우랄 산맥, 야구티아 공화국, 타이미르반도, 러시아에 있는 지역들을 포함한 유라시아 댜륙의 광범위한 지역들에 있어서 온도에 따른 연륜 재구성으로부터 관측되어왔다. 산불은 러시아의 극동지역에 있는 호랑이 서식지를 위협하고 있다. 기후 변화는 식생 피복지에 화재가 발생하는 것을 증가시키는 원인 중 하나이며, 보다 짧아진 산불 재현 주기를 초래하여 아한대 생태계에서 탄소가 기존에 축적되어 있던 것보다 더 많이 방출되고 있다. 우주로부터의 관찰과 모니터링은 지역의 건조 상태가 증가하고 야생지 화재가 심해지고 있다는 증거를 제공한다. 그러나 화재 발생을 증가시키는 경향은 인간 활동으로부터 야기되고 있다. 지속적인 산림경영은 산림벌채의 감소와 나무 생장의 유지 또는 향상, 목재 수확 중 토양교란과 잔존 임분 피해를 최소화 시키고, 사회적으로 수용 가능한 산림보호 또는 지역사회 기반 경영 프로그램을 채택하는 것; 벌채된 산림과 화재, 곤충 또는 질병으로 인해 피해를 본 산림의 만족스러운 천연 갱신을 보증하는 것; 산불 진화와 관리 능력을 향상시키는 것; 벌목 작업의 영향을 줄이는 방법을 채택하는 것; 그리고 도로 건설과 유지가 환경에 끼치는 부정적인 영향을 최소화 하는 것 등을 포함한다.

REGIONAL/NATIONAL IMPACT OF CLIMATE CHANGE ON FIRE REGIMES IN CENTRAL ASIA

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Abstract

In Central Asia climate change can cause a comparatively rapid (comparing to earlier climate fluctuations) northward shift of forest species. The 20th century warming has been observed in tree-ring reconstructions of temperature from widespread regions of Eurasia, including sites in the Polar Urals, Yakutia, and the Taymir Peninsula, Russia. Wildfires threaten tiger habitat in the Far East of Russia. Climate change is one of the causes leading to an increased fire scope and occurrence on vegetated lands, resulting in shorter fire return intervals, with more carbon being released from boreal ecosystems than is being stored. Space observations and monitoring provide evidence of increasing regional aridity and severity of wildland fires. The trend of increasing fire occurrence, however, is being driven by the anthropogenic activities. Sustainable forest management involves the decrease of deforestation, maintaining or improving tree growth, minimizing soil disturbance and residual stand damage during timber harvesting, adopting socially acceptable programs of forest protection or community-based management; ensuring satisfactory natural regeneration of harvested forests and forests damaged by fire, insects, and disease; improving forest fire suppression and management capabilities; adopting reduced-impact logging practices; and minimizing the negative environmental impact of road construction and maintenance.

1. INTRODUCTION

Central Asia includes Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, China, Russia and Mongolia. The region is rich in forest resources mainly due to Russia. The countries' wealth is distributed unevenly and in some states the standard of living is very low. Due to Climate Change Central Asia experiences environment alterations and forests, soils, atmosphere and water resources are at risk of severe effects. The terrestrial ecosystems of Central Asia play a globally important role which will likely change over the coming decades as a result of global environmental change. Climate change is expected to lead to:1) Movement of boreal forests northwards, increasing tree cover and above-ground biomass, increased productivity (e.g., longer growing season, enhanced nutrient dynamics), increasing carbon sink; 2) Increase carbon sinks thanks to northwards movement of boreal forests and enhanced productivity. But increased temperatures and possibly longer dry periods trigger increasing aerobic decomposition(oxidation) of soil carbon compounds and growing CO2 emissions. Overall effect difficult to determine; 3) Enhanced soil emissions due to increased temperatures and longer dry periods. They also create new level of disturbance (fire and insects), slowing northward movement of forests, converting some forests to grasslands, and leaving other forests in early successional stage. Overall effect is that high latitudes become a weaker sink or even a source of carbon in the coming decades.

Climate change is resulting in growing of disasters frequencies creating conditions that will contribute to the fire regime changes. The statistics shows that in Central Asia the number of fire incidents, especially, big fires continues to grow bringing significant damage to nature and society. Thus, vegetation fires may stay one of the main factors of the forest cover destruction. [J.G. Goldammer, et al. 2004]. Climate change events make Central Asia countries to construct their response policy or at least to form their participation in international activities, improve national legislation and support the attempts of wildland fire management. Climate change in Central Asia goes hand in hand with current socio-economic restructuring conditioning the society attitude to fire management policy arrangement and fire situation in the region.

2. Expected consequences of climate change in Central Asia

The concern over climate change is specifically growing since it impacts Central Asia scant resources and can lead even to political tensions. At the same time, Central Asia significantly contributes to global warming by evolving large volumes of greenhouse gas (GHG) emissions. For example, Kazakhstan, not taking into account Russia or China, is the 30th largest emitter of carbon dioxide worldwide. [WRI, 2005]. In Central Asia Climate Change is leading to many environmental transformations [IPCC, 2007] including increase of flooding, rock avalanches, and worsening of water resources supply and quality. One quarter glacial ice reduction is registered in Tien Shan Mountains (China) in four last decades. Warming becomes noticeable in vast regions of Central Asia, especially in Siberia. The average annual temperature in Mongolia has went up by about 0.7°C over the past 50 years. As a result, 1,081 glaciers in the Pamir-Altai disappeared. Temperatures in the mountains of Kyrgyztan have increased by 0.5-1.5°C since the 1950s with such follow up as lowered river flows due to the glaciers recede. Temperature growth in 1°C will lead to at least 10% increase in agricultural irrigation demand in arid and semi-arid regions of Asia. Besides, vast areas of tundra permafrost are melting creating problems in construction, oil and gas industries and railway roads.

Slow vegetation and wildlife northward migration is expected in the northern parts of Russia in the nearest several decades. Mixed effects of Climate Change in some regions, including some benefits such as reduced demand for heating and increased forest growth are also projected. Though some negative effects(more frequent winter floods, endangered ecosystems and increasing ground instability) are likely to outweigh Climate Change benefits.

Changing environment will condition health problems for population. Health risks due to heat waves and wildland fire smoke formation can increase and the frequency of wildland fires peatland fires is expected to increase. Climate Change could significantly impact the way of living of many indigenous peoples, and adversely affect more than a billion people by the 2050s.

Studies and daily information provide for numerous examples of Climate Change manifestations. For example, in 2001 Tajikistan had the worst precipitation situation in 75 years. This year was the third consecutive year of drought, which has destroyed half the wheat crop. The IPCC 4th Assessment Report [2007] presented dozens of facts showing significant consequences of Climate Change to

China's environment including increase in mean annual temperature, rainfall, frequency of heat waves, greater number of warmer days and nights. Frequent extreme events and disasters negatively impacted water regimes, forest sustainability, and biodiversity. It is projected that a 2°C increment in mean air temperature could reduce rain-fed rice yield by 5 to 12% in China.

Tibetan Plateau glaciers of < 4 km in length are projected to disappear with 3°C temperature rise and no change in precipitation. If current warming rates are maintained, glaciers located over Tibetan Plateau are likely to shrink at very rapid rates from 500,000 km2 in 1995 to 100,000 km2 by the 2030s. Freshwater availability in Central Asia, particularly in large river basins, is projected to decrease. Warmer climate, precipitation decline and droughts in most delta regions of China have resulted in drying up of wetlands and severe degradation of ecosystems.

The noticeable changes are recorded in Russia: 2-3°C temperature rise during the past century. Heatwaves exceeded 22-year record in May 2005. Heavy rains become more frequent in western Russia and decline in Siberia. Temperature rise in 1°C and rain decrease cause droughts and vegetation fires with the help of human activities. Warming leads to changes in the seasonality of river flows where much winter precipitation currently falls as snow in the entire Russian territory.

Russian Arctic Rivers experience increasing frequency of catastrophic floods (0.5-1%) in recent years due to earlier break-up of river-ice and heavy rain. Increasing winter temperature considerably changes the ice regime of water bodies in the northern regions. In several northern mountain systems, tree lines have already markedly shifted to higher elevations during the 20th century (the Urals). In northern regions, mean annual temperature of frozen soil and rocks and the depth of seasonal thawing will increase in 2020 by as much as 4°C for the depth of 0.8 m and by at most 2.2°C for the depth of 1.6 m. Loss of summer sea ice will bring an increasingly navigable Northwest Passage, and the Northern Sea Route will create new opportunities for cruise shipping. Polar bears will face a high risk of extinction with warming of 2.8°C above pre-industrial. The IPCC projects that by 2100, between 10 and 50% of the Arctic tundra could be replaced by forests.

Climate Change seriously impacts Indigenous peoples of the Russian North (comprising a mere 2% of the entire northern Russian population and number approximately 200,000 individuals belonging to forty different peoples) and their traditional subsistence activities including reindeer herding, hunting, fishing, gathering wild plants. Under this condition, indigenous systems of traditional resource use are under threat. Fires are contributing to the degradation of reindeer pastures and to the decline in reindeer herding. For example, in the Tyumen region alone over 1.5 million hectares of reindeer pasture have been destroyed by fire. One of the causes of escalation of fires in the tundra, the taiga–tundra zone, and the taiga might also be climate warming, especially summer droughts. Climate Change may interfere with the human–nature cycle of reindeer herding, where herders follow the paths of reindeer between summer grazing lands in the tundra and mountains and winter grazing lands in the treeline. [Vlasova, Volkov, 2001].

Table 1. Global Climate Change: Recent impacts and Future trends

Phenomena	Likelihood that trend occurred in late 20th century
Cold days, cold nights, frost less frequent over land areas	Very likely
More frequent hot days and nights	Very likely
Heat waves more frequent over most land areas	Likely
Increased incidence of extreme high sea level (excluding tsunamis, which are not due to climate change)	Likely
Global area affected by drought has increased (since 1970s)	Likely in some regions
More frequent heat waves over most land areas	Likely
Increase in intense tropical cyclone activity in North Atlantic (since 1970)	Likely in some regions
Global Climate Change: Future Trends	
Contraction of snow cover areas, increased thaw in permafrost regions, decrease in sea ice extent	Virtually certain
Increased frequency of hot extremes, heat waves and heavy precipitation	Very likely to occur
Increase in tropical cyclone intensity	Likely to occur
Precipitation increases in high latitudes	Very likely to occur
Precipitation decreases in subtropical land regions	Very likely to occur
Decreased water resources in many semi-arid areas, including western U.S. and Mediterranean basin	High confidence
Definitions of likelihood ranges used to express the assessed probability of occurrence: virtually certain >99%, very likely >90%, likely >66%.	

Source: Summary for Policymakers, IPCC Synthesis report, November 2007. http://www.ipcc.ch/

All these data and facts show that favorable conditions for wildland fires in Central Asia countries have been created. And together with other consequences the wildland fire presents more and more growing threat.

3. Climate Change and forests of Central Asia

Forest can be both source and stock of carbon. They react sensitively to a changing climate. The impact of Climate Change on frests varies from region to region. In Central Asia, a group of the primary environmental parameters affect the distribution of forests. Global warming can be considered sufficient to trigger structural changes in forests. Shifts in temperature and precipitation may result in altered growing seasons and boundary alterations[IPCC, 1996].

The studies results show that boreal forests are experiencing shifts in distribution (area reductions of up to 50%) and productivity [Dixon et al., 1996]. Grasslands and shrublands in boreal regions may expand significantly, whereas the tundra zone may decrease by up to 50%. Climatic warming also would increase the release of methane as well as CO2 [IPCC, 1996]. The widely spread species in Siberia is larch which is vulnerable to damage by fires and insects, and may occur more frequently under global warming. Increased steppe area also may be expected in the southern part of eastern Siberia [Kobak et al., 1996]. However, the biomass densities of larch (Larix sibirica), Scotch pine (Pinus silvestris), Siberian pine (Pinus sibirica), and birch (Betula platyphylla) are projected to decrease [Ulziisaikhan, 1996]. Such decreases seem to be caused by warming air temperature and reduced rainfall during the summer season. Gobi and steppe areas in Mongolia would therefore expand.

It is important to undermine that Climate Change is accompanied by strong impact of human activities. Such influences are often realized in the form of rapid, large, and frequent changes in land and resource use creating new stresses and the potential for change in the climate system. Climate change and anthropogenic factors combination originates its affect through a myriad of processes and migration of boreal species northward and coastward, increased probability of fire; enhanced or curtailed soil nutrient availability, increased emissions of greenhouse gases, and extended probability of outbreaks of pests, particularly insects, to drought-stressed trees [Pastor et al., 1996]. Almost all forest trees would grow better under a warmer climate, but increases in diseases, insect damages, and other meteorological hazards (e.g., severe storm damage) also may result [Tsunekawa et al., 1996a]. When the original species in a forest decline, other species from neighboring forest zones more suitable for warmer conditions would grow. In drier continental regions of Central Asia, increased temperatures may induce droughty conditions, decreasing forest production [Loustau, D., et al., 2005] and encouraging the replacement of closed forest with grasslands, savannahs or semi-desert in some places.

According to 4th IPCC report, under the existing trends to the growth of the world GHG emissions, the temperature by 2100 will raise almost by 4°C. If there will be a stabilization of anthropogenic emissions, the temperature growth accounts for not more than 2°C. In the first case (4°C), the process of forests retreat from the south to higher latitudes will begin on the whole territory of Russia. It will be more scaled that the advancement of forest border to the north. Natural deforestation will cover almost all middle stripes of European Russia and Western Siberia. In the second case (2°C), the green migration will affect only the south of Western Siberia. The total areas of forest cover will extent due to spreading in the current tundra zone. The borders of vegetation areas are late comparing with the climatic trends. Thus, the vegetation cover species composition demands tens and hundreds of years. According to Institute of Atmosphere Physics RAS, in case of 1°C warming expected in the nearest years (30-50 years of XXI century), there will be no scale disappearance of Russian forests. However, for example, in Volga-Vyatka interfluve and in the upper flow of Ob River not great areas of pine stands will die out. On 70% of pine stand area and on the half of spruce stands area the succession processes will begin. Less vulnerable to the warming are mixed forests and oak-groves where successions will impact only 1/5 of the territory. The most stable will be the larch forests of East Siberia (less than 5% of successions). These results are quite comparable with IPCC forecast relating to the disappearance by 2100 of 30% of planet's pine and spruce forests.

In some regions of Russia the changes in vegetation zones border are evident. According to Institute of plants and animals Ecology UD RAS, Polar Urals area in 90 years (1910-2000) the tundra share has decreased from 76% to 59%. At the same time the share of closed forests has increased from 1 to 10%. Sparse growth of trees has also increased from 11 to 18%, larch stands came up to 320 meters above the sea level (comparing to former 260 m). The causes of this are connected to the local warming trends which seem to be higher than the global climate changes.

Large-scale disturbance, including fire, insect and pathogen outbreaks, drought, flooding and wind and ice storms affect forest production both by damaging existing forests and by altering competitive dynamics. Disturbance frequency, type, intensity, size and duration are strongly affected by climate change [Dale, V.H., et al., 2001], and will likely have greater effects on overall forest production than climatic effects on physiological processes [Thornton, P.E., et al., 2002]. Changing disturbance regimes, however, are likely to have greater effects.

Climate change is likely to enhance the frequency and intensity of forest fires in Central Asia, exacerbating an already pronounced problem of emissions, haze and habitat destruction. It is expected that fires will originate more frequently, as well as there will be more scale fires under changing fire regime.

4. Conclusion

In Central Asia the influence of Climate Change factors sometimes is very high. Thus, adaptation to Climate Change is an important task. There is a need in further research development, improvement of the systematic observation networks and environmental monitoring and data collection, interpretation and dissemination; enhancement of weather forecasting, climate modeling and early warning systems for minimization of wildland fire risk; capacity building to strengthen institutional, technical and human resources. Protection of forest resources and the lives and property of people makes inevitable the work on fire management while concern about climate change should enhance the sense of urgency.

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Change in Land Cover and Carbon Dioxide Sequestration by Forest Fire

산불 발생에 따른 토지 피복 및 CO_2량 변화

Han bin KWAK, Woo Kyun LEE, Sungho CHOI, Myoung Soo WON, Kyo Sang KOO

Abstract

This study was to analyze the forest fire scales and damaged area, and to estimate the changes of carbon dioxide by deforestation in forest fire area. For the analysis, last-five-year national forest fire data, collected from 2003 to 2007, was prepared from Korea Forest Service. Also, for the specific regional forest fire case, fire data of Yang-Yang, Kangwon province, was collected.

As results of analysis, calculated national change of carbon dioxide was annually up to 113,791.20 TCO2. In addition, the forest fire in Yang-Yang region, one of the extensive disaster events, resulted of 24,301.84 TCO2 of carbon dioxide change.

With estimated results, it would be able to analyze the effect of forest fire events on the atmosphere with various green house gases. Furthermore, these analyses would provide optimized forest fire management system in further research.

요 약

2003년부터 2007년까지 일어난 최근 5년간 전국 산불발생 자료와 2005년 4월 5일 발생한 강원도 지역의 양양산불에 대한 자료를 토대로 산불의 규모와 피해 면적을 분석하고 산림면적의 비산림화에 따른 이산화탄소 변화를 추정하였다. 전국 산불 발생 자료는 산림청 산불대장에 기록된 최근 5년간 산불발생자료를 이용하였다.

이 결과를 토대로 추정된 이산화탄소 변화는 전국적으로 연평균 113,791.20 TCO_2에 달하였고 지역규모의 비교적 대규모 산불에 해당하는 양양산불에 따른 이산화탄소 변화는 24,301.84 TCO_2에 이르렀다.

산불발생 이후 산림이 대기 중 온실가스 방출에 미치는 영향을 분석하면 산불 발생 관리를 위한 최적의 방안을 찾을 수 있을 것이라고 기대된다.

Change in Land Cover and Carbon Dioxide Sequestration by Forest Fire

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1. 서론

제 11차 기후변화당사국총회에서 논의한 결과 2012년 이후의 부속서 1국가들의 온실가스 감축의무에 대해서 논의하였고 개도국의 참여를 강조하였다. 이처럼 점차 우리 나라도 탄소감축의무가 강조되고 있는 상황에서 산림생태계 관리에 일환인 산불 관리를 통한 이산화탄소 통제의 효과에 대한 연구의 필요성이 대두되고 있다.

산림생태계가 대기 중 탄소고정에 하는 역할은 중요하다. 특히 식물체를구성하고 있는 원소 중 그 양이 가장 많은 것이 탄소로서, 임목의 경우 건중량의 약 50%가 탄소이다(Satoo and Madgwick, 1982; 송칠영 등, 1997). 하지만 산불의 대형화로 한번 산불이 발생했을 경우 산림의 파괴가 극심하게 이루어져 산림생태계의 이산화탄소 흡수원로써의 역할이 크게 감소하게 된다.

우리나라는 '기후변화협약대책위원회'를 설립하여 기후변화협약 대응 종합대책을 3차에 걸쳐 마련하고, 기후변화 대응을 위한 국제적 노력에 동참하고 있으며 온실가스 저감에 노력하고 있으나(한화진, 2005) 산불 발생과 진화가 온실가스에 미치는 영향에 대한 연구는 미흡한 실정이다. 특히, 2005년 양양산불과 같은 대형산불의 발생이 증가하고 있어 연구의 필요성이 더욱 강조되고 있다.

미국 Oregon University에서 개발한 기후변화 모델인 MC1 model의 경우와 같이 기후변화 모델에서 산불발생과 관련한 서브모델이 포함되는 것도기후변화에 대한 산불의 영향을 반증하는 것이다.

본 연구에서는 산불발생이 이산화탄소 변화에 얼마만큼의 영향을 주는지 산출하였다. 이 결과를 토대로 향후 산불진화 최적시점 도출 등의 연구를 수행하여 최종적으로 종합적인 산불 관리 대책수립에 기여할 수 있을 것이다.

2. 연구대상지

2.1. 전국단위 산불

산림청 산불대장을 이용하여 최근 5년간 전국을 대상으로 발생한 산불을 중심으로 산림이 비산림화가 되었을 때 발생하는 이산화탄소 배출량을 산출하였다.

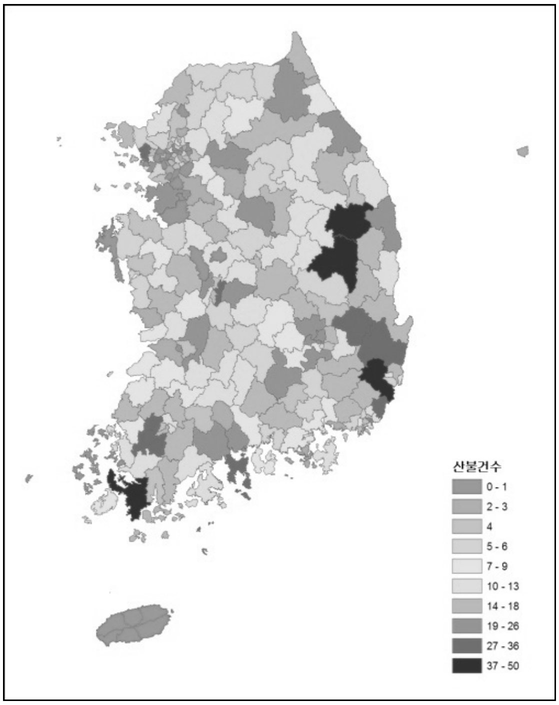


Figure 1 Recently 5 years, distribution of forest fire in Korea

2.2. 지역단위 산불

최근 발생한 산불 중 가장 대표적인 강원도 양양 산불에 대하여 디지털항공사진 및 LiDAR를 이용하여 파악된 피해지역 결과와 다른 연구결과들을 종합하여 이산화탄소 배출량을 산출하였다.

3. 연구방법

전국 및 지역단위에서 발생한 산불에 대한 기본적인 분석을 실시하고 그 결과를 토대로 이산화탄소 배출량을 산출하였다. 전국단위 산불자료는 산림청 산불대장에 기록된 최근 5년간 산불발생자료를 활용하였고 지역단위 산불자료는 대표적으로 2005년 발생한 양양 산불의 연구 결과들을 종합하여 이용하였다.

3.1. 바이오매스를 이용한 이산화탄소 배출량 산출

산림생태계는 바이오매스와 토양에서 살아있는 강력한 탄소흡수원으로서 중요한 역할은 차지하고 있다. 최근 탄소배출저감 및 탄소흡수에 대한 관심이 높아지면서 산림탄소저장량에 대한 연구가 활발하게 이루어지고 있다.

산림의 임분별 이산화탄소 흡수량을 산출하기 위해서 개체목당 건중량 산출식에 적용하여 수종별 바이오매스를 구하는 방법이 있다. IPCC에서 권고한 방법에 따라 수종별 탄소 축적량을 알기 위해 임목 전체의 건중량에 탄소 구성비 0.5를 곱한다 (Satoo and Madgwick, 1982; 박인협 등, 2005). 특히, 노남진 등(2006)은 바이오매스 추정식을 개발하고 이를 바탕으로 바이오매스와 바이오매스 확장계수를 추정한 바 있다. 그 결과, 1-2 영급, 3-4 영급, 5-6 영급에서 낙엽송 개체목의 평균 건중량(kg/tree)은 각각 57.8, 185.4, 1047.9, 지상부 바이오매스(ton/ha)는 71.1, 195.6, 180.6, 임목 전체 바이오매스 (ton/ha)는 96.3, 265.7, 244.5로 나타났다. 또한, 1998년 임업연구원에서는 흉고직경을 가지고 바이오매스를 추정하였다. 임업연구원은 총 바이오매스 산출에 필요한 건중량을 수종별 계수와 DBH를 개체목 당 건중량 산출식에 적용하여 계산하였다. 『아리랑 2호 위성영상을 이용한 산림의 이산화탄소 흡수기능 평가기법 개발』, 2008년 위성자료공공활용연구 보고서에서 항공우주연구원은 식생탄소저장량을 전환비를 적용하여 이산화탄소흡수량(Carbon Dioxide Absroption, CDA)를 계산하였다.

CDA = 식생탄소저장량 VCS x (44/12)
CDA : 이산화탄소흡수량 (kg이산화탄소/tree)
(44/12) : 전환비

반면, Heath 등 (2007)은 산림의 면적을 이용하여 이산화탄소 흡수량을 산정하는 방법을 사용하였다. 현장조사 자료를 바탕으로 단위면적당 탄소량을측정하고 식생탄소저장량을 구한 뒤 전환비를 이용하여 이산화탄소 흡수량을계산하였다. 산불이나 벌목 등의 이유로 더 이상 산림이 존재하지 않을 경우,현재 탄소저장량과 과거 탄소저장량의 차이를 통해 연간 탄소변화량을 계산할수 있다.

Carbon Stock = Carbon/Area x Area
Carbon Change = (C stock $_2$ – C stock $_1$) / year
이산화탄소 = Carbon Stock x (44/12)

본 연구에서는 산림 면적과 제적을 이용하여 이산화탄소 배출량을 계산하였다. 2003년부터 2007년까지 조사된 지역별 임목축적량과 임야면적을 통해 ha당 임목축적량을 산출하고 이에 건중량비와 바이오매스 확장계수를 사용하여 총 이산화탄소 배출량을 산출하였다.

3.2. 산불 발화시 방출되는 이산화탄소량 산출

Bachelet 등 (2001)은 MC1 모델의 서브모델인 MCFIRE 모델을 통해 산불발생과 산불로 인한 바이오매스의 소모 및 이산화탄소 등의 배출에 대한 시뮬레이션을 연구하였다 (Figure. 2). 특히, Keane과 Long (1998)의 알고리즘을 이용해 식생의 종류에 따라 이산화탄소 등의 배출계수를 다르게 설정하였다. 또한, 이산화탄소의 배출은 나무가 불꽃(Flame)에 의해 직접 연소하여 배출하는 경우와 내연(Smoldering)에 의해 배출하는 경우로 나누어 총 배출량을 계산하였다. 산불연료 (fuel)를 각각 1-hr, 10-hr, 100-hr, 1000-hr 연료로 구분하였는데, 이는 연료가 포함하고 있는 수분량에 따라 나누어 진다. 본 연구에서는 MC1 모델의 알고리즘을 사용하되 1-hr, 10-hr, 100-hr, 1000-hr산불연료가 모두 Flame에 의해 직접 연소되어 Smoldering에 의한 이산화탄소발생은 없는 것으로 가정하였다.

Fire emission CO2 = Total Fuel Carbon X Fire Emission Factor (FEF)
(활엽수림 FEF = 3389, 혼효림FEF = 3401, 침엽수림 FEF = 3458)

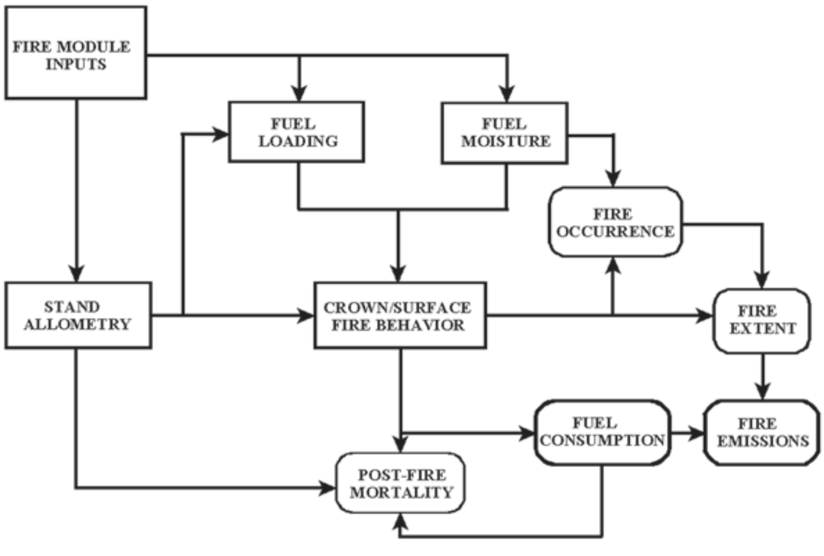


Figure 2 Flow Diagram of the fire module: MCFIRE (Source: Bachelet et al, 2001)

4. 연구결과

4.1. 전국 단위 산불

4.1.1. 최근 5년간 산불 분석

산림청 산불대장에 의거하면 최근 5년간 전국에서 발생한 산불은 총 2154건이 일어났다. 2005년까지 꾸준한 증가를 보이다가 2006년부터 조금 감소하였으나 산불발생 건수는 과거보다 크게 증가한 상황이다. 다만 피해면적은 2005년 이후 크게 감소하는 경향을 보인다.

Table 1 Recently 5 years, forest fire occurrence and damaged area.

	2003	*2004*	*2005*	*2006*	*2007*	*Total*
Fire occurrence	271	544	516	405	418	2154
Average area (ha/fire)	0.48	2.50	3.63	0.62	0.53	1.78
Total area(ha)	130.93	1358.93	1873.95	251.58	222.4	3837.79

월별 발생을 살펴보면 10 월부터 소폭 상승하다가 2 월부터 급격하게 산불발생이 증가하는 경향을 보인다. 우리 나라는 전국토의 65%가 산지이고 침엽수가 43%로 가장 많아 산불발생의 위험이 높으며, 대륙성 계절풍으로 인한 봄 가을 건조기가 전국적으로 지속되며, 해풍 또는 푄현상 등 바람의 영향으로 전국 동시 다발적인 경향이 상존하고 있다(이시영, 1999).

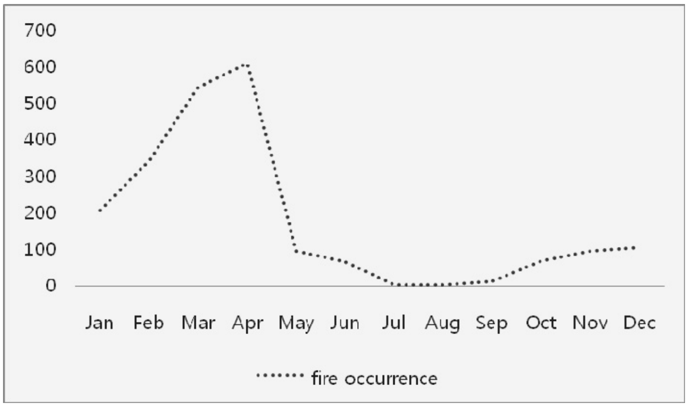


Figure 3 Monthly forest fire occurrence (recently 5years)

4.1.2. 지역적 피해 경향

지역별로 경북과 전남에서 많은 산불이 발생하지만 평균 피해면적에 있어서는 강원지역에서 가장 넓은 것으로 파악되었다(Figure 3). 이 같은 경향을 보이는 이유는 강원도의 임분 구조가 동해안을 따라 소나무 단순림으로 구성되어 있고 급경사, 험준지가 대부분 이어서 산불이 발생했을 경우 확산이 빠르고 진화인력의 접근이 어려워 더욱 피해면적이 커지는 것으로 알려져 있다(이시영, 1999).

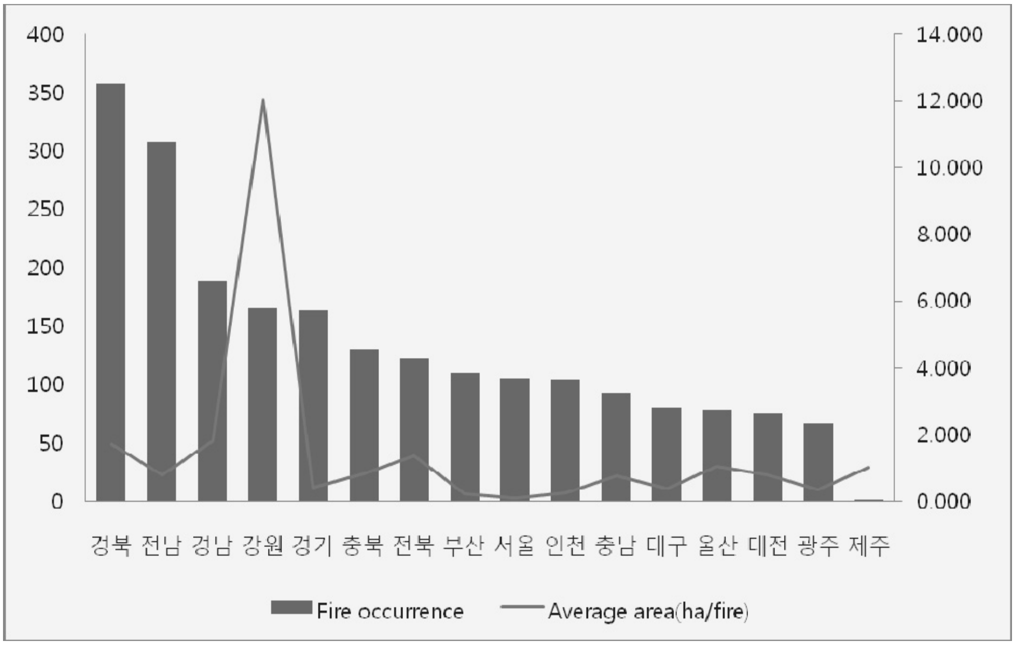


Figure 4 Average forest fire damaged area per each fire and total fire occurrence

4.1.3. 발생 원인 및 피해 수종

현재까지 산불 발생의 원인은 대부분 입산자 실화(44%)에 의한 경우가 대부분이고 담뱃불 실화와 논밭두렁 소각이 각각 10%정도 차지하였다. 발화지점 수종은 대부분 소나무로 나타났다. 두번째로 많은 비율을 차지하는 수종이 활엽잡목으로 나타났다.

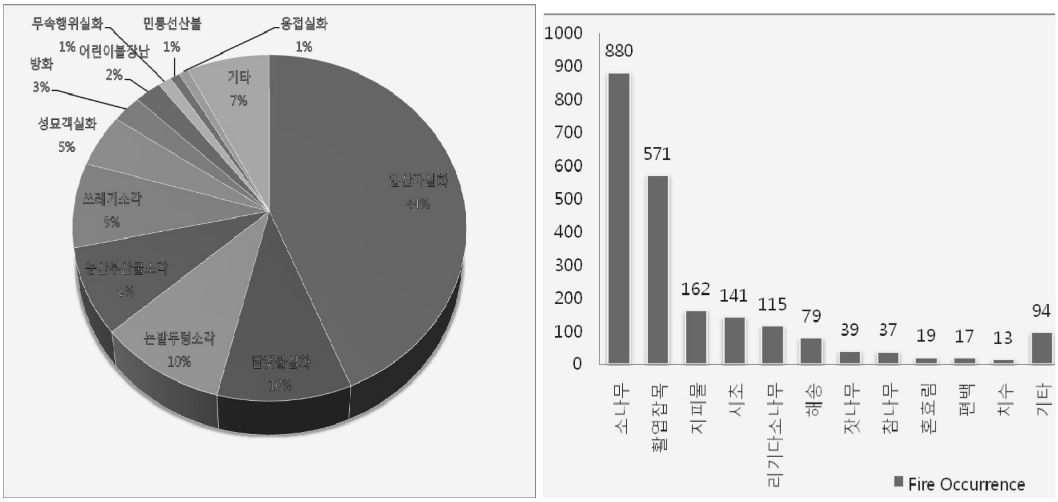
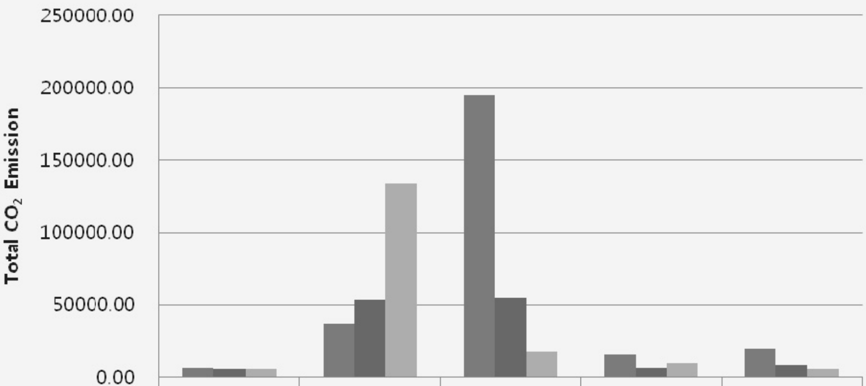


Figure 5 The reason of forest fire and species of fire occurrence

4.1.4. 피해지의 비산림화에 따른 이산화탄소량 산출

최근 5년간 산불발생 대장 정보에 따라 산불이 발생한 지역의 임황에 근거하여 산불발생으로 산림이 비산림화 되었을 때 이산화탄소 배출량을 산출하였다. 산불피해면적에 2003년부터 2004년까지 집계된 각 지역별 입목축적량(산림기본통계, 산림청)을 곱하여 피해제적량을 계산하고 그 값에 수종별 건중량(침엽수 0.47, 활엽수 0.80)을 곱하고 최종적으로 바이오매스 확장 계수(침엽수 1.6512, 활엽수 1.7202) 를 곱하여 산출하였다(임업연구원, 1996).

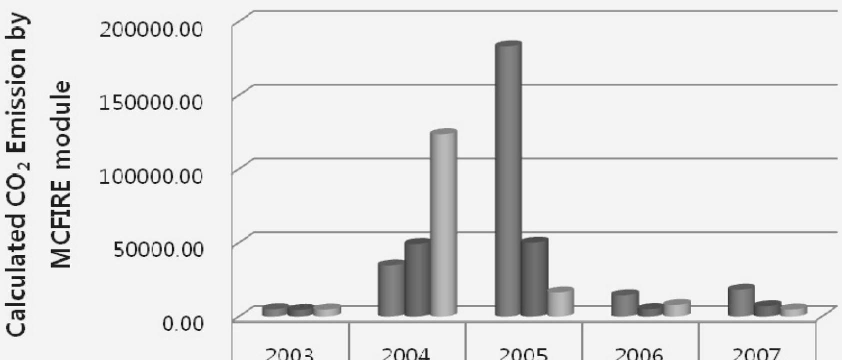


	2003	2004	2005	2006	2007
Coniferous	5549.58	36901.81	194291.61	15257.41	19460.55
Broadleaf	5122.70	53252.74	54247.69	5775.21	7998.05
Mixed	5386.06	133678.24	17705.77	8887.14	5441.42

Figure 6 CO_2 sequestration change after forest fire

그 결과 2004 년과 2005 년에 많은 양의 이산화탄소 배출이 있었고 이것은 특히 산불피해면적에 비례하는 것으로 보인다.

4.1.5. MCFIRE 모듈을 통한 CO_2 배출량 도출



	2003	2004	2005	2006	2007
Coniferous	5233.76	34801.77	183234.65	14389.12	18353.07
Broadleaf	4734.78	49220.05	50139.66	5337.87	7392.38
Mixed	4995.81	123992.64	16422.91	8243.23	5047.17

Figure 6 CO_2 sequestration change calculated by MCFIRE module

MC1모델에 포함되어 있는 산불 가스배출모듈인 MCFIRE의 알고리즘을 이용하여 도출된 이산화탄소 배출량은 수종 별로 차이가 있지만 유사한 경향을 나타낸다.

4.2. 지역규모 산불(양양 산불)

지역적 측면에서의 산불 피해지역에 대한 이산화탄소 흡수량 변화의 차이를 알아보기 위해서 2005년 발생한 강원도 양양지역 산불을 이용하였다. 강원도 양양 산불은 973ha의 산림피해와 낙산사 동종 등 문화재 및 건축물 416동이 소실되는 피해를 입힌 대규모 산불이었다. 현재 양양지역의 산불에 대한 많은 연구결과들이 존재하여 산불발생에 따른 이산화탄소 흡수량 변화 산출에 가장 적합할 것으로 판단되어 이 지역은 선정하였다.

4.2.1. 양양 산불 피해규모 평가

원격탐사를 통한 산불 피해/규모를 평가하는 방법에는 여러 가지가 있다. 장광민 등(2007)은 현장조사를 이용하였고, 최근에는 항공사진과 현장조사를 병행하고 있다. 최근에는 스테레오 위성영상을 사용하여 대규모 면적에 산불 피해 정도를 분석할 수 있게 되었고, 최근 능동적인 센서를 사용하는 LiDAR를 사용하는 방법이 연구되고 있다.

4.2.2. 피해 강도에 따른 면적 산출

본 연구에서는 곽두안(2008)이 도출한 LiDAR를 이용한 피해지역 강도평가 자료에 따른 3 등급화 된 피해지역을 통해 이산화탄소 흡수량의 감소를 산출하고자 하였다. 우선 피해강도 등급은 생물학적, 물리적 피해가 둘 다 높은 1 등급지역이 461ha(43.9%)로 가장 넓었고 생물학적 피해가 크지만 입목이 도복되지 않아 물리학적 피해가 적다고 판단된 2 등급지역이 290ha(27.6%)를 차지하였고, 산불 피해를 거의 입지 않아 생물학적, 물리학적 피해가 모두 적게 나타난 3 등급지역은 300ha(28.6%)로 파악되었다.

4.2.3. 이산화탄소 흡수량 변화 산출

1등급지와 2등급지는 식생지수로 판단하였을 때 생물학적으로 완전히 피해를 입은 지역으로 모두 비산림화 되었다고 판단할 수 있다. 따라서 1등급지와 2등급지로 파악된 지역에 대하여 비산림화로 인한 이산화탄소배출량을 산출 하였다. 산림청 2005년 임업기초통계자료를 이용하여 양양지역 침엽수에 대한 산림청 통계자료를 사용하여 CO_2 방출량을 산출하였다. 그 결과 총 산불발생 피해가 심각한751ha에 대한 이산화탄소 발생량은 24,301.84TCO_2로 나타났다. 이 결과는

5. 결론

산림청 산불대장을 이용하여 전국 산불 피해면적에 대한 이산화탄소 배출량을 산출한 결과 연평균 113,791.20TCO_2로 나타났으며 대규모 산불이 발생하였을 때와 그렇지 않았을 때의 격차가 컸다. 지역단위 산불인 강원도 양양지역 산불에 대해서도 산림면적의 비산림화로 인한 이산화탄소 배출량 산출결과 24,301.84TCO_2정도로 나타났다.

본 연구는 상층부의 이산화탄소량만을 계산하였다. 하지만 최근에는 산림의 하층식생 및 낙엽에 대한 바이오매스량에 대한 연구도 활발하게 이루어 지고 있다. 앞으로 산불이 기후변화에 미치는 영향을 면밀하게 분석하기 위해서는 상층부뿐만 아니라 산림에서 보유하고 있는 정확한 탄소보유량 연구가 중요하다고 사료된다.

또한 기후변화 모델에 서브모델로 포함되어 있는 산불모델에 대한 연구을 통해 산불을 통제 했을 때와 그렇지 않았을 때 변화를 파악하는 것도 가능할 것이다.

더 나아가, 지역 단위에서부터 전국 단위로 산불 발생 피해지에 대한 이산화탄소 배출량 산출을 통해 산불이 기후변화에 어떤 영향을 미치는지 파악하고 더 나아가 산불로 발생되는 이산화탄소가 기후변화에 가장 영향을 적게 미치는 순간을 도출하여 정확한 산불진화시점을 파악하는 연구도 가능할 것이다.

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National Impact of Climate Change on Fire Regimes, Thailand Report

기후 변화가 태국 산불형에 미치는 국가적 영향

Siri Akaakara

Abstract

The Holdridge Life Zone Classification was used to characterize the forest cover of Thailand, a model that correlates climatic features with vegetation distribution. Six Holdridge life zone types of forest cover are found in Thailand : subtropical dry forest, subtropical moist forest, subtropical wet forest, tropical dry forest, tropical moist forest, and tropical wet forest. Climate change scenarios were simulated by three general circulation models : two United Kingdom Meteorological Office models (the low and high resolution versions) and the Goddard Institute for Space Studies model. These scenarios were used to simulate the effects of future climate change on Thai forests. The ratios of precipitation and the absolute values of temperature changes were incorporated into a baseline climate scenario from the International Institute of Applied Systems Analysis. Under the climate change scenarios simulated by the three general circulation models, the subtropical dry forest could potentially disappear, and areas of tropical very dry forest would appear. In general, the area of subtropical life zone would decline from about 50% to 20%-12% of total cover, whereas the tropical life zone would expand its cover from 45% to 80%. All three general circulation model scenarios suggest that the tropical dry forest has the greatest potential to extend into the subtropical moist forest. This analysis suggests that global climate change would have a profound effect on the future distribution and health of Thai forests.

Statistically, about 25,426 ha of forests is affected by fire annually, yet little is known about how climate changes have impacts on fire regime in Thailand. The last 15 years fire statistics fluctuated from year to year partly depended on ENSO condition. However since model predicted that most of forests will become increasingly arid, therefore they also will become increasingly subjected to high

wildfire risk as well.

요 약

Holdridge의 생물대 분류법은 태국의 산림대를 특징짓는데 사용되었다. 태국 산림대는 기후 특장과 식생 분포를 서로 관련시키는 모델이다. 6개의 Holdridge 생물대가 태국 산림대에서 발견되었다. : 아열대성 건조 산림, 아열대성 습윤 산림, 아열대성 우림, 열대성 건조 산림, 열대성 습윤 산림, 열대우림. 기후 변화 시나리오들은 세개의 일반적인 순환 모델에 따라 만들어졌다. : 두 개의 영국 기상청 모델과 저해상판과 고해상판, Goddard 우주연구소 모델.이 시나리오들은 태국 산림의 미래에 나타날 기후 변화를 예측하는 데에 사용되었다. 강수량의 비율과 기온 변화의 절대치는 국제 응용계 분석 연구소에서나온 기후 시나리오의 기준선에 통합했다. 세 새의 일반적 순환모델에 의해 만들어진 기후 변화 시나리오에 의하면 아열대성 건조림은 어쩌면 사라질 수도 있고, 열대성과 건림이 나타날 것이라고 한다. 일반적으로 아열대성 생물대는 전체 산림식피 중 약 50%에서 20~12%로 하락했지만 열대성 생물대는 반대로 45%에서 80%로 확장될 것이다. 세 가지 일반 순환 모델 시나리오들 모두 열대성 건조림이 아열대성 습윤림으로 확장될 정도의 커다란 잠재력을 가지고 있다고 제시한다. 이 분석은 세계 기후 변화가 미래 태국 산림의 분포와 건강에 깊은 영향이 있을 것임을 시사하고 있다.

통계적으로 매년 약 25,426 ha의 산림이 산불에 의해 피해를 입는다. 하지만 어떻게 기후 변화가 태국의 화재형에 영향을 미치는 지에 대해서는 거의 알려져 있지 않다. 지난 15년간 산불 통계는 매년 변동하였으며 부분적으로 ENSO 상황에 의해 좌우되었다. 그러나 모델이 대부분의 산림이 점점 더 건조해 질 것이라고 예측한 이상, 이 산림들도 높은 산불위험도에 의해서도 점점 더 큰 영향을 받을 것이다.

National Impact of Climate Change on Fire Regimes, Thailand Report

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Abstract

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increasingly arid, therefore they also will become increasingly subjected to high wildfire risk as well.

1. Introduction

Forests respond to prevailing environmental conditions, including climate and topography, which are the primary factors that control their distribution. It is generally accepted that the broad-scale patterns of forest distribution are at equilibrium with present soil and climate condition. On a local scale, many environmental factors such as soil characteristics, altitudes, and slope aspect are involved in the distribution of vegetation patterns.

Increasing greenhouse gases in the atmosphere are expected to lead to change in climate. The changes could include temperature rise, changes in seasonality, changes in precipitation patterns, and accelerated sea level rise. The warming rate is estimated to be about 0.3 oC per decade. Changes in the seasonality of climate variables could have marked impacts on forest and finally all have impacts on fire regimes as well.

2.Climate change scenarios

2.1 Climate Change scenarios

Knowing future climate change is necessary to understand its impacts and to prepare for necessary adaptation.

GCMs

General Circulation Models (GCMs) have been used to construct future climate change scenarios. GCMs are mathematical models based on physical laws that simulate heat exchange among the main components of the Earth's climatic systems.The model is complicated and requires sub-models of extensive information of the Earth's climates. Some institutes in developed countries possess GCMs. Climate change scenarios from these models vary depending on the input data, the hypotheses, and the assumptions used. Therefore, it is important to utilize a number of GCMs to explore and evaluate the trends in future climate changes and to study the impacts and the adaptations that need to be made. It is estimated that average global temperatures will increase between 1.4 and 5.8

oC, and sea levels will rise at least 0.09 meters and up to 0.88 meters because of the melting of polar ice and the thermal expansion of ocean waters (IPCC, 2001). The consequences of these changes are tremendous and affect precipitation patterns, increasing maximum and minimum temperatures as well as causing droughts and floods. These in turn will impact upon the equilibrium of natural ecosystems, food production, health and other systems, which finally have a negative effect on the socioeconomic development of the country.

RCMs

GCMs are global models, which work on a large spatial scale. Downscaling the output to a smaller country's area may not capture enough information to carry on impact studies. Regional Climate Models (RCMs) have been developed to construct climatic change scenarios for smaller areas of the regions, which are more appropriate for impact studies. However, developing countries have limited access to GCMs and RCMs because of inadequate technical experts and funding. In 1997 Thailand selected three GCMs to develop climate change scenarios to study the impact of climate change on forest distribution. One RCM was used to construct a climate change scenario for the Mae Khong river basin. It is necessary to use at least three more RCMs to construct climate change scenarios for studying the effects offuture climate change and the adaptations needed.

2.2 Current climate

Measuring and recording climatic parameters in real time is necessary for weather forecasting of natural disasters and climate related catastrophes. It is also a source of input data needed to simulate climate change scenarios. The climate is a large continuous system; changes in one place affect others. The World Meteorological Organization (WMO) recommends a distance of 150 km between each climate station for efficient data uses. Thailand has 90 climate stations that meet WMO standards. The country needs to establish a network of climate stations to strengthen weather forecasting capabilities and to use for assessing climate change scenarios.

2.3 Paleoclimate

Paleoclimate is the study of ancient climatic patterns, which can be traced by tree rings, the pollen deposited in sediments and the air bubbles trapped in glaciers that have not melted for several thousand years as in the Antarctic. Paleoclimatic data provides information about the Earth's climate by centuries and millennia before the present. This information is necessary for the validation of climate models used to construct scenarios of future climatic change. Climate models that accurately simulate past climates would be used to construct climate change scenarios that are close to real events.

3. Thailand's Climate change scenarios

Three GCMs were chosen to construct precipitation and temperature scenarios over Thailand (TEI, 1999). The three GCMs used in the study were UK 89, UKMO and GISS . Every model shows the increase in average temperature from 21.5- 27.5 oC to 25-32 oC approximately. The temperature increases by 2.5 oC in the northeast region and by 3-3.5 oC in the central, north, and west regions. The amount of rainfall is dispersed differently from the base year. The amount of rainfall in the northeast is constant while it increases by 40% in the south. The amount of rainfall in other parts of the country increases by 20% o x 0.5 o resolution using ARC/INFO software.

4. Impacts of climate change in Thailand

4.1 Climate Change Hot Spots in Thailand

Climate change hot spots are the areas that will be severely impacted from climate change due to the extreme altering of temperatures and amount of rainfall. The ecosystems within the areas may change their types. Even as information related to climate change hot spot was identified. The impact, vulnerability and adaptation to climate change will be focused in these areas.

4.2 Impacts of climate change on national parks and wildlife sanctuaries

The preservation of natural habitat plays a crucial role in species conservation. In fragmented habitats due to roads and urban expansions, species in stress would be incapable of moving into new habitats, cooler areas up north will be affected by global warming. The species that cannot adapt to the new conditions may be threatened with extinction. Of the national parks and wildlife sanctuaries distributed all over Thailand, 32 are situated in climate change hotspots.

4.3 Thailand's forest distribution expected to change from the impacts of climate change

Plant communities are highly sensitive to changes in climate conditions, increase in CO2 concentration, amount of rainfall, light intensity and exposure period; all impact their growth and development. Climate change, preceding forest fires, disease and pest outbreaks, could tremendously affect timber production and the existence of forests. For instance, after a severe drought in Panama in 1983, the loss of plant life in a 50 hectare ecological permanent plot in Barro Colorado Island (BCI) was as high as 50%, compared to normal years. (Condit et al. 1996, Hubbell and Foster 1983 cited from Sarayut Bunyavetcheewin B.E. 2545). It is expected that unrestrained climate change will cause irreversible changes in forest ecosystems. Furthermore, changes in vegetation cover will have a major feedback on the climate system through evapotranspiration, which affects the water and carbon cycles. The interaction of the terrestrial carbon cycle and the climatic processes has been simulated by Dynamic Global Vegetation Models (DGVMs). These mathematical models incorporate intensive vegetation data into the climate change scenarios generated by GCMs. Thus, the impact of climate change on forest production and wild life can be assessed. It is important to note that the existing models have been developed for temperate regions, whereas the environment in tropical regions is different. Climate-vegetation models that are appropriate for local conditions of the tropical regions need to be developed.

Current theoretical types and boundaries of forest cover in Thailand according to the Holdridge classification based on biotemperature and precipitation data from IIASA . There are six types of forests in Thailand: subtropical dry forest, subtropical moist forest, subtropical wet forest, tropical dry forest, tropical moist forest, and tropical wet forest. Under current climate, subtropical moist forest dominates, occupying 48% of the forest cover, and tropical dry forest and tropical moist forest contribute 32 and 15%, respectively. The other forest types are found in small areas, ranging from 5% to less than 1%. The potential distributions of forests under the climate change scenarios simulated by the UK89, GISS, and UKMO models as classified according to the Holdridge mode. The area and proportion of each forest type are shown in Table 1.

Subtropical forest is reduced under all three models' scenarios and is replaced by tropical dry forest. A new type of forest, tropical very dry forest, appears in the GISS and UKMO simulated climates. All three models predict a decline in areas of the subtropical moist forest and subtropical wet forest, and an increase in tropical dry forest, tropical moist forest, and tropical wet forest (Table 1). The relative extent of major forest types under current climate and under the UK89-simulated changing scenario reveals the potential extension of tropical dry forest into subtropical moist forest in the north and northeastern region and tropical moist forest expansion into subtropical moist forest in the south. Tropical wet forest replaces subtropical wet forest in the south and central-west region. The areas of subtropical moist forest and subtropical wet forest decline from 48 to 18% and 5 to 1% of the total area, respectively. In addition, the areas of tropical dry forest and tropical moist forest increase from 32 to 44% and 15 to 34% of the total area (Table 1). Although the extent of tropical wet forest, present in small areas of less than 1% under the current climate, has the highest percent change with an estimated increase to about 3% of total area under the climate change scenario (Table 1). The simulated changes in biotemperature and precipitation from the GISS scenarios indicate that subtropical moist forest, previously dominant in the area under 1 x CQ, is almost entirely replaced by tropical dry forest. Its area declines from 48 to 2%, whereas the area of tropical dry forest increases from 32 to 70% (Table 1). There is a lesser increase of tropical moist forest, from 15 to 25%, mostly replacing subtropical wet forest. The small area previously designated subtropical dry forest turns into tropical dry forest and tropical very dry forest. Potential forest cover simulated by the UKMO scenario demonstrates an extension of tropical dry forest and tropical moist forest into subtropical moist forest, whereas tropical wet forest has the potential to replace subtropical wet forest. The increases in tropical dry forest, tropical moist forest, and tropical wet forest are from about 32 to 59%, 15 to 26%, and 0.3 to 2% of the total area, respectively. Alternately, subtropical moist forest is subject to a tremendous decline, from 48 to 12%, whereas subtropical wet forest has the potential to decline from 5 to less than 1%. The previous subtropical dry forest is replaced by tropical dry forest and tropical very dry forest (Table 1). The study revealed that, the forests in Thailand will be changed under climate change scenarios of doubling carbon dioxide concentration of the atmosphere. Most of them will become increasingly arid (Boonpragob and Santisirisomboon, 1997).

Table 1. Areas of major forest type in Thailand under current and changed climate conditions according to three GCM scenarios

Forest Type	Current Area km2*1000 (%)	Climate Change Area km2*1000 (%)		
		UK89	GISS	UKMO
Subtropical Dry Forest	5.9 (1.2)	-	-	-
Subtropical Moist Forest	234.5 (47.7)	87.7 (17.8)	9.5 (1.9)	59.4 (12.1)
Subtropical Wet Forest	22.2 (4.5)	6.6 (1.3)	5.3 (1.1)	1.8 (0.4)
Tropical Very Dry Forest	-	-	11.9 (2.4)	3.0 (0.6)
Tropical Dry Forest	156.5 (31.8)	218.6 (44.4)	341.3 (69.3)	290.1 (58.9)
Tropical Moist Forest	71.5 (14.5)	166.8 (33.9)	120.5 (24.5)	128.0 (26.0)
Tropical Wet Forest	1.6 (0.3)	12.6 (2.6)	3.7 (0.8)	9.9 (2.0)

Table 2. Comparison trend of forest change in northern Thailand from 2010-2089

Forest type	Forest area (%)				
	2010-2019	2020-2029	2030-2039	2050-2059	2080-2089
Evergreen Forest					
Hill Evergreen Forest	1.45	1.37	1.34	0.68	0.42
Dry Evergreen Forest	0.01	0.00	0.00	0.00	0.00
Mixed Coniferous Forest	18.28	17.40	14.89	12.25	6.81
Deciduous Forest					
Mixed Deciduous Forest	69.30	68.97	71.24	73.18	71.99
Dry Dipterocarp Forest	10.97	12.26	12.53	13.89	20.78

Source : Nathsuda Pumijumnong, Mahodol University

5. Impacts of climate change on fire regime in Thailand

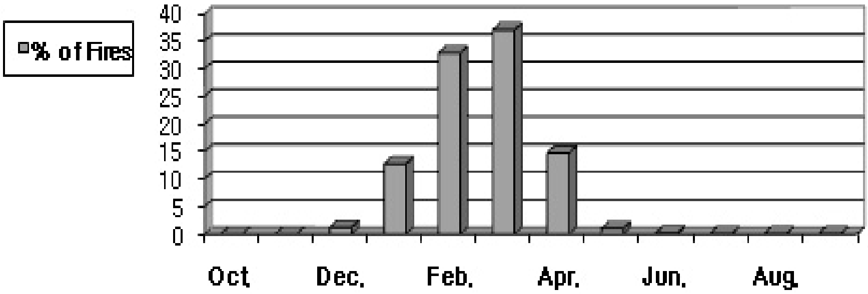
5.1 Current fire regime

5.1.1 Types and Occurrences

Forest fires in Thailand are mainly classified as surface fires, mostly take place in Mixed Deciduous Forest, Dry Dipterocarp Forest, Secondary Growth and Forest Plantations, and to some extent in Dry Evergreen Forest, Hill Evergreen Forest or event in some parts of the Tropical Rain Forest. In certain extremely dry sites, double burning in one season is common. These surface fires consume surface litter, other loose debris on the forest floor and small vegetation.

5.1.2 Duration

Forest fires in Thailand annually occur during the dry season from December to May with their peak in February-March. During the day, most fire activities concentrate from noon to 4 pm.



5.1.3 Causes of forest fire

According to the official statistics collected since 1985, there was very few number of nature-caused fires recorded. Therefore generally speaking all fires are man-caused, especially by the rural people who live in or adjacent to forests. The statistics revealed the various reasons for setting fire and their average percentage as follows:

- Gathering of forest non-timber products: This includes all rural people who traverse the forest during the dry season mainly for collecting forest products such as fuel wood, bamboo, honey, mushrooms, etc. These people mainly set fire to clear out litter, grass, and undergrowth on the surface floor in order to make travelling and collecting such products more convenient .
- Agricultural debris burning: To prepare agricultural land after harvesting, farmers traditionally set fires without any control, to eliminate the residue, and the fire escapes into the nearby forest. This cause is very serious in areas where shifting cultivation is still widely practiced .
- Incendiary fire: Attempt of rural people to convert forest into cultivation land and when there is a conflict taking place between rural people and forest officers .
- Hunting: In pursuing small game, people set fire todrive the animals fromhiding places.

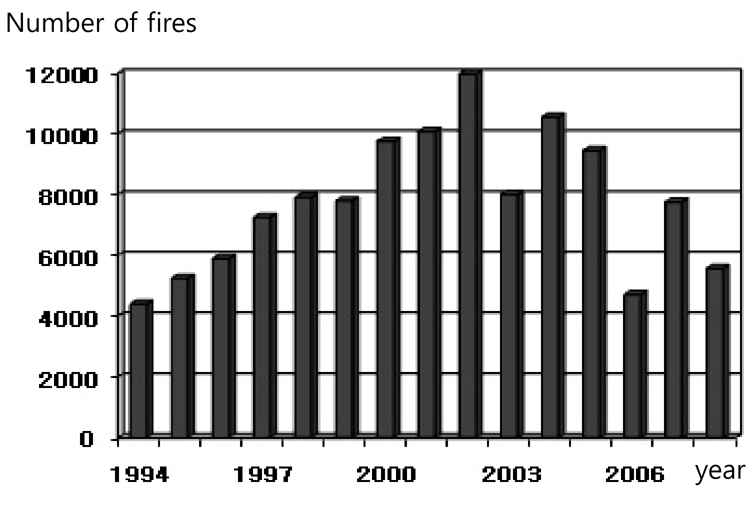
- Carelessness: Mainly from camping fire and cigarette butts from tourists as well as local people.
- Illegal logging: Carelessly burning forest during their illegal operation.
- Cattle raise: Burning the open forest in order to produce new and tender shoot of grass to feed livestock.
- Unidentified causes: There is no clue for tracing the cause.

Table 3. Causes of forest fire

Causes	**Percentage (%) Average from 1998-2008**
1.Gathering forest non-timber products	37
2. Agricultural debris burning	17
2. Incendiary fire	5
4. Carelessness	2
5. Hunting	20
6. Illegal logging	2
7. Cattle raise	4
8. Unidentified causes	13
Total	**100**

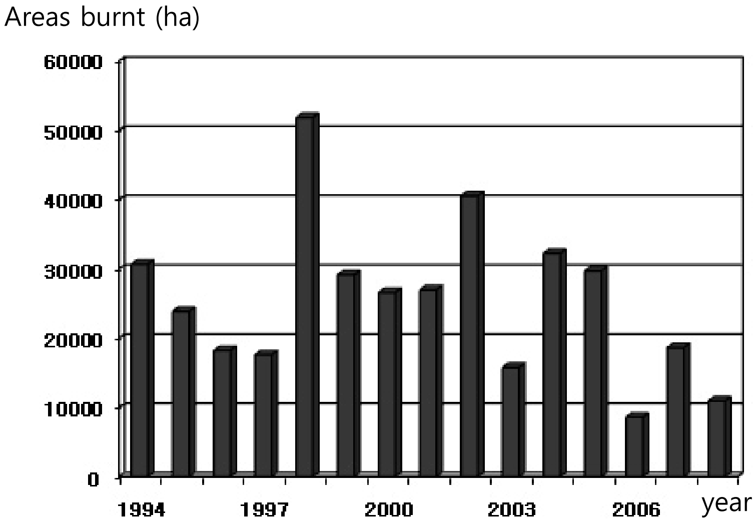
5.1.4 Fire frequency

The average of 7,758 fires is occurred annually.



5.1.5 Areas burnt by fires

The average of 25,426 ha of forests is burnt by fire annually.



5.2 Fire regime under climate change

Little is known about how climate changes have impacts on fire regime in tropical region. There is no specific research on such impacts on fire regime in Thailand. Fire statistics recorded during 1994-2008 revealed the fluctuation of fire frequency, duration and burnt areas from year to year partly depending on ENSO condition. However since all model predicted that most of forests will become increasingly arid (Table 1 and Table 2), therefore they also will become increasingly subjected to high wildfire risk as well.

The three GCMs namely, UK 89, UKMO and GISS all showed the increase in average temperature from 21.5- 27.5 oC to 25-32 oC approximately. The temperature increases by 2.5 oC in the northeast region and by 3-3.5 oC in the central, north, and west regions. Although temperature is not necessarily a critical factor influencing fire regimes in the tropical region. However higher mid-day temperature will lead to quicker drying of fuels, thus potentially influencing fire intensity and severity. (Goldammer, J.G. and Colin, P. 1998)

All models also showed that the amount of rainfall is dispersed differently from the base year. The amount of rainfall in the northeast is constant while it increases by 40% in the south. The amount of rainfall in other parts of the country increases by 20%.. This implied that the regions with increase of rainfall will be subjected to higher fire risk due to the fact that increase precipitation will lead to the build-up of more continuous fuelbeds that may carry more frequent and larger –sized wildfires. (Goldammer, J.G. and Colin, P. 1998)

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Poster Session

Greenhouse Gas emissions from natural disturbances in Korea
자연교란에 의한 산림부문 온실가스 배출

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Abstracts

The greenhouse gass emissions from natural disturbances have been estimated in accordance with the LULUCF-GPG. The carbon loss from natural disturbances highly varied depending on disturbance type and time from 0.1 to 2,338 Gg C and ranged from 14 to 2,338 for forest fire(71%), 26 to 173 for Insect and disease(13%), 8 to 227 for flood, 0.1 to 46(2%) and 0.1 to 0.8 for snow(0.03%), respectively. Especially, the carbon loss and variation were highest for forest fire. So, the protection and management technique for big forest fire are absolutely required to reduce GHG emissions. The observation and protection system for forest fire were already adopted, and therefore the GHG emissions by natural disturbances was decreased from 2000 in Korea.

요 약

우수실행지침(GPG2003)을 따라 손실부분 중 자연 교란에 의한 온실가스 배출량을 현재 적용가능한 수준으로 추정해 본 결과, 교란 유형별 손실량(Gg C)은 산불 14-2,338(71%), 병해충 26-173(14%), 수해 8-227(13%), 풍해 0.1-46(2%), 그리고 설해 0.1-0.8(0.03%) 등의 범위로 나타났다. 이처럼 자연 교란에 의한 온실가스 배출변이는 상당히 크며, 특히 산불에 의한 배출이 가장 많으면서도 변이가 가장 큰 것으로 나타났다. 따라서 자연 교란에 의한 온실가스 배출을 감소시키기 위해서는 대형산불 예방 및 관리기술이 절대적으로 요구된다. 다행히 우리나라는 이미 산불 감시 및 예방시스템이 구축되어 운용되고 있어, 2000년 이후 산불로 인한 온실가스 배출량은 감소하는 경향을 보이고 있다.

서론(Introduction)

우리나라는 이제까지 IPCC 1996 가이드라인(1996GL)에 근거하여 온실가스 국가보고서를 작성하였으나, 기후변화당사국 총회는 부속서I 당사국으로 하여금 우수실행지침(GPG2003)에 근거한 통계보고를 의무하고 개도국에 대해서도 국가보고서 작성 시 사용을 권장하였다. 우수실행지침(GPG2003)을 따라 적용할 수 있는 추정방법은 축적차이법(stock difference method)과 획득손실법(gain-loss method)이 있으나, 현재 우리나라의 자료 여건에 따라 적용할 수 있는 추정방법은 획득손실법이 타당하다. 그동안 산림부문 온실가스 인벤토리 작성을 위해 국가 고유계수 개발에 상당한 노력을 기울여 획득부분에 필요한 탄소관련 계수들의 개발은 거의 완료 단계에 이르렀으나, 손실부분의 일부 활동자료들과 탄소관련 계수들의 개발은 이제 시작하는 단계이다. 이 연구는 손실부분 중 자연 교란에 의해 손실되는 온실가스량을 현재 적용가능한 수준으로 추정하는데 그 목적이 있다.

재료 및 방법(Methodology)

자연 교란의 유형은 임업통계연보에서 자료를 확보할 수 있는 산불, 설해, 풍해, 병충해, 수해 등으로 제한하였다(1999-2007). 유형별 온실가스 배출량은 다음의 식을 이용하여 추정하였다(IPCC 2003).

$\mathbf{L_{other\ losses} = A_{disturbance} \cdot BW \cdot (1 - f_{BL}) \cdot CF}$ **<등식 3.2.9.>**

$L_{other\ losses}$ = 기타 연간 탄소 손실량, tonnes C yr^{-1}

$A_{disturbance}$ = 교란(산불)의 영향을 받은 산림면적, ha yr^{-1}

BW = 산림지역의 평균 바이오매스 축적량, 밀도, tones d.m. ha^{-1}

f_{BL} = 산림에 남아 부후하는 바이오매스 비율
(고사 유기물로 전환; 기본값=0.15)

CF = 건중물 탄소 함량(기본값=0.5), tonnes C $(tonne\ d.m.)^{-1}$

결과 및 고찰(Results and Discussion)

1999-2007년 동안 교란에 의한 연간 온실가스 배출량(Gg C)은 134-2,404의 범위로 나타났으며, 연간 온실가스 배출량(Gg C)이 가장 큰 자연교란은 산불(377)이였으며, 병충해(75), 수해(72), 풍해(12) 그리고 설해(0.2)

순이었다. 교란 유형별 손실량(Gg C)은 산불 14-2,338(70.3%), 병해충 26-173(14.0%), 수해 8-227(13.4%), 풍해 0.1-46(2.2%), 그리고 설해 0.1-0.8(0.03%) 등의 범위로 나타났다(Figure 1). 이처럼 자연 교란에 의한 온실가스 배출 변이는 상당히 큰 것으로 나타났으며, 여러 교란들 가운데 산불에 의한 배출이 가장 많으면서도 변이가 가장 큰 것으로 나타났다. 그 원인은 대형산불의 발생때문으로 분석되었으며, 지난 25년간의 산불에 의한 온실가스 배출량을 Figure 2에 제시하였다.

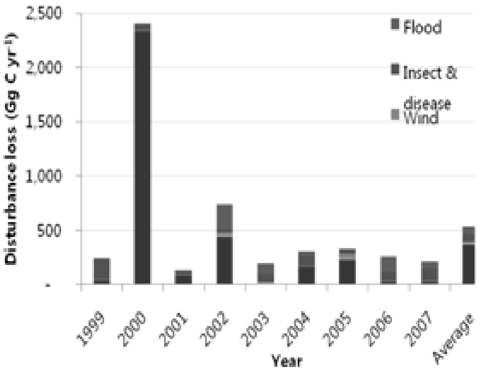

Figure 1. CO_2 emissions by disturbances.

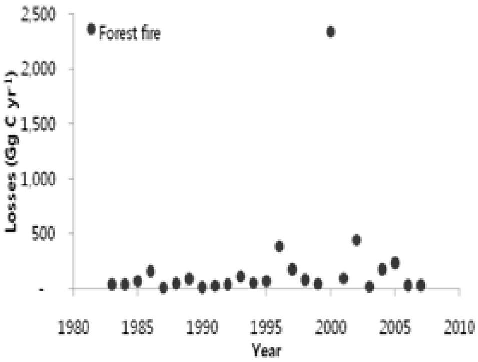

Figure 2. CO_2 emissions from biomass burning.

또한 산불은 이산화탄소 배출뿐만 아니라, 상당한 양의 CH_4, CO, N_2O, NOx 등의 Non-CO_2 가스를 추가적으로 배출하여 산불에 의한 온실가스 배출은 다른 교란보다 그 영향력이 큰 것으로 나타났다. 따라서 자연 교란에 의한 온실가스 배출을 감소시키기 위해서는 대형산불 예방 및 관리기술이 절대적으로 요구된다. 다행히 우리나라는 이미 산불 감시시스템과 예방시스템이 구축되어운용되고 있어, 2000년 이후 산불로 인한 온실가스 배출량은 감소하는 경향을 보이고 있다.

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Application of Goal Programming for Optimization of Carbon Sink in Youngdong-Gun, Korea
탄소흡수원 최적화를 위한 목표계획법의 적용

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Abstracts

To facilitate the sustainable forest management and enhance the carbon storage in the forest, it is necessary to develop an optimized forest management plan by using a quatatative method. This study was intended to generate a strategic management plan for Youngdong-Gun in Korea by using the goal programming. The management objective in this study was to make the study size evenly distributed for the age classes and to allow an even harvest volume through a 50 year time horizon. The resulted management plan was appropriate for achieving the management objectives.

요 약

지속가능한 산림경영의 이행과 안정적 탄소흡수원의 확충을 위해서는 정량적 모델링을 이용한 최적화된 산림경영계획의 수립이 필수적으로 요구된다. 본 연구에서는 목표계획법을 적용하여 영동군의 산림을 대상으로 장기적인 산림경영계획을 수립하고자 하였으며, 그 결과 지속가능한 영급구조를 유도하고 목재자원을 안정적으로 공급하는데 적합한 최적화된 산림경영계획을 제시하였다.

서론(Introduction)

최근 급속한 산업발전과 인구증가로 인한 지구온난화, 오존층파괴

그리고 열대림의 황폐화 등과 같은 심각한 환경문제가 발생하면서 지속가능한 산림경영(Sustainable Forest Management)은 전 세계적인 산림경영의 새로운 패러다임으로 자리매김하고 있다. 따라서 산림경영계획 수립을 위한 경영목표와 의사결정 범위가 매우 복잡해지고 다양해 졌다. 우리나라 산림경영 방침은 지속가능한 산림경영을 실현하기 위하여 산림의 기능을 생태적, 환경적으로 지속가능하도록 유지하고, 보전할 수 있는 계획수립을 요구하고 있다. 이 연구는 2005년 우리나라에서 탄소흡수원 확충과 안정된 목재공급원으로 지정된 경제림육성단지에 대하여 장기경영계획수립하는 것이며, 경영기법으로 목표계획법을 이용하였다.

재료 및 방법(Methodology)

연구대상지는 충청북도 영동군으로서 탄소흡수원으로 집중적으로 관리되는 산림면적은 약 44,216ha(전체산림면적의 70%)이고, 산림기능별 면적은 Table 1과 같다. 모델 수립을 위한 기본조건으로 계획기간은 시작년도가 2009년, 종료년도 2059년으로 전체 50년이다. 그리고 분기연수는 10년이고, 최소 Ⅲ영급이상 벌채수확이 가능하고 벌채 직후, 조림을 실시하는 것으로 하였다.

Table1. The Forest Area by Forest Funtions in Youngdong-Gun

Forest Funtion	Urban Interface	Natural Preserve	Recreation	Timber Production	Watershed Protection	Total
Area(ha)	4,346	1,638	8,543	25,082	4,607	44,216
Rate(%)	(5%)	(21%)	(47%)	(24%)	(3%)	(100%)

그리고 경영목표는 다음과 같이 우선순위를 갖는다. 첫번째, 전체 계획기간 동안 목재생산림을 지속가능한 영급구조로 유도한다. 두번째, 분기별(10년간) 수확량을 10%씩 증가시킨다. 세번째, 생활환경림과 산림휴양림은 전체 산림면적의 30%, 수원함양림은 20%, 자연환경보전림은 10% 이내로 벌채수확한다. 목표계획법 모델의 의사결정변수는 산림기능구분, 영급, 임상, 경영안 등의 조합으로 구성되고, 제약조건은 현실면적제약, 총수확량, 지속가능한 영급구조 개선, 산림기능별 벌채면적 제약, 분기별 수확량 조절 등 5가지이다. 일반화된 목표계획법 모형을 부호로표시하면 아래와 같다.

$$\textit{Minimize} \quad Z = W^{-}d^{-} + W^{+}d^{+}$$

Subject to

$$Ax - d^{+} + d^{-} = M$$
$$Bx \approx b$$
$$X \geq 0, \quad d^{+} \geq 0, \quad d^{-} \geq 0$$

Where $\approx$ can be $\leq$ or $=$ or $\geq$;

Z objective function

W^{-} vector($1 \times m$) of weights, assciatged to the positive deviations of the goals and they express the importance of each goal

W^{+} vector($1 \times m$) of weights, assciatged to the negative deviations of the goals and they express the importance of each goal

A matrix($m \times n$) of technological coefficients of the goal constraints

B matrix($m \times n$) of others constraints

M vector($1 \times m$) that represents the goals that shoud be reached

결과 및 고찰(Results and Discussion)

모델분석을 위하여 LINGO6.0 최적화 프로그램을 이용하였다. 분석결과, Table 2와같이 목재생산림은 Ⅰ ~ Ⅴ 영급까지 4,180ha의 영급구조를 가지게 되고, 지속가능한 영급구조와 분기별 수확량조절, 산림기능구분에 따른 벌채면적제약조건도 만족하였다. 계획기간동안 전체면적 44,216ha중에서 약 58%인 25,892ha가 임목수확을 실시하는 것으로 나타났다. 계획기간말 영급구조는 Ⅰ ~ Ⅹ 영급까지 분포하는 것으로 나타났다.

Table2. Schedule of Harvesting Optimized from the Goal Programming

	Area scheduled for Harvesting (ha)					Area of No Harvesting (ha)				
	Period1	Period2	Period3	Period4	Period5	Period1	Period2	Period3	Period4	Period5
Urban Interface	188	1,115	-	-	-	119	581	1,884	459	-
Natural Preserve	91	84	-	-	-	-	192	890	381	-
Recreation	2,085	-	499	-	-	-	1,452	1,964	2,082	461
Timber Production	4,180	4,180	4,180	4,180	4,180	-	-	782	2,293	1,107
Watershed Protection	87	758	85	-	-	124	969	1,404	1,165	15
Total	6,631	6,137	4,764	4,180	4,180	243	3,194	6,924	6,380	1,583

Figure 1은 2009년 현재와 계획기간말인 2059년도 영동군의 영급구조를 나타내고 있다. 지속가능한 영급구조의 개선은 벌채면적 또는 계획기간의 조절을 통해 그 달성 속도를 달리할 수 있다.

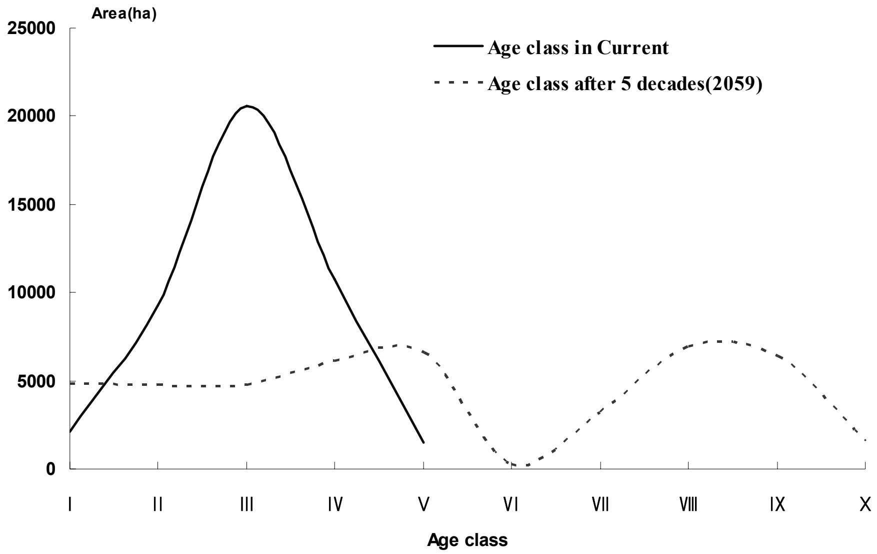

Figure1. Changes in the Distribution of Age classes after 5 decades in Youngdoong-Gun

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Estimating carbon stock in litterfalls and forest soils, Korea
한국 산림토양의 탄소 축적량 추정

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Abstract

Forest soil plays very important roles in carbon sequestration of terrestrial ecosystems. This study was carried out to estimate the soil organic carbon (SOC) stock based on 5th Korean National Forest Inventory(NFI) being composited of 200 permanent plots in 2007. Samples were catched in organic layer(L and F+H) with 900cm^2-quadrate and mineral soil horizon within each 10cm interval up to 50cm. Mean carbon density in organic layers was 6.47 Mg ha^{-1} for coniferous forests, 5.54 Mg ha^{-1} for mixed forests, and 4.19 Mg ha^{-1} for deciduous broadleaf forests. The variation within forest types was very large, as the variation coefficient was ranged from 50% to 92%. The C stock in organic layer increased with crown density and forest age class. We made regressive equations between litterfall dry mass and the carbon stock by forest type(e.g. C_{con} = 0.0046*O.M +0.0884, P<0.001). In mineral soil, mean SOC for coniferous forests was 46.8 Mg ha^{-1}, 49.6 Mg ha^{-1} for mixed forests, and 75.9 Mg ha^{-1} for deciduous forests. The SOC amounts were negatively related with soil depth. The about 55 % of total mean SOC stock was accumulated in 0-20cm out of 50cm depth. Even though there were large variation coefficient and small numbers of samples, sandy clay loam soils(SCL) among soil textures had greatest SOC, and moderately moist brown forest soils(B_3) among forest soil types did. We just started SOC monitoring in Korea and need more data to increase accuracy and precision in estimating the changes in forest soil carbon stock, this study is valuable information for national forest carbon inventory.

요 약

육상생태계의 탄소 고정에 있어서 산림토양이 매우 주요한 역할을 담당하고 있다. 본 연구는 5차 산림자원조사 중 2007년의 200개 고정표본점 자료를 토대로 산림 토양탄소를 추정하기 위해 수행되었다. 유기물층(L층과 F+H층) 시료는 900cm^3 방형구를 이용하여 채취하였고 토양층 시료는 토심 50cm 깊이까지 10cm 깊이별로 구분 채취하였다. 유기물층의 평균 탄소축적량은 침엽수림 6.47 Mg ha^{-1}이었으며, 혼효림과 활엽수림에서는 각각 5.54 Mg ha^{-1}과 4.19 Mg ha^{-1}이었다. 유기물층의 탄소축적량은 수관밀도와 영급과정의 상관관계를 보였다. 임상별 유기물층의 건물량을 이용하여 탄소 축적량을 추정하기 위한 회귀식을 도출하였다(예 : C_{con} = 0.0046*O.M +0.0884, P<0.001). 토양층에서는 침엽수림, 혼효림, 활엽수림의 탄소 축적량(SOC)이 각각46.8 Mg ha^{-1}, 49.6 Mg ha^{-1}, 75.9 Mg ha^{-1}이었다. 토양탄소 축적량은 토양의 깊이와 부의 상관을 보였으며, 전체 축적량의 약 55%가 토심 20cm 이내에 분포하였다. 토양탄소 축적량이 가장 큰 토양은 갈색적윤산림토양(B_3)의 사질식양토(SCL)이었다. 우리나라 산림토양탄소(SOC) 모니터링은 이제 초기단계로서 정확도 높은 추정을 위해 더 많은 자료가 요구되며, 국가 산림탄소 계정 등에 유용한 자료로 이용될 것이다.

서론(Introduction)

국가 차원의 산림탄소 계정은 학술적 활용뿐만 아니라 정책적 지원에 있어서도 필요한 부분이다 (Woodbury et al., 2007). 특히 산림 토양탄소는 산림생태계의 전체 탄소 풀의 중요한 위치를 차지하기 때문에 이에 대한 모니터링과 추정 연구는 지대한 관심을 모으고 있다. 그러나 대부분의 국가에서 공간적 변이성 및 시료채취 상의 어려움으로 토양탄소 축적량에 대한 자료가 부족한 실정이다. 그럼에도 불구하고 교토의정서에 대응하기 위한 국가 규모의 산림 토양탄소 축적량 정보 구축은 탄소계정 및 모델개발에 반드시 필요한 항목이다. 다행이 우리나라의 경우 2006년부터 제 5차 국가산림자원조사가 시작되어 이에 대한 기반조성은 되어 있는 상황이다. 따라서 본 연구는 2007년 국가산림자원조사 자료를 토대로 유기물층과 토양층의 탄소 축적량을 조사, 분석하였다.

재료 및 방법(Methodology)

본 연구의 조사지는 2007년 국가산림자원조사의 200개 고정표본점을 대상으로 하였다. 유기물층 탄소 축적량은 30cmx30cm 방형구내의 유기물층을 채취하여 항건시킨 후 건중량과 탄소농도를 구하여 산출하였다. 토양층 탄소 축적량은 400cm^3 토양 시료채취기를 이용하여 10cm 깊이별로 50cm 깊이 까지 구분채취하여 용적밀도, 석력비, 유기탄소농도를 분석하여 산출한 후 깊이별 축적량을 합산하여 산출하였다.

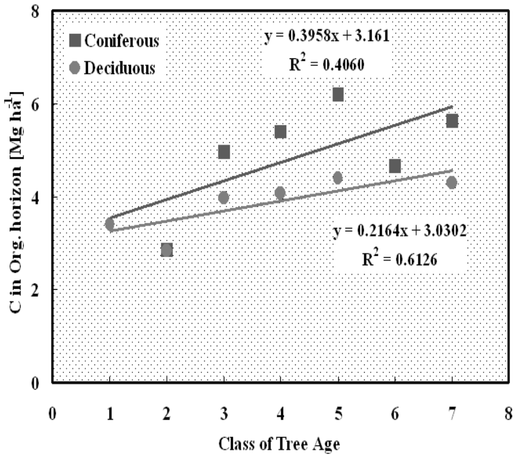
결과 및 고찰(Results and Discussion)

유기물층 탄소 축적량

유기물층의 평균 탄소축적량은 침엽수림 6.47 Mg ha^{-1}, 혼효림과 활엽수림 각각 5.54 Mg ha^{-1}과 4.19 Mg ha^{-1}으로 나타났다(Table 1). 유기물층의 탄소 축적량은 수관밀도와 영급과 정의 상관관계를 보였다. 임상별 유기물층의 건물량을 이용하여 탄소 축적량을 추정하기 위한 회귀식을 임상별로 도출하였는데, 모든 회귀식의 유의성이 95% 이상 매우 높게 나타나 그 활용성이 높을 것으로 판단된다.

Table 1. Average carbon storage in organic layers(L+F+H) by forest types

Forest type	C storage (Mg ha^{-1})	Standard deviation
Coniferous forests	6.47	5.56
Mixed forests	5.54	5.36
Deciduous broadleaf forests	4.19	3.76



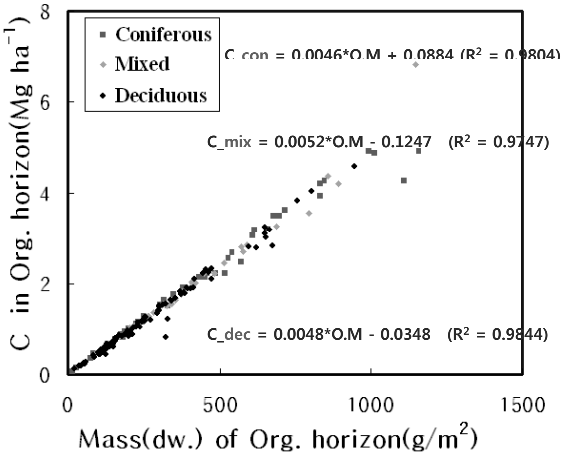


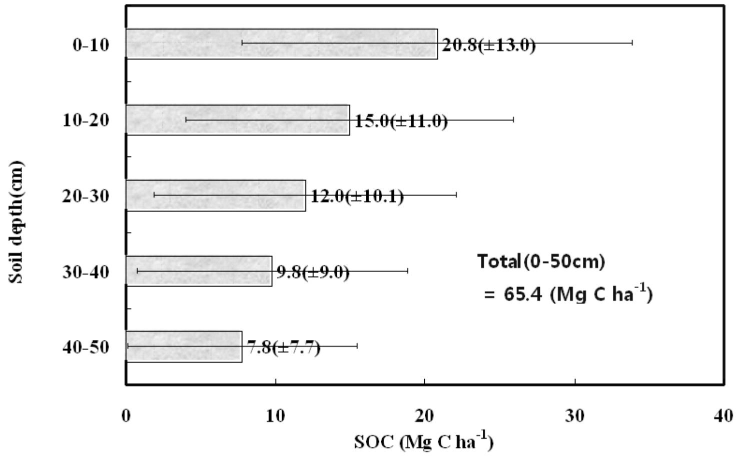
Figure 1. Relation of carbon storage among tree age(left) and dry weight(right) in organic layers(L+F+H) by forest types

토양층 탄소 축적량

토양층에서는 침엽수림, 혼효림, 활엽수림의 탄소 축적량(SOC)이 각각 46.8 Mg ha^{-1}, 49.6 Mg ha^{-1}, 75.9 Mg ha^{-1}이었다. 토양탄소 축적량은 토양의 깊이와 부의 상관을 보였으며, 전체 축적량의 약 55%가 토심 20cm 이내에 분포하였다. 토양탄소 축적량이 가장 큰 토양은 갈색적윤산림토양(B_3)의 사질식양토(SCL)이었다. 우리나라 산림토양탄소 계정은 초기단계이므로 추정을 위해 더 많은 자료와 정확도가 요구되며, 본 연구결과는 국가산림탄소 계정에 유용한 자료로 이용될 것이다.

Table 2. Average carbon storage in mineral soils(0-50cm) by forest types

Forest type	C storage (Mg ha^{-1})	Standard deviation
Coniferous forests	46.8	27.7
Mixed forests	49.6	26.8
Deciduous broadleaf forests	75.9	53.0



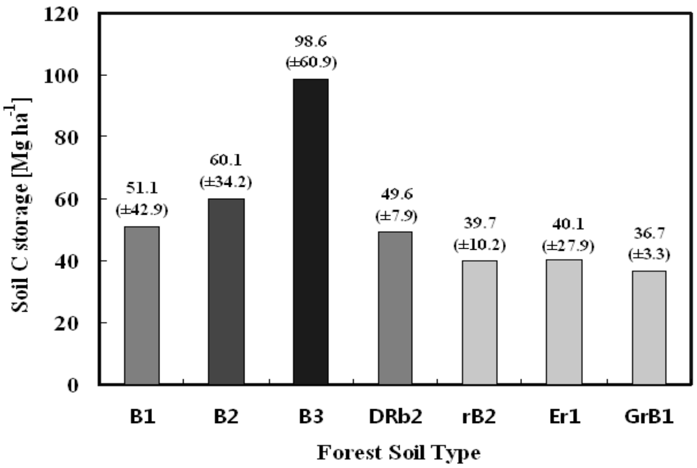


Figure 2. Vertical distribution of SOC(left) and soil carbon storage by forest soil types(right)

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The enhanced national forest inventory design and its role for carbon estimation in Korea
탄소축적조사를 위한 새로운 국가산림자원조사 체계와 역할

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Abstracts

From 1972, the National Forest Inventory in Korea has conducted four times on a regular base; the 1st NFI(1972-1975), the 2nd NFI(1978-1981), the 3rd NFI(1986-1992), the 4th NFI(1996-2005). The purpose of the previous NFIs was mainly to provide basic information on the forest resources under the periodic inventory system. Recently, there has been increasing demand for accurate and timely forest information from international processes and conventions. Korea also is expected to submit GHG inventory report under UNFCCC from 2013. These kinds of external and internal pressure led us to change and improve NFI program. Based on the results of a pilot research project on the development of new NFI program, the 5th NFI(2006-2010) program was re-designed with the emphasis on supporting carbon inventory at international level as well as production of reliable forestry statistics at national level. The core elements of the new design are as follows; transition from periodic to annual inventory, systematic layout of 4,000 permanent sample plots, new ground plot design, re-measurement strategy on 5-year cycle, more measurement variables related to carbon stock and biodiversity, etc. The enhanced NFI design will provide accurate and timely information on forest resources and ecosystem. Use of NFI data for carbon estimation will minimize uncertainty and maximize efficiency and accuracy of national GHG inventory. It is, therefore, considered that the enhanced NFI will be a core component of national forest carbon accounting system and play important roles in assessing and monitoring forest carbon pool and carbon pool changes as the most cost-efficient alternative.

요 약

한국의 산림자원조사는 1972년 시작하여 제4차 조사(1996-2005)를 완료하고 현재 제5차 조사(2006-2010)를 실시 중이다. 과거 전국산림자원조사는 전통적으로 정기순환조사체계(Periodic inventory system)로서, 목적은 산림자원량을 파악하여 국가의 산림자원 기본통계를 생산하는 것이었다. 하지만 최근 산림관련 국제기구와 협약으로부터 산림자원 및 산림환경정보를 포함하는 다양한 산림통계의 제출 요구가 증가하면서, 이에 대응하기 위한 수단으로서 제5차 조사(2006-2010) 체계를 개편하기에 이르렀다. 새로운 조사체계 개편의 핵심은 5년 주기 매년조사체계로(Annual inventory system)의 전환, 새로운 표본설계 및 지상표본점 설계, 조사항목의 확대 세분화 등이다. 특히 산림부문에서 국가적 현안으로 대두되고 있는 기후변화협약(UNFCCC)의 온실가스통계와 관련하여 산림탄소흡수원의 추정이 가능하도록 설계하였다. 제5차 국가산림자원조사의 목적은 산림자원과 산림생태계 변화의 지속적인 모니터링으로서, 전국 산림에 대한 지속 가능한 산림경영의 지표를 평가하여 신뢰도 높은 국내외 요구산림통계의 생산이 가능할 것으로 기대한다.

서론(Introduction)

1992년 브라질 리우에서 개최된 유엔환경개발회의(UNCED) 이후 범세계적으로 지구환경보호라는 명제가 대두되면서 목재자원을 중시하는 임업의 가치관이 산림의 환경적 기능을 중시하는 방향으로 변하고 있다. 이와 함께 SFM, 경제협력개발기구(OECD), 유엔기후변화협약(UNFCCC), 국제식량농업기구(FAO) 등 국제협약과 기구에서는 산림환경정보를 포함하는 국가산림통계의 제출을 의무화하는 추세이다. 특히, 지속 가능한 산림경영과 기후변화협약의 온실가스통계 관련 탄소배출권 문제는 국가 차원에서 대응해야 하는 현안 과제로 대두되고 있는 실정이다. 산림을 개발, 이용하되 산림 환경이 건전하게 유지 증진하도록 경영하는지 그 증거를 제시하라는 얘기다. 이를 이행하지 않을 경우 국제무역에서 경제적 불이익을 감수해야 하는 상황에서 전국 규모의 국가산림자원조사만이 이러한 국제적 요구에 대응할 수 있는 실질적인 대안으로서 재조명 되고 있다. 따라서 과거 임목통계 위주의 산림자원조사 체계에 따른 국내외 여건 변화에 대한 수요 한계로 인하여 제5차 국가산림자원조사에서는 이에 대한 수요 대응이 가능하도록 새로운 조사체계로 개편하였다.

새로운 조사체계 개요
(Introduction to new surveying system)

최근 국가산림자원조사의 국제 동향은 산림자원의 평가뿐만 아니라 산림환경의 변화 동태를 지속적으로 모니터링하는 방향으로 변화하는 추세이다. 따라서 새로운 조사체계의 개편방침을 과학적인 산림자원 모니터링 조사체계를 정립하고, 신뢰성 있는 국가기본산림통계 생산 및 국제수준의 산림환경통계 생산 인프라를 구축하는 것으로 정하였다. 표본설계, 지상표본점 구조, 조사항목의 설정에 있어서도 이와 같은 국제동향을 고려하였다. 특히, 지속 가능한 산림경영의 기준과 지표(C&I)와 FAO 산림통계 항목을 면밀히 분석함으로서 향후 새로운 산림자원조사의 추진 방향을 정립하였다. 또한, 1990년대 후반부터 산림자원 모니터링조사체계를 갖춘 미국, 카나다, 핀란드 등 선진 임업국의 사례를 벤치마킹하여 우리나라의 실정에 적합한 새로운 산림자원조사시스템의 모델을 제시하였다. 새로운 조사체계의 핵심내용을 정리하면 다음과 같다.

- 조사주기 : 과거 10년 주기의 지역별 정기순환조사체계를 5년 주기의 매년 조사체계로 전환하여, 매년 고정표본점의 20%씩 조사
- 표본설계 : 전국 산림에 4㎞ x 4㎞ 간격의 격자점을 기준으로 고정표본점(Permanent sample plot) 약 4,000개를 계통적으로 배치
- 표 본 점 : 0.04ha 크기의 원형 subplot 4개로 구성되는 집락표본점 (Cluster-plot), 각 Subplot은 3개의 조사원으로 세분화
- 조사항목 : 임목자원 조사항목 외에 바이오매소, 산림식생, 토양탄소/낙엽낙지, 고사목, 벌근 등과 같은 산림생태 및 환경인자를 추가. 산림식생과 토양탄소조사(낙엽낙지 포함)는1,000plot에서만 조사
- 자료분석 : 일차적으로 국가의 산림자원통계를 분석하며, 자료의 이차 가공을 통하여 국제 수준의 산림통계 지표(Indicator)를 분석
- 참여기관 : 산림청(총괄), 국립산림과학원(주관), 산림조합중앙회 산림자원조사본부(실행) 등 3개 기관의 유기적인 협조체계 하에 추진

결과 및 고찰(Results and Discussion)

과거 임목통계 위주의 조사에서 산림환경 및 생태자원의 통계 수집이 가능한 체계로 전환하였다. 주기적인 산림자원 및 산림생태계 변화 모니터링 기반을 구축함으로서 신뢰도 높은 산림통계의 국내외 수요에 능동적으로 대처할 수 있을 것으로 예상된다. 특히, 기후변화협약 (UNFCCC)과 관련한 산림부문 온실가스통계의 산림탄소흡수원(Carbon pools)에 대한 추정이 가능할 것으로 기대된다.

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Forest wild fire and carbon management – a geospatial approach

자연 산불 및 탄소 관리 – 지리공간적 접근

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Abstract

Forests, one of the magnificent resources on earth, act as a source and sink of carbon in the atmosphere. It is estimated that as of 2007, the shrinking forests in the tropics were releasing 2.2 billion tons of carbon per year. The deforestation in Asia is driven primarily by the fast-growing demand for timber. In Latin America, by contrast, it is the growing demand for soybeans and beef that is deforesting the Amazon. In Africa, it is mostly the gathering of fuelwood and the clearing of new land for agriculture as existing cropland is degraded and abandoned. Two countries, Indonesia and Brazil, account for more than half of all deforestation. The Democratic Republic of the Congo, also high on the list, is a failing state, making forest management difficult. There are many tree planting initiatives from government and non-government sectors to stabilize climate and to conserve forests worldwide. In spite of that, deforestation is still on as a continuous process owing to various causes. The fast-growing demands on timber, need of new lands for agriculture, urbanization, industrialization, wild fire and so on degrade forests drastically. Among all factors, forest fire eradicates forests and adds carbon to the atmosphere very quickly. The present study estimates the amount of carbon released to atmosphere as a result of forest fire and models the forest area prone to forest fire in the future for conservation. This study was carried out in the Eastern Ghats of India. The living carbon, including the above and below ground, in the forest area was estimated by non-destructive method after classifying the forest with appropriate satellite data along with random field measurements. Fire affected forest areas were identified and demarcated using

high-resolution Global Positioning System (GPS). Spatial data related to fuel type, topography, and socio-economic were created from appropriate data sources. Analytic Hierarchy Process (AHP) was followed to assign weights to each layer and spatial model was created to identify forest area prone to fire. This provides a quick reference on carbon available at present and the carbon released to the atmosphere as a result of forest fire and the vulnerable fire prone forest areas for effective conservation.

요　약

산림은 대기 중에 탄소를 공급하는 주요 배출원인 동시에 저장고의 역할을 하고 있다. 2007 년을 기준으로 열대 지방에서 사라지는 산림에 의해 연간 22 억 톤의 탄소가 배출되었다. 특히 아시아 지역에서의 산림감소의 주 원인은 증가하는 목재 수요량이다. 한편, 라틴 아메리카 지역에서는 콩과 육류 생산을 위해 아마존 지역에서 산림을 벌채하고 있다. 아프리카에서는 연료용 목재를 벌채하거나, 기존 농지의 기능이 저하됨에 따라 새로운 농지를 개간하기 위해서 산림을 훼손하고 있다. 인도네시아나 브라질과 같은 경우 전세계 산림개간의 절반 가량의 책임이 있으며, 콩고 공화국 같은 경우는 국가상태가 악화됨에 따라 산림 관리가 어려워지고 있다. 전세계적으로 정부 또는 비정부적 차원에서 기후를 안정화시키고 산림을 보호하기 위한 다양한 시도가 이루어지고 있다. 그럼에도 불구하고 산림개간은 여러 가지 요인에 의하여 계속적으로 진행되고 있다. 즉, 증가하는 목재 수요량과 농지 확장, 도시화, 산업화, 자연 산불 등이 주요 원인이다. 이러한 요소들 중 산불은 산림을 훼손할 뿐만 아니라 대기에 탄소를 매우 빠르게 공급한다. 본 연구에서는 산불에 의해 대기에 방출되는 탄소의 양을 측정하고, 산불이 일어날 가능성이 높고 보호가 요구되는 산림지역 취약성분석을 시도했다. 실험 대상 지역으로는 인도의 Eastern Ghats을 선택하였으며, 지표면 위와 아래를 포함하여 산림에 현존하는 탄소의 양을 측정하기 위하여, 임의의 지역을 대상으로 한 인공위성 영상으로부터 산림을 분류하는 방식을 사용하였고 GPS를 활용해서 산불발생지역 위치정보를 취득하였다. 관련 공간정보 레이 어에 가중치를 부여하기 위하여 Analytic Hierarchy Process(AHP)를 사용하여 산불취약지역 공간분석 모델링을 수행하였다. 본 연구를 통해 현존하는 탄소의 양과 산불에 의해 대기에 방출되는 탄소의 양을 추정하고, 산불에 취약한 산림 지역 추정하는 일련의 방법론을 제안했다.

Main

Forests, one of the magnificent resources on earth, act as a source and sink of carbon in the atmosphere. It is estimated that as of 2007, the shrinking forests in the tropics were releasing 2.2 billion tons of carbon per year. The deforestation in Asia is driven primarily by the fast-growing demand for timber. In Latin America, by contrast, it is the growing demand for soybeans and beef that is deforesting the Amazon. In Africa, it is mostly the gathering of fuelwood and the clearing of new land for agriculture as existing cropland is degraded and abandoned. Two countries, Indonesia and Brazil, account for more than half of all deforestation. The Democratic Republic of the Congo, also high on the list, is a failing state, making forest management difficult. There are many tree planting initiatives from government and non-government sectors to stabilize climate and to conserve forests worldwide. In spite of that, deforestation is still on as a continuous process owing to various causes. The fast-growing demands on timber, need of new lands for agriculture, urbanization, industrialization, wild fire and so on degrade forests drastically. Among all factors, forest fires are considered to be a potential hazard having physical, biological, ecological and environmental consequences (Chuviceco 1992, Christensen et al. 1996), which eradicates forests and adds carbon to the atmosphere very quickly.

The present study, carried in Kolli Hill in the Eastern Ghats of India, estimates the amount of carbon released to atmosphere as a result of forest fire and models the forest area prone to forest fire in the future for conservation. This study was carried out in the Eastern Ghats of India. The living carbon above ground in the forest area was estimated by non-destructive method after classifying the forest with appropriate satellite data along with random field measurements by Ramachandran et al.(2007). Fire affected forest areas were identified and demarcated using high-resolution Global Positioning System(GPS). The above ground carbon released to atmosphere as a result of already occurred forest fire was calculated. Spatial data related to fuel type, topography, and socio-economic were created from appropriate data sources(Fig. 1). Analytic Hierarchy Process(AHP) was followed to assign weights to each layer and spatial model was created to identify forest area prone to fire. Finally spatial model for fire prone forest area was created integrating all the spatial layers in the GIS domain.

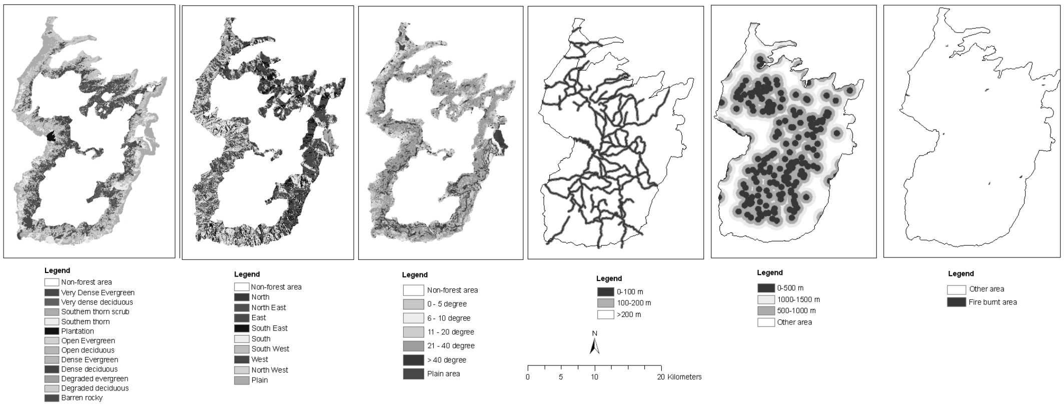

Fig.1. Thematic layers used for fire risk assessment, Fuel type: a) Forest cover density; Topography: b) aspect, c) slope; Socio-economic: d) road buffer, e) settlement buffer; f) fire burnt area

Fire has already occurred at the deciduous, secondary deciduous, southern thorn and scrub forest types to a total area of 66.95 ha so far. The total amount of above ground carbon released to atmosphere as a result of fire was estimated to be 4751.29 tons, in which, deciduous forest alone contributed to a maximum of 67.2%.

The result of spatial model in table 1 shows the distribution of vulnerable forest areas prone to fire. The highly vulnerable category having 563.65 ha should be given more priority for concervation than other areas. This study provides a quick reference on the status of available carbon at present and the carbon released to the atmosphere as a result of forest fire and the vulnerable fire prone forest areas for effective conservation.

Table 1. Forest areas under various risk categories of fire

Sl. No.	Categories	Area in hectare	Percentage
1	Very low	777.46	2.8
2	Low	12327.60	45.5
3	Medium	12443.20	46.0
4	High	563.65	2.1
5	No risk area	988.09	3.6

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Analysis of the seasonal characteristics of forest fires in South Korea using the multivariate analysis approach
다변량 통계 분석을 이용한 한국 산불의 계절적 특성 분석

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Abstracts

For efficient forest fire management, special precautions are required in dry and strong-wind seasons vulnerable to severe forest fires. To extract the seasonal characteristics of forest fires in South Korea, the statistics over the past 16 years, 1991 through 2005, were investigated. The daily records of the number of fire occurrences, the total area burned and the average burned area per occurrence were examined to identify the seasonal patterns of forest fires using cluster analysis and principal component analysis; the risk of daily fires was also assessed using the ordered logit model. As a result, the fire patterns were classified into five clusters and a general danger index for forest fires was derived from the first principal component, showing relatively large-scaled fire regimes in spring, and frequent small-scaled fire regimes in autumn and winter. In connection with the ordered logit model, the probability for the five ranks of forest fire risk was calculated and the threshold for high-risk fires was detected, resulting in the borderline values of 1.0, 1.36 and 0.23 for log-transformed values of the number of fire occurrences, the total area burned and the average area burned per fire, respectively. As an implementation of the results above, the proper forest fire precautionary period in South Korea was estimated, and consequently, October 21 through May 17 was recognized as a dry season at a high-risk of forest fires. This period began 10 days earlier in autumn and extended into midwinter (late December and January) as opposed to the existing precautionary period, indicating the need of more cautious forest fire management earlier in autumn and continuing through midwinter.

요 약

효율적인 산불관리를 위해서는 산불발생이 많은 시기에 대한 집약적인 관리가 필요하다. 본 연구에서는 1991년부터 2005년까지의 산불통계를 이용하여 한국산불의 계절적 특성을 분석하였다. 일별 산불발생건수, 연소면적, 건당연소면적의 자료에 대하여 군집분석을 수행하여 산불유형별 그룹을 분류하였으며, 주성분분석을 통하여 산불위험도에 대한 분석지표를 개발하였다. 또한 순위로짓모형을 이용하여 일별산불위험도 확률 계산 및 각 변수에 대한 위험경계값을 추출하여 산불위험기간을 고찰하였다. 연구결과, 군집분석에서는 봄철의 대형산불과 가을철의 소규모 빈번한 산불 경향을 잘 나타내어 주는 5개의 그룹으로 분류되었으며, 주성분분석을 통하여 85%의 높은 설명력을 가지는 제1주성분의 '산불위험도 종합지표'를 도출하였다. 군집별 제1주성분점수를 계산해본 결과, 군집3부터 양(+)의 값을 가져 실제적인 산불위험도를 나타내었다. 순위로짓모형을 통해 각 변수에 대해 위험경계값을 추출한 결과 발생건수, 연소면적, 건당연소면적 각각 1.0, 1.36, 0.23의 경계값을 가졌다. 세 변수의 위험경계값을 적용하여, 그 이상값을 가지는 날에 대해 공통적으로 추출된 기간을 살펴본 결과 10월 21일부터 5월 17일까지가 산불위험기간으로 선택되었다. 이는 현 산불조심기간보다 가을철에는10일 일찍 시작되며, 겨울철 또한 위험기간으로 포함하고 있다.

서론(Introduction)

효율적인 산불관리를 위해서는 산불의 계절적 특징을 파악하고 시기별 적절한 산불 예방 및 진화대책을 마련하는 것이 요구된다(Husari and Mckelvey, 1996). 국내에서도 산불발생이 빈번한 봄(2월 1일~5월 15일)과 가을(11월 1일~12월 15일) 동안 '산불조심기간'을 설정하여 인적·물리적 자원을 집중적으로 배치하여 산불관리의 효율성을 높이고자 하였다. 하지만 아직까지 산불의 계절적 발생·확산특성에 관한 체계적인 분석이 미흡한 실정이며, 산불조심기간 설정 또한 과학적 분석에 근거하기보다는 행정담당관료들의 직관적인 판단에 기반하고 있다. 따라서 본 연구에서는 산불의 시간적 특성을 효율적으로 분석할 수 있는 산불통계자료를 이용하여 한국 산불의 계절적 특성을 분석하고, 나아가 현행 산불조심기간에 대한 고찰 및 재조정 방안을 살펴보았다.

재료 및 방법(Methodology)

재료

1991년부터 2005년까지 구축된(산림청, 2005) 일별 산불발생건수, 연소면적, 건당연소면적에 관한 산불통계자료를 이용하였다. 세 변수 간의 단위크기 차이와 각 변수의 분산 안정화를 위하여 로그변환을 실시하였다.

방법

일별 산불 발생패턴 파악과 위험도 분석을 위하여, 다양한 다변량 통계분석을 수행하였다. 우선, 군집분석(K-means 방법)을 통하여 한국 산불을 유형별로 분류하였으며, 분류된 군집들 사이의 유의미한 차이를 고찰하기 위하여 ANOVA 및 post-hoc (Duncan's multi-range test) 분석도 실시하였다. 또한 주성분분석을 통해 산불발생패턴 분석을 위한 주요한 인자를 도출하였으며, 마지막으로 순위로짓모형을 이용하여 산불발생 위험도 확률모형을 구축하고, 일별·계절별 산불발생 위험도를 분석하였다.

결과 및 고찰(Results and Discussion)

산불 위험도 별 그룹화

k-means 군집분석 결과 5개의 그룹으로 분류되었다. Table 1에 나타난바와 같이 '군집1'에서 '군집5'으로 갈수록 발생건수, 연소면적, 건당연소면적의 값이 증가하는 경향을 보였다. 계절별 군집분포에서는 봄은 '군집4'와 '군집5'가, 여름에는 '군집1'과 '군집2'이 분포하고 있으며, 겨울에는 '군집3'이 주로 분포하고 있다(Figure 1).

산불위험도 지수

주성분분석 결과 제1주성분과 제2주성분이 총 99.3%의 높은 설명력을 보였다(Table 2). 높은 설명력(85.5%)을 보이는 제 1주성분의 경우, 세 변수의 eigen vector 값이 모두 비슷한 값을 가지고 있어, '산불위험도에 대한 종합적인 지표'로 해석될 수 있다. 또한 군집별 제1주성분 점수를 분석한 결과, '군집3'부터 제1주성분점수가 (+)의 값을 보이며 실제적인 산불위험도를 나타내었다(Figure 1).

산불위험도 확률과 경계값

순위로짓모형을 이용하여 세 변수에 대한 5등급의 산불위험도 확률식 및 각 변수에 대한 위험경계점을 도출하였다. 특히 유의미한 산불위험 시작점인 3등급이 될 확률 1.0을 가능케하는 세변수의 경계값으로 발생건수는 1.0, 연소면적은 1.36 그리고 건당연소면적은 0.23을 가졌다.

산불조심기간 진단

Figure 2와 같이 세 변수에 대해 각각의 위험경계값을 적용하여, 그 이상값을 가지는 날에 대해 공통으로 추출된 기간을 살펴본 결과 10월 21일부터 5월 17일까지가 산불위험기간으로 선택되었다. 특히 이 기간은 현 산불조심기간에서 제외된 겨울철에도 여전히 산불위험도가 높음을 지적하고 있다.

Table 1. Results of the cluster analysis and the *post-hoc* test

Cluster	Number of days in each cluster	Mean for number of fire occurrences	Mean for total burned area	Mean for burned area per fire
1	113	0.27 [d]	0.14 [e]	0.09 [d]
2	144	0.92 [c]	0.88 [d]	0.31 [c]
3	72	1.54 [b]	1.71 [c]	0.41 [c]
4	33	1.83 [a]	2.45 [b]	0.73 [b]
5	3	1.86 [a]	3.84 [a]	1.99 [a]

[a-e] means that the same letter is not significantly different at the 0.05 level according to Duncan's multi-range test.

Table 2. Eigen vector for each variable and variance proportion for PC1 and PC2

Principal component	Eigen vector of number of fire occurrences	Eigen vector of total area burned	Eigen vector of average area burned per fire	Cumulative proportion of variance (%)
PC1	0.57	0.62	0.54	85.5
PC2	-0.65	-0.07	0.76	99.3

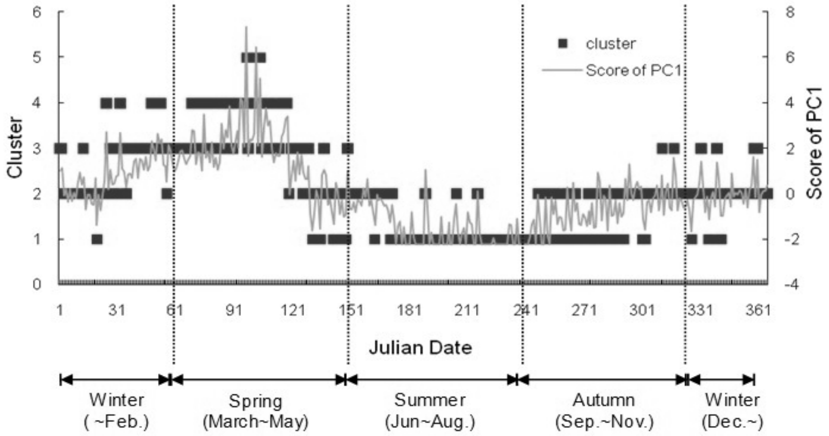

Figure 1. Types of clusters and scores of the 1st principal component for 365 days

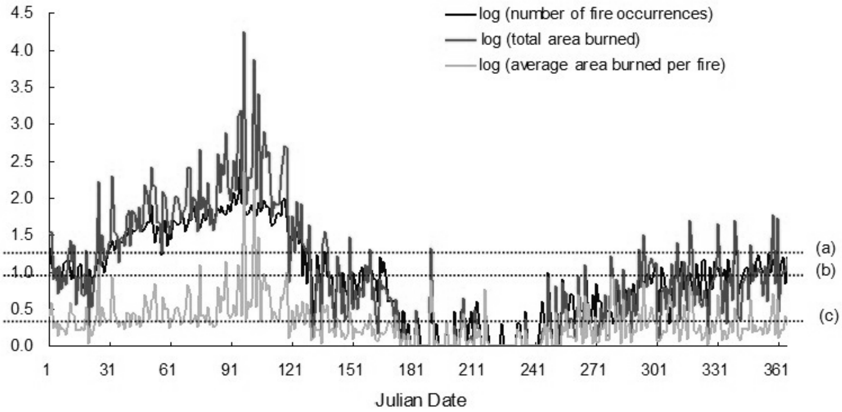

Figure 2. High-risk days above the borderline values for variables. (a) 1.36 is the borderline value for total area burned, (b) 1.0 is the borderline value for the number of fire occurrences, and (c) 0.23 is the borderline value for average area burned per fire.

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A study on factor of forest fire using Canadian Fire Weather Index in Korea
캐나다 산불 기상 지수를 이용한 산불 영향인자에 관한 연구

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Abstracts

Fine fuel moisture code (FFMC), a main component of Forestfire weather index(FWI) in the Canadian forest fire danger rating system(CFFDRS), indicated a probability of ignition through expecting a dryness of fine fuels. According to this code, A Rising of temperature and wind velocity, a decreasing of precipitation and decline of humidity in the atmosphere show a rising a danger rate of forest fire. In this study, we analyzed a weather condition during 5 years in Kangwon province, calculated a FFMC and examined an application of FFMC. For developing of forest Fire occurrence probability prediction model we used a logistic regression function with forest fire occurrence data and classified mean FFMC during 10 days. Accuracy of a developed model was 63%. To improve this model, we need to deal with more meteorological data during overall seasons and to associate a meteorological condition with a forest fire occurrence with more research results.

요 약

캐나다의 산불 위험등급 시스템의 구성요소인 산불 연료지수는 지상 미세 연료 건조 여부 예측을 통해 산불의 발화 위험성을 나타내는 지수로써, 본 연구에서는 5 년간 강원도 지역의 기상 자료를 분석하고, 이를 이용하여 산불 연료지수를 도출하여, 그 분포와 적용성을 검토하였다. 봄철 산불조심 강조기간을 대상으로 순기 평균 산불 연료지수에 대한 로지스틱 분석을 실시한 결과 약 63%의 판별율을

나타내었다. 하지만, 상관관계가 약하게 있으며, 모형의 정확도 향상을 위한 기상 자료의 보다 정확한 분류가 필요할 것으로 판단된다.

Introduction

우리나라는 산림이 전국토의 60%를 차지하고 있어 산불의 영향을 받기 쉬우며, 1990 년대 들어 산불 발생 건수가 지속적으로 증가하고 있으며, 그 규모 또한 대형화 되고 있다. 또한, 지구 온난화로 인한 산불 환경의 변화는 산불 발생 빈도와 대형화 가능성의 변화를 가져올 것이 필연적인 상황이지만, 자연 발화가 대부분인 미국과 캐나다 등과는 달리 우리나라의 산불 발생은 인위적인 원인에 의해 대부분이 일어나며, 이것은 지상의 연료 건조 정도와 바람의 영향에 의해 불로 발전하게된다. 따라서, 본 연구에서는 산불 발생을 예측하고, 이에 대한 대비책의 수립의 기본 자료를 제공하기 위해, 현재 캐나다 산불 예보시스템(CFFDRS)의 구성 요소 중 하나인 FWI(Fire Weather Index)의 주요 인자인 미세 연료의 수분함량(FFMC)을 활용하여, 지상 연료의 수분 변화에 따른 산불의 발생 여부를 구명하고자 한다.

Methodology

산불 기상지수의 적용을 위한 필수 입력 자료로써 최고 온도, 평균 습도, 최대 습도, 최대 풍속, 강수량의 자료를 필요로 한다. 금번 연구에서는 기상청의 협조를 받아 강원도의 속초, 철원, 대관령, 춘천, 강릉 관측소의 기상자료를 사용하였으며, 관측 시기는 2002 년부터 2006 년까지의 5 년간의 자료를 사용하였다. 산불 발생자료는 동년의 산림청 산불 통계 자료를 이용하였으며, 연구기간 동안 발생한 산불 발생 사례 중 강원도 지역만을 선택하였다. 산불발생과 기상 인자간의 분석을 위하여 산불 발생을 1, 미발생을 0 으로 각각 입력하여 FWI에서 산출된 FFMC의 산출 결과와 비교 분석하였다. 조사된 자료는 SPSS 12.0.1 프로그램을 사용하여 로지스틱 분석을 이용한 통계 분석을 실시하였다. 모델의 개발을 위해, 산불의 위험성이 낮은 시기를 결측 값으로 계산하였으며, 10 일 단위의 기상자료를 바탕으로 10 일 단위의 평균 FFMC를 사용하여 재분석을 실시하였다. 빈도 분석의 결과에 의해 순기별 FFMC를 백분위 수에 의해 4 개 지수로 분류하여 지수화하였다.

Results and Discussion

분석 결과 얻어진 산불 발생 확률 모형의 결과를 통해 식(1)을 얻을 수 있었다.

$$P = e^{-0.529 + 0.421INDEX} / 1 + e^{-0.529 - 0.421INDEX} \tag{1}$$

여기에서 P는 산불 발생 확률 이며 INDEX는 지수화된 FFMC이다. 지수화된 FFMC는 산불 발생과 5% 수준에서 통계적으로 유의성을 갖는 것으로 나타났다. 즉, 지수화된 FFMC가 높을 수록 산불 발생 위험이 증가하는 것으로 나타났다. 추정 모형의 -2LL은 73.294였고, 분류 정확도는 지난 5년간의 데이터를 이용하여 검증한 결과 이 모델이 봄철 산불 조심 강조 기간에 미 발화된 27번의 순기 중 16번의 순기를 미발화 한 것으로 예상하였고, 산불이 발생한 29번의 순기 중 19번을 발화한 것으로 예측하였으며, 전체 정확도는 63.6% 였다.

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Development of Fire Resistant Forest Establishment Techniques by the Differences of Site Type and Stand Density Controls
임분밀도 조절과 입지형태에 따른 내화림 조성기법 개발

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Abstract

Basic data was provided by dividing forest type through the analysis of existing data and field survey data. Two demonstrations were constructed to enhance fire resistance of non-damaged and damaged pine forest (*Pinus densiflora* sieb. et zucc). First, in the non-damaged healthy pine forest located in Jungmaeup-ri, Nogok-myeon, Samcheok-si, demonstration area of 3.1ha was constructed to establish fire resistance enhancing practice method for non-damaged healthy pine forest. Two types of striped thinning were applied to the demonstration area; one is vertical striped thinning and the other is horizontal striped thinning, and four thinning intensities were applied (medium intensity low thinning, high intensity low thinning, remaining superior trees (300trees/ha and 100tree/ha) to them. Second demonstration area was constructed in the fire-damaged pine forest located in Imwon-ri, Weondeok-eup, and Samcheok-si, and was consisted of fish-bone type (10 ha) and complex type (13ha). After the construction of two demonstration area, to understand the changes in the stand, understory vegetation change was investigated. And the number and growth of sprouts and seedlings were surveyed.

요 약

산불피해지에 대한 기존 조사 자료를 재분석하고 현지조사를 통하여 임분유형 및 입지형태를 고려하여 내화성 소나무림 조성을 위한 기초자료를 제공하고자 하였다. 소나무림의 임분유형별 내화림 시업방법 정립을 위하여 적도하층간벌, 강도하층간벌, 우량목 존치 등의 방법을 적용하여 벌채양식에 따라 종식대상벌채, 횡식대상벌채에 의한 실연지 3.1ha를 조성하고 작업과정을 조사 . 분석하였으며, 상층목의 생장과 하층치수 및 맹아발생 동태를 분석하였다. 또한 내화력을 증진시킬수 있는 복원방법을 적용하기 위하여 임분유형 및 입지형태에 따라 산불피해지에 대하여 구릉지에 어골형실연지 10ha, 산악지역에 복합형실연지 13ha를 조성하였으며 이들 실연지의 잔존목생장, 고사율, 치수발생, 맹아발생 등을 분석하였다.

서 론(Introduction)

우리나라 인공조림지의 대부분은 침엽수 일제 단순림으로 구성되어 있고 생육단계별 적절한 시업이 이루어지고 있지 않은 실정으로 임목밀도가 높은 임지가 많아 동해안 산불과 같은 대형산불의 위험성이 항상 내재되어 있다고 볼 수 있다. 내화성 증진을 위하여 임분유형별로 내화력이 큰 임분구조를 구명하고, 내화림 조성을 위한 시업방법정립과 시업기술을 개발할 필요가 요구되었다. 따라서 본 연구에서는 시업기술을 적용하여 산불피해지 및 건전소나무림에 대하여 내화력이 강한 산림으로 유도하고자 함이 그 목적이다.

재료 및 방법(Methodology)

내화성 증진이 뛰어난 실연지를 조성하기 위하여 두 곳의 실연사업지를 선정하였는데, 첫번째는 산불피해지를 내화력이 강한 임분구조로 입지형태, 임분유형을 고려하여 복원하기 위한 방법이고, 두번째는 기존의 건전한 소나무임분에 간벌 등의 시업 방법을 적용하여 내화력이 강한 임분으로 조성하는 방법이다.

Table 1. Classification and application of the site type in mountain terrain damaged by forest fire

Site classification items	Low hilly area	High mountain area	References
Elevation	Below 200m	Above 400m	
Slope length	Under 300m	Above 300m	
Slope degree	Above 30°	Above 31°	
Application of site	- Foot of hill : below 3 ridges (Strip type) - Hillside : from 3 to 7 ridges (Fishbone type) - Hilltop : above 8 ridges above (Complex type)		

결과 및 고찰(Results and Discussion)

건전소나무림 내화력증진 실연시험은 대상개벌형 방법을 적용하였 으며 종식대상벌채와 황식대상벌채로 나누어 적용하였다. 소나무 임분 밀도를 적정간벌, 강도간벌, 300본/ha 존치, 100본/ha으로 조절하였다. 시업후 맹아 발생은 굴참나무, 졸참나무, 신갈나무, 상수리나무 등으로 나타났다. 산불 피해지에 대한 내화력 증진 실연지는 소나무 건전목 존치구, 활엽수건전목 존치구, 피해목존치구, 피해목벌채구로 구분하였 으며, 지형에 따라 어골형, 복합형(횡식대상벌채지, 종식대상벌채지) 실연지를 조성하였다. 참나무류 맹아는 굴참나무, 졸참나무, 신갈나무, 갈참나무의 4종으로, 전체적으로 그루터기당 평균 2~15개의 맹아 발생을 보였으며, 치수발생량은 소나무 1,800 12,500본/ha, 참나무류는 400~5,000본/ha의 범위로 나타났다. 처리후 식생은 상층간벌을 통하여 밀도조절을 실시한 임분은 시간이 지남에 따라 원식생과 유사한 종구성의 안정도를 보여주었다. 하지만 상층의 피해목을 존치시킨 임분에서는 종다양성 측면에서 초기 피해상황과 비교하여 그 변화가 미비하게 나타났다. 즉, 이는 상층 피해목을 방치한 피해지의 임상은 피해목을 제거한 임상보다 식생회복이 느리게 진행됨을 알 수 있었다.

Table 2. Important factors of study site.

	Year	Non-damaged sites by forest fire		Damaged sites by forest fire			
		Before forest fire	Thinned	Upperstory and understory removed	Upperstory removed and understory remained	Upperstory remained and understory removed	Upperstory and understory remained
Species richness	2004		16±2	17±7	16±3	23±8	21±5
	2005	21±8	18±3	18±5	19±4	23±11	
	2006		21±2	27±5	23±3	17±2	17±7
Species diversity	2004		1.64±0.02	1.87±0.27	2.08±0.16	1.59±0.50	1.48±0.33
	2005	1.57±0.31	1.61±0.19	1.97±0.16	1.59±0.22	1.61±0.36	
	2006		1.83±0.22	1.95±0.18	2.07±0.11	1.32±0.09	1.40±0.70
Eveness	2004		0.57±0.02	0.66±0.06	0.17±0.04	0.52±0.08	0.48±0.09
	2005	0.54±0.10	0.58±0.05	0.73±0.14	0.58±0.09	0.58±0.05	
	2006		0.60±0.08	0.59±0.09	0.65±0.01	0.46±0.05	0.49±0.18
Relative important value	2004		0.43±0.02	0.34±0.06	0.29±0.04	0.49±0.08	0.52±0.07
	2005	0.46±0.10	0.42±0.05	0.27±0.14	0.42±0.09	0.42±0.05	
	2006		0.40±0.08	0.41±0.09	0.35±0.01	0.54±0.05	0.51±0.18

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ANAYSIS OF RELATIONSHIP BETWEEN ONSET OF VEGETATION DATE ANF FOREST FIRE DATE

개엽일과 산불발생시기간의 상관성 분석

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Abstract

Forest fire usually occurs in dry season which has rare vegetation. Therefore, understanding spatial and annual patterns of spring vegetation development is helpful for diagnosis of the current status of forest biomes. In this study, we attempted analysing of relationship between onset of greenness date and forest fire date using MODIS LAI derived onsetmap and together with observed fire date data. First, we enhanced the canopy onset (CPO) detection method suggested by Kang et al. (2003) and devised a method using flowering onset data for determining both thresholds of onset detection and model parameters. The reliability of MODIS CPO was then successfully evaluated by using limited number of the field CPO data. As a result, the MODIS CPO dates were well linearly correlated with the field CPO dates (r>0.9). Forest fire date data were collected by regional groups (8 provinces and 7 cities) for only limited term from 1st January to 30th June. Using the percentage of the fire date and MODIS onsetmap, we were calculated threshold date for reduction of fire frequency. The patterns between onset date and threshold date for reduction of fire frequency showed similar, however, the scale of area was too big to understand status of forest biomes. In future study, it will be necessary analysing in more smaller scale.

요 약

임관 개엽일과 산불 재해일 간의 연관성을 파악하기 위해 MODIS 개엽모형으로부터 산출된 남한의 개엽일 지도와 산불 발생일 정보를

이용하였다. MODIS 기반의 개엽일 지도를 작성하기 위해 Kim et al. (2008)에 의해 제안된 개엽 모형을 이용하였고, 모형의 입력자료로써 8일 단위로 제공하는 MODIS15 Leaf Area Index (LAI) Product를 이용하였다. 개엽일과 산불 재해일 간의 연관성을 알아보기 위해 지역별(8개 도, 7개 광역시) 평균 개엽일을 산출하였다. 지역별 산불 재해일은 1월 1일부터 6월 30일까지의 기간 동안의 산불 재해일을 조사하여 퍼센타일(percentile, 백분지수)을 이용하여 산불 발생 빈도 저감 임계일을 산출하였다. 산불 발생 빈도 저감 임계일은 전체 산불 발생일 중 70 퍼센타일인 것을 산출하였다. 전체적으로 개엽일과 산불 발생 저감 임계일간의 일치도가 비슷하게 나타났지만, 대체적으로 넓은 공간 규모인 도 또는 광역시를 경계로 두 자료의 관계를 판단하는 것에는 약간의 무리가 따를 수 있다. 때문에 향후 보다 세밀한 공간 규모인 시 또는 군 규모로 공간 스케일을 낮추어 개엽일과 산불 발생 빈도 저감 임계일간의 관계를 분석하는 것도 필요할 것이라고 판단된다.

INTRODUCTION

Global climate is recognized to be undergoing significant changes in recent year. Together with climate change, forest fire is one of issues for forest management. Forest fire usually occurs in dry season which has rare vegetation. Therefore, understanding spatial and annual patterns of spring vegetation development is helpful for diagnosis of the current status of forest biomes. In this study, we attempted analysing of relationship between onset of greenness date and forest fire date using MODIS derived onsetmap and together with observed fire date data.

ONSET OF VEGETATION

The phenological phases are one of most sensitive variables and easily-observed indicator of the biotic responses to climate change change (Bradley et al., 1999; Beaubien and Freeland, 2000; Sparks et al., 2000; Schmerbach, 2000; Chmielewski and Rötzer, 2002). In recent years, remote sensing data has been applied for

phenological research, because of its potential for periodic collection of vegetation indices from a regional to a global scale (e.g., Myneni et al. 1997). In this study, we enhanced the CPO detection method suggested by Kang et al. (2003) and devised a method using flowering onset data for determining both thresholds of onset detection and model parameters. The reliability of MODIS CPO was then successfully evaluated by using limited number of the field CPO data. The method was further applied to produce CPO maps for Korea.

Monitoring of onset of vegetation using MODIS

Spring onset in canopy level detect in South Korea using time series of 8-day composite MODIS Leaf area index(LAI), FparLai_QC data from 2001 to 2006 together with 2004 MODIS IGBP landcover at 1km spatial resolution and calibrated with ground measured cherry blossom flowering data from Korea meteorlogical administration. Although it is difficult to conclude significant relationship between the flowering date and the CPO dates of woody plant species, there are abundant indirect evidences that those dates are closed related. For example, Kim and Ryu (1985) found that flowering and leaf onset dates of *Rhododendron mucronulatum* and *R. schlippenbachii* at the same elevation were linearly related. Min and Choi (1993) suggested that both budding and flowering times of several woody species were related to local temperatures. These indirect evidence suggests that woody plant flowering data (e.g., cherry blossom flowering dates) can be utilized as a surrogate for CPO dates of woody plant species.

Our methodology required 5-times smoothing process for annual time series of LAI and then we assume that onset is expected to occur when the normalized LAI increases over specific onset threshold from 0.1 to 0.4 in 0.01 intervals. The correlation between MODIS CPO and flowering date was the highest at the threshold value of 0.15 (r = 0.70). The correlation gradually decreased as the threshold was far away from 0.15. Validation of the MODIS predicted CPO is accomplished by comparison with the field CPO data recorded at Gwangneung and Gyebangsan sites. As a result, the MODIS CPO dates were well linearly correlated (ME = -1.9 , RMSE = 4.6 day).

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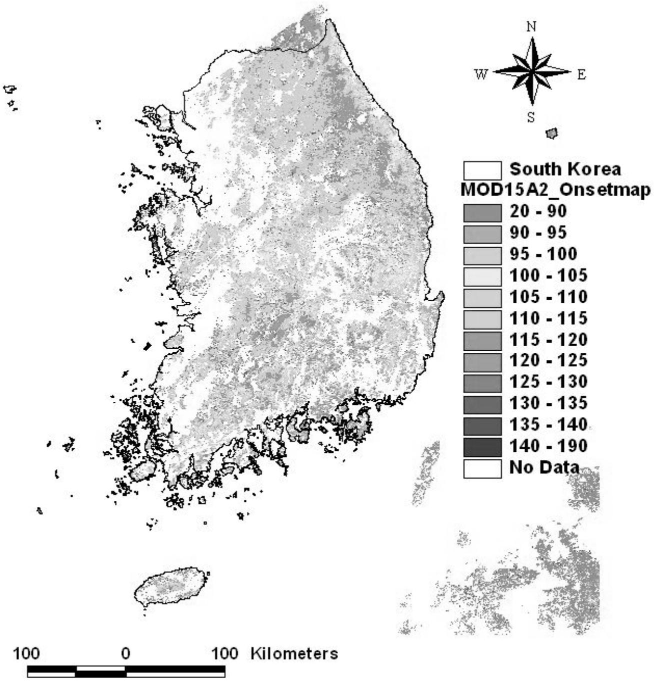

Figure 1. Onsetmap of South Korea from MODIS15 LAI product

The MODIS-derived CPO maps showed reasonable spatial patterns along the gradient of latitude and elevation. This show that the method was efficient in generating maps for onset dates in Korea (Fig. 1)

Phenological onset model

Not only monitoring of onset of greenness but also modeling of onset of greenness are important for understanding responses of vegetation to climate change. Generally, two alternative models were used for predicting phenological transition dates. One is “Chill days” model which is based on two sequential processes of bud dormancy and budburst. It considers both chilling accumulates to break rest and heating accumulates to overcome quiescence (Sarvas, 1974; Cannell and Smith, 1983; Hänninen, 1990; Linkosalo, 2000). The other is “Thermal” model which is only considering thermal accumulation. Using MODIS derived onset, we were developed phenology models to predict spring canopy onset of vegetation.

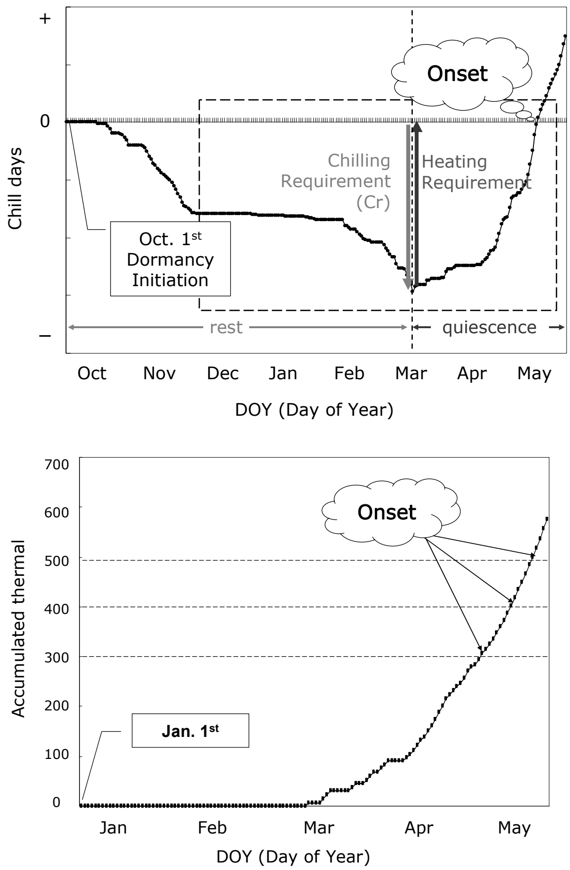

Figure 2. Concept of Chill days model (left) and thermal model (right).

Estimated future onset of vegetation by climate change

Through simulating with two developed models, we were estimated various phenology changes in future effects of global warming. The simulated CPO dates resulted in similar spatial patterns with temperatures. Warm area (i.e. southern Peninsula) showed earlier CPO date than cold area. The latest CPO was observed in high mountain region in the North. With the AIB climate warming scenario, the simulated CPO dates were generally advanced in periods of 2021-2050 and 2071-2100 against the current climate (1972-2000) for the alternative CPO models. The spatial patterns and magnitudes of the CPO changes were, however, different.

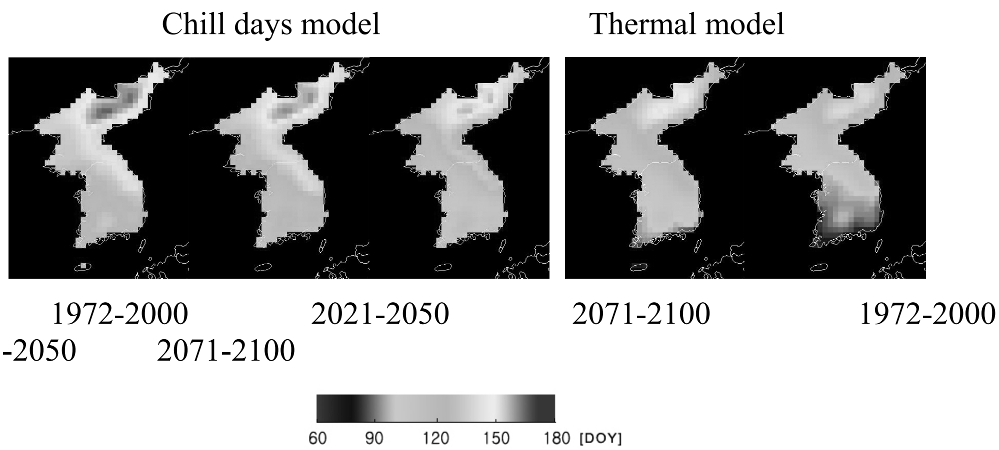

Figure 3. Simulated CPO dates from 1972 to 2100 using chill days model and thermal model under the SRES AIB scenario.

RELATIONSHIP BETWEEN ONSET DATE AND FOREST FIRE DATE

Forest fire date data were collected by regional groups (8 provinces and 7 cities) for only limited term from 1st January to 30th June. Using the percentage of the fire date and MODIS onsetmap, we were calculated threshold date for reduction of fire frequency.

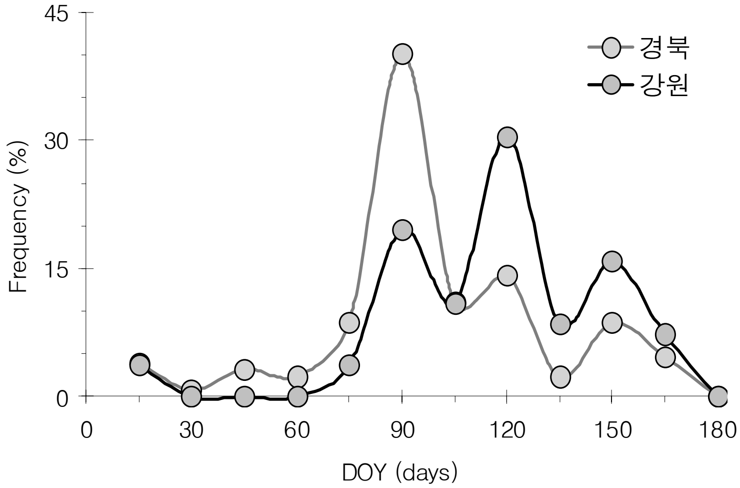

Figure 4. Frequency of forest fire by regional group

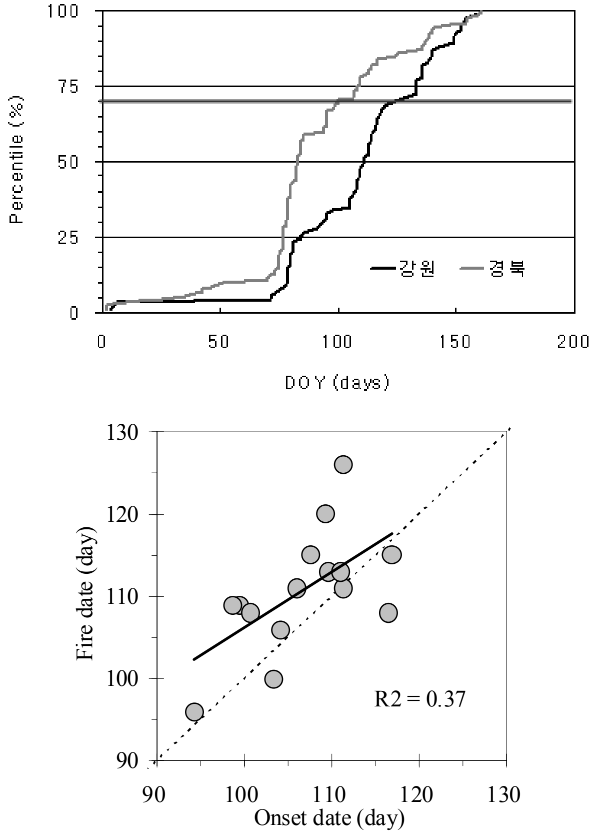

Figure 5. Samples for calculating threshold date for reduction of fire frequency (left) and scatter plot of onset date and threshold date for reduction of fire frequency (right) on year 2001.

The onset was the earliest in Busan (DOY 74) and the latest in Jeollanam-do (DOY 117). Threshold date for reduction of fire frequency was the earliest in Busan (DOY 96) and the latest in Gangwon-do (DOY 126) applied 70% threshold. The patterns between onset date and threshold date for reduction of fire frequency showed similar, however, the scale of area was too big to understand status of forest biomes. In future study, it will be necessary analysing in more smaller scale.

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Estimation of above ground tree biomass using airborne laser scanning data
항공레이저스캐너 자료를 이용한 지상부 임목바이오매스 추정

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Abstracts

The objective of this study is to estimate the biomass of individual trees by tree height, diameter at breast height (DBH), density and volume extracted from airborne LiDAR data from which the 3D information can be analyzed. As a result, tree height and stand density can be measured with reliable accuracy. However LiDAR-derived DBHs were underestimated due to the overlay between trees and the characteristic of airborne LiDAR. LiDAR-derived Biomass and volume were also underestimated by the influence of underestimated DBHs.

요 약

이 논문에서는 산림의 3차원적 특성(위치 및 높이)을 분석할 수 있는 항공 LiDAR 영상을 이용하여 수고, 밀도, 재적 등을 계산하고 이를 이용하여 임목의 바이오매스를 측정 할 수 있는 기법을 제시하였다. 그 결과 수고 및 밀도의 경우 비교적 정확한 측정이 가능하였으며, 흉고직경은 수관의 형태와 항공 라이다가 가지고 있는 특성으로 인하여 과소추정되었다. 재적 및 Biomass는 과소추정된 흉고직경에 의해 영향을 받아 역시 과소추정되는 것으로 나타났다.

서론(Introduction)

LiDAR(Light Detection And Ranging)는 2차원적 산림정보뿐만 아니라 산림의 3차원적 특성인 수직적 분포를 분석할 수 있는 장점으로 인하여

다양한 분야에서 그 활용가능성이 주목받고 있으며, LiDAR 영상의 관측 및 활용기술의 개발에 많은 연구가 이루어지고 있다. 외국의 경우 임목의 수고, 수관폭, 흉고직경, 지하고 등과 개체목의 재적, 단위면적당 재적 및 바이오매스 추정 등에 관한 연구가 이루어지고 있으나, 우리나라의 경우 LiDAR 영상을 촬영할 수 있는 장비가 도입된 것이 최근의 일로 아직 적극적으로 활용하지 못하고 있는 실정이다. 또한 지형이 복잡하고 다양한 수종구성을 보이고 있는 우리나라의 상황에 적합한 분석기술을 개발할 필요성이 있다.

산림자원 조사 및 임분구조해석, 기후변화협약, 산림재해분야 등에 활용가능성이 증대되고 있는 LiDAR 자료를 이용한 산림측정 기술은 우리나라의 산림을 보다 신속·정확하게 해석하기 위한 효율적인 측정 기술이 될 수 있으며, 효율적이고 과학적인 산림자원 조사 및 정보관리 기술로 활용될 수 있다. 따라서 본 논문에서는 산림의 3차원적 특성(위치 및 높이)을 분석할 수 있는 항공 LiDAR 영상을 이용하여 수고, 밀도, 재적, 바이오매스 등 산림의 정량적 정보를 해석 할 수 있는 기술을 개발한다.

재료 및 방법(Methodology)

본 연구는 국립산림과학원 광릉시험림 내에있는 전나무, 소나무, 낙엽송 및 잣나무 임분을 대상으로 수행하였다. 분석에 사용된 항공 LiDAR 및 디지털 칼라 항공사진은 2007년 4월 3일 촬영하였다. 비행고도 1400 m에서 항공 LiDAR 레이저 반복율 35㎐, Scan angle ± 20도로 촬영하였다. 분석된 자료의 결과를 검증하기 위하여 표준지를 설치하고, 각 표준지 내에 분포하고 있는 모든 임목에 대하여 수종, 흉고직경, 수고, 지하고, 수관폭(남북, 동서 방향) 측정하였다.

항공 LiDAR자료는 First Returns와 Last Returns의 분류하고 First Returns를 이용하여 DSM(Digital Surface Model)을 구성하고 Ground Return을 분류하여 DEM(Digital Elevation Model)을 제작하였다. 제작된 DSM과 DEM의 차이를 구하여 DCM(Digital Canopy Model)을 구하여 분할에 이용하였다. 분할의 정도를 높이기 위하여 가우시안 필터 및 H-Maxima변환을 통하여 원DCM을 정제한 후에 Watershed방법을 이용하여 분할을 실시하였다.

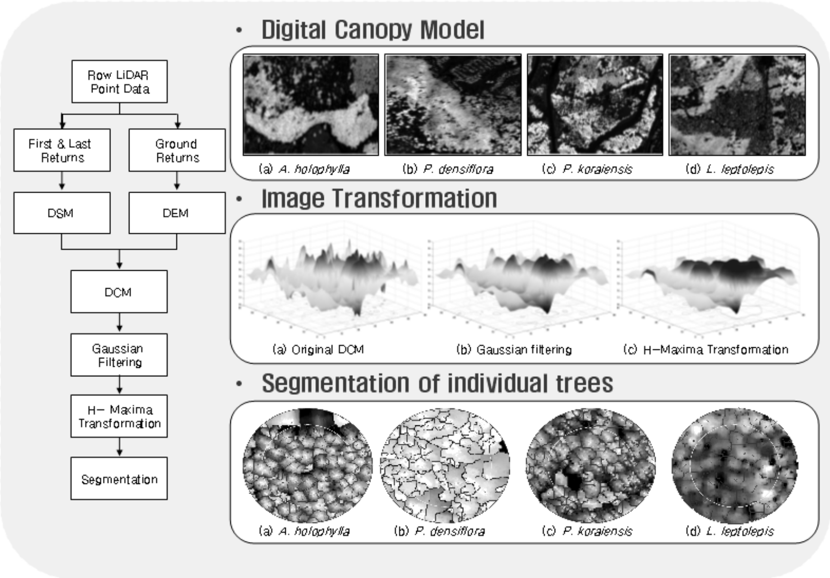

Figure 3. Segmentation process and results

결과 및 고찰(Results and Discussion)

분할된 라이다 영상의 폴리곤은 임분내에 포함된 개별목의 수관을 나타낸다. 따라서 각각의 폴리곤에 포함된 DCM의 최고점을 찾으면 해당 임목의 수고가 된다. 또한 DCM의 최고점이 표준지 경계안에 포함된 모든 폴리곤의 수는 해당임분의 임목본수로 간주하게 된다. Table 1.에는 항공 LiDAR를 이용한 수고 및 임분밀도의 측정결과를 보여준다. 한편 현지측정 DBH와 수관면적 사이의 관계를 이용하여 회귀식을 유도하였다. 또한 분할된 각 폴리곤은 수관의 면적에 해당하므로 이를 이용하여 흉고직경을 추정한 결과 과소추정되는 것으로 나타났다. 이는 항공라이다에서 분할되는 수관은 수관의 겹침부분을 반영하지 못하기때문으로 사료된다.

Table 1. Measurement results of stand density, tree height and DBH using airborne LiDAR

	Stand Density (Trees/0.1 ha)		Mean Height (m)		Mean DBH (cm)	
	Field	LiDAR	Field	LiDAR	Field	LiDAR
Abies holophylla	54	56	29.8	28.1	37.1	27.5
Pinus densiflora	45	47	18.1	19.2	32	24.8
Pinus koraiensis	45	45	15.7	15.3	21.2	17.6
Larix leptolepis	20	17	24.1	24.7	26.3	24.6

임분의 재적을 추정하기 위하여 흉고직경과 수고를 변수로 하는 재적식을 사용하는 것은 과소추정된 흉고직경으로 인하여 과소치를 나타낸다. 따라서 표준지 조사자료를 바탕으로 수고만을 변수로 하는 재적식을 유도하여 재적추정에 이용하였다. 또한 목재 기본밀도와 바이오매스 확장계수를 이용하여 임분의 바이오 매스를 추정하였으며, 그 결과는 Table 2.에 주어져 있다.

표준지 자료와 비교 할 때 소나무를 제외한 나머지 수종의 경우 대체로 과소추정되는 경향을 보이고 있다. 이러한 결과는 수관의 형태에 영향을 받는 것으로 사료되며, 보다 많은 경우를 이용한 검증이 필요하다.

Table 2. Estimation Results of stand volume and biomass using airborne LiDAR

	Volume(㎥/ha)		Biomass(kg/ha)
	Field	LiDAR	
Abies holophylla	740.8	608.3	368834.2
Pinus densiflora	275.1	288.5	174917.6
Pinus koraiensis	223.0	105.4	63904
Larix leptolepis	123.6	100.5	60933.2

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Fuel Type Classification and Biomass Evaluation considering Vegetation Indices and Soil Condition

식생지수와 토양조건을 고려한 산불연료형 구분 및 바이오매스 평가

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Abstracts

The purpose of this study was to investigate the spatial patterns of fire hazard potential in forest by using remotely sensed data combined with field observations. The forests in the study areas were classified into forest cover types, and above ground biomass(AGB) and fuel loading of surface layer(SB) were estimated. Seventy field plots were established for building a biomass estimating model and data were measured in the fire season for model validation. The field observations indicated that AGB and SB were strongly related with the soil condition. Thus we classified coniferous forests(C) into three fuel types by soil condition(moderately moist, slightly dry, dry soil) considering the relationships of AGB and SB of *Pinus densiflora* Sieb. et Zucc with soil condition. Hardwood(H) and mixed(M) forests were recognized as different land cover types. The cover type map for the study area was generated with the three land cover types(C, H, M) by a hybrid classification method using Landsat TM data. Then cover type map was overlaid with the thematic map defined degree of soil humidity to generate the fuel type map including five different fuel types. To produce a biomass map, AGB values computed from field observations including the tree height and DBH were coupled with band reflectance derived from Landsat TM data through multiple regression analysis. The relationship between predicted AGB(ton/ha) from remote sensing-based models and the AGB computed from

field observation is $AGB_{Estimated}$ = 0.717×Observed+9.005, and R^2 value of the relationship was *0.7143*. Therefore the fire fuel type classification and AGB estimation using degree of soil humidity and Landsat TM data can be used as baseline information for future landscape level studies such as estimating fire hazard potential.The land policy in Korea has been two-sided. Korean government has enlarged public lands like natural parks or water-front lands on the one hand and minimized such public lands through dissolution of protected areas like green belts on the other hand.

요 약

본 연구는 위성영상자료를 활용하여 임상을 분류하고, 임상별 상.하층 바이오매스량과 연료하중을 추정하여 임내의 산불잠재위험성을 사전에 파악하는데 목적이 있다. 70개소에 대한 현장조사 결과, 상층과 하층의 바이오매스량은 입지별 차이에 따라 상관성이 있는 것으로 나타났다. 따라서 토양건습도(적윤, 약건, 건조)에 따라 소나무림을 상층과 하층의 바이오매스 상관관계를 고려하여 3개 유형으로 구분하였으며, 활엽수림과 혼효림은 각각 1개형으로 구분하였다. 침·활·혼의 분류를 위해 Landsat 영상자료를 이용하여 영상분류 절차에 따라 감독분류와 무감독분류를 혼성하여 산림지역의 Cover type map을 제작하였다. 제작된 Cover type map과 토양건습도 주제도를 중첩하여 5개 유형의 산불연료형 구분도를 제작하였다. 산불연료형 구분 및 연료지도 구축 간소화를 위해 위성영상자료를 활용하는 방안은 전국단위 DB구축을 위한 효율성 측면에서 매우 유용하다고 할 수 있다. 본 연구에서는 Landsat 영상자료의 밴드별 반사특성(reflectance)을 이용하여 현장조사에서 얻어진 상층부 바이오매스(AGB)와의 상관분석을 통해 임상별 AGB 추정식을 도출하였다. 이상에서 구축된 위성영상을 이용한 산림지역 cover type, 토양건습도, 산불연료형, Landsat 밴드별 AGB 추정식을 활용하여 산림지역의 바이오매스량을 공간자료화 하였다. Landsat 영상으로부터 추정된 지상부 바이오매스(AGB)와 현장조사에 의한 AGB간 정확도 비교 결과, Estimated AGB = 0.717×Observed+9.005 (R^2=*0.7143*)로 나타났다. 따라서 산불연료형 구분 및 바이오매스 추정을 위해 Landsat 영상과 토양건습도를 활용하는 방안은 향후 산림의 산불잠재위험성 평가를 위한 기본자료로 활용될 수 있을 것으로 판단된다.

Introduction

Estimation of AGB is necessary for studying productivity, carbon cycles, nutrient allocation, and fuel accumulation in terrestrial ecosystems. Remote sensing techniques allow scientists to examine properties and processes of ecosystems and their interannual variability at multiple scales because satellite observations can be obtained over large areas of interest with high revisitation frequencies. Many studies have demonstrated that indices such as spectral vegetation index(SVI), simple ratio(SR), normalized difference vegetation index (NDVI), and corrected normalized difference vegetation index(NDVIc) obtained from satellite data are useful predictors of leaf area index(LAI), biomass, and productivity in grasslands and forests. Stand level biomass is frequently calculated from linear and nonlinear regression models established by species with field measurements. Although estimates of AGB vary with species composition, tree height, basal area, and stand structure, bole diameter at breast height(dbh) is the most commonly used and widely available variable for calculating AGB. Numerous regression models have been developed to estimate AGB in many regions; while these models are accurate at tree, plot, and stand levels, they are limited when considering spatial pattern analysis of AGB across the landscape. In order to scale AGB estimates to the landscape level, the estimates have to be linked with various vegetation indices derived by remote sensing data. The purpose of this study was to classify fuel types in the Central Interior region of South Korea and investigate the spatial patterns of fire hazard potential in forest by using remotely sensed data combined with field observations.

Methodology

On-site survey area(lat 36˚ 21′N, 128˚ 19′ 21″E) for fuel type classification Uiseong-gun, Gyeongbuk-Do, Korea. AGB and surface biomass(SB) was calculated from tree height, dbh and dry weight of 10×10m quadrates at seventy survey plots. Calculation of AGB was used $W=aD^2H$ equation. Correlations between AGB and SB were analyzed by the degree of soil humidity which is one of soil conditions. Cover type map of forest area was made by hybrid classification method(Maximum Likelihood Classifier and K-means) with Landsat TM data. Multiple regression analysis was carried with AGB values computing from field observations and band reflectance derived from Landsat TM data to estimate correlation of remotely sensed data and AGB. Finally, biomass map was produced by estimation equations of fuel types.

Results and Discussion

It showed the field observations indicated that AGB and SB collected through field survey were strongly related with the soil condition. Thus we classified coniferous forests(C) into three fuel types(moderately moist; C-1, slightly dry; C-2 and dry soil; C-3) considering the relationships of AGB and SB of *Pinus densiflora* Sieb. et Zucc with soil condition. Hardwood(H) and mixed(M) forests were recognized as different land cover types. The cover type map for the study area was generated with the three land cover types(C, H, M) by a hybrid classification method using Landsat TM data. Then cover type map was overlaid with the thematic map defined degree of soil humidity to generate the fuel type map including five different fuel types. To produce a biomass map, AGB values computed from field survey data including the tree height and DBH were coupled with band reflectance derived from Landsat TM data through multiple regression analysis. The result of correlation between AGB and band reflectance showed that AGB of C-1 type was $-0.3204 \times R_1 - 132.84 \times RVI + 128.9905$ ($R^2=0.6262$), $AGB = 0.2458 \times R_1 + 0.3237 \times R_3 + 47.4180 \times NDVI - 30.9215$ ($R^2=0.5725$) for C-2, $AGB = -48.4420 \times RVI + 57.7988$ ($R^2=0.4310$) for C-3, $AGB = 0.4171 \times R_1 + 4.4826 \times R_4 - 241.0938$ ($R^2=0.6115$) for D type and $AGB = -9.5309 \times R_1 + 2.5071 \times R_7 + 593.2628$ ($R^2=0.7086$) for M type. The relationship between predicted AGB(ton/ha) from remote sensing-based models and the AGB computed from field observation is $AGB_{Estimated} = 0.717 \times Observed + 9.005$, and R^2 value of the relationship was *0.7143*.

A relatively good relationship exists between AGB estimate and band reflectance of Landsat data from five fuel types by degree of soil humidity. Furthermore, there is a possibility that fuel accumulation in forest ecosystems, a necessary input for most fire models, can be theoretically determined by AGB. Therefore, distribution of AGB across the landscape is necessary for quantifying landscape level fuel accumulation and its relationship to fire behavior and intensity. By combining our soil type map and the AGB map, fuel type and amount may be determined, which can be useful information for studying fire ignition and spread across the landscape. Such information could be helpful for resources managers to conduct fuel reduction plans to prevent catastrophic fire risk. Therefore, the fuel type classification, AGB estimation using degree of soil humidity and Landsat TM data can be used as baseline information for future landscape level studies such as estimating fire hazard potential.

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Effects of spatially optimized fuel reduction treatments on simulated human-caused wildfires
공간적으로 최적화된 연료제거시업이 인위적 산불에 미치는 영향

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Abstracts

In this research, we simulated wildfires that originated from hypothetical human-caused ignition points to determine whether a broad-scale schedule of fuel reduction treatment would be effective in reducing wildfire size or severity. The study area was a large watershed in Northeastern Oregon (USA). The fuel reduction treatment included thinning and thinning followed by prescribed fire treatment. The fuel reduction treatments were distributed across the landscape in a way as to simultaneously optimize both an even-flow of timber harvest volume and spatial patterns of activity. The results indicated that the clumped and the regular pattern of management activities seemed to reduce severity of simulated wildfires most effectively, while a dispersed pattern or a random pattern had no recognizable effect on simulated haman-caused wildfires.

요 약

본 연구는 대면적산림에 분포된 연료제거시업이 인위적 산불에 어떠한 영향을 미치는지 파악하기 위해, 미국 오레곤 주 동북부의 산림을 대상으로 산불확산행태를 모델링하였다. 연료제거시업으로는 간벌 및 간벌 후 처방화입의 두가지 유형을 적용하였으며, 연료제거시업의 공간적 패턴을 다양화하고 목표로 하는 목재량을 수확할 수 있도록 시업안을 최적화하였다. 산출된 시업안에 대해서 산불확산모델링을 수행한 결과, clumped 패턴과 regular 패턴이 인위적 산불의 확산을 억제하는데 효과가 높은 것으로 나타났으며, dispersed 패턴과 random 패턴은 크게 효과가 없는 것으로

나타났다.

서론(Introduction)

지난 수십년간 기후변화로 인한 기온의 상승과 임분내 산불연료의 과다한 축적은 세계각지에서 빈번한 산불의 발생을 불러왔으며, 산불의 위협을 줄이기 위한 다각적인 노력들이 이루어지고 있다. 특히 서북미 지역에서는 연료제거시업을 통해 산림 내에 과다 축적된 산불연료의 양을 줄임으로써 산불에 저항성을 갖는 건전한 산림으로 유도하려는 노력들이 확대되고 있다. 연료제거시업의 효과에 대해서는 이미 여러 연구들을 통해 검증되었으나(Helms,1979; Martin et al.,1989; Age and Skinner, 2005) 대부분 임분단위로 이루어져, 대규모 산림을 대상으로 적용할 경우 실제로 어떠한 효과를 가지는지를 규명한 연구는 미흡한 실정이다. 비록 연료제거시업이 산불 강도를 줄이는데 효과가 있다고 하더라도 전체 산림에 적용하는 것은 경제적/생태적/사회적으로 문제가 있다. 따라서 산불의 강도를 효과적으로 저감하면서도 지속가능한 산림경영이 가능하도록 최적화된 시업안이 제시할 필요가 있다. 본 연구에서는 휴리스틱 기법을 적용하여 대면적산림을 대상으로 연료제거시업들의 공간적 패턴을 다양화하고, 이들 시업을 통해 일정량의 목재생산이 가능하도록 시업안을 최적화하였다. 또한 각각의 패턴에 대해 산불확산을 모델링하여 인위적 산불의 행태를 효과적으로 억제할 수 있는 시업안을 제시하고자 하였다.

재료 및 방법(Methodology)

본 연구는 미국 오레곤주 동북부에 위치한 약 178,000ha의 산림을 대상으로, 총 사업기간(100년)동안 매 분기(10년)별로 목표벌채량(10,000MBF≈ 24m³)의 수확이 가능하도록, 또한 시업들이 네가지 공간적 패턴(dispersed/ clumped/random/regular)을 가지도록 최적시업안을 도출하였다 하였다. 최적화 모델링에는 휴리스틱 기법인 Great Deluge Algorithm(Dueck, 1993)을 이용하였다. 연료제거시업으로는 간벌과 간벌후 처방화입 두가지를 적용하였으며, 각 시업안에 따른 변화된 임분조건에 대해 산불확산을 모델링하였다. 산불확산 모델링에는 FARSITE(Finney, 1998)를 이용하였으며, 산불의 크기/방화선 강도/화염길이 등을 비교 분석하였다. 도로 인접지역에서 인위적 산불이 발생하는 것으로 가정하여 연구대상지 내 주요도로의 10m 완충지대(Buffer)

에서 임의로 5개소의 발화위치를 선정하였으며, 5개를 한 세트로 3세트의 발화위치를 적용하여 산불확산모델링을 수행하였다. 산불확산모델링의 결과를 토대로 전체 산불피해면적과 고강도산불(Rothermel and Rinehart, 1983) 피해면적을 비교함으로써 연료제거시업안의 효과를 분석하였다.

결과 및 고찰(Results and Discussion)

본 연구 결과, 연료제거시업들이 네가지 공간적 패턴을 가지도록 하고(Figure1), 매 사업분기별로 목표량의 목재 생산이 가능한 최적 시업안을 도출할 수 있었다.

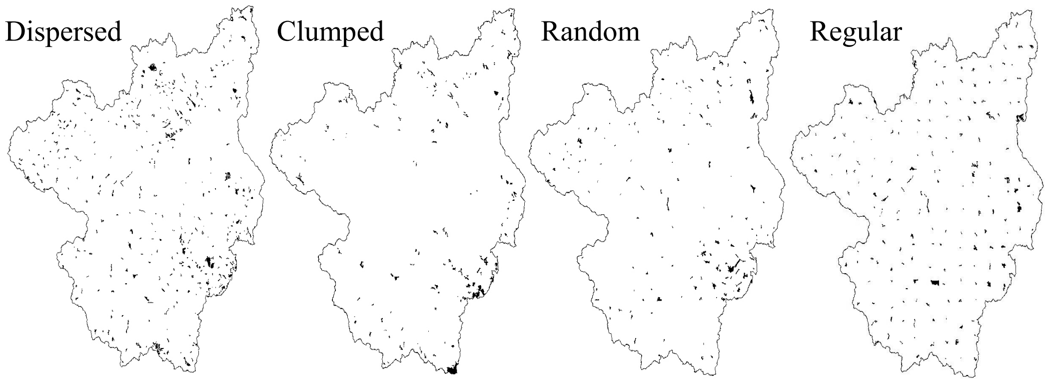

Figure1. Optimized patterns of fuel reduction activities

각 패턴별로 최적화된 시업안에 대해서 산불확산모델링을 수행한 결과, 발화위치에 따라 다소 차이가 있었으나 clumped패턴과 regular패턴의 시업안이 효과가 높은 것으로 나타났다. 세트1을 제외하고는 전체 산불피해면적을 크게 감소시켰으며, 고강도 산불 피해면적을 줄이는데도 효과가 있었다(Table1). 특히 regular패턴의 경우 고강도 산불 피해면적의 감소가 두드러지게 나타났다. 반면 dispersed패턴과 random패턴의 경우에는 세트2를 제외하고는 산불피해면적의 감소가 적었으며, 고강도 산불 피해면적에서도 두드러지는 효과가 나타나지 않았다 (Table1). 산불확산 억제 효과가 시업을 통해 제거되는 연료량과 관계가 있는지를 살펴보기 위하여 각 시업안별로 제거되는 연료의 양을 비교하였는데, 단위면적당 벌채량이 dispersed패턴과 random패턴에 비해, clumped패턴과 regular패턴이 1.5-2배 가량 높은 것으로 나타났다. 따라서 인위적 산불의 확산 가능성을 줄이기 위해서는, 약한 강도의 시업을 넓은 지역에 시행하는 것보다, 강한 강도의 시업을 발화 가능성이 높은 지역에

집중적으로 시행하는 것이 효과가 있는 것으로 판단된다.

Table1. Fire simulation results (Unit: hectare)

Characteristic	Ignition set	Control	Pattern of fuel reduction activities			
			Dispersed	Clumped	Random	Regular
Fire size (±)*	Set1	**20,483** **-**	**20,471** **(-12)**	**20,603** **(+120)**	**20,524** **(+41)**	**20,815** **(+333)**
	Set2	**20,317** **-**	20,169 (-148)	20,060 (-257)	20,181 (-136)	19,891 (-426)
	Set3	**19,741** **-**	**19,756** **(+15)**	19,486 (-255)	**19,838** **(+97)**	19,575 (-166)
Area in severe fire (±)*	Set1	**2,604** **-**	**2,624** **(+20)**	**2,622** **(+18)**	**2,636** **(+32)**	**2,638** **(+34)**
	Set2	**1,647** **-**	**1,669** **(+22)**	**1,669** **(+22)**	**1,646** **(-1)**	1,564 (-83)
	Set3	**2,360** **-**	2,347 (-13)	2,354 (-6)	**2,360** **-**	2,330 (-30)

*** Changes from control**

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Effects of Periodic Fire on the Soil Properties and the Vegetation of Saebyeol-Oreum Volcanic Cone, Jeju Island

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정기적 화입이 제주도 새별오름의 토양 및 식생에 미치는 영향

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Abstracts

This study was conducted to determine the effects of artificial fire on the changes of soil chemical properties and vegetation in Saebyeol-Oreum parasitic cone, Jeju Island. Before the fire the pH of surface soil (0～20 ㎝ in depth) decreased with the decrease of altitude, while the pH of surface soil showed no significant differences among different altitudes after the fire. After the fire, organic matter content of the soil was lowest in the middle elevation. This is because flammable materials such as firewood and dried grass were used for setting fire. Concentrations of total nitrogen and available phosphorus in the surface soil were not significantly different between before and after the fire. After the fire, contents of potassium, calcium and magnesium except those of sodium showed significant differences among different elevations. Potassium and sodium contents decreased after the fire whereas calcium and magnesium contents increased. On the other hand, total base contents, cation exchange capacity, and base saturation did show significant differences among different elevations as well as between pre- and post-fire. *Imperata cylindrica* var. *koenigii* and *Miscanthus sinensis* were dominant in Saebyeol-Oreum parasitic cone. After the fire, some of plants such as *Ligularia taquetii* newly appeared and importance value of most plants including *Imperata cylindrica* var. *koenigii* and *Miscanthus sinensis* changed. For a better understanding of the issue on the fire

effects on vegetation change, further studies such as long-term monitoring should be needed.

요약

주기적으로 화입이 이루어지고 있는 제주도 새별오름의 남사면에서 토양의 화학적 특성 및 식생변화를 조사한 결과 다음과 같은 결론을 얻었다. 화입 이전의 토양 pH는 고도가 낮아질수록 감소하는 것으로 나타났으나 화입 후에는 고도에 따른 유의적인 차이가 없었다. 화입에 따른 토양유기물함량은 다른 지역에 비해 장작이나 건초와 같은 연소재를 많이 태우는 중부조사구에서 크게 감소하였다. 토양내 총질소와 유효 인산은 화입이전과 이후 간에 통계적인 차이를 나타내지 않았다. 나트륨을 제외한 칼륨, 칼슘, 마그네슘 함량은 조사구별로 차이가 인정되었는데, 화입 후에 칼륨과 나트륨의 함량은 감소한 반면 칼슘과 마그네슘함량은 증가하였다. 또한 총 염기함량과 양이온 치환용량, 그리고 염기포화도 등은 화입 전과 후 그리고 조사구에 통계적인 유의성을 나타내었다. 새별오름 화입지의 식생은 띠와 참억새가 우점하는 초지로서 화입전과 후에 나타나는 종이 있으며 띠와 참억새를 포함한 출현종의 중요도가 화입 전과 후에 변화가 있었다. 그러나 식생의 변화는 장기간의 모니터링이 필요한 요소이므로 정확한 자료를 얻기 위해서는 오랜 기간에 걸친 보다 많은 연구가 요망된다.

서론(Introduction)

본 연구는 제주도 관광자원의 하나로 자리매김하고 있는 들불축제의 대표적인 지역인 새별오름의 들불놓기 전과 후를 비교하여 초지 토양의 화학적 특성과 식생의 변화 정도를 밝히고자 수행되었다.

재료 및 방법(Methodology)

제주특별자치도 제주시 애월읍 봉성리에 위치한 새별오름의 동남쪽 사면을 대상으로 하였다. 토양채취는 오름의 고도를 기준으로 상, 중, 하의 3개 조사구로 구분하여 각 조사구별로 2개소를 선정하여 채취하였다. 채취된 토양시료는 농업기술연구소 토양화학분석법(1988)에 준하여 분석하였으며, 식생조사는 9개 지점에 1×1(m)의 방형구를 설치하여 출현종, 종별 밀도 및 피도를 측정하였다.

결과 및 고찰(Results and Discussion)

제주도 새별오름의 인위적 화입이 토양의 화학적 특성 및 식생변화의 조사에서 다음과 같은 결론을 얻었다.

1. 화입 이전의 토양 pH는 고도가 낮아질수록 감소하는 것으로 나타났으나 화입 이후에는 고도에 따른 토양특성변화에 유의적인 차이가 없었다.
2. 화입에 따른 토양유기물함량은 다른 지역에 비해 중부조사구에서 크게 감소하였는데 이는 중부조사구에서 집중적으로 장작이나 건초와 같은 연소재를 태우기 때문이라 사료된다.
3. 토양내 총질소와 유효 인산은 화입 이전과 이후간에 통계적인 차이를 나타내지 않았다.
4. 나트륨을 제외한 칼륨, 칼슘, 마그네슘 함량은 부위별로 차이가 인정되었으며, 화입 후에 칼륨과 나트륨의 함량은 감소한 반면 칼슘과 마그네슘함량은 증가하였다. 또한 총 염기함량과 양이온 치환용량, 그리고 염기포화도 등은 화입 전과 후 그리고 조사구간에 통계적인 유의성을 나타내었다
5. 새별오름 화입지의 식생은 띠와 참억새가 우점하는 초지로서 화입전과 후에 나타나는 종이 있으며 띠와 참억새를 포함한 출현종의 중요도가 화입 전과 후에 변화가 있었다. 그러나 식생의 변화는 장기간의 모니터링이 필요한 요소로서 화입 이후의 식생변화에 대한 정확한 자료를 얻기 위해서는 오랜 기간에 걸친 보다 많은 연구가 요망된다.

Table 1.Characteristics of stands and mineral soils (0 ~ 20 ㎝ depth, n=6) in Saebyeol-Oreum parasitic cone in Jeju Island. Values are averages of plots with standard errors of the mean in parentheses.

	Control	Before fire
General stand characteristics		
Latitude (N)	33° 21'47	33° 21'47
Longitude (E)	126° 21'34	126° 21'34
Above sea level (m)	519	519
Soil characteristics		
Texture	Silt loam	Silt loam
Depth of A horizon (㎝)	41.4	38.9
pH (1: 5 H_2O)	6.00 (0.34)	5.97 (0.30)
Total N (%)	0.60 (0.25)	0.50 (0.15)
Available-P (ppm)	6.40 (2.07)	6.83 (4.44)
Organic matter (%)	13.36 (5.34)	10.21 (2.96)
Exchangeable Cations ($cmol^+$/kg)		
K	0.53 (0.11)	0.56 (0.36)
Ca	2.47 (0.86)	2.33 (0.93)
Mg	1.87 (1.21)	1.91 (1.32)
Na	0.23 (0.03)	0.23 (0.05)
Total base ($cmol^+$/kg)	5.10 (1.81)	5.03 (1.98)
Cation Exchangeable Capacity ($cmol^+$/kg)	25.21 (3.25)	23.72 (2.71)
Base saturation (%)	20.23 (3.84)	21.21 (4.51)

Table 2. Changes of cation contents (cmol+/kg) in soil after wild fire in the study site (soil depth=0~20 ㎝, n=6).

Time	Part	K^+	Ca^{2+}	Mg^{2+}	Na^+	Total base	CEC	Base Saturation
		($cmol^+$/kg)						(%)
Before fire	Upper	0.36b±0.15	2.56a±0.94	2.25a±1.78	0.24a±0.05	5.41a±0.73	21.78b±1.93	24.84a±2.11
	Middle	0.46b±0.09	2.56a±0.11	2.20a±1.19	0.22a±0.03	5.44a±0.36	23.68ab±3.32	22.97a±3.13
	Lower	0.85a±0.50	1.87b±1.28	1.29b±0.80	0.22a±0.08	4.23b±0.67	25.70a±0.99	16.46b±1.54
After fire	Upper	0.65a±0.54	2.76b±1.62	3.44a±1.39	0.17a±0.02	7.02b±0.89	25.23a±2.22	27.82a±3.09
	Middle	0.42b±0.35	4.34a±2.42	3.51a±1.31	0.18a±0.03	8.45a±1.03	25.56a±1.73	33.06a±2.14
	Lower	0.41b±0.26	3.11b±2.62	1.91b±1.25	0.21a±0.07	5.64c±1.05	25.92a±1.90	21.76b±3.52

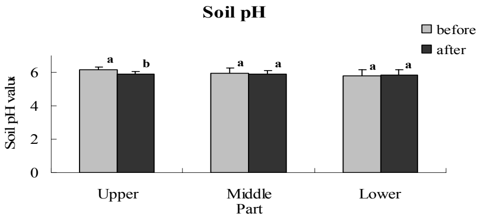

Fig. 1. Changes of soil pH value following wild-fire in Saebyeol-Oreum parasitic cone. Vertical bars are one standard of the means. The same letters between before-fire and post-fire are not significantly different at p=0.05.

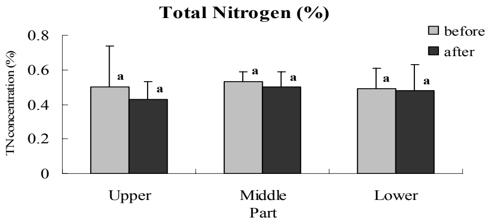

Fig. 3. Changes of total nitrogen concentrations (%) following wild-fire in Saebyeol-Oreum parasitic cone. Vertical bars are one standard of the means. The same letters between before-fire and post-fire are not significantly different at p=0.05.

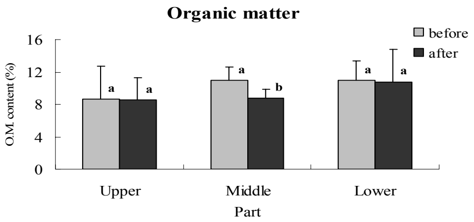

Fig. 2. Changes of soil organic matter contents (%) following wild-fire in Saebyeol-Oreum parasitic cone. Vertical bars are one standard of the means. The same letters between before-fire and post-fire are not significantly different at p=0.05.

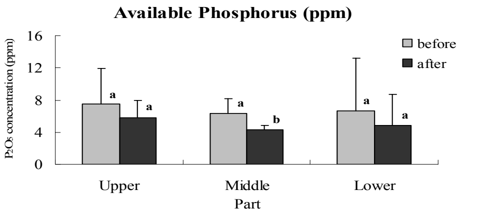

Fig. 4. Changes of available phosphorus concentrations (%) following wild-fire in Saebyeol-Oreum parasitic cone. Vertical bars are one standard of the means. The same letters between before-fire and post-fire are not significantly different at p=0.05.

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GIS-driven Forest Responses to the Large-Scale East Coast Fires in Korea
동해안 산불에 의한 삼림 피해 및 초기 재생의 GIS분석

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Abstract

We investigated stands in the whole of 23,794 ha burned forest regions, in terms of burn severity and vegetation regeneration as a measure of community stability. Using GIS technique, we analyzed the differential severity and postfire recovery among prefire forest types of different stand age at stand level. Analysis showed that pine (*Pinus densiflora*) stands were the most severely burned, while conversely pine-hardwood and hardwood stands were less vulnerable. This implied that pine forests had fire-prone characteristics. Vegetation recovery went the opposite way; that is, the vegetation cover was 71% at regenerating prefire hardwood stands, and those of pine-hardwood and pine stands were 65% and 53%, respectively. However, these recovery rates were strikingly fast, considering that investigation took place about three months after the fires. Fire did not initiate successional processes, but tended to accelerate the predicted successional changes by releasing prefire understory species that survived the fires and regenerated by sprouting. The dominant prefire tree species (*Pinus densiflora*) was susceptible to fire and not resilient enough to reestablish in competition with oak species. Contrary to pines, the abilities of oak species, mainly *Quercus mongolica* and *Quercus variabilis,* to survive fires and to resprout vigorously made them dominant at most postfire stands. These shifts in species abundance

caused drastic changes to the landscape: from pine-dominated to oak-dominated stands without any notable change in species composition. The patterns in forest regeneration that we observed in Korea may be representative of forest responses to any long-term repeated disturbances, including fire.

요 약

2000년 동해안 산불피해지역에서 23,794 ha의 전 지역을 약 241,000개 (30 x 30m)의 cell로 나누고, 산불시 숲의 피해정도와 산불 직후 임상의 재생 정도를 조사하여, 산불 전의 식생형과 임령에 따른 차이를 GIS 기법으로 분석했다. 분석 결과, 소나무 숲의 산불피해가 가장 컷고 활엽수림은 피해가 가장 작았다. 임상의 재생은 산불피해와 반대로 소나무숲에서 가장 느려서 평균 재생피도가 53%였고, 혼합림은 65%, 활엽수림은 71%에 달했다. 조사시기가 산불 약 3개월 후인 것을 감안하면 다른 나라의 연구결과와 비교할 때 재생속도가 매우 빨랐다. 임령이 낮을수록 세 식생형 동일하게 산불피해는 큰 반면 재생은 느렸다. 소나무숲에서 산불이 새로운 천이과정을 유도한다기 보다 하층에 억압되고 움싹재생력이 큰 참나무의 재생을 유도하여 천이과정을 가속화하는 것으로 나타났다. 반면 산불 전 우점종인 소나무는 움싹재생능이 없어서 초기 경쟁력이 낮으므로 산불 전 면적중70%에 달했던 소나무림은 산불 후 크게 감소하게 되었다. 우리나라 숲에서 산불피해 후 이같이 빠른 재생능은 산불과 같이 장기적이고 잦은 교란에 대한 진화적 적응인 것으로 해석된다.

Introduction

More than 80% of forests in South Korea are secondary forests of less than 30 years old, strongly implying that until recently, there have been frequent and serious disturbances to forested landscapes. In the early 1970s, however, the government implemented strong forest resource policies including changing fuel sources from wood to coal, prohibition of slash-and-burn farming, prevention and suppression of forest fires, and plantation of large areas. These policy changes have affected the recovery and successional patterns of forests throughout Korea.

The East Coast Forest fires, the largest recorded, occurred in April 2000 and burned a total of 23,794 hectares of forested land, an area equivalent to 0.37% of the total forested area in South Korea (Fig. 1). After the East Coast fires, serious controversial issues were raised regarding conventional forest recovery management and the capacity of natural regeneration capacity in the affected forests. The actual spatial patterns of burn severity and recovery, and their implications over large-scale landscape processes have been little studied in Korea. The Lack of information has lead to the establishment of 'the Joint Association for the Investigation of the East Coast Fires' with the support of the government. This association has subsequently investigated various aspects of disturbances and forest recovery over the range of affected forests. The considerable attention given was enough to spur various landscape-scale studies of the impacts of fires on forest dynamics in Korea.

We investigated the whole affected area, ca. 24,000 ha, in the East Coast fire regions to understand forest responses in terms of resistance and resilience. Specific aims are: (i) to investigate susceptibility of the type and stand age of the forests and their topographic locations; (ii) to investigate regeneration of the above; (iii) to predict large-scale landscape change resulting from different susceptibility and regeneration of prefire forests so that this information can be used by the forest management of those areas affected by forest fires.

Methodology

Field investigation

Field survey was carried out from June to August 2000 immediately after the fires. To evaluate the resistance, we measured the burn severity, divided into two classes: 'light burn' and 'severe burn'. To evaluate the resilience only in severe burn patches, vegetation recovery was measured based on the vegetation cover, which were classified into three levels; low (cover < ⅓), intermediate (⅓～⅔) and high (> ⅔). At each regenerating stand, canopy composing of tree species was identified if it covered more than ⅓ of the stand.

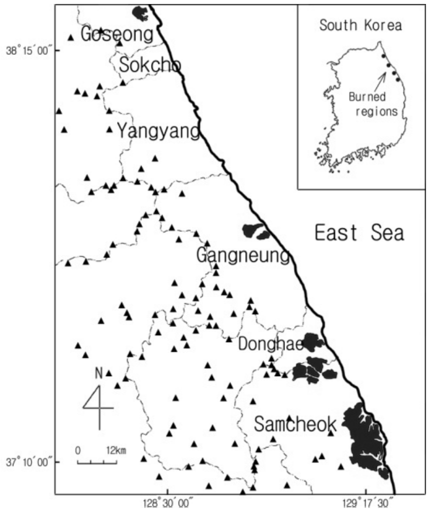


Figure 1. Map of the regions affected by the East Coast Forest Fires in South Korea (shaded area). Over 1,000 m high mountains (▲) run from north to south, making the local climate drier and hotter in these regions.

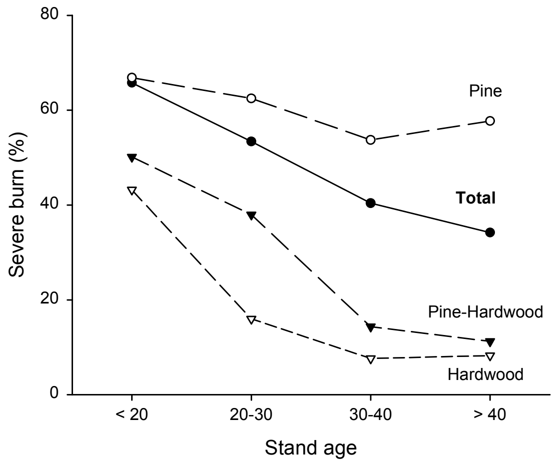
Geographic information system (GIS) analysis

To reveal the relationship of prefire vegetation and postfire responses, and to explain the effect of the topography on the relationship, the GIS technique was applied (the Bessel ellipsoid Transverse Mercator Projection by ArcView GIS version 3.2, ESRI Co). Three thematic maps were divided into 30 m mesh raster data. Information of the total 241,306 cells (ca. 21,718 ha) was available except for some cells with non-forest area or with no information.

Results and Discussion

Burned regions were a mosaic of severely burned and lightly burned patches (Choung 2002). Overall the regions turned out to be 51% severely burned and 49% lightly burned forest stands. The burn severity differed among forest types. Pine forests were damaged the most among the three forest types (Fig. 2). 61% of pine forests were severely burned, while those of pine-hardwoods and hardwood forests were only 29% and 17%, respectively. Burn severity exhibited a negative relationship with stand age: the younger, severely damaged and the older, less damaged. However, the trend of the slopes differs among vegetation types.

Following the fires, the extent of forest regeneration showed variations from patch to patch. Most of the burned stands, however, showed strikingly fast recovery rates immediately after fires even though vegetation recovery was examined for only severe burned stands. 47% of the whole area had a high regeneration, while 34% was intermediate ad 20% was low. On average, therefore, vegetation cover at regenerating stands was 55%. Immediate vegetation recovery differs among forest types: low in pine stands and high in mixed and hardwood stands (Fig. 3). Immediate vegetation recovery is not clearly related to the stand age even though it shows the tendency to increase with it.



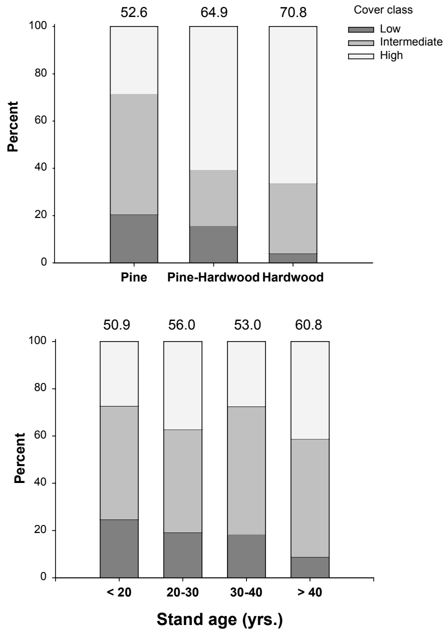


Figure 2. (left). Comparison of burn severity among forest types with stand age.
Figure 3. (right). Postfire regeneration measured by three regenerating vegetation cover classes according to forest type and stand age. Average cover for each bar is shown above.

These results imply that pine forests had fire-prone characteristics. Vegetation recovery went the opposite way; that is, the vegetation cover was 71% at regenerating prefire hardwood stands, and those of pine-hardwood and pine stands were 65% and 53%, respectively. These recovery rates were strikingly fast, considering that investigation took place about three months after the fires. Fire did not initiate successional processes, but tended to accelerate the predicted successional changes by releasing prefire understory species that survived the fires and regenerated by sprouting. The dominant prefire tree species (*Pinus densiflora*) was susceptible to fire and not resilient enough to reestablish in competition with oak species. Contrary to pines, the abilities of oak species, mainly *Quercus mongolica* and *Quercus variabilis,* to survive fires and to resprout vigorously made them dominant at most postfire stands. These shifts in species abundance caused drastic changes to the landscape: from pine-dominated to oak-dominated stands without any notable change in species composition.

Litter and Duff Combustion Characteristics in Rock Bed according to Fuel Moisture Content
함수율에 따른 암반지형의 재발화 연소특성

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Abstracts

This paper shows the litter and duff combustion characteristic in rock bed according to fuel moisture content. To simulate reignition in rock bed a gap is built between two stone plates. Also fallen leaves and duff are put into the gap. 40 thermocouples are placed in the gap to monitor the temperature. The moisture content of fuel is the variable and the duration and spread rate of smoldeling fire are measured.

요 약

본 연구에서는 암적지형에서의 모의 연소실험을 통한 뒷불 재발화에 대한 연구를 하였으며, 연구를 통해 얻어진 데이터로 암반층 재발화로 인한 산불확산과 산림연료의 종류, 함수율에 따른 산불 재발화의 관계를 분석하고 산불 재발화의 기초 데이터로 제공하여 연소특성 및 진화관리 기술을 연구 하였다.

1. 서 론

매년 국내에서도 년 540건의 산불이 발생하여 이로 인한 피해가 약 1,800ha에 이르고 있다. 산불이 대형화되고 있는 추세이다.

본 연구에서는 암적지형에서의 모의 연소실험으로 연구를 통해 얻어진 데이터로 암반층 재발화로 인한 산불확산과 재발화의 관계를 분석하고 산불 재발화의 기초 데이터로 제공하여 연소특성 및 진화관리 기술을 연구 하였다.

2. 실험 장치 및 방법

1) 실험장치

Fig 1.은 암석지 재발화 모의 연소실험 장치로 온도센서가 설치되는 단면을 가로 40 ㎝, 세로 40 ㎝의 대리석을 이용하여 현장과 유사하게 만들었으며, 암반과 암반사이 간격을 10㎝로 하였고 그 사이에 토층 1㎝, 분해층 10㎝, 낙엽층 5㎝의 높이로 설치하여 실험하였다. 모의실험은 암석지 재발화 시간에 따른 온도 데이터 측정을 위하여 총 40개의 Thermocouple(K-type)을 이용하여 수직-수평 온도분포를 측정하였으며, 데이터 수집은 Agilent사의 DAQ(Data acquisition : 34970A) 이용하여 1분 단위로 측정 분석 하였다.

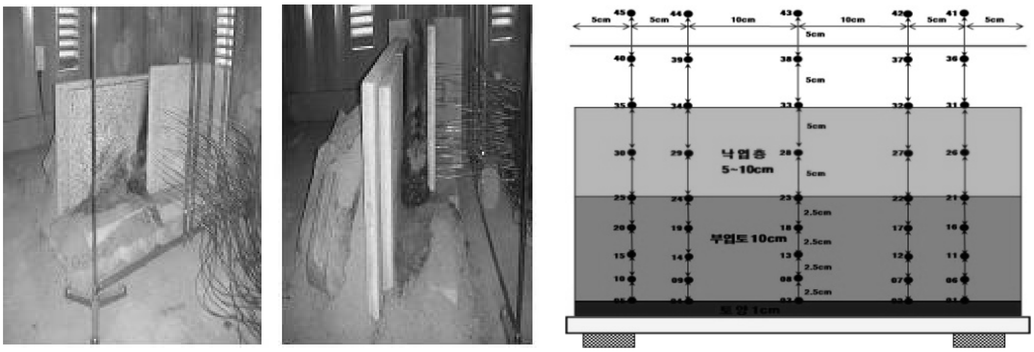

Figure 1. Thermocople 배치 사진 및 단면도

2) 실험 시료 및 방법

침엽수종인 소나무 낙엽과 활엽수종인 굴참나무 낙엽, 그리고 부엽토를 자연 상태에서 채집하여 현장과 유사한 시료를 사용하였으며, 최대한 자연재취 상태를 보존하고 동일한 함수율 조건을 맞추기 위해 건조기에 하루정도 건조를 시켰다. 건조시킨 낙엽들과 부엽토는 실험시에 1g씩 채취하여 CORETECH사의 MX-50(가열방식 수분계)으로 3회 측정하여 낙엽의 평균값을 15%대로 유지시켰으며 분해층은 20%, 30%, 40%대의 함수율로 실험하였다. 이때 함수율이 높게 측정되면 다시 건조시키고 함수율이 낮게 측정되면 수분을 증가하여 함수율을 높였다.

3. 결 과

Fig 2.은 함수율에 따른 지속시간으로 굴참나무 20%, 40%에서 재발화가 발생하지 않았으며, 평균적으로 굴참나무 낙엽보다 소나무 낙엽의 연소 지속 시간이 더 길게 측정되었다. 또한 30%대에서 연소 지속 시간이 가장 길게 측정되었다. Fig 3.은 함수율에 따른 수직/수평 전파속도를 나타낸 그래프로서 수평 전파속도에서 함수율 40% 이상이면 화염의 전파가 안 되는 것으로 측정되었고, 수직 전파속도는 침엽수/활엽수가 거의 동일한 패턴을 보이고 있다.

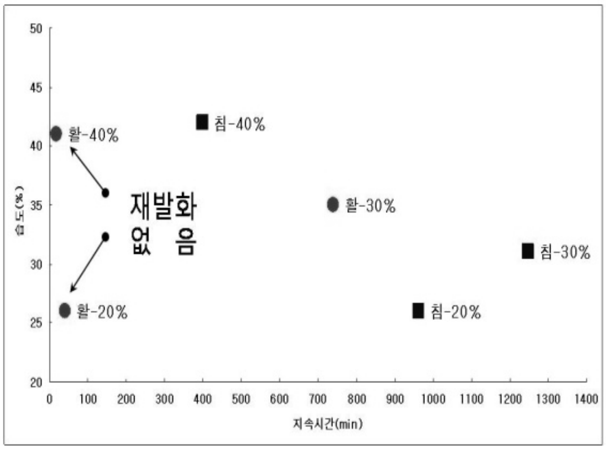

Figure 2. 함수율에 따른 지속시간

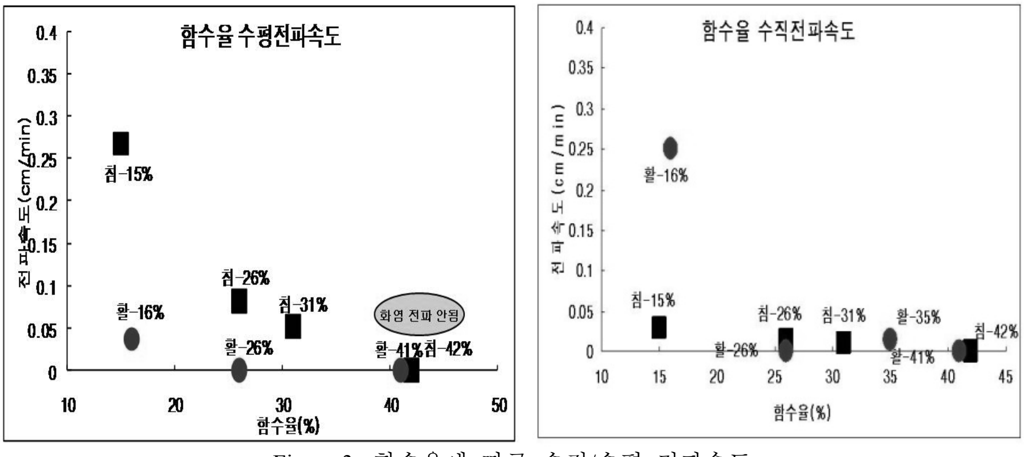

Figure 3. 함수율에 따른 수직/수평 전파속도

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Spatial Distribution Patterns of Forest Types and Forest Fire in South Korea

한국의 임상분포구조와 산불특성

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Abstracts

The objectives of this study were to examine correlation between the spatial distribution patterns of forest cover and forest fire regime by the ecoregions of South Korea. The results showed that coastal ecoregions covered higher percentage of forested area had more burned areas and faster spread of fire growth rate. The canonical correlation between the landscape indices for pine forests and the statistics of forest fires were showed that combustion time per fire was longer in the ecoregions which had larger and more aggregate pine forest patches.

요 약

본 연구에서는 우리나라의 지역별 임상분포구조와 산불특성을 분석하고 두 인자간의 상관관계를 도출하고자 하였다. 연구결과 산림면적비율이 높은 생태지역에서는 발생건수는 적은 반면 피해면적이 넓고, 빠른 확산속도를 나타내는 것을 알 수 있었다. 또한, 산불특성은 소나무 임분의 경관지수와 유의한 상관관계가 있었는데, 소나무 임상의 조각면적이 크고 응집된 구조를 갖는 생태지역일수록 장시간 산불이 지속되어 피해면적이 큰 특성을 보였다.

서론(Introduction)

산불의 발생과 확산에 영향을 미치는 요인은 지형, 기후, 인간활동 등으로 알려져 있다. 이러한 요인들 중 효율적인 산불예방 및 지속적인 산림관리와 관련하여 산불과 임상특성의 관계를 구명하는 것이 중요하다. 특히 우리나라는 소나무림이 대형산불에 취약하다고 알려져 있으므로, 이러한

지역을 대상으로 내화수림대 조성 및 연료관리를 위해서는 임상분포와 산불과의 연관성을 밝히는 것이 시급하다고 볼 수 있다. 따라서 본 연구에서는 우리나라의 생태지역별 산불특성 및 임상분포구조를 산불통계 및 수치임상도의 경관분석을 통해 파악하고 두 인자간의 상관관계를 분석하고자 하였다.

재료 및 방법(Methodology)

생태지역별 임상분포구조를 파악하기 위해 전국 751 도엽의 수치임상도를 생태지역별로 구획하고 Fragstats 3.3을 이용해 경관지수를 산출하였다. 경관분석은 경관수준 및 클래스 수준의 두개 스케일로 나누어 수행하였는데 경관수준에서는 생태지역내 모든 임상을, 클래스수준에서는 산불에 취약한 소나무 임상을 대상으로 하였다.

생태지역별 산불특성을 파악하기위해 1991년부터 2006년까지 총 16년 간의 산림청 산불통계자료를 이용하여, 건당 피해면적, 건당 연소시간, 확산속도(ha/hr)와 더불어 1000ha당 산불발생건수, 1000ha당 연소면적을 산불특성 변수로 산출하였다.

또한, 생태지역별 산불특성과 임상분포패턴간의 상관관계를 규명하기 위해 SAS 9.1을 이용해 정준상관분석을 수행하였다. 즉, 경관분석을 통해 추출한 전체산림과 소나무 임분의 경관지수를 독립변수집단의 변수로, 생태지역별 산불통계자료를 종속변수집단의 변수로 이용하여 분석을 수행하였다.

결과 및 고찰(Results and Discussion)

전체임상의 제1주성분(임상패치의 크기 및 형태적 복잡성)에서 유도된 정준변수(V_1)는 logAWMPS, AWMPFD와 0.8 이상의 강한 양의 상관관계를 가지며, 산불특성변수 중 1000ha당 발생건수와는 음의 상관관계(-0.612)를, 건당 연소시간과는 높은 양의 상관관계(0.75)를 보였다. 또한 제3주성분 (임상패치의 파편화)에서 유도된 정준변수(V_1)는 PD와 강한 양의 상관관계(0.992)를 가지며, 산불 통계치 중 건당 연소시간과 높은 음의 상관관계(-0.692)를 나타내었다 전체임상의 제1주성분, 제3주성분에서 추출된 경관지수군과 산불 통계치 간의 정준상관계수(Canonical correlation coefficient)는 모두 0.7 이상으로 비교적 높은 상관관계를 갖는 것으로 나타났으나 유의수준 0.05에서 유의하지 않아 전체

임상분포패턴만을 가지고 산불특성과의 관계를 설명하기에는 무리가 있었다(Table 1).

Table 3. Results of canonical correlation analysis on landscape indices selected from each principal component for whole forest types, showing the relationships between dependent(fire characteristics) and independent (spatial patterns of whole forest types) variables.

Principal Components	**Canonical Weights**	**Canonical Loading**	**Canonical Cross-Loading**
Whole forest types (PC1)			
Dependent variables(W1)			
Fires/1000ha	-0.226	-0.804	-0.612
Combustion time/fire	0.829	0.987	0.750
Independent variables(V1)			
logAWMPS	0.519	0.846	0.643
AWMPFD	0.626	0.897	0.682
Redundancy Index	0.563		
Canonical correlation coefficient	0.760(0.057)		
Whole forest types (PC3)			
Dependent variables(W1)			
Fires/1000ha	-0.394	0.467	0.337
Combustion time/fire	-1.234	-0.959	-0.692
Independent variables(V1)			
PD	0.991	0.992	0.715
SHDI	0.128	0.131	0.094
Redundancy Index	0.479		
Canonical correlation coefficient	0.721(0.084)		

소나무 임분의 제1주성분(패치형태의 복잡성 및 패치간 근접성)에서 유도된 정준변수(V_1)는 logAWMPS에 가중치가 가장 높았으며, 제2주성분(소나무 임분의 파편화)에서 유도된 정준변수(V_1)는 AI에 가중치가 가장 높았다. 또한 제1주성분과 제2주성분에서 유도된 정준변수(V_1)는 모두 산불특성 변수 중 1,000ha 당 발생건수와는 음의 상관관계를, 건당 연소면적과는 강한 양의 상관관계를 나타내었다. 이를 종합해 볼 때, 소나무 임분 패치의 면적이 크고 응집되어 나타나는 지역일수록 산불발생시 연소시간이 길어짐을 알 수 있다. 정준중복지수(Redundancy index)를 살펴보았을 때, 소나무 임분의 제1주성분과 제2주성분을 대표하는 경관지수군 모두 산불특성을 설명하는데 있어 약 70% 이상의 높은 설명력을 나타내는 것을 알 수 있다. 이는 우리나라의 산불특성이 소나무 임분의 분포특성과 밀접한 관련을 가지고 있음을 증명하는 결과라고 볼 수 있다(Table 2).

Table 4. Results of canonical correlation analysis on landscape indices selected from each principal component for pine forests, showing the relationship between dependent(fire characteristics) and independent (spatial patterns of pine forests) variables.

Principal Components	Canonical weights	Canonical Loading	Canonical Cross-Loading
Pine forests (PC1)			
Dependent variables(W1)			
Fires/1000ha	0.104	-0.643	-0.604
Combustion time/fire	1.070	0.997	0.938
Independent variables(V1)			
logAWMPA	1.052	0.768	0.722
AWMPFD	0.268	0.319	0.300
MENN	0.924	0.116	0.109
Redundancy Index	0.879		
Canonical correlation coefficient	0.940*(0.001)		
Pine forests (PC2)			
Dependent variables(W1)			
Fires/1000ha	0.101	-0.643	-0.539
Combustion time/fire	1.068	0.997	0.835
Independent variables(V1)			
PD	-0.201	-0.672	-0.563
AI	0.878	0.986	0.826
Redundancy Index	0.698		
Canonical correlation coefficient	0.838*(0.013)		

A Prototype Development for the Forest Spatial Data Warehouse
- A Case Study on Korea Forest Research Institute
산림공간데이터웨어하우스 프로토타입 개발연구 - 국립산림과학원을 사례로

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Abstracts

The variety of the information is explosively increasing in the present information society. So, it is harder to obtain user-required information from the huge database with wide point of view. Data Warehouse is the tool for the information analysis and decision support and is the developing concept to solve this problem for an existing system. In this pilot study, we designed a conceptual framework and developed a prototype for the FSDW (Forest Spatial Data Warehouse) which is applied with this data warehouse concept for the forest spatial data in Korea.

The target for the FSDW prototype is the Korea Forest Research Institute where many kinds of research such as forest management, environment, forest engineering, and forest genetics are going on in a diverse field site for a long time.

The purposes of the development of FSDW are first, to set up sharing infrastructure for the spatial data and the field survey data second, to connect with 3rd National GIS (NGIS) master plan of which main issue is common spatial information infrastructure third, to boost up an effective quality control for spatial data by loading data filtered with standard into FSDW. For the development and the utilization of FSDW, 2 steps for the development strategy are suggested. The first step is the clearinghouse development for a sharing and a distribution. The second step is the forest spatial data warehouse development based a subject analysis. For a successful FSDW development, first of all, standardization for data and a thematic map from each research post and each system must be done and each metadata must be built.

Based on these conceptual frameworks, FSDW prototype is developed. The main function is a gateway function such as metadata search, data search and data distribution. The sub functions which are user defined map creation and subject analysis are developed. Single Sign On(SSO) login can be made, so user can more easily access to the system. And existing system is connected with FSDW. Through the development of this FSDW prototype, forest spatial data with a broad geographical distribution range and a various type can be effectively utilized.

Keywords : Spatial Data Warehouse, Clearinghouse, Prototype, Framework Data, Metadata, GIS Standard

요 약

본 연구에서 사용한 FSDW(Forest Spatial Data Warehouse)는 산림과학 분야에서 공통적으로 필요로 하는 공간데이터와 현지조사 데이터를 한 곳에 모아놓은 일종의 데이터 창고의 개념으로 규정하였다. FSDW의 구축 목적은 첫째, 공간데이터 및 현지조사 데이터의 과학원 내부공유기반 조성에 있다. 둘째, 국가GIS 기본계획과의 연계이다. 셋째, 표준화를 거친 데이터를 SDW에 적재하게 됨에 따른 공간데이터의 효율적인 품질관리의 도모이다. GIS를 이용하여 새로운 정보를 생산하거나 통계정보를 산출하고자 할 때 SDW에 적재된 신뢰할 수 있는 유일한 원천 데이터를 활용함으로서 품질을 보증할 수 있게 되며 이를 통해 온실가스통계 등 국제통계에 대한 신뢰도 제고의 효과도 기대할 수 있다. 본 연구에서는 국립산림과학원의 각종 현지조사자료 및 공간자료를 대상으로 FSDW 프로토타입을 구축하여 다양한 방식의 데이터 검색, 국가산림자원정보시스템 등 연계시스템 정보 검색 및 FSDW 적재 데이터를 이용한 주제분석 모듈 등을 구현하였다. 이러한 프로토타입 개발을 통해 광범위한 지리적 분포 범위와 다양한 주제 영역을 지닌 산림공간 데이터의 효율적인 공유 및 활용의 토대를 마련하고자 한다.

Introduction

Korea Forest Research Institute having 80-year history has accumulated enormous field survey data and analysis data in each research area including forest management, environment and genetic resources, etc. It is also running management system in each research area and has abundant spatial data.

However, it has been taken a long time to search and to get a data because the information of each research area wasn't shared in common. And budget is doubled because of each research area having the duplicate of basic spatial data such as digital topographic map, DEM, land cover map, administrative map and satellite image, etc. Also different version and data source for the same kind of GIS data in each research area has brought out difficult data management. Also, there are some problems in absent of sharing infrastructure such as integrated database for analysis with integrated sight, absent of access tools and guideline for data access. These kinds of problems more happen in Korea Forest Service managing huge forest area and operating various distributed system.

Methodology

This study is executed by four steps. At the first step, we reviewed general structure and properties of DW, case study of SDW construction and SDW standards. At the second step, we analyzed present status of GIS and the field survey data in Korea Forest Research Institute, and selected common spatial data with the questionnaire. At the third step, we designed conceptual model for FSDW and standard metadata for common spatial data. Then, we designed function module and GUI based on requirements. At the last step, we developed FSDW prototype based on design. Developmental environment is as follows:

OS : Windows XP professional
H/W : Hp xw 8200
S/W : ESRI ArcIMS 9.2, ArcSDE 9.2

Results and Discussion

FSDW Conceptual model

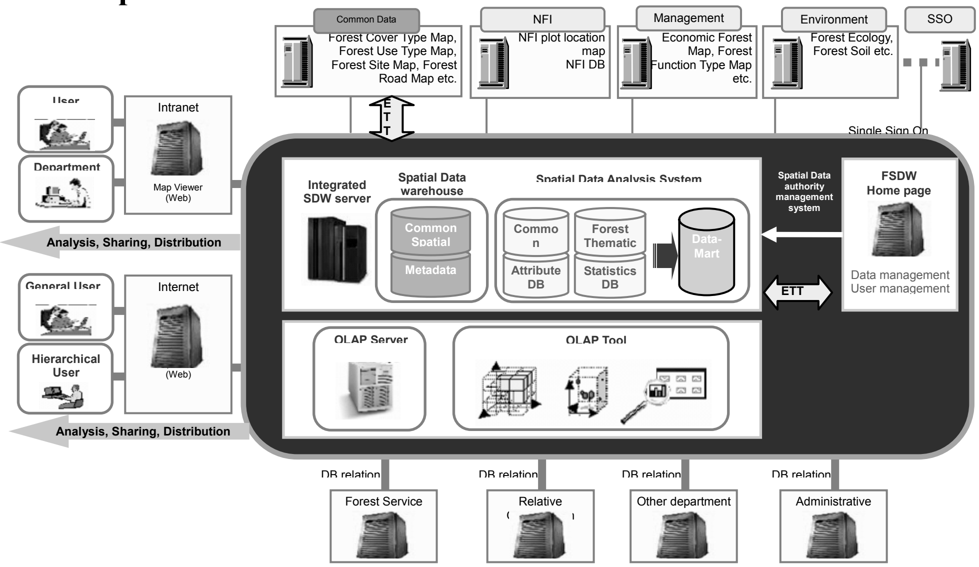

Figure 1. Conceptual model for FSDW

Construction of FSDW prototype

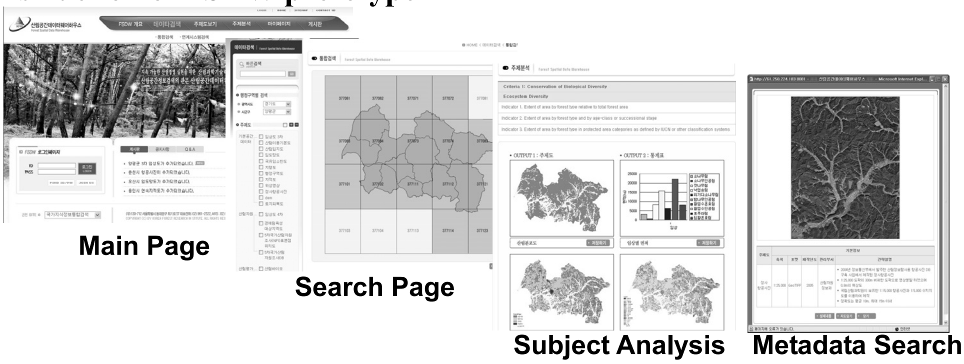

Figure 2. Examples of FSDW prototype

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NDVI and NBR Change of Forest Burnt Area using Multi-temporal Satellite Image Data
다중시기 위성영상자료를 이용한 산불피해지의 식생지수 및 산화지수 변화

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Abstracts

Using multi-temporal Landsat TM and ETM+ data and image differencing, NDVI and NBR changes were analyzed according to forest type and damage class in order to examine the vegetation recovery after forest fire. Both NDVI and NBR values were rapidly decreased after containment of the fire and gradually increased over time. However, NBR curve showed much clearer tendency of vegetation recovery than NDVI over time. Both indices yielded the lowest values in severely damaged red pine forest. Considering these results the vegetation cover and/or the vigor of forest burnt area was getting higher and recovered over time.

Introduction

Satellite can repeatedly observe the wide area at once and continuously acquire the information about the ground features and environmental changes. Likewise the spectral reflectivity of the ground features detected by satellite sensor can show the characteristics of phenomena about pre-fire and post-fire vegetation. Thus, it is more useful to use satellite images to investigate the forest damage affected by forest fire and to monitor the recovering process. Therefore, the objective of this study was to detect vegetation recovery over time after forest fire occurred in April 2000, Samcheok city using multi-temporal Landsat image data obtained in 1989, 2000, 2001 and 2002. In order to examine the vegetation changes over time, NDVI and NBR values were derived from time series image data, respectively and *image differencing* algorithm was adopted for change detection.

Methodology

Satellite Image Data

The forest fire over the study area was broken out in April 7, 2000 and lasted over a week until it was extinguished in April 15. To quantitatively monitor the vegetation change over forest burnt area using multi-temporal image data, date of imaging is very important. Because the satellite sensors record the reflectance about the surface characteristics, it might be ideal to use the image data acquired at the same time of day, considering the plant phonologies and the soil moisture conditions and so on. Thus, considering the seasonal variation of the plant phenology, all the image data sets were selected to be acquired at close to the day of May 25 as shown on Figure 1.

Radiometric and Geometric correction

The DN-Reflectance transformation model developed by Markhamand Burker (1986) and NASA (1998) was referred to radiometric correction for multi-temporal image data.

2000 image data was rectified with *Nearest Neighbor* resampling method and transformed to a Transverse Mercator coordinate system, and the other images were co-registered with *image to image registration* method. The total root mean square error (RMSE) of the registered image was 0.25pixel. In general, RMSE limit for the change detection is preferred less than 0.5pixel when registering the images.

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Normalized Difference Vegetation Index

Vegetation Index is often used to explain the vegetation phenomena from image data as a means to interpret the differences among various vegetation types, and between vegetation and artificial objects. Various mathematical combinations of the Landsat TM channel 3(Red band) and channel 4(NIR band) data have been found to be sensitive indicators of the presence and condition of green vegetation. Vegetated areas will generally yield high values for VI index because of their relatively high reflectance in NIR and low in visible wavelength. The NDVI values vary from (-) 1 to (+) 1 according to vegetation conditions. Likewise, as NDVI image has a very low contrast, radiometric enhancement such as a contrast stretching was introduced to the NDVI image. Finally the transformed NDVI image having the 8bit data from 0 to 255 was produced using Eq. (1).

$$tNDNI = \left(\frac{NearIR(Band4) - \mathrm{Re}\,d(Band3)}{NearIR(Band4) + \mathrm{Re}\,d(Band3)} + 1 \right) \times 127.5 \qquad (1)$$

Normalized Burn Ratio

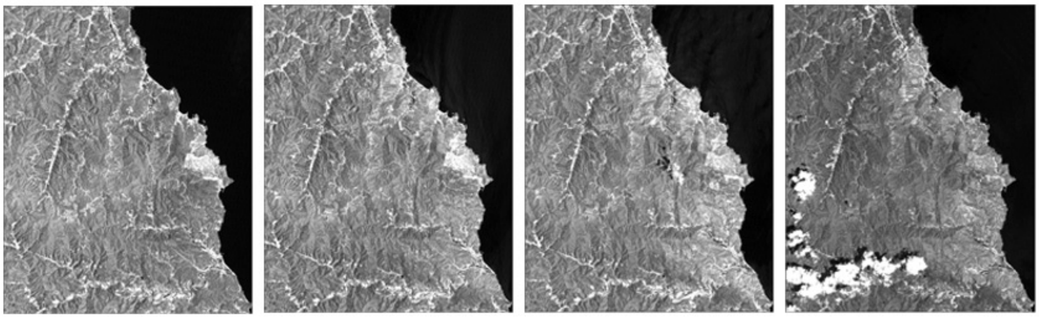
Key and Benson (1999) devised the Normalized Burn Ratio, considering the fact that the reflectance rate of Band 7 and Band 4 of Landsat data reacted very sensitive to the forest fire. That is, the reflectance value of Band 7 is increased while the value of Band 4 is decreased after the containment of the forest fire. Like the NDVI, the NBR value also varies from (-) 1 to (+) 1 according to vegetation conditions and has a very low contrast, too. Thus, the NBR image was transformed to have 8bit data using the Eq. (2).

$$tNBR = \left(\frac{NearIR(Band4) - MiddleIR(Band7)}{NearIR(Band4) + MiddleIR(Band7)} + 1 \right) \times 127.5 \qquad (2)$$

Results and Discussion

Interpretation of forest damage in multi-temporal image data

Figure 1 shows the data sets of Landsat TM and ETM+ images covering the study area located in Samchuk city, Gangwon Province. Image (A) was obtained in May 20, 1998(pre-fire), image (B) was acquired in May 25, 2000(a month later after fire extinction), image (C) was acquired in May 28, 2001(a year later after fire), and image (D) was acquired in May 23, 2002(two years later after fire), respectively.



(A) May 20, 1998 (B) May 25, 2000 (C) May 28, 2001 (D) May 23, 2002

Figure 4. Satellite image data used for change detection

All the data sets were acquired in the same season to avoid the seasonal variation of plant phenology and its radiometric characteristics. Vegetation covers damaged by fire appeared reddish color in the image (B). On the other hand, the post-fire image (C) and (D) vividly showed the vegetation recovery over time after fire extinction. Typically the vegetation of burnt area appeared greenish in 2002 image compared with the 2000 image.

NDVI and NBR Change of Burnt Forest

From Table 1, the mean NDVI value of burnt area was revealed to be 173.5 in 2000 image, and this value was lower than 209.2 of 1998 pre-fire image. Also NDVI value tends to increase after the fire extinction. The mean NBR value was revealed to be 159.6 in 2000 image and this value was much lower than 229.3 of 1998 image.

Table 1. NDVI and NBR change of burnt forest area over times

Date of Imaging	NDVI Statistics				NBR Statistics			
	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
May 20, 1998	209.2	11.62	116	231	229.3	7.73	154	251
May 25, 2000	173.5	22.20	104	228	159.6	32.07	87	225
May 28, 2001	198.8	17.22	131	237	179.6	23.78	104	255
May 23, 2002	200.6	14.78	131	233	192.1	18.27	121	234

As shown in Figure 2, the trend of the mean NDVI and NBR values of burnt area are very similar. However, NBR curve showed much clearer tendency of vegetation recovery than NDVI over times. There was no change of the NDVI value between 2001 and 2002, while NBR showed a continuous increase distinctly.

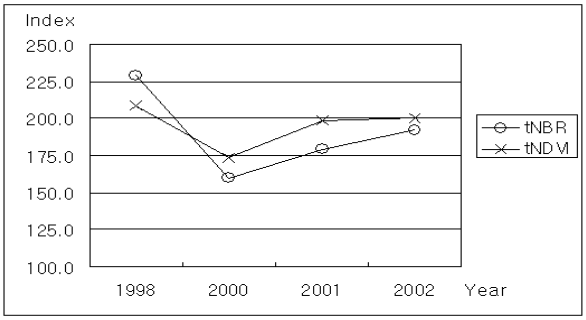


Figure 2. NDVI and NBR change

The study area was divided into the damaged and undamaged forest area. Then NDVI and NBR values of all image data were computed for each forest type. From Figure 3 all forest types in undamaged forest area showed no difference in NDVI value over time, but they showed a rapid decrease between 1998 and 2000, a increase between 2000 and 2001, and no-change between 2001 and 2002 in damaged area. In case of NBR, however, the value also decreased rapidly between 1998 and 2000 image, and continuously increased regardless of forest type and fire effect since 2000. These patterns are assumed to indicate the vegetation recovery over times in damaged area. Both the NDVI and NBR curves of coniferous forest - especially red pine forest - yielded the lowest values in damaged area. In fact, most of the red pine forest in study area were prone to forest fire and severely damaged. In 1998 pre-fire image, NDVI values among forest types were slightly different, but there were no differences in NBR values. This means that NDVI image is more useful to discriminate the forest types in a dense forest rather than NBR image.

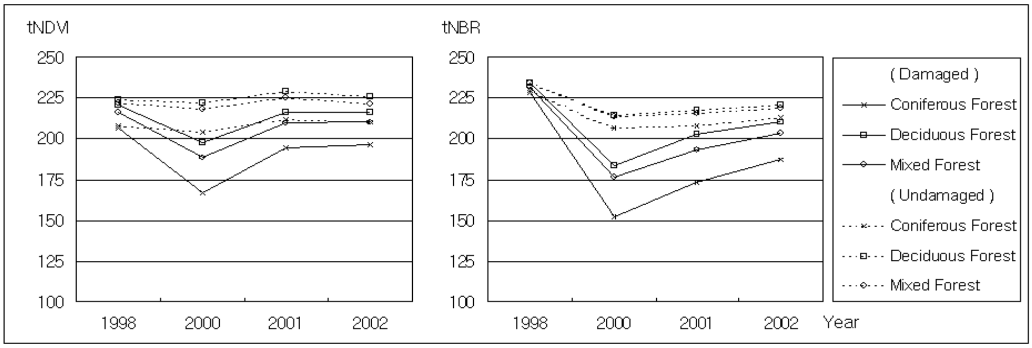


Figure 3. tNDVI and tNBR change according to forest types

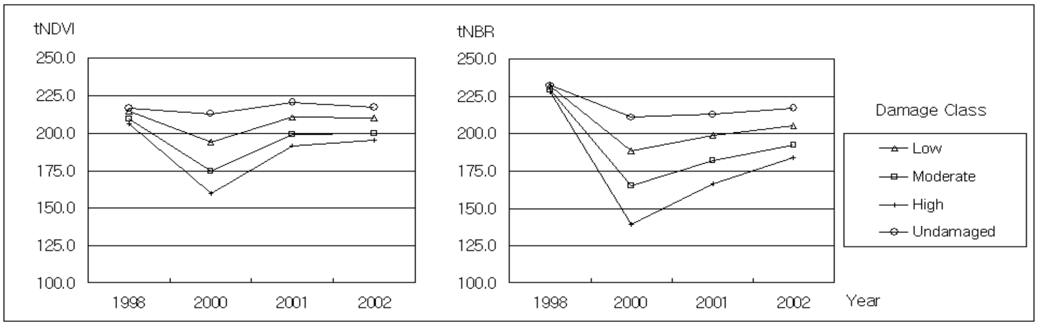


Figure 4. NDVI and NBR change according to damage class

NDVI and NBR change according to damage class is depicted in Figure 4. In particular, both indices were rapidly decreased in the severely damaged forest, and the gradient of decreasing rate was getting smooth in accordance with the damage class varying from high to low. In general, both indices of NDVI and NBR showed the similar patterns with them of Figure 2. As stated above, the NBR illustrated the clear difference according to damage class. On the contrary, the NBR variation by damage class is higher than NDVI in 2000 image. This means NBR is more useful for discriminating the damage effects than NDVI.

Therefore, in order to examine the forest fire effects it is more useful to introduce the NBR with the combination of IR Band 4 and Band 7, responding sensitive to soil characteristics rather than NDVI.

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A Literature Review for Landscape Ecological Strategies to Forest Restoration of Burned Areas in Korea:

산불피해지의 경관생태적 복원전략에 관한 문헌 연구

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Abstracts

In Korea, recent trends of forest fires can be characterized with magnification of fire size, increase of diversity in damages and relevant interest groups due to global warming, increase of forest visitors, complex land use near forests and accumulation of fuels in forests. Compared to the recent trends of forest fires in Korea, current restoration models used before have focused on emergency responses aiming for mitigating soil erosions and greening the burned areas without considering these complex characteristics of recent forest fires. And there has been increased demand about a comprehensive restoration models for burned forests that can encompass the complex characteristics of recent forest fires. In the light of these, the presented study aims to explorer strategies of landscape ecological restoration models for burned forests. Landscape ecological models have been widely used to handle complex environmental problems in North America and Europe, and the models have been known to be able to encompass the complex aspects of damages of forest fires. The study was investigated primarily with literature reviews including published articles, brochures and project reports in North America and Europe. Findings are optimized forest structure that has persistence to fire, hierarchical approach, aiming THE (Total Human Ecosystems), considering multi-landscape scales, and using multi-criteria. From literature reviews about landscape ecological models for burned forests, the study was able to conceptualize the strategies for landscape ecological restorations of burned areas in Korea. However, Due to the limitations of the study focusing on literature reviews, more detailed investigations are required to finalize and to validate the conceptual model of this study in the future. The presented study is a brief report of a long term study in building landscape ecological restoration models for burned forests in Korea.

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요약

우리나라의 산불은 최근 지구온난화, 산림탐방객의 증가, 산림의 축적 등에 의하여 대형화, 피해 양상의 복잡화, 피해 이해집단의 다양화 등의 특징을 갖는다. 이에 비하여 현재까지의 복원은 응급복구에 치우쳐 있는 실정으로, 이러한 우리나라 산불의 특징을 담아낼 수 있는 복원모형의 수립이 매우 절실한 실정이다. 본 연구는 외국에서 근래에 많이 이용되고 있는 경관생태적 복원 모형에 기초하여 우리나라의 산불 피해지의 복원모형 도출을 위한 기본전략의 수립에 초점을 두고 수행되었다. 연구방법은 주로 연구논문, 선진국의 복원사례 등 문헌연구에 기초하여 이루어졌으며, 연구결과는 아래와 같다. 연구결과 산불피해지의 경관생태적 복원 전략의 주요 특징은 산불에 저항성을 가지며 동시에 생태적으로 기능을 하는 산림의 구조적 조성, 복원의 규모와 위계적 접근방법, THE(Total Human Ecosystem)의 추구, 광역적/계량적 접근방벙의 이용, 다기준 접근방법 등으로 나타났다. 본 연구는 문헌에 기초한 연구이므로 가설적 모형은 도출해 낼 수 있었으나, 실제적으로 한국적 상황에 어떻게 적용될 수 있는지는 추후의 연구에서 보다 심도있는 연구가 필요한 것으로 판단된다.

Introduction

Since 1990s, Korea has been experiencing many catastrophic forest fires resulted in thousand hectares of burned forests, lives, houses, and other economic losses. KFS(Korea Forest Service) characterized these recent fires with magnified fire size, complexity of damages including ecological, environmental and socio-economic areas, and high diversity of relevant interest groups (KFS, 2005). However, post-fire restoration plans for damaged areas were very limited in strategies, goals, methods, and action plans, and they were not able encompass the main characteristics of recent catastrophic fires into restoration plans. With these characteristics of recent fires and increased demands for environment-friendly restorations, there have been calls for comprehensive restoration methods for burned forests that can integrate the complexity and diversity of fire damages, as well as magnified fire size of burned forests into decision making processes including assessment, evaluation, and making alternative plans. In the light of these, this study aims to explorer strategies of landscape ecological restoration strategies for burned forests. Landscape ecological models have been widely used to handle complex environmental problems in North America and Europe, as well as other parts of the world, and the models have been known to be able to encompass the complex aspects of environmental issues (Baker, 1992; Collins et al., 2007). The study was investigated primarily with literature reviews including published articles, brochures and project reports in North America and Europe.

Main Traits of Landscape Ecology

Many studies have shown that forest structure including forest composition and configuration has impacts on fire behavior such as fire ignition, fire spread, fire severity, and post-fire regenerations (Brown and Smith, 2000; Cardille and Ventura, 2001; Collins et al., 2007; Gustafson et al., 2004). Thus it appears that making and managing appropriate forest structure is an important for forests that are persist to recurrence of fires. It has been widely accepted that most ecological phenomena is scale dependent including forest fires (Turner et al, 2001). Forest fires varies in size, affects forest ecosystems accordingly, differently at different level of scale in the forest ecosystem hierarchy. Thus restoration plans should be different corresponding to fire scales. Landscape Ecology takes human dimensions into account in understanding environmental phenomena, as well as ecosystems. And the present landscapes are resulted from interactions between human systems and ecosystems (Naveh, 2000). Restorations are viewed as the process to build better THE integrating human systems and ecosystems together. For this, multi-criteria in decision making processes and inter-disciplinary approaches are necessary, which is called “holistic approach” or “comprehensive approach.”

Landscape Ecological Restoration Strategies

1. Restoration phases

Landscape ecology deals with landscape structure and functions (Turner et al, 2001). And forest structure appears to be important for fire behavior, regeneration and functions of forests. And, considering that the final goals of the restorations in damaged forests is building THE, we can classify the restoration processes into three phases: short-term restoration (structural restoration), intermediate-restoration (functional restoration), and long-term goals (THE). And these should be feedback systems that can allow adjusts the courses of previous phases (see Table 1).

Table 1. Comparison between short-, intermediate, and long-term restoration phases

phases	time	cost	scale	goals	main actions
SR	0 – 2 yrs	+++	+	structure	Assessment, evaluation, planning, field works
IR	2 – 10 yrs	++	++	function	monitoring, supplementary field works
LR	10 – 30 yrs	+	+++	THE	Communications, education, land sue changes

SR: Short-term restoration, IR: Intermediate-restoration, LR: Long-term restoration

2. Restoration hierarchy

Hierarchy theory strongly suggests that we should consider at least three different scales to understand the true nature of ecological phenomena (Turner et al, 2001). The same principle can be applicable to forest restorations. There can be three different levels of scales in forest restoration to consider. They are ecoregion scale, damaged scale, and sub-damaged scale. The ecoregion scale allows us to understand the ecological meanings (core areas, buffers and edges, critical habitats, and etc) and contexts (connectivities, gaps, and etc) of damaged forests, provides restoration goals of damaged areas, and should be assessed prior to the fire events. The damaged scale is the main scale of interests in restoration and includes actual burned areas, and should be right after the fire event. The sub-damaged scale is subsets of damaged areas, including variations and changes in environmental and ecological conditions (see Figure 1). Thus sub-damaged restoration is dependent to damaged forest scale, and the damaged forest scale is dependent to ecoregion scale. Higher scale restoration plans can provide guidelines for lower restoration scales. It is noteworthy that the presented study is a brief report of a long-term study on building landscape ecological restoration models for burned forest in Korea. It is a beginning stage, and more details', theories and models are planning to be integrated into the study later to shaping the models.

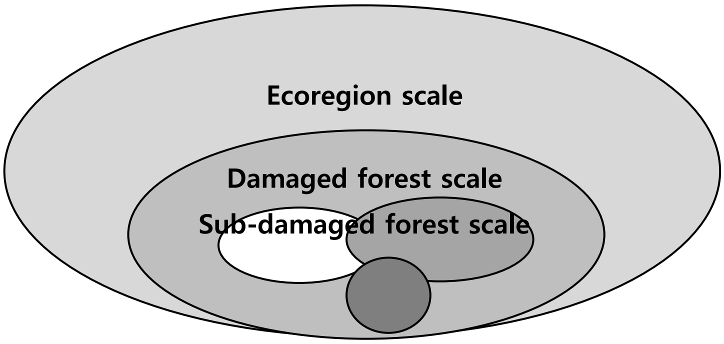

Figure 1. Conceptual hierarchy of restoration plans

ACKNOWLEDGMENT

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Changing Patterns of Ecosystem Components after Fire in East Coast Region

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동해안지역 산불피해지의 생태계변화 경향

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Abstracts

This is the result from monitoring the changes of ecosystem after forest fire in the East Coast Region that was burnt in 1996 and 2000. Canopy components did not chang in species, but Oak species, *Quercus variabilis, Quercus mongolica, Quercus serrata*, grew and dominated the T_2 layer. Species in the herb layer of hare severe fluction last for 10 years. Especially the cover of sun grasses changed with the increasing coverage of shrub or T_2 layer. The number of *parus major*, the king of mountainors birds, decreased in the early stage after fire and increase 7~8 years after. Small mammalias were dominated by open space or glass land. In the case of insect or aquatic species that habited in the disturbed site are appeared as a dominant. Qutflow of soil stopped in 3years after the fire, and the water quality of streams recovered to the first level in 2years after fire.

요약

1996년과 2000년 동해안 산불이후 실시한 생태계 변화 모니터링의 결과, 교목층에 있어서 종의 변화는 없었으며, 아교목층은 우점종으로 나타나는 굴참나무, 신갈나무, 졸참나무 등 관목층에서 아교목층까지 수고진계생장을 하여 새로이 종수가 증가하였다. 초본층에서는 산불 후 10년 동안 종의

증감이 심하게 나타났으며 주로 양지성 초본류의 증감현상은 관목층 및 아교목층의 피도증가에 의한 광환경 변화에 의한 것으로 사료된다. 조류는 초기에 산림성인 박새류가 감소하였다가 점차 증가하는 경향을 보였으며, 소형 포유류는 개활지 및 초지성 종이 우점하였다. 또한 곤충과 수서생물의 경우 훼손지 출현종이 우점하는 경향을 나타냈다. 산불피해지 토사유출은 3년차부터 안정되었으며 계류수질은 2년차부터 1급수로 회복하는 경향을 보였다.

서론(Introduction)

1996년 4월 23일 강원도 고성군 죽왕면에서 발화하여 고성일대의 3,762ha를 태운 산불은 당시로는 우리나라 산불통계를 기록한 이후 최대 규모의 산불이었다. 2000년에는 보다 큰 규모의 산불이 발생하여 강원도 고성군•강릉시•삼척시•동해시 및 경상북도 울진군에서 동시다발적으로 발생하여 여의도 면적의 약 80배에 달하는 23,794ha의 산림이 소실되었다. 산불은 산림 생태계를 교란시키는 가장 큰 원인중의 하나로서 산불이 발생하면 토지피복, 토지이용, 생물종다양성, 기후변화와 산림 생태계를 포함한 물리적 환경에 영향을 미친다. 따라서 산불로 인한 산림생태계의 영향과 그 회복과정을 파악하는 것은 산림생태계 관리와 산불피해지 복구를 위해서 매우 중요하다. 이 연구는 산불피해지의 생태계 변화를 모니터링하여 친환경적 산불피해지 복구 및 관리 방안 수립을 위한 토대 마련에 목적이 있다.

재료 및 방법(Methodology)

강원도 고성군 죽왕면 일대 자연복원지 100ha와 강원도 삼척시 원덕읍 일원에 약 4000ha의 영구조사지(Long Team Ecological Research Site)를 대상으로 조사하였다. 생태계 변화 연구는 식생변화 및 임목동태, 지표지질 및 수문환경, 토사유출 및 토양변화, 곤충 및 야생동물상, 어류 및 수서생물 등의 분야로 나누어 조사를 실시하였다. 식생변화 및 임목동태는 임목 피해도•조림 수종 및 활착률•입지별 식생, 수문환경조사는 토양의 침투능•저류능•수질, 야생동물은 조류상•포유동물상에 대한 조사를 실시하였고, 곤충상은 토양곤충•수목곤충•산림해충에 대한 조사를 실시하였다. 어류 및 수서생물은 출현도•우점종•종조성•수환경을 조사하였다.

결과 및 고찰(Results and Discussion)

식생 변화 및 임분동태

산불 발행시 지표식생이 소실되지만 그 중 일부의 맹아, 뿌리, 종자등이 생존하며 1년 후에는 싸리•고사리 류등의 초본, 관목층이 발생하고 5년 경과후에는 참나무류가 우점하면서 싸리등은 감소한다. 10년 후에는 참나무림의 층위가 분화되며 생장을 지속하거나 척박지에서는 둔화하였다.

무기환경 변화

계류수질은 산불 후 부유물질이 증가하였으나 2년후부터 1급수로 회복되었고, 수문환경의 경우 산림피해지의 조공극률이 비산불지보다 낮아 산불로 인한 표층 토양의 수원함양기능이 감소되었으며, 이로 인하여 산불 발행 후 3년차 까지도 산불피해지의 물저류능은 회복되지 않았지만 점차 회복되는 경향을 보였다. 또한, 토사유출은 산불 피해 후 1-2년에 극심하였지만 그 후 급격히 감소하여 3년차부터는 감소추세가 둔화되어 안정화되었다. 산불로 인한 토양의 화학적 변화는 비산불지에 비해 토양pH와 유기물, 치환성 양이온인 칼륨, 칼슘, 마그네슘 함량이 증가되는 것으로 나타났지만 5cm 이하의 깊이에서의 토양성질은 산불강도에 따라 뚜렷한 차이는 없었다.

곤충상 변화

곤충의 경우 산불초기에 다양한 식생이 들어옴에 따라 곤충상도 풍부해지지만,시간이 지남에 따라 풍부도나 다양성은 점차 줄어드는 것으로 나타났다. 특히, 딱정벌레등 초지성 종이 증가하는 경향을 나타냈다. 반면, 나비의 경우는 전체적으로 감소하는 경향을 보였으나, 산림성에 비해 초지성 나비류가 우점하는 현상이 나타났다.

야생동물상 변화

중대형포유류는 멧토끼, 고라니등 초식성이 증가하였으나 설치류의 경우는 흰넓적다리붉은쥐 등 산지성은 감소하였으나 등줄쥐 등의 초지성은 증가하는 경향을 나타냈다. 또한 조류에서는 산림성인 박새가 감소하였다가 7-8년후 증가하는 경향을 보였고, 딱다구리 등 개활지 선호종이 증가하였다.

어류 및 수서생물상 변화

어류는 수변부 파괴로 종의 변화가 나타났지만 식생회복과 함께 회복되었다. 수서생물은 종의 감소로 인하여 우점도는 감소하였으나 다양도는 증가하였다. 매년 섭식기능군의 종수 및 개체수가 비교적 증가하는 경향을 나타냈으나 금년 조사 시 GC(Gathering-Collector : 몸의 구조물이나 망을 이용하여 물속에 떠 있는 미세유기물을 걸러서 먹는 무리, 대표종 : 갈색우묵날도래류, 깔따구류, 부채하루살이, 애호랑하루살이 등)를 제외하고 종수가 감소하였다. 이는 청정 수질이 유지되고 조사 전 오랜기간 강우의 영향이 없었고, 저서대형무척추동물의 먹이원이 다소 감소하여 전체적인 종수와 개체수 그리고 이에 따른 섭식기능군이 감소되었다.

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Fertilization effects on pine seedling growth at the post-fire stands
산불발생지에서 시비가 소나무 묘목 생장에 미치는 영향

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Abstracts

Forest fire degraded forest soil properties through direct and indirect processes resulting in decreasing forest productivity. We investigated fertilization effects on pine seeding growth at the post-fire stands in Kangwon Province for 4 years. The first study was to measure the effect of combined N, P, K fertilizers on pine seedling growth and the second was to compare the effect of harden- and slow-released fertilizer on pine growth. NPK3:8:1 treatment had the highest height and root collar diameter(RCD). In the second study, triple amounts of harden- and slow-released fertilizer showed higher height and RCD than others. The effect of slow-released fertilizer on height and RCD growth was higher than solid combination fertilizer by 10 and 4.5%, respectively. We cautiously recommend NPK3:8:1 and double amount application of slow-released fertilizer to maximize pine seedling growth at the post-fire stands in Kwangwon Province.

요 약

산불은 산림내 지상부 임상과 지표의 유기물층을 소실시키기 때문에

미생물 활동 위축, 토양 침식 및 토사 유출로 인하여 토양 비옥도를 감소시키며 토양내 양분의 불균형을 유발한다. 이 연구의 목적은 다양한 비료배합 비율과 시비량 연구로 산불피해지에 적합한 시비법을 구명하는 것이다. 연구대상지는 강원도 삼척시 2000년 동해안 산불이 발생한 지역으로 소나무 용기묘를 식재한 곳에서 2003년부터 2006년까지 각각 6가지의 비료배합 비율(Study I)과 비종별 시비량 시험(Study II)을 수행하였다. Study I에서 수고는 NPK=3:8:1에서 가장 높았고, 근원경은 NPK=6:4:1과 NPK=3:8:1에서 유의하게 높은 생장을 보였다. Study II에서 수고생장은 고형복합비료와 완효성복합비료 2배량구와 3배량구에서 각각 가장 높은 생장을 보였고, 근원경은 두 비종 모두 3배량에서 가장 높았으나 2배량구와 3배량구간에는 유의성이 없었다. 고형복합비료에 비하여 완효성 복합비료 처리는 수고는 10%, 근원경은 4.5% 이상 증가시켰다. 산불피해를 입은 갈색건조산림토양에서 식재된 소나무의 초기 생장을 증가시키기 위해서는 비료 배합비율은NPK=3:8:1시비가 우수하며, UF 완효성 복합비료 2배량 시비가 적합하게 나타났다.

서론(Introduction)

산불은 지상부 biomass와 산림 내 유기물층을 제거하여 직·간접적으로 산림 토양의 물리·화학적 성질을 변화시킨다. 특히 산불 후 초기에 미생물 활동 위축, 토양 침식 및 토사 유출은 토양 비옥도를 감소시키며 토양 내 양분의 불균형을 심화시킨다. 이러한 현상은 산나물과 송이 등 임내 산물의 감소와 산림의 생산성을 저하시키는 원인으로 작용할 것이다. 따라서 임산물로 생계를 유지하는 산촌민을 위한 조기 복구방법과 산림의 생산성을 지속적으로 유지하기 위한 산림 토양관리가 이뤄져야 할 것이다.

현재 우리나라에서 산림사업용으로 사용하는 비료는 질소, 인산, 칼륨의 성분비율이 3:4:1인 산림용 고형복합비료만을 사용하고 있으며 산불피해지에서의 효과는 연구되지 않았다. 이 연구는 기존 비료를 포함하여 다양한 비료배합 비율과 시비량 연구로 산불피해지에 적합한 시비법을 구명하기 위하여 수행하였다. 연구대상지는 강원도 삼척시로 2000년 4월에 산불이 발생한 지역으로 2003년 6월 소나무 용기묘를 식재한 곳이다. 이 연구 결과는 산불피해지의 지형(topography) 및 토양특성에 따른 효과적인 토양 비배관리 방법을 제시할 수 있을 것이다.

재료 및 방법(Methodology)

연구지역은 강원도 삼척시 근덕면 궁촌리 70임반 가소반이며, 2000년도

4월에 산불이 발생하였다. 2003년 6월에 소나무 1년생 용기묘를 식재하였다. 토양 단면을 조사하였고 시비 전 토양의 물리·화학성을 분석하였다(Table 1).

비료배합 비율(Study I)은 무시비구를 포함하여 6가지를 아래와 같이 수행하였다. 무시비구, 3:4:1 처리구, 3:4:1+퇴비 처리구(부숙톱밥퇴비 1 kg을 토양과 골고루 섞어 이용), 3:4:2 처리구, 3:8:1 처리구, 6:4:1 처리구로 질소비료는 요소, 인산비료는 용과린, 칼륨비료는 염화가리를 이용하였다. 시비량은 모두 동일하게 본당 30g을 등고선 방향으로 반원형 시비하였다. 각 처리별 조사구의 크기는 10m × 20m이며, 처리별 3반복씩 총 18 조사구를 설치하였다. 처리구와 반복 사이에는 5m의 완충지대를 두었다.

비종별 시비량 시험(Study II)은 산림용고형복합비료와 UF완효성복합비료 두가지 비종에 대하여 각각 표준구, 2배량구, 3배량구 6개 처리를 두었다. 조사구의 크기는 10m × 15m이며, 처리별 3반복씩 총 18 조사구를 설치하였다. 처리구와 반복 사이에는 5m의 완충지대를 두었다.

시비 처리전 2003년 6월에 기초생장 조사를 실시하였으며, 2003년부터 2006년까지 매년 10월에 수고 및 근원경 생장을 조사하였다. 비료배합 비율과 비종별 시비량 시험 처리에 따른 수고 및 근원경 차이는 Duncan의 multiple comparison을 이용하여 유의수준 5%에서 분산분석(ANOVA)하였다.

Table 1. Soil characteristics of study sites.

Site	Soil layer	pH	Organic matter (%)	Total N (%)	Available P_2O_5 (mg kg^{-1})	CEC	K^+	Na^+	Ca^{2+}	Mg^{2+}
						---- cmol$_c$ kg^{-1} ----				
Study I	A	5.50	7.30	0.24	9.00	11.59	0.54	0.11	2.48	0.90
	B	5.40	5.70	0.20	7.00	11.67	0.48	0.11	1.80	0.78
Study II	A	5.20	5.80	0.16	7.00	11.18	0.43	0.10	1.40	0.59
	B	5.10	4.00	0.12	4.00	11.37	0.38	0.10	0.59	0.47

결과 및 고찰(Results and Discussion)

시험지 토양형은 갈색건조산림토양(Dry brown forest soil : B_1)으로 토심은 40~70cm이며 토양 견밀도는 12~16mm(1.8~3.5 kg cm^{-2})로 나타났다. 시험지 토양의 pH는 5.1~5.5이며 유기물 함량은 4.0~7.3%로 갈색건조산림토양에 비해 비교적 높았다. 유효인산은 4~9mg kg^{-1}으로 매우 낮고 치환성 양이온도 갈색건조산림토양의 평균값에 비해 다소 낮은 경향을 보였다(Table 1).

다양한 비료배합 비율 시험(Study I)에서 대조구에 비하여 모든 처리구에서 처리후 1년 그리고 4년 후에 수고 및 근원경 생장이 높았다(Table 2). 무처리를

제외한 모든 처리에서 유의한 차이는 없었으나 수고 NPK=3:8:1에서 가장 높은 생장을 보였다. 근원경은 NPK=6:4:1과 NPK=3:8:1에서 유의하게 높은 생장을 보이고 있다($P < 0.05$).

Table 2. Height and root collar diameter growth after various combined fertilizer treatments (Study I).

Treatments	Height (cm)			Root collar diameter (cm)		
	2003 yr	2004 yr	2006 yr	2003 yr	2004 yr	2006 yr
Control	9.1	25.4	55.4	0.25	1.01	2.28
NPK3:4:1	9.6	34.5	95.1	0.26	1.32	2.95
NPK3:4:1+Manure	9.6	31.6	101.1	0.25	1.23	3.32
NPK 3:4:2	9.0	33.4	98.8	0.24	1.26	3.16
NPK6:4:1	9.1	32.7	101.2	0.25	1.49	3.84
NPK3:8:1	9.3	33.6	103.5	0.25	1.50	3.81

비종별 시비량 시험(Study II)에서 두 비종 모두에서 시비량이 증가하면서 수고 및 근원경 생장이 증가하였다(Table 3). 수고생장은 고형복합비료와 완효성복합비료 2배량구와 3배량구에서 각각 가장 높은 생장을 보였으나 두 처리간에는 유의성이 없었다. 근원경은 두 비종에서 모두 3배량에서 가장 높은 생장을 보였다. 고형복합비료에 비하여 완효성복합비료 처리는 수고는 평균 10%, 근원경은 4.5% 이상 증가시켰다.

산불피해를 입은 갈색건조토양에 식재된 소나무의 초기 생장을 증가시키기 위해서는 기존 시비기준인 NPK=3:4:1보다는 NPK=3:8:1 조합의 시비가 양호하며, 고형복합비료보다는 UF완효성복합비료 2배량 시비가 적합하게 나타났다. 다량의 시비가 산림의 생태적 또는 환경적 안전성과 지속적 생장에 미치는 영향을 조사하기 위해서는 향후 장기적인 모니터링이 요구된다.

Table 3. Height and root collar diameter growth after solid combination fertilizer and slow-released combination fertilizer treatments (Study II).

Fertilizer types &	**Height (cm)**			**Root collar diameter (cm)**		
Amount	**2003 yr**	**2004 yr**	**2006 yr**	**2003 yr**	**2004 yr**	**2006 yr**
Solid, Standdard	10.5	34.3	91.2	0.25	0.39	2.86
Solid, Double	9.8	35.6	105.2	0.28	0.39	2.72
Solid, Triple	10.1	36.2	108.2	0.22	0.47	3.06
Slow-released, Standard	9.3	36.9	100.6	0.25	0.38	2.83
Slow-released, Double	10.0	38.1	118.0	0.24	0.41	3.30
Slow-released, Triple	8.3	34.9	115.1	0.23	0.50	3.90

Characteristics of soil erosion in early stage measured by the collecting method at catchment outlet in burned forest area
소유역 출구조사방법에 의한 산불피해지역의 초기 토사유출 특성

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Abstracts

This study was carried out to measure soil erosion in early stage after forest fire occurred at Yangyang in 2005. The measuring the volume of soil erosion had been conducted just after fire occurrence. We used the method that collects the erosion soil in outlet of small catchment area. The results are as follows. Leaf Area Index (LAI) was decreased from 0.82 to 0.54 after forest fire occurrence. The volume of soil erosion was increased according to the decrease of coverage by 33 percents. There is a big difference in the volume of the soil erosion between forest fired area and general area until burned forest area was not covered by vegetation. The difference of the volume in two sites is increased as the unit rainfall volume is increasing. The difference of the soil erosion volume was very huge until July, but the difference was not so big after August owing to shrub invasion. In comparing with yearly volume of soil erosion, 1,310 kg/ha in burned area was almost 10 times more than 134 kg/ha in unburned area.

요 약

2005년 4월 강원도 양양에서 발생한 산불을 대상으로 발생초기 산불지 토사유출량과 일반산지 토사유출량의 차이를 비교하기 위하여 기존 설치된 구곡막이를 활용하여 강우별 토사유출량을 측정하였다. 산복과 계곡을 포함하는 유역단위의 토사유출량을 측정하기 위하여 유역 출구조사방법을 이용하였다.

산불 발생 이후 산불지와 비산불지에서 당해년도인 2005년 13차례

토사유출량을 측정•비교한 결과는 다음과 같다. 연구대상지인 양양산불지역의 엽면적지수 (LAI)는 산불지 0.54, 비산불지 0.82로 산불이후 산림울폐도가 33% 감소하였고 지표면 노출로 토사유출량이 증가하였다. 산불발생 이후 하층식생이 도입되기 전까지 산불지와 비산불지의 토사유출량 차이가 컸으며, 단위강우량이 많을수록 두 유역간 토사유출량의 차이가 큰 것으로 나타났다. 연간 시기별로 살펴보면 산불발생 직후부터 7월까지 산불지와 비산불지의 토사유출량은 큰 차이를 나타냈지만 8월 이후에는 토사유출량 차이가 거의 없는 것으로 나타났다. 산불 당해연도의 산불지와 비산불지의 연간 총토사유출량을 비교하면 산불지 1,310 kg/ha, 비산불지 134 kg/ha로 나타나 약 10배 정도 값의 차이를 나타냈다.

서론(Introduction)

산불은 임산물의 소실로 인한 물질적 피해뿐만 아니라 임상의 피복물까지 연소시킴으로써 토양이 노출되어 수분침투능 저하와 지표유출을 증대시켜 토사유출을 가속화하는 등 산림환경에도 막대한 피해를 야기시킨다(임업연구원, 2002). 마호섭 등(1997)은 산불지에서 강우량이 많으면 표면유출수가 증가하여 토사유출량이 많아진다고 하였고, 이창우 등(2004)은 토사유출량은 사면방위와 관련이 있다고 하였으며 고성산불의 경우 3년이 지나면 사면이 안정된다고 하였다. 또한 恩田 등(1997)은 첨두유량과 토양침식깊이와의 관련성에 대하여 보고하였다. 과거 산불피해지에서의 토사유출량 및 유출 특성에 관한 연구는 많이 있으나 (Wells 등, 1987; 이원규 등, 1988; 마호섭 등, 1997; 恩田 등, 1997; 이창우 등, 2004), 산불 당해년도의 토사유출에 관한 정보와 유역단위의 정확한 토사유출량에 관한 자료는 많지 않다.

재료 및 방법(Methodology)

토사유출시험지는 강원도 양양군 강현면 침교리와 적은리내 임야 2개 소유역을 대상으로 하였다. 산불발생 3일후 산불지 (유역면적 0.3ha, 남사면, 조사지점 위치 : 동경 128°35′16″, 북위 38°7′1″)와 산림지역인 비산불지 (유역면적 0.6ha, 북동사면, 조사지점 위치: 동경 128°35′54″, 북위 38°6′49″)에 있던 기존 구곡막이 대수면에 쌓인 토사를 준설하여 바닥에 천막재를 깔아 토사유출량 측정시험구를 설치하였다. 산불지와 비산불지 유역의 거리는 약 1km로서 지형 및 임상이 비슷한 지역이다.

토사유출량 조사는 강우가 있을 때마다 구곡막이 대수면에 쌓인 토사를 수거하여 실내에서 건조후 건조중량을 측정하였다. 각 기간 강우량은 인근 기상대인 속초기상대에서 강우자료를 취득하여 활용하였다. 침식은 주로 지표면에서 이루어지므로 하층식생밀도의 영향을 많이 받으나 상층목에 의한 공간개폐도 또한 영향을 주므로 엽면적지수를 측정하기 위하여 Hemisphere photography로 2005년 4월 20일 한차례 측정하여 비교하였다.

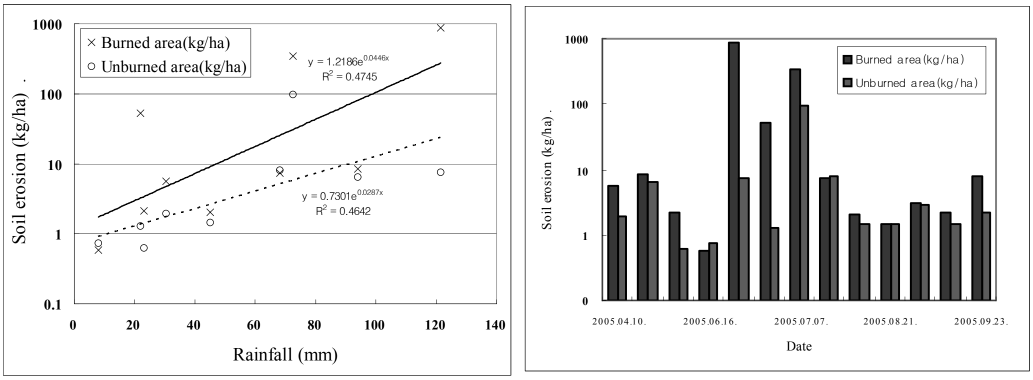
결과 및 고찰(Results and Discussion)

1. 엽면적지수 비교

산불이 발생하면 열로 인하여 수관에 영향을 주게 되며 울폐도가 감소하게 된다. 산불지와 비산불지 유역에서 5개의 엽면적지수를 평균하면 산불지의 경우 0.54, 비산불지의 경우 0.82로 산불이후 울폐도가 33% 감소한 것으로 나타났다.

2. 토사유출량 비교

2005년 8월 이전 강우를 대상으로 한 강우량별 토사유출량은 Figure 1의 (a)와 같이 지수함수적으로 증가하며 소량의 강우에서는 침식량에 큰 차이를 보이고 있지 않으나, 강우량이 집중되고 많아지는 하기에는 토사유출량의 차이가 커지는 것으로 나타났다. 본 결과는 마호섭 등(1997)이 강우량이 많을수록 표면유출수량도 많아지기 때문에 토사유출량도 많아진다고 한 주장과 동일한 결과라 할 수 있다. 반면, Figure 1의 (b)에서 같이 연간 시기별로 살펴보면 산불발생 직후부터 산불지와 비산불지의 토사유출량은 큰 차이를 나타냈지만, 산불지에서 하층식생이 침입하여 안정된 상태인 8월 이후에는 산불지와 비산불지의 토사유출량의 차이가 거의 나타나지 않았다. 따라서 산불피해지는 피해 당해연도 식생이 침입하기 전에 많은 토사가 유출되는 것으로 분석되었다.



(a) The volume of soil erosion as rainfall **(b) Temporal variation of soil erosion**

Figure 1. Comparison of the volume of soil erosion between burned and unburned area.

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Study on Function of Soil Erosion Control works in Damaged Area by Forest Fire

산불피해임지 사방공작물의 토사유출억제에 관한 연구

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Abstracts

Recently, the large forest fire has been increased in east Korea because of dried wind from the west at winter and spring season. The forest fire induce the 2nd disaster such as soil sediment disaster by soil erosion and hillslope collapse because of increasing frequence of heavy rainfall and typhoon by climate change. Therefore, damaged area by forest fire is required to rehabilitation as soon as possible to prevent soil sediment disaster. This study was carried out to suggest proper rehabilitation countermeasures of damaged area by forest fire through investigating effects and ecomomical efficity for each method used in soil erosion control woks. 10 plots including control plot, which are Tree Planting, Treatment of Soil Stabilizer, Hydro-Seeding, Burned-Log Barrier Works and so on, was constructed at June 2002 in Samchuk city where was damaged area at April 2000. The result shows that the average soil erosion was decreased from 3.88 ㎏/ha/㎜ (2002. 8. ～ 2003. 6.) to 0.26 ㎏/ha/㎜ (2005. 10. ～ 2006. 10.). The economic effecity on preventing soil erosion of each soil erosion control works were as follows order ; Tree Planting > Treatment of Soil Stabilizer > Hydro-Seeding > Burned-Log Barrier Works > Terrace-Sodding Works > Vegetation Sack Works > Stone Masonry > Works   Direct Seeding.

요 약

산불피해임지의 복구에 사용되고 있는 토사유출억제용 사방구조물의 효과구명을 위해 2000년 4월 산불피해가 발생한 강원도 삼척지역의 산지사면을 대상으로 다양한 사방구조물을 설치하여 공종별 토사안정효과를 구명하였다. 피해목 잔존구, 피해목 제거구 등 대조구를 포함하여 일반조림, 종자뿜어붙이기, 전면파종, 산돌쌓기, 불탄나무 편책공, 선떼붙이기, 녹색마대공, 토양안정제 처리 등 10개의 시험구를 조성하였으며, 시험규모는 각 공종별 10m×15m이다. 시험구별 처리는 2002년 7월에 완료하였으며, 8월부터 강우량과 토사유출량을 조사하였다. 토사유출량은 전시험구 평균 3.88㎏/ha/㎜ (2002. 8. ～ 2003. 6.), 0.29 ㎏/ha/㎜ (2003. 7. ～ 2004. 6.), 0.32㎏/ha/㎜ (2004. 7. ～ 2005. 10.)으로 다소 늘었다가, 다시 0.26㎏/ha/㎜ (2005. 10. ～ 2006. 10.)으로 감소하였다. 각 구조물의 경제성 평가를 위해 토사 1kg을 저지하는 필요한 시공단가(2004년 기준)를 비교한 결과, 전면파종 > 산돌쌓기 > 녹색마대공 > 선떼붙이기 > 불탄나무 편책공 > 종자뿜어붙이기 > 토양안정처리 > 일반조림 순으로 단가가 높은 것으로 나타나 일반조림, 토양안정처리, 종자뿜어붙이기 등이 토사저지효과가 우수한 것으로 나타났다.

서론(Introduction)

우리나라는 봄과 겨울철 건조하고, 동해안 지역의 높새바람에 의한 기후 특성상 산불이 다발하고 있다(동해안 산불피해 공동조사단, 2000). 특히 1996년 고성산불, 2000년 동해안 산불, 2005년 양양산불의 사례처럼 산불이 점점 대형화되는 추세이며, 이로 인해 중요한 산림자원은 물론 문화재마저 소실되는 등 많은 재산피해가 발생되고 있다. 산불은 임산물의 소실로 인한 물질적 피해뿐만 아니라 임상의 피복물까지 연소시킴으로써 토양이 노출되어 강수 침투능의 저하와 지표유출을 증대시켜 토사유출을 가속화하는(恩田 등, 1997)등 산림환경파괴 및 토사재해와 같은 2차피해를 야기시킨다. 2000년 동해안 산불피해지역에서 2002년 태풍 ‘루사’ 내습시 산사태 및 토사유출로 인해 타 지역보다 많은 피해가 발생한 바 있다(임업연구원, 2002). 최근 연구결과에 따르면 산불피해지의 토사유출은 산불발생 후 1-2년기간에 심각한 수준인 것으로 보고되고 있으므로(이창우 등, 2004), 산불피해지의 복원과 관련하여 2차 토사재해방지를 위한 효율적 대책을 검토할 필요가 있다. 본 연구에서는 현재 산불피해지역에 시공되고 있는 다양한 사면처리공법에 대한 토사유출억제

측면에서 실효성을 파악하기 위해 산불피해지 현지에 사면처리공법을 적용하여 각 공법들의 토사유출저감효과와 경제성을 비교, 검토하였다.

재료 및 방법(Methodology)

산불피해지 산지사면에 사방구조물을 설치하여 토사안정효과를 조사하기 위하여 2000년 4월 산불피해지인 삼척 국유림 내에 시험지를 선정하였다. 시험규모는 각 공종별 10m×15m로 피해목 잔존구, 피해목 제거구 등 대조구와 일반조림, 종자뿜어 붙이기, 전면파종, 산돌쌓기, 불탄나무 편책공, 선떼붙이기, 녹색마대공, 토양안정제 처리 등 10개의 시험구를 조성하였다. 각 시험구별 처리는 2002년 7월에 완료하였으며, 8월부터 강우량과 토사유출량을 조사하였다. 2002년 5차례, 2003년 5차례 총 10차례 토사유출량을 기간별로 조사하였고, 2004년 이후 2006년까지는 년 1차례 조사하였다. 조사항목은 강수량, 토사유출량이며, 2003년 10월에 식생피도를 조사하였다. 강수량은 태백 기상대의 일별 강우량을 이용하였으며, 토사유출량은 각 시험구별로 사면하부에 토사를 수집, 기간별로 채취하여 기건 상태의 중량을 측정하였다. 또한, 시험구별 토사유출량은 강수량 1mm당 토사유출량(kg/ha)으로 비교 하였다.

결과 및 고찰(Results and Discussion)

총 조사기간(2002.8.- 2006.10.) 중 처리공법별 토사유출량은 피해목 제거구 (2.98kg/ha/mm), 피해목 잔존구 (2.29kg/ha/mm), 전면파종 (1.96kg/ha/mm), 선떼붙이기 (1.41kg/ha/mm), 산돌쌓기 (0.94kg/ha/mm), 토양안정제처리 (0.78kg/ha/mm), 일반조림(0.75kg/ha/mm), 종자뿜어붙이기(0.64kg/ha/mm), 녹색마대공 (0.51kg/ha/mm), 불탄나무 편책공(0.11kg/ha/mm)순으로 높게 나타나, 산불피해지는 자연방치구가 사면처리구보다 많은 토사를 유출시키므로 토사유출억제를 위해서는 사면처리가 필요한 것으로 판단되었다. 특히 불탄나무 편책공, 녹색마대공, 종자뿜어붙이기 등이 토사유출억제 효과가 큰 것으로 나타났고(Figure 1), 불탄나무 편책공은 현지재료를 그대로 사용할 수 있으며 토사유출억제 효과가 뛰어나 효율적인 방법으로 판단되었다.

각 사면처리별 토사 1kg억제 단가를 비교함으로써, 사면처리에 의한 경제성을 분석하였다. 그 결과, Figure 2에 나타낸 바와 같이 전면파종 > 산돌쌓기 > 녹색마대공 > 선떼붙이기 > 불탄나무 편책공 > 종자뿜어붙이기 >

토양안정처리 > 일반조림 순으로 시공단가가 높은 것으로 나타나, 일반조림, 토양안정처리, 종자뿜어붙이기가 산불피해지 토사유출억제에 가장 경제적인 것으로 판단되었다. 일반조림지는 토사유출억제 능력에서는 4번째로 나타났으나, 사면처리 후 경제적 측면에서는 가장 탁월한 것으로 나타났다. 따라서 산불피해지 토사유출억제를 위한 사면처리를 계획할 경우에는 토사유출억제 혹은 경제성 중 어느 것을 우선으로 할 것이냐를 검토한 후 계획을 수립하면 효율적일 것으로 판단된다.

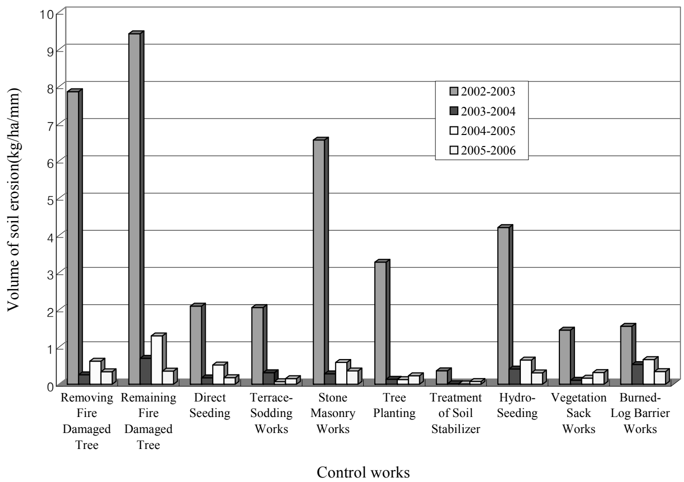

Figure 1. The volume of soil erosion by each plots and period.

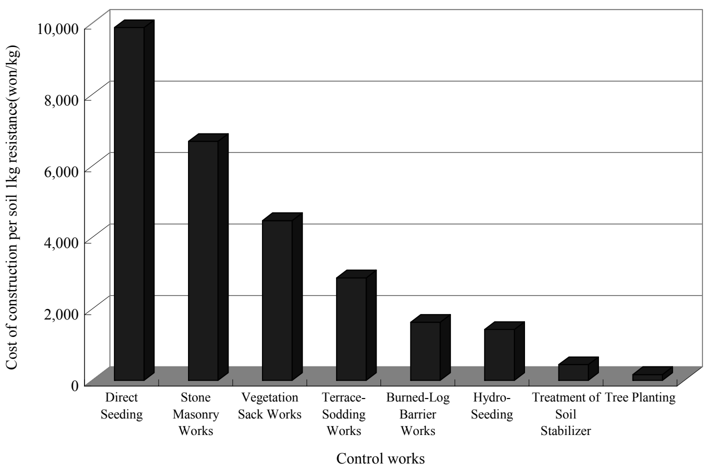

Figure 2. Construciton cost per soil 1kg resistance(won/kg) by each plots.

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Changes of suspended solid and characteristics of runoff in forest fire area, the east coast Korea
동해안 산불피해지역의 유출특성과 계류수의 부유물질 변화

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Abstracts

The dry seasons of Korea are particularly prone to fire due to the drought and accumulation of grassy fuels. The effects of forest fire on water discharge and suspended soild loading in flowing streams were examined for burned and unburned catchments in the east coast of Korea. Water discharges from the unburned catchment in dry season were much larger than that from the burned catchment because there was sustainable stream flow from the unburned catchment during drier, which may regulate the water retention from forest catchment into stream. Suspended soild of the burned catchment was higher than that of the unburned catchment because sediments were being easily discharged into the streams at the burned area even during low rainfall events. The destruction of leaf litter and vegetation by the fire contributed to the reduction on water discharge and the increase on suspended soild yield caused by a strong water-repellency layer formed.

요 약

한국의 건기는 적은 강우량 및 낙엽과 식생의 건조로 인해 산불이 발생하기 쉬운 경향이 있다. 본 연구는 산불에 의한 물환경 변화 특성을 규명하기 위해, 동해안의 산불발생유역과 산불비발생유역에서 계류의 유출량과 부유물질의 농도 변화 특성을 규명하고자 실행하였다. 산불비발생유역에서

갈수기의 계류 유출량은 산림 수원함양에 따른 물의 일정한 공급으로 산불발생유역의 유출량보다 많았다. 또한 산불발생지에서 부유물질의 유출은, 적은 강우량에도 부유물질이 쉽게 유출되기 때문에 산불비발생지보다 높은 농도값을 나타내었다. 산불에 의한 식생과 표토 보호물인 낙엽의 제거는 토양의 물리적 성질을 악화시켜 토양표면에 불투막을 형성하게하여 계류수의 유량을 감소시키고 부유물질의 유출을 증가시키는 것으로 나타났다.

서론(Introduction)

산불피해지에서 표면유출의 증가에 따른 다량의 부유물질, 양분 및 그 외 물질들의 유출은 인접하는 계류와 호소 등으로 유입되어 수질악화와 수생생물의 서식환경을 악화시키고 있다(Townsend & Douglas, 2004). 또한 산불로 인한 토양 물리성의 악화는 수분 침투능과 수분 보유력을 악화시켜 산림의 수원함양 기능을 저해시키고 있다(정용호 등, 2004).

한국의 봄과 가을(갈수기)은 강우량이 적어 산림 내 식생과 낙엽 등이 건조해져 있기 때문에 산불이 잘 발생하는 경향이 있다. 1990년대 이후, 동해안의 대부분의 산림은 산불로 인하여 피해를 받았다. 하지만 산불 피해로 인한 계류의 수질과 유량 변화에 미치는 영향을 밝히는 연구는 거의 실시되지 않고 있다(정용호 등, 2004). 따라서 본 연구는 산불에 의한 물환경 변화 특성을 규명하기 위해 산불발생유역과 산불비발생유역에서 계류의 유출량과 부유물질의 농도 변화 특성을 규명하고, 산불발생유역의 물환경 보전대책수립을 위한 자료를 확보하고자 실행하였다.

재료 및 방법(Methodology)

산불에 의한 물환경 변화를 규명하기 위하여 강원도 삼척시에 소재한 산불발생유역과 산불비발생유역을 조사지로 선정하였다(Figure 1). 산불발생유역은 유역면적이 61ha로 2000년 4월에 발생한 산불로 인하여 피해를 받은 지역이다. 조사지의 모암은 화강편마암이며, 소나무림이 주요한 식생이다.

산불에 따른 계류의 수환경 변화를 규명하기 위해, 계류수의 유량은 산불발생유역과 산불비발생유역에서 2001년 2월부터 8월까지, 부유물질은 2001년 9월9일의 강우(총강우량 217mm)에 대하여 수문관측을 실시하였다.

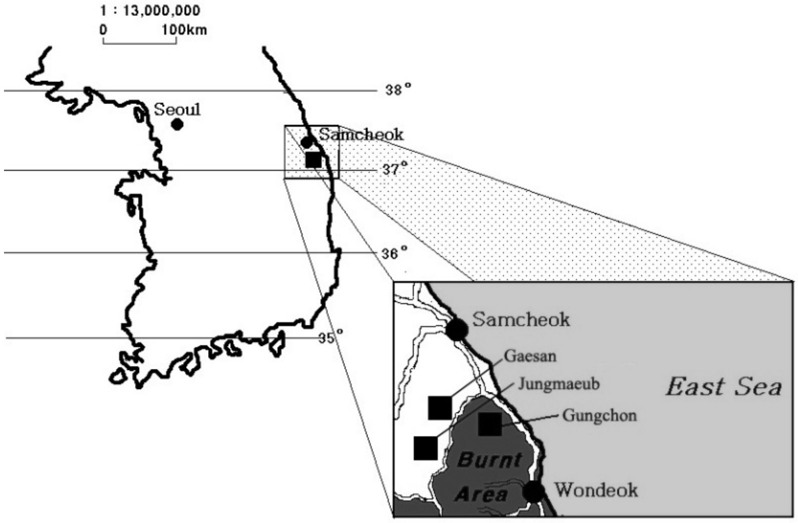

Figure 1. The location of experimental catchments.

결과 및 고찰(Results and Discussion)

산불에 따른 계류의 유량 변화

강우가 없는 평수기에서, 산불비발생지의 유량은 산불발생지보다 높게 나타났다(Figure 2a). 특히 산불비발생유역에서 갈수기(3월)의 유량은 산림 수원함양에 따른 물의 일정한 공급으로 인해 산불피해지보다 유출량이 현저히 많았다.

그러나 강우에 따른 유량 변화의 경우, 산불발생지의 최대 홍수유출량은 $0.67m^3/hr/ha$로서 산불비발생유역 $0.38m^3/hr/ha$의 약 1.8배 높았다(Figure 2a). 이는 산불에 의해 낙엽층과 식생이 파괴되어 표토가 건조해지면서 단단해지는 불투막이 형성되어 지표유출이 증가되었기 때문으로 판단되었다.

산불에 따른 부유물질의 농도 변화

부유물질은 유량이 증가함에 따라 증가하고 있었으며, 산불발생지유역의 부유물질 농도는 산불비발생유역보다 현저히 높게 나타났다(Figure 2b). 이는 산불로 인해 낙엽 등의 임상물이 유실됨에 따라 토양의 물리적 성질이 악화되어 지표유출이 증가되고 표층토양의 침식이 가속화되었기 때문으로 판단되었다.

산불은 계류수의 유량 감소와 부유물질의 유출 증가 등의 물환경 악화에 영향을 미치고 있으며, 이를 개선하기 위해서 토양 물리성을 회복시키기 위한 조림 등의 식생복원사업이 시급히 실행되어야 할 것으로 생각된다.

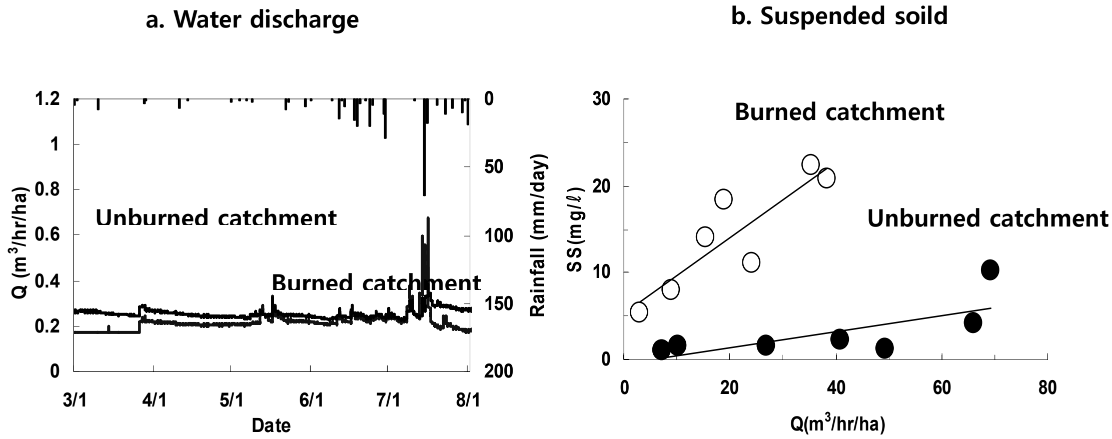

Figure 2. The water discharge (a) and suspended soild (b) in flowing streams at burned and unburned catchments.

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The Characteristics of Post-Fire Areas by Stand Structure and Topographical Factors
임분구조 및 입지환경인자에 따른 산불피해지 특성

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Abstracts

This study was carried out to support the development of forest fire management systems. We need a better understanding of how the compositions of stand structure and topographical factors are linked to forest fire causes. On the basis of data obtained from post-fire areas(Gosung-gun, Eastern coastal region, Yesan-gun, Cheongyang-gun, Yangyang-gun, stand structure and topographical factors were analyzed using Quantification theory(I). Forest fire hazard in the broad-leaved forest and mixed forest was low but *Pinus. densiflora* and higly stand density seemed to be high. As a result of the quantification analysis, main factors that would lead to forest fire intensity were shown in order of forest type(*P. densiflora*), slope(30°≤), crown density(low), and so on. In the partial correlation analysis between forest fire damage and topographical factors, it was shown that in the order of stand density, forest floor, slope, however aspect was not significant.

요　약

본 연구는 산불에 대한 새로운 관리방안을 수립하기 위하여 산불 피해지역의 임분구조와 입지환경인자간의 연관성에 대하여 분석하였다. 이를 위하여 고성군, 동해안지역, 예산군, 청양군 그리고 양양군 등의 과거 산불발생지역으로부터 얻은 임분구조와 입지환경인자 자료를 바탕으로 수량화(Ⅰ)류에 의한 분석을 실시하였다. 임분구조에 따른 산불피해는 활엽수림과 혼효림 임분은 낮았으며, 단순 소나무림과 임분밀도가 밀할수록 피해도가 높은 것으로 조사되었다. 수량화분석을 통하여

산림의 입지환경인자와 산불피해와의 관계를 분석한 결과 임상과 경사도 30° 이상, 그리고 수관밀도 순으로 영향을 미치는 있는 것으로 조사되었다. 또한 산불피해 정도와 입지환경인자간의 편상관분석을 실시한 결과 임분밀도와 임상, 경사도 순으로 영향을 미치고 있으며, 방위는 유의성이 없는 것으로 나타났다.

서론(Introduction)

산불은 산림의 식생 분포에 있어서 가장 큰 교란의 원인이 된다. 특히 우리나라의 산림식생은 침엽수림 분포가 높고, 또한 단순림으로 구성되어 있어 산불에 취약한 실정이다. 우리나라의 산불은 대부분 춘기에 많이 발생되고 있으며, 특히 영동지역의 경우 유사푄(Quasis-foehn) 현상으로 인해 건조하고 강풍이 심하게 불어 대형 산불이 빈번하게 발생하고 있다(Lim, 2000). 따라서 산림의 효율적인 관리를 위해서는 해당 산림의 임분구조 및 입지적 환경요인에 따라 적절한 산림경영을 시행해야한다(Lee *et a*l., 2008; Park, 2002). 본 연구의 목적은 산불발생지역의 임분구조와 입지환경인자 분석을 통하여 산불에 대한 산림관리방안을 제시하는 것이다.

재료 및 방법

산불피해지역의 임분구조 및 입지환경을 분석하기 위하여 1996년 강원도 고성산불, 2000년 동해안 산불, 2002년 충남 예산, 청양산불 그리고 2005년 강원도 양양 산불피해지역에 대한 현지조사와 자료분석을 실시하였다. 또한 임분구조에 따른 산불피해 정도를 분석하기 위하여 지위지수, 수령, 임목본수, 수고, 흉고직경, 재적 등의 인자를 조사하였다. 조사자료에 대하여 산림의 입지환경인자와 임상조건에 따른 산불피해도간의 관계를 파악하고자 독립변수가 질적변량이고, 종속변수가 양적변량인 자료의 분석에 적합한 수량화 (I)류의 방법을 적용하였다. 자료의 분석을 위하여 입지환경인자들에 대하여 인자별 카테고리를 구분하였으며(**Table 1**), 투입된 인자 각각의 Score, Range등의 값을 이용하여 기여도를 분석하였으며, 편상관분석을 실시하여 산불피해도 분석에 투입된 인자들의 기여율을 분석하였다.

Table 1. Classification of category for stand structure and topographical factors.

Item	Category
Altitude	Topographical map of 10m unit
Aspect	North, South, East, West
Slope(°)	30° < , < 30°
Forest type	Pure pine forest Mixed oak orest Mixed forest of broad-leaved Mixed forest needle and broad-leaved.
Local topography	Hilltop Hillside Foot of hill Plain
Crown density	Dense, Medium, Rare
Stand density	0.1 - 0.5, 0.6 - 1.0, 1< 3
Degree of damage	No. of dead trees / No. of total trees

결과 및 고찰(Results and Discussion)

산불 피해지 임분유형

수종 및 임분구조 유형이 산불 발생시 산림에 미치는 피해 영향을 구명하기 위하여 산불 피해지역의 임분구조를 분석한 결과 대부분 침엽수와 활엽수 혼효임분으로 구성되어 있었으며, 임상유형에 따른 산불 피해정도를 분석한 결과 활엽수림의 경우 피해 정도가 낮은 것으로 조사되었다. 특히 굴참나무와 참나무류 혼효임분의 경우 피해가 경미하였는데 이는 굴참나무가 산불에 강한 내화성수종이기 때문인것으로 판단된다. 그러나 침엽수림의 경우 수종에 상관없이 대부분 피해가 심한 것으로 조사되었으며, 특히 소나무 단순림은 임분구조에 상관없이 피해 정도가 매우 높아, 산불에 취약한 것으로 나타났다. 조사대상지 임분의 영급구조는 3~4영급, 임목밀도는 450 ~ 1,800본/ha, 울폐도의 범위는 다양하게 구성되어 있으나, 이들 인자와 피해도와의 관계는 명확하게 나타나지 않는 것으로 분석되었다. 산불의 피해정도에 영향을 미치는 인자에는 산불당시의 풍향과 풍속, 입지 조건, 임분 상태 등 여러 환경조건이 있으나, 임분구성만을 가지고 판단한다면, 임분 상 . 하층의 층위구성 및 종의 분포 구성이 상호 관련성이 있는 것으로 조사되었다.

수량화 및 편상관분석

산불피해에 영향을 미칠 것으로 예상되는 입지환경인자와의 관계를 분석하기 위하여 수량화 (I)류의 방법을 적용한 후, Score 계산 및 편상관분석을 실시하였으며, 입지환경인자를 Range 값으로 분석한 결과 산불피해에 영향을 많이 미치는 인자는

임목도, 임상, 경사도 순이었으며, 기여율이 높은 인자들에 대한 항목별 기여도를 살펴보면 임상에서는 활엽수, 표고 200m이하, 경사 30° 이상에서 피해율이 높은 것으로 판단되었다(**Table 2**). 그러나 각 인자내의 항목에 따른 기여율은 일률적으로 해석하기가 곤란하였다. 따라서 이 부분에 대한 해석은 자료의 재분류, 추가, 제거 등 다양한 방법으로 분류를 실시, 재검토해야 할 것으로 사료된다. 또한, 입지환경 인자에 대하여 편상관분석을 실시한 결과 임목도, 임분 구성 수종과 경사도가 유효한 인자로 분석되었으며, 방위의 기여도가 가장 낮았다(**Figure. 1**).

Table 2. Score table of stand structure and topographical factors in post-fire areas.

Item	Category	Estimate	Standard error	t-Value	Pr>|t|	Range
Constant	Intercept	86.3	15.7	5.5	<.001	
Forest type (X1)	*P. densiflora*	-14.9	12.0	-1.3	0.219	40.96
	Mixed forest of oak	-27	17.4	-1.6	0.129	
	Broad-leaved forest	-40.9	15.1	-2.7	0.010	
	Mixed forest coniferous and broad-leaved	0				
Altitude(X2)	100m >	2.4	9.2	0.26	0.792	8.278
	200m >	8.3	10.3	0.8	0.427	
	200-400m	4.0	10.2	0.4	0.694	
	400m <	0	0	0	0	
Aspect(X3)	East	-2.8	10.6	-0.3	0.794	4.158
	West	-3.9	8.8	-0.4	0.662	
	South	0.3	8.9	0.03	0.973	
	North	0	0	0	0	
Slope(x4)	30 <	15.3	7.3	2.09	0.043	15.27
	30 >	0	0	0	0	
Local Topography (x5)	Hilltop	5.1	9.2	0.55	0.583	9.77
	Plain	-1.1	11.9	-0.1	0.928	
	Foot of hill	8.7	8.9	0.97	0.336	
	Hillside	0	0	0	0	
Crown density(X6)	Rare	10.7	9.4	1.13	0.263	10.68
	Medium	7.4	10.1	0.74	0.466	
	Dense	0	0	0	0	
Stand density (X7)	0.1-0.5	-56.2	14.1	-4	3E-04	57.5
	0.6-0.9	1.5	8.1	0.19	0.854	
	1<	0	0	0	0	

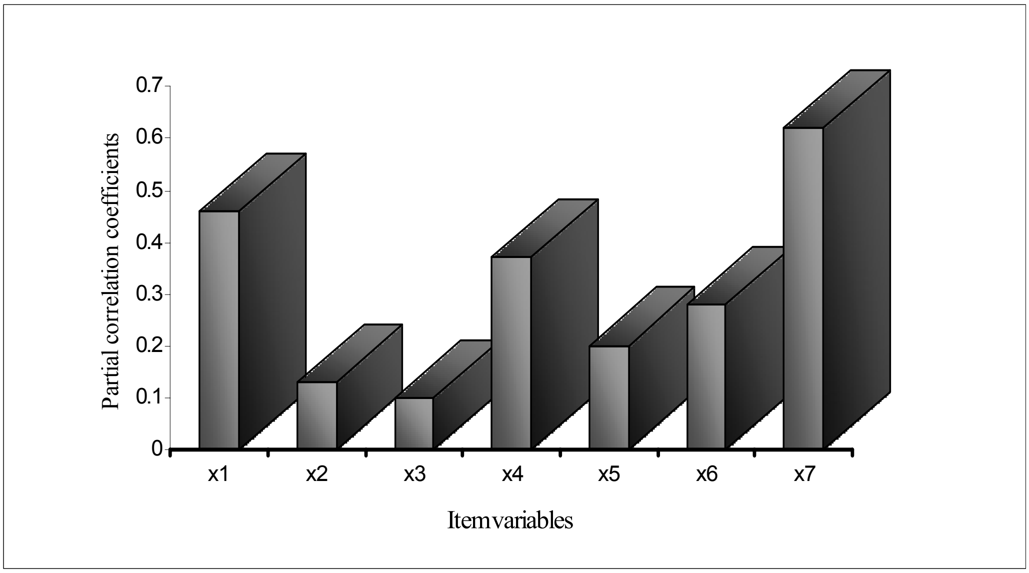

Figure 1. Partial correlation coefficients of stand structure and topographical factors for forest fire damage intensity.

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Forest Fire and Life Strategy of Butterflies
산불과 나비의 생존전략

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Abstracts

In early yeas after forest fire, butterflies of generalist which have high mobility, feed on diverse food plants, live on wide range of physical condition, and have weak competitive ability against other species may be abundant. However, as vegetations recover in fired forest, butterflies of specialist which have low mobility, feed on specific food plants, live on narrow range of physical condition, and strong competitive ability may increase. We tested this hypothesis using data of butterfly monitoring that were monthly surveyed from April to October for 2 years at 4 sites, which include fired forest of 0-1 years, 5-6 years, secondary pine forest of about 40 years, and primary deciduous forest of about 100 years. Butterflies having 1-2 generations per year and feeding on plants of one family was classified as specialist, and those having 3 or more generations per year and feeding on plants of 2 or more families as generalist. Proportion (%) of generalist decreased in number of species as year of forest increased, but that of specialist did not show significant relationship with year of forest. However, proportion (%) of generalist and specialist in abundance (i.e. number of individuals) corresponded with the hypothesis. Generalists were high in early years of forest fire, and declined as year of forest increase. The opposite was the case in specialist. Abundance (%) of specialist showed highest value of correlation with forest year, implying high possibility of indicator for forest recovery or forest years.

요 약

산불 초기에는 이동성이 강하면서 먹이의 특이성이 낮고 서식가능한 물리적 범위가 넓으나 경쟁에는 약한 generalist의 나비류가 많이 나타났다가, 식생이 회복됨에 따라 먹이나 서식범위가 좁으나 특정 환경에서 경쟁력이 높은 specialist의 나비류가 증가할 것 으로 예상된다. 이러한 가설을 산불이 발생한지 0-1년된 산림, 5-6년 된 산림, 임령이 40년 가량된 이차림(소나무림), 임령이 100년 가량된 극상활엽수림의 4곳에서 4월부터 10월까지 월 1회씩 2년간 조사한 나비조사자료를 이용하여 검정하였다. 나비류의 생존전략은 연간 세대수가 1-2세대이면서, 한 개 과의 식물을 섭식하는 종들을 specialist, 3세대 이상이면서, 한 개과 이상의 식물을 섭식하는 종들을 generalist로 정의하였다. 종수의 비율을 보면 specialist는 임령과 별다른 관계가 없었으나, generalist 는 임령이 높아 질수록 줄어드는 경향이 나타났다. 개체수의 비율은 가설과 일치하는 경향을 보였다. Generalist 는 산불초기에는 개체수의 비율이 높았다가 임령이 높아질수록 낮아지는데 비해, specialist는 반대의 경향이 나타났다. Specilist의 개체수 비율은 임령과 가장 높은 상관을 보여, 산림회복이나 임령에 대한 지표로서의 가능성을 보여주었다.

Introduction

The generalist/specialist strategy is generated along a continuum of selection pressures associated with different levels of disturbances (Kithara et al. 2000). We tested whether the generalist/specialist concept may be applied to butterfly communities along disturbance gradients caused by forest fire.

Methodology

For the disturbance gradient after forest fire, four sites were selected for this study (Table 1). Abundance of butterflies were monthly monitored from April to October for 2 years at each site using the line transact count (Pollard 1977, Pollar and Yates 1993, Yamamoto 1975). We modified Kitahara and Fuji's method (Kitahara and Fuji 2000) to classify butterflies into generalist or specialist. They classified butterflies into generalist or specialist based on votinisms (i.e. number of generations per year) and numer of species of food plants. They defined multivoltinism (more than bivoltine) as seasonal generalists, and oligovoltines (uni- or bivoltines) as seasonal specialists. They defined “species whose larvae feed on ten or fewer species belonging to one taxonomic family” as feeding specialists, and “species whose larvae feed on more than ten plant species belonging one family or plants belonging two or more families” as feeding generalists. We simplify their classification method on feeding strategies as followings; “species whose larvae feed on plants belonging to one family” as feeding specialists and “species whose larvae feed on plants belonging to two or more families” as feeding generalists. Butterflies which were classified as feeding generalist and seasonal generalist were defined as generalist, whereas butterflies classified as feeding specialist and seasonal specialist were defined as specialist.

Table 1. Location, vegetation and year of vegetation for study sites

Location	Vegetation			Year of vegetation
	before fire	after fire	no fire	
Gyongbuk Uljin	pine forest	grasslands		0-1 y
"			pine forest	~ 40 y
Kwangwon Samcheok	pine forest	shrubs and grasslands		5-6 y
Kyunggi Pochon			deciduous forest	~ 100 y

Results and Discussion

Number of species and individuals of butterflies which were counted for two years at four study sites are shown in table 2. The values of species richness and abundance are highest in the site which were fired before 5-6 years. The sites of being fired before 0-1 years and of secondary forest were intermediate in species richness and lowest in abundance of butterflies. Meanwhile, the site of primary forest is lowest in species richness and highest in abundance. Species richness and abundance do not show linear relationships with forest recovery. However, proportion of generalist and specialist have linear relationships with forest recovery, corresponding with the generalist/specialist hypothesis. In the case of species richness, proportion of generalist decrease as year of forest increase, whereas that of specialist did not have linear relationship with year of forest (Fig. 1, Table 2). In the case of abundance, butterflies of generalist have negative correlation with year of forest and those of specialists have positive correlation with year of forest.

Table 2. Number of species and individuals of generalist and specialist butterflies at four study sites

Life strategy	Fire 0~1 y (1.5 y)		Fire 5~6 y (5.5 y)		Secondary forest (40 y)		Primary forest (100 y)	
	no of species	no of ind.	no of species	no of ind.	no of species	no of ind.	no of species	no of ind.
generalist	11	175	11	336	10	171	4	149
specialist	18	48	23	227	15	85	15	529
micellaneus	25	276	35	503	27	177	27	323
total	54	499	69	1066	52	433	46	1001

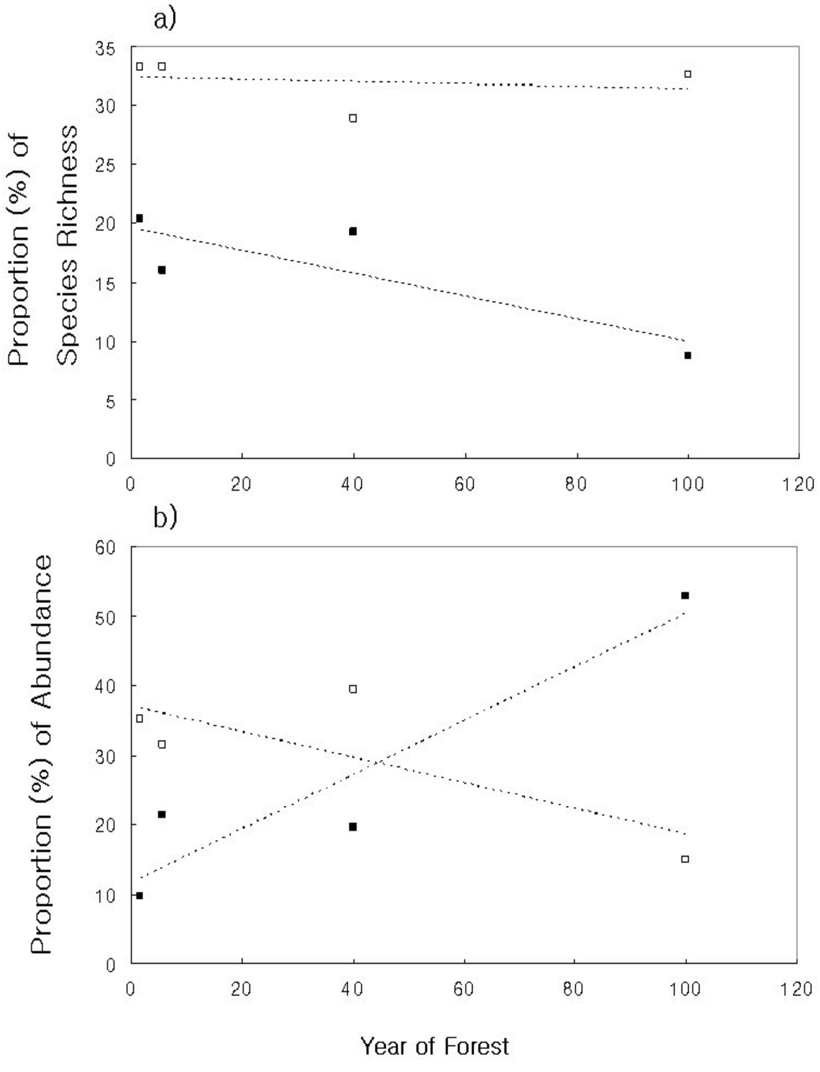

Fig. 1. Proportion (%) of generalist and specialist in butterfly communities at four study sites. White and black rectangles indicate specialist and generalist, respectively.

Table 2. *Regression analysis between proportion (%) of values (i.e. number of species or number of individuals) and years of forest. The values are shown in fig. 1.*

Items	Strategy	F	df	p	R^2
No of species	generalist	4.8	1, 2	0.16	0.706
	specialist	0.088	1, 2	0.79	0.042
No of individuals	generalist	3.186	1, 2	0.22	0.614
	specialist	14.724	1, 2	0.06	0.88

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Evaluation for Damaged Degree of Vegetation by Forest Fire using LiDAR and Digital Aerial Photograph

LiDAR와 항공사진을 이용한 산불발생지역의 식생피해등급 평가

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Abstracts

The amount of vegetation physically damaged by forest fire can be evaluated using LiDAR (Light Detection And Ranging) data because the loss of canopy height and width by forest fire can be relevant to the number of points transmitted to the ground through the canopy of the damaged forest. On the other hand, biological damage of vegetation caused by forest fire can be obtained from the Normalized Difference Vegetation Index (NDVI), which determines the vegetation vitality. In this study, the degree of physical damage from the LiDAR data was classified into two classes, Serious Physical Damage (SPD) and Light Physical Damage (LPD). The degree of biological damage using NDVI was likewise classified into two classes, Serious Biological Damage (SBD) and Light Biological Damage (LBD). Overall, the area damaged by forest fire was graded into the following four categories: 1) SPD and SBD, 2) LPD and SBD, 3) SPD and LBD, and 4) LPD and LBD.

요 약

본 연구에서는 이러한 LiDAR의 특성을 이용하여 산불이 발생한 강원도 양양지역 산림의 물리적 피해를 분석하였으며, 디지털 항공사진으로부터

Normalized Difference Vegetation Index (NDVI)를 추출하여 산림의 생물학적 피해를 분석하였다. LiDAR Returns 비율이 0.49 이상인 경우 물리적 피해정도를 고(高, Serious Physical Damage; SPD), 지표면 반사비율이 0.49 이하인 경우 물리적 피해정도를 저(低, Light Physical Damage; LPD)로 나타내었다. 또한 생물학적 피해는 0.12를 기준으로 구분하였으며, 0.12 이하의 값을 나타내는 지역은 피해정도를 고(高, Serious Biological Damage; SBD), 0.12 이상의 값을 나타내는 지역은 저(低, Light Biological Damage; LBD)로 나타내었다. 최종적으로는 데이터를 융합하여 SPD-SBD 지역은 1등급, LPD-SBD 지역은 2등급, SPD-LBD 지역은 3등급, LPD-LBD 지역은 4등급으로 구분하였다.

서론(Introduction)

산불이 발생한 후, 피해지역의 규모를 평가하는 것과 피해의 등급을 산정하는 것은 산림의 복구계획을 위해 반드시 필요하다. 산불이 발생했을 경우 산불의 진행 패과 산불의 규모를 규정짓는 임관의 부피 및 수직적 구조를 모델링하거나 측정하는데 LiDAR 원격탐사기술이 사용된다 (Rianõ 등, 2003; Rianõ 등, 2004; Andersen 등, 2005). 본 연구에서는 이러한 LiDAR 원격탐사기술과 수치항공사진을 이용하여 산불피해지역의 수직적 구조분석을 통한 물리적 피해정도와 식생활력도 분석을 통한 생물학적 피해정도를 산정하였다. 그리고 물리·생물학적 피해정도를 융합하여 최종적으로 산불피해지역을 등급화하였다.

재료 및 방법(Methodology)

본 연구는 강원도 양양군에서 2005년 4월 5일 산불이 발생한 지역을 대상으로 하였다. 산불로 인한 산림의 물리학적 피해는 한 임분 내에서 반사된 모든 LiDAR 포인트 데이터에 대한 임관을 투과하여 지면에서 반사된 LiDAR 포인트 데이터의 비율로 판단할 수 있다 (Equation 1). NDVI는 산불 발생 후 산림의 식생활력도를 평가하고 생물학적 피해를 등급화하기 위해 생성하였다 (Equation 2). GRR 데이터는 산불 후 임목이 도복(倒伏)되지 않고 물리적으로 존재하는지, 또는 전소되어 임목이 물리적으로 소실되었는지를

기준으로 분류하였다. 또한 NDVI 데이터는 산불 후 식생의 활력도를 이용하여 식생이 생물학적으로 생존하였는지 고사(枯死) 하였는지를 기준으로 분류하였다. 두 개의 군집으로 분류하기 위해 현장조사자료를 바탕으로 GRR 및 NDVI 데이터를 그래프로 도식화하였으며, 각각의 데이터가 교차하는 지점을 군집분류의 기준값으로 설정하였다. 또한 데이터가 오분류될 확률은 정규분포를 따른다는 가정하에 확률밀도함수를 이용하여 추정하였다.

$$\text{Ground Return Ratio} = \frac{\text{Number of Ground Returns}}{\text{Number of Total Returns}} \quad \textbf{(1)}$$

$$\text{NDVI} = (\text{NIR} - \text{Red})/(\text{NIR} + \text{Red}) \quad \textbf{(2)}$$

결과 및 고찰(Results and Discussion)

GRR은 0.49, NDVI는 0.12가 분류기준의 교차점으로 분석되었다. 또한 임목이 물리적으로 도복된 지역이 임목이 존재하는 곳으로 오분류될 확률은 18.44%로, 반대의 경우는 11.13%로 분석되었다. 또한 임목이 생물학적으로 고사된 지역이 살아있는 곳으로 오분류될 확률은 0.06, 그리고 반대의 경우는 21.28%로 분석되었다. 분류 결과 각 등급별 면적은 1등급 지역이 60.98ha(52.70%)로 가장 넓고, 2등급 지역이 44.68ha(38.61%), 3등급 지역은 0.76ha(0.66%)를 차지하고 있었으며, 4등급 지역은 9.3ha (8.04%)를 점유하고 있었다.

Figure 1. Grading of area damaged by forest fire

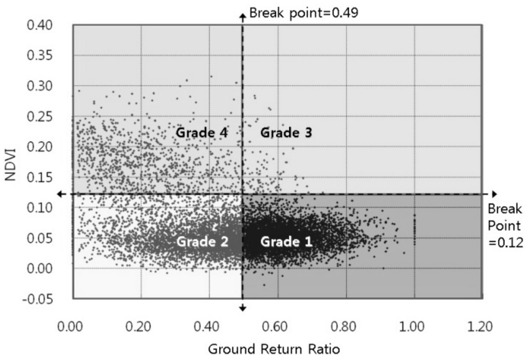

Figure 2. NDVI and LIDAR-derived ground return ratio thresholds

그런데 분석된 결과 3등급 지역은 SPD와 LBD로 분류된 지역으로 대부분 묘지, 초지 또는 식생의 밀도가 낮은 지역을 의미하는 것으로 밝혀졌다. 그러므로 3등급 지역은 4등급 지역으로 병합이 되어야 한다. 최종적으로 산불피해지는 3개의 등급

으로 분석이 되었고, 병합된 결과는 Figure 3, 4와 같다.

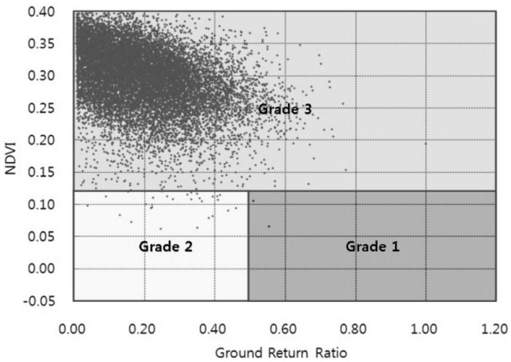

Figure 3. Grading of area damaged by forest fire

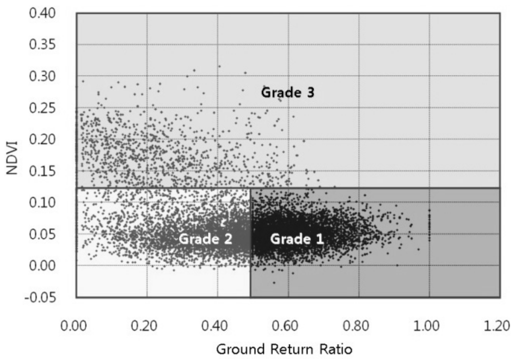

Figure 4. NDVI and LIDAR-derived ground return ratio thresholds

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Comparison of Phytosynthetic Characteristics between Dominant Shoot and Recessive Shoots of *Quercus variabilis*

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굴참나무 우•열 맹아지의 생리적 특성 비교

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Abstracts

In order to investigate the influence of the vigor difference of coppice shot on photosynthetic production, two-year-old coppice shoots of *Quercus variabilitis* were classified into the dominant shoots and the recessive shoots, and their dry matter productions and physiological properties have been investigated. The dominant shoots showed much more leaves and branches than the recessive shoots, suggesting that the dominant shoots have more assimilatory organ. In addition, each leaf of the dominant shoots was wider and their chlorophyll content and photosynthesis rate at light saturation point were higher, indicating that the material productivity of each leaf is high. Moreover, the dominant shoots have shown higher specific leaf dry mass (g/m^2), higher maximum amount of water storage, and more resistance ability to water loss, which means that they are more tolerant to water stress.

요약

본 연구에서는 맹아가지(coppice shoot)의 우열(vigor)의 차이가 물질생산성(photosynthetic production)에 미치는 영향을 조사하기 위해서, 굴참나무(*Quercus variabilis*) 2년생 맹아가지(coppice shoot)를 우세가지(dominant shoot)와 열세

가지(Recessive Shoot)로 구분하고, 이들 가지의 기관별 건물중과 잎의 생리적 특성(physiological properties)을 조사하였다. 그 결과, 우세가지는 잎과 가지의 양이 열세가지에 비하여 현저하게 많은 값을 나타내, 우세가지는 광합성을 수행할 수 있는 동화기관이 열세가지에 많음을 알 수 있었다. 그리고 우세가지는 성숙한 잎 하나하나의 면적이 넓고, 엽록소 함량과 광포화점(light saturation point)에서의 광합성속도(photosynthesis rate)가 열세가지에 비하여 높은 값을 나타내, 잎 하나하나의 물질생산능력(material productivity)이 높음을 알 수 있었다. 또한 우세가지는 잎의 두께를 나타내는 specific leaf dry mass(g m^{-2})와, 잎이 최대한으로 수분을 보유할 수 있는 양, 그리고 수분손실에 저항하는 능력이 열세가지에 비하여 높은 값을 나타내, 수분스트레스(water stress)에 대한 내성(tolerance)이 높음을 알 수 있었다.

서론(Introduction)

산림 내 천연교란 중 하나인 산불은 막대한 재산피해 및 인명 피해를 야기시키는 큰 재해로 인식되고 있으며, 현재는 산림의 연소를 통해 배출되는 다량의 이산화탄소와 탄소 고정흡수원의 파괴적 측면에서 국가적 손실이 확대되고 있다. 맹아는 산불 후의 연속적인 갱신형태로써 근계가 미리 형성되어 있기 때문에 생장이 빠르고, 높은 생존률을 보인다. 참나무는 맹아 갱신력이 우수하며 그 분포면적이나 용도 및 생태학적인 측면에서의 가치 등을 고려할 때 우리나라를 대표하는 활엽수라 할 수 있다. 또한 참나무의 맹아 발생 특성상 초기에 많은 개체수의 맹아를 발생시키지만 해가 거듭될수록 감소하다가 4년 후 부터는 개체수가 안정화 되는 경향을 나타낸다. 이 연구는 참나무 맹아를 우세가지와 열세가지로 구분하여 광합성과 엽록소의 특성을 조사하여 생리적 특성을 파악하는데 그 목적이 있다.

재료 및 방법(Methodology)

조사지 및 재료

연구 대상지는 충청북도 충주시 상모면 수회리에 위치하고 있으며, 2006년 가을에 벌채한 지역으로 상층에는 굴참나무가 우점하고 있다. 조사 지역내에서 맹아지의 직경 및 생장 등을 고려하여 우세가지와 열세가지로 구분하여 각 5본의

굴참나무 맹아지를 선정하여 시료를 채취하였다. 시료 채취시에는 포수된 상태에서 가지를 절단하고 운반이 용이한 용기에 옮겨 실험실로 운반하였으며, 운반한 시료는 항온항습기에서 온도 25℃, 습도 90%의 상태로 보관하였다.

광합성 및 엽면적 측정

굴참나무 맹아의 우세지와 열세지의 광합성반응은 시료의 휴면상태를 고려하여 수분 스트레스의 영향을 작게 받는 시간대(9:00-14:00)에 측정하였다. 측정은 휴대용 광합성 측정기(Li-6400, Li-Cor, Nebraska, USA)를 이용하였다. 광(PPF)-광합성 관계의 측정은 대기 조건(25℃, CO_2 농도 370ppm)에서 측정하였다. 엽면적 조사를 위해 채취한 시료를 엽면적계(Li-3100, Li cor)를 이용하여 엽면적, 개엽면적, specific dry mass 등을 측정하였다.

엽록소 함량 조사

엽록소의 측정을 위해 현장에서 각 개체별로 절편을 채취하여 10ml의 Dimethyl Sulfoxid(DMSO)가 들어있는 vial병에 넣은 후 70℃의 항온수조에서 색소를 추출하였다. 추출한 용액의 흡광도를 분광광도계(UV/VIS spectro-photometer, Kotron)를 이용하여 측정하고 Hiscox and Israelstam(1979)의 방법에 따라서 추출용액에 함유된 엽록소 함량을 산출하였다. 산출된 값을 사용하여 엽면적(mg m_{-2})당 a, b 함량을 구하고, 이를 사용하여 엽록소 a+b, a/b를 산출하였다.

결과 및 고찰(Results and Discussion)

기관별 현존량 및 형태적 특성

굴참나무 맹아가지의 광합성 수행능력에 영향을 미치는 동화기관의 양을 파악하기 위하여 기관별 건물중을 조사하였다(Tabal 1). 그 결과, 우세가지의 잎과 가지의 양은 830g으로 93~275g의 열세가지에 비하여 현저히 높은 값을 보였다. 이는 광합성을 수행할 수 있는 동화기관의 양이 열세가지에 비해 많음을 나타낸다.

Table 1. Dry weight of sample tree for estimation the above-groung biomass of the *Quercus variabilis*.

Components	1	2	3	4	5	6
	g (%)					
Stem	720 (46.5)	460 (62.5)	300 (59.8)	310 (56.7)	260 (61.0)	160 (63.2)
Branch	490 (31.6)	160 (21.8)	130 (25.9)	150 (27.5)	80 (18.7)	50 (19.7)
Leaf	338.4 (21.9)	115.2 (15.7)	72 (14.3)	86.4 (15.8)	86.4 (20.3)	43.2 (17.1)
Total	**1548.4 (100)**	**735.2 (100)**	**502 (100)**	**546.4 (100)**	**426.4 (100)**	**253.2 (100)**

맹아가지의 우열차이가 잎의 특성에 미치는 영향을 조사하기 위해서 개엽의 면적, 엽건중, 엽면적 당의 건물중(specific dry mass)을 조사 하였다 (Table 2). 우세가지는 열세가지에 비하여 수분 보유량 및 수분 유실에 대한 저항성과 상관성이 높은 엽면적당 건물중의 값이 높았으며, 최대 수분보유량과 상대함수율(Relative Water Content)의 값도 높게 나타났다. 이는 우세가지가 열세가지보다 수분스트레스에 대한 내성이 높음을 의미 한다.

Table 2. Leaf characteristics of the *Quercus variabilis*.

	Leaf Area (cm^2 $leaf^{-1}$)	Leaf DW (g $leaf^{-1}$)	Specific dry mass (g m^{-2})
Dominant Shoot	62.3	0.7	105.7
Recessive Shoot	36.6	0.3	89.5

광합성 특성조사

우세가지와 열세가지에서 광도에 대한 광합성 반응을 측정한 결과를 Fig. 1에 나타냈다. 초기의 광합성 속도는 큰 차이가 없었으나 점차 증가하여 광포화점에서는 우세가지가 높은 값을 나타냈으며, Table 2에서 개엽의 면적이 열세가지에 비하여 넓은 결과를 보였다. 또한, 동화기관의 물질생산능력과 상관관계에 있는 염록소 함량을 조사한 결과 우세가지가 높게 나타남으로서 잎의 물질생산능력은 열세가지에 비하여 우세가지가 높음을 알 수 있었다.

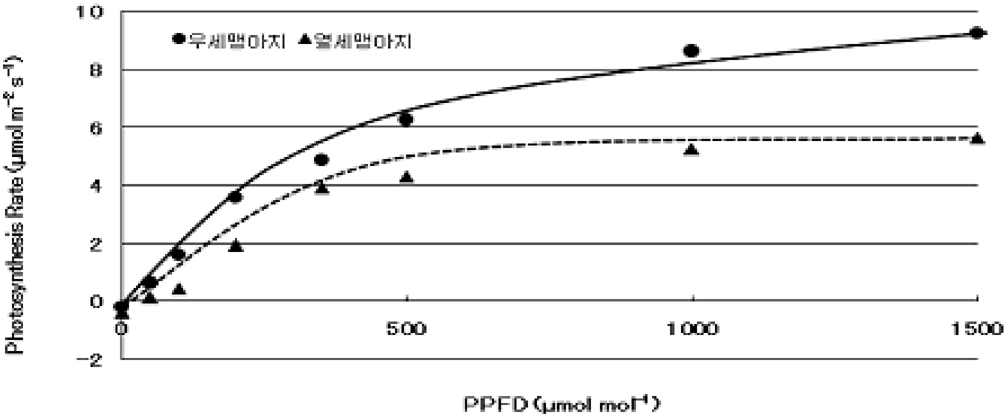

Figure 1. Light response curves between Dominant Shoot and Recessive Shoots of *Quercus variabilis.*

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Changes in bird species richness and community composition after forest fire

산불 후 조류 종 풍부도 및 군집 조성의 변화

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Abstracts

This study was conducted to clarify the changes in bird species richness and community composition after forest fire from 2001 to 2008 at Mt. Gumbong of Samchuk which was damaged by fire in 2000. Line transect was also surveyed in unburned and two burned sites (silvicultured and natural restored sites) from February 2007 to December 2008. Total 1,614 individuals of 48 species were detected and there were no differences in bird species richness and community composition in landscape level. Otherwise, bird species richness and community composition were significantly different among sites. Several studies on the importance of CWD to wildlife have tested, so we need to consider the postfire management for snag retention in burned forests.

요 약

본 연구는 산불 피해 후 연도별 조류 종 풍부도 및 군집 조성의 변화를 파악하기 위해 2000년도 산불피해지역인 삼척 검봉산 일대에서 2001년부터 2008년까지 총 20회에 걸쳐서 선조사법을 통해 조류 조사를 실시하였다. 또한 2007년 2월부터 2008년 12월까지 산불피해지역 내 미피해지, 조림지, 자연복원

지에서 조사를 실시하였다. 그 결과 총 48종 1,614개체의 조류가 관찰되었으며, 경관수준에서의 조류 종 풍부도 및 군집 조성의 변화는 일어나지 않았으나, 조사지역 내 각 서식환경에 따른 종풍부도 및 조류군집은 차이를 보였다. 동해안 산불의 경우 모자이크 형태의 다양한 서식지를 창출하기 때문에 조류상의 변화는 크지 않으나, 고사목 및 피해목의 처리 유무로 인해 피해지역 내 서식환경별 조류 종 풍부도 및 군집 조성은 크게 차이를 보였다. 산림생태계에서 고사목 등의 수목잔존물은 번식 장소와 먹이 공급원으로 야생동물에게 중요하게 활용되기 때문에 산불 피해 후 일부 지역의 고사목과 피해목 등의 수목잔존물 방치에 대한 검토가 필요할 것으로 생각된다.

서론(Introduction)

산불은 중요한 자연 발생적인 교란 현상으로서, 안정된 산림생태계를 교란시키며 천이의 방향을 바꾸는 기능을 하거나(이경준 등, 1999), 동식물 군집의 형성과 개체군 동태에 영향을 미치는 간섭 요인으로 작용한다(smucker et al., 2005).

국내의 경우 산림의 성장과 함께 산림 내부의 가연물질이 지속적으로 축적되고 있어 산불 발생 가능성이 증가하였고, 특히 동해안 지역은 강한 바람과 건조한 기후 등으로 인해 산불이 대형화되는 추세에 있다(임업연구원, 1997).

그러나 국내에서 산불이 야생동물, 특히 조류에 미치는 영향 및 시간의 흐름에 따른 조류 종풍부도와 군집 조성의 변화에 대한 연구는 미비한 실정이다. 따라서 본 연구는 2000년도 산불피해지역인 강원도 삼척 검봉산 일대에서 산불 후 조류 종풍부도 및 군집 조성 변화를 파악하기 위해 2001년부터 2008년까지 조사를 실시하였다.

재료 및 방법(Methodology)

연구 대상 지역은 강원도 삼척시 검봉산 일대의 2000년도 산불피해 지역으로써, 산불 피해 이전에는 소나무(*Pinus densiflora*)와 참나무류(*Quercus spp.*)가 상층식생을 우점하고 있었다. 산불 후에도 현재 일부 미피해지가 모자이크 형태로 존재하고 있었으며, 대부분 조림을 실시하고 있고 일부 지역에는 생태연구를 위해 자연복원이 이루어지고 있다.

산불피해지 전역에서는 2001년부터 2008년까지 총 20회에 걸쳐 임의 조사로를 선정하여 경관수준(landscape level)에서의 조류상 조사를 실시하였으며, 특히 2007년 2월부터 2008년 12월까지는 총 24회에 걸쳐 미피해지, 자연복원지, 조림지 내에서 조사를 실시하였다. 모든 조사는 선조사법(line transect)을 통해 이루어졌으며, 약 2km 조사로를 걸으면서 좌우 25m 내의 조류를 기록하였다.

결과 및 고찰(Results and Discussion)

2001년부터 2008년까지 총 20회에 걸쳐서 산불피해지 전역에 대한 조류조사를 실시한 결과 총 48종 1,614개체의 조류가 관찰되었으며, 연도별 관찰된 종수를 비교한 결과 조금씩 증가하는 경향을 보이다가 2007년부터는 소폭 감소하였다. 연도별 조류 군집의 변화를 파악하기 위해 10개의 분류군으로 나누어 각 분류군별 관찰된 종수 및 개체수의 비율을 분석한 결과 연도별 각 분류군의 종수 비율의 변화는 큰 경향을 보이지 않았다. 또한, 연도별 각 분류군의 개체수 비율의 변화에 있어서는 산림성 조류인 박새과의 개체수 비율이 증가하고, 초지 및 개활지를 선호하는 멧새과의 개체수 비율이 약간 감소하는 경향을 보였으나 큰 차이를 보이지는 않았다. 이러한 결과는 삼척 산불피해지역의 경우 지형이 험하고 산불피해 당시 바람이 강하게 불었기 때문에 대부분은 수관화가 일어났으나, 일부지역은 피해를 입지 않았거나 지표화만 발생했기 때문이며, 조사지역 내에서도 경피해지, 전소지 등 다양한 환경이 조성되어져 있기 때문에 전체 조사지역 내에서의 조류 종군집 변화는 크지 않은 것으로 생각된다.

그러나 미피해지, 조림지, 자연복원지으로 나누어 조사를 실시한 결과 종다양도 및 종풍부도에서 미피조림지점 순으로 나타났다. 이러한 결과는 우리나라 동해안 산불의 경우 산불 및 산불 후 관리로 인해 모자이크형태의 다양한 서식환경이 창출되기 때문에 경관 수준에서의 시간에 따른 조류 종풍부도 및 조류군집의 변화는 크지 않은 반면, 산불 후 관리에 의해 조류 종풍부도 및 조류 군집의 차이를 보이는 것으로 판단된다. 산림의 벌채 과정에서의 고사목 존치가 생물다양성 보전을 위한 중요한 관리 방안으로 간주되고 있으며(Lehmkuhl *et al.*, 2003; Schwab *et al.*, 2006), 산불 역시 고사목의 형성에 중요한 요인이므로, 산불 후 관리 과정에서도 산불의 부정적 효과를 줄이고 생물다양성을 유지학 위해 산림 벌채시 고사목 존치와 유사한 형태로 산불 피해목을 남겨두는 관리 방안이 필요한 것으로 생각된다(Hutto, 2006).

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Influence of Vegetation Recovery on Runoff and Sediment yield Following a Forest Fire in Samcheok, Korea

삼척 산불 후 식생회복이 표면유출수와 토사유출량에 미치는 영향

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Abstract

Runoff and sediment yields were measured for 6 years, from the fourth year (2003) to the ninth year(2008), in the *Pinus densiflora* forest severely burnt by East Coast fire in Samcheok, Korea in 2000. Influence of rainfall events have been mitigated as the vegetation has recovered following the forest fire. Therefore, there were marked decrease in runoff yields from the eighth year, and sediment yields from the sixth year. Nevertheless, significant differences of runoff yields between vegetation classes maintained for six years. To lower the losses from the 'intermediate'and the 'low' plots to the level of the 'high' plots, at least several years would be needed. For six years total, the sediments of total 10.6 and 17.9 ton ha^{-1} have been produced from the 'intermediate' and the 'low' plots, respectively. These are 2.2 and 3.7 times of the 'high' plots (4.9 ton ha^{-1}). Proper hill treatment such as mulching should be applied immediately after fires to reduce soil erosion and to restore burnt forests fast.

요 약

2000년 동해안 산불 피해지 중 수관화 피해를 입은 강원도 삼척시의 산불 전 소나무림에서 산불 후 초기재생정도가 다른 21개의 토사유출시험구를 설치하여 산불 4년 후부터 9년까지 지표유출수와 토사유출량을 총 6년간 측정하였다. 식생의 영향은 지표유출수의 경우 8년째부터, 토사유출의 경우

7년째부터 강우량이 영향보다 더 커졌다. 그러나 초기 식생등급 간의 차이는 6년간 유의하게 지속되었다. 6년간 식생등급 '중'과 '하' 시험구에서 유실된 토사유출량은 각각 10.6, 17.9 ton ha^{-1}으로서 '상' 시험구 4.9 ton ha^{-1}의 각각 2.2배와 3.7배 많았다. 산불 직후부터 측정하지 못한 3년간은 유출량이 훨씬 컸을 것이다. 따라서 유출량을 감소하기 위해서는 산불 직후 초기 재생이 느린 지역을 대상으로 식생의 효과를 대신해주는 멀칭 등의 입지처리를 해야 할 것이다.

Introduction

Due to the differential vegetation recovery resulted from pre-fire vegetation and post-fire microsite factors, studies on the temporal change of soil erosion following fires should be carried out including its large spatial variation. From this study, we aimed to examine the temporal change of the relative effect between the rainfall and vegetation on runoff and sediment yield according to their vegetation recovery and irregular rainfall events with time.

Methodology

Runoff and sediment yields were measured for 6 years, from the fourth year (2003) to the ninth year (2008), in the *Pinus densiflora* forest severely burnt by the East Coast fire in Samcheok, Korea in 2000. The experiments were performed from 21 experimental runoff-plots which have the large spatial variation in vegetation.

Results and Discussion

Since the difference in initial vegetation was largely established among the runoff plots, their vegetation coverages ranged 10-90% (average 46%) in 2003 but they narrowed to range 35-90% (average 67%) in 2008 due to the fast recovery of the low coverage plots. On average, vegetation coverages consequently have increased to 21% (Table 1).

Table 1. Vegetation recovery over time during 6-year study period

Parameter	Vegetation coverage (%)					
	2003	2004	2005	2006	2007	2008
Minimum	10	20	20	30	35	35
Maximum	90	90	90	90	90	90
Average	45.7	51.9	54.0	59.5	63.1	66.7
Standard deviation	21.4	19.4	20.4	19.1	20.2	22.2

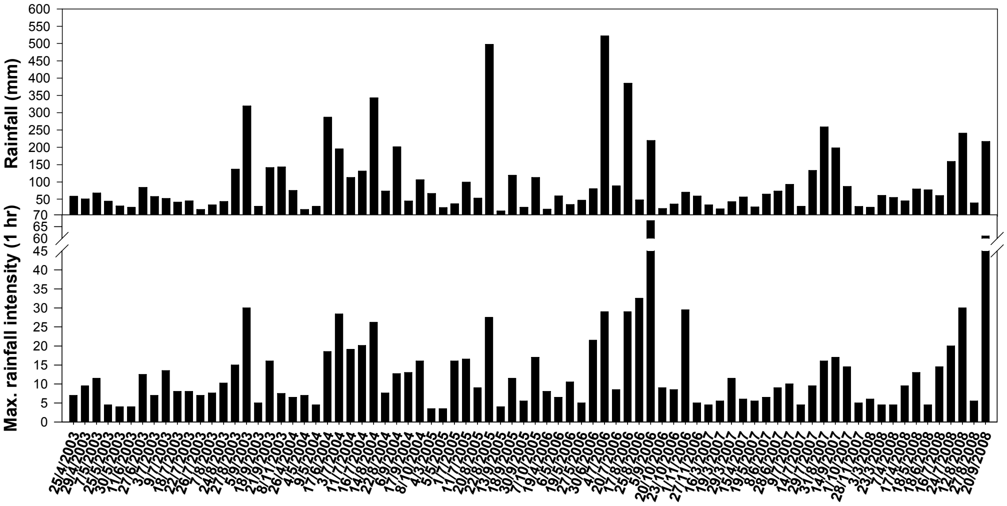

Fig. 1. Rainfall and maximum rainfall intensity during 6-year study period.

The influences of rainfall on the runoff and sediment yields were stronger than that of vegetation till the sixth year, however, the influence of vegetation became stronger from the eighth year for the runoffs and from the seventh year for the sediment yield (Fig. 2).

The trend to decrease was marked at the eighth year for the runoff coefficient, and at the sixth year for the sediment yields from only 'high' and 'intermediate' vegetation plots (Fig. 3). The sediment yields per events from 'low' vegetation plots did not show the significant trend yearly due to high variation among plots. The differences in runoff coefficient between vegetation classes maintained for all six years, while no significant differences in the sediment yields from the sixth year between the classes.

Total runoff yields were average 11.1% (range 1.0-31.4) of total annual rainfall in the fourth year and then reduced to 4.2% (range 0.3-14.4) in the nineth year (Table 2). Total sediment yields of average 3.2 ton ha^{-1} yr^{-1}(range 0.7-9.7) in the fourth year have been reduced to 0.43 ton ha^{-1} yr^{-1}(range 0.01-1.47) in the eighth year, but they vary from year to year.

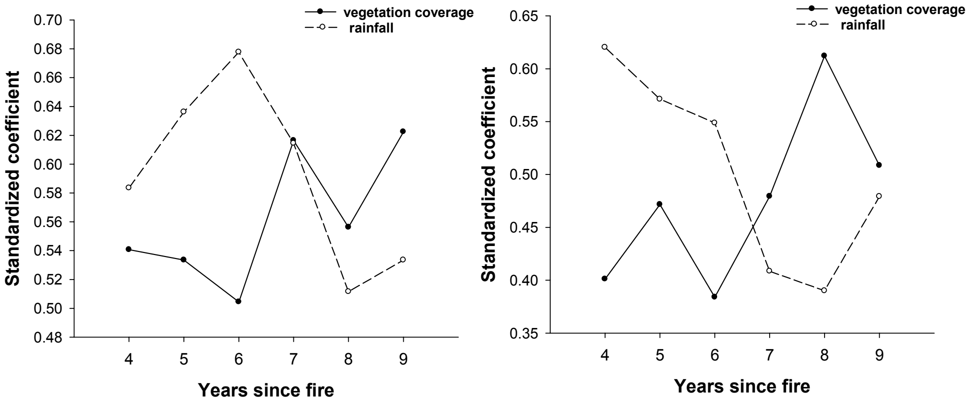

Fig. 2. Relative effects of rainfall and vegetation coverage on runoff (left) and sediment yield (right) for 6-year period.

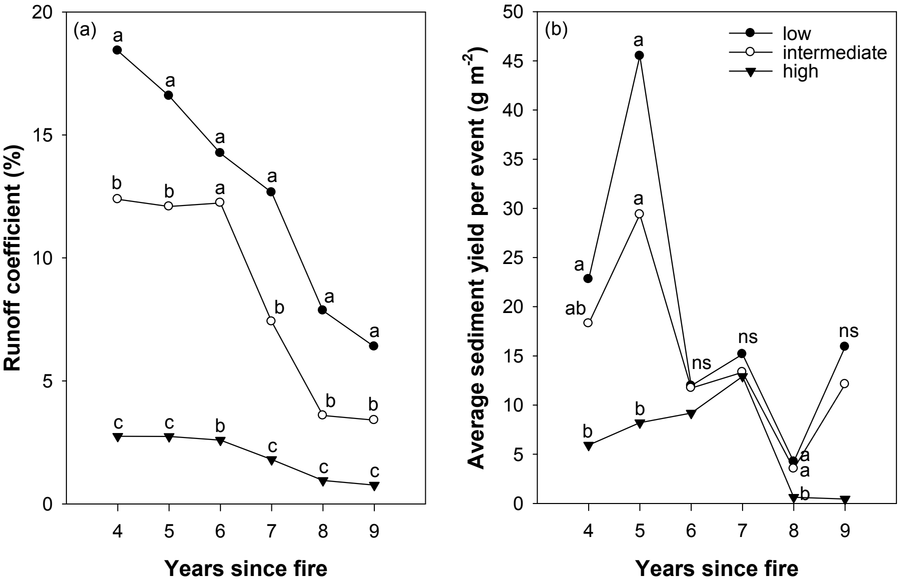

Fig. 3. Change in three parameters (a-b) at runoff plots with different vegetation class for 6-year period. Average runoff coefficient per event(a) and average sediment yield per event(b). Different letters indicate significant difference between vegetation class within a year.

Table 2. Total annual runoff and sediment yield, and runoff coefficient from the plots during 6-year study period

Year	Rainfall (mm)	Runoff yield (106 L ha^{-1} yr^{-1})		Runoff coefficient (%)		Sediment yield (ton ha^{-1} yr^{-1})	
	Total	Average	Min-Max	Average	Min-Max	Average	Min-Max
2003	1,541.3	1.71	0.15-4.84	11.1	0.97-31.43	3.20	0.72-9.73
2004	1,654.0	1.87	0.19-5.11	11.3	1.17-30.88	3.57	0.44-11.57
2005	1,248.0	1.21	0.04-2.85	9.7	0.31-22.82	1.01	0.03-3.95
2006	1,835.5	1.23	0.14-3.55	6.7	0.74-19.34	1.94	0.06-8.46
2007	1,195.5	0.55	0.01-1.97	4.6	0.11-16.47	0.43	0.01-1.47
2008	1,086.0	0.46	0.04-1.56	4.2	**0.33-14.37**	**1.17**	**0.01-3.75**

Effects of Soil Conservation Measures in a Partially Vegetated Area after Forest Fires
산불 후에 자연복원이 느린 지역에서 토양보전을 위한 여러 기법의 효과

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Abstract

After forests fires on the east coast of Korea in 2000, some burnt areas were left untreated. Although 80% of the area was reasonably revegetated within three months, about 20% of the area was partially vegetated, mainly due to a low density of sprouters and poor growing conditions (eroded soil and steep slopes). Three years after the fires, the effect of soil conservation measures, such as mulching with wood chips, seeding with native plant species and log erosion barriers (LEBs), on runoff and soil erosion were examined using runoff plots. Wood chip mulching greatly reduced runoff and sediment yields and these effects were consistent regardless of the volume of rainfall. Neither seeding nor LEBs reduced runoff and sediment yields. No positive or negative effects of mulching, seeding or LEBs on ground vegetation cover were observed. The ineffectiveness of seeding and LEBs may have been due to the steep slope, the failure of germination and establishment of seeded plants, and the small diameter of logs. Treating hill slopes with mulch should be considered where post-fire regeneration is slow and there is an absence of organic material such as litter.

요 약

2000년 동해안 산불피해지역에서 산불 후 3개월 내에 약 80%의 면적은 식생이 상당히 자연복원되었으나 20%의 지역은 움싹재생능이 낮거나 침식토양 등 입지조건이 열악하여 재생이 느렸다. 따라서 토사유출구를 설치하고 우드칩, 종자산포 및 통나무 경사막이의 사면처리를 시도하고 표면유출수와 토사유출량에 미치는 효과를 분석하였다. 우드칩에 의한 멀칭이 표면유출수와 토사유출량에 미치는 효과가 가장 컸으며 강수량에 관계없이 효과가 지속되었다. 그러나 종자산포와 통나무 경사막이는 효과가 유의하지 않았다. 이러한 이유는 높은 경사, 낮은 발아률과 정착률 및 가는 통나무의 사용 등이 원인일 것이다. 산불 후 재생이 느리고 낙엽과 같은 유기물이 적은 곳에는 멀칭에 의한 사면처리의 도입이 토사침식을 막는데에 효과적이라는 사실을 입증했다.

Introduction

Because the risk of erosion is greatest in the first year after fire, post-fire treatments for soil conservation are required (Robichaud et al., 2000). The effects of soil conservation measures on the sediment yields of burnt hill slopes, such as grass seeding, mulching and log-erosion barriers (LEBs) have been quantitatively evaluated in the USA (Wright et al., 1982; Robichaud et al., 2000; Robichaud et al., 2005; Robichaud et al., 2006; Wagenbrenner et al., 2006), Spain (Bautista et al., 1996; Pinaya et al., 2000) and Portugal (Thomas et al., 2000). The objective of the present study was to assess the effectiveness of such soil conservation measures as wood chip mulching, LEBs and seeding on runoff and soil erosion in a partially vegetated area, three years after the fires.

Methodology

In July of 2003, 15 closed runoff plots were established in the PVA and 2 in the DVA. The plots were 3 m × 10 m, delineated by steel strip borders. The slope steepness of all plots ranged from 38% to 63% and the aspects ranged from 130º to 280º (Table 1). Three runoff plots were mulched with wood-chips at a rate of 1.7 kg fresh weight per m^2 to cover about 70% of the plot surface. LEBs were constructed for three runoff plots from the trunks of burnt dead pine trees. The logs were 7–10 cm in diameter and were staked securely on the slopes. The third treatment was seeding. Seeds of two nitrogen-fixing legumes, *Lespedeza cyrtobotrya* and *L. cuneata*, and two perennial grasses, *Miscanthus sinensis* and *Zoysia japonica* were mixed in even proportions and sown in three replicated plots at a rate of 20 g/m^2. Six runoff plots in the PVA were left untreated to serve as a control. Two runoff plots in the DVA were also left untreated.

A significant difference was found only between the vegetation cover of DVA plots and other plots (Fig. 1). The overall vegetation cover was greater in 2003 than 2004 ($F_{1,24} = 5.98$, $P = 0.022$). From 2003 to 2004, mean vegetation cover slightly increased in the PVA control plots, seeded plots and DVA plots, due to the increases in plant growth.

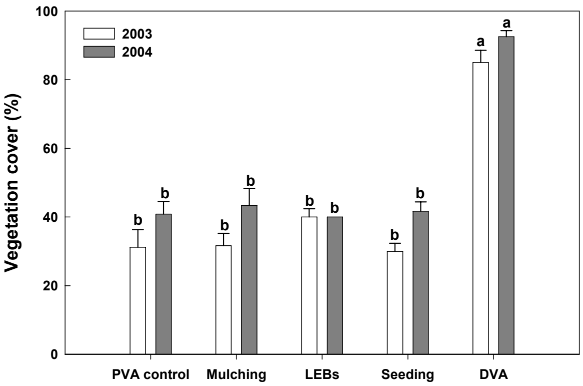

Fig. 2. Changes in mean ground vegetation cover (%) in the runoff plots. Data are means + standard errors. Values followed by the same letters are not significantly different (LSD test, P < 0.05).

Table 1. Characteristics of the study sites (PVA: partially vegetated area; DVA: densely vegetated area)

Characteristics	PVA	DVA
Slope (%)	52.3 (2.2)	56.1 (1.6)
Aspect (°)*	180-280	130-190
Ground vegetation cover (%)	32.8 (2.5)	85.0 (3.5)
Soil depth (cm)	37.1 (1.6)	53.1 (1.1)
Soil pH	4.36 (0.02)	4.51 (0.01)
Organic matter content (%)	6.8 (0.3)	5.9 (0.9)
Total-N (mg/g)	0.75 (0.06)	0.70 (0.07)
Available-P (mg/kg)	0.13 (0.01)	0.16 (0.01)
Sand (%)	71.8 (0.9)	69.9 (0.8)
Clay (%)	11.5 (0.7)	12.2 (0.9)
Silt (%)	16.6 (0.9)	17.9 (1.7)

Data are means and standard errors in parentheses. *:range

Results and discussion

During the study, runoff yield (mm) and sediment yield (g/m^2) from the runoff significantly increased with increasing rainfall (Fig. 2). The relationships between rainfall and runoff or sediment yield for the seeded plots and LEBs plots were similar to those for the PVA control plots. Significant differences were observed between the regression lines for runoff ($F_{4,245}$ = 7.77, P < 0.001) and sediment yields ($F_{4,245}$ = 4.33, P = 0.002). The slopes of these regression lines were less in the mulched and DVA plots than in the PVA control plots. The runoff and sediment yields of mulched plots were consistently lower than the PVA control plots regardless of rainfall. Similar results were also observed for the relationships between maximum rainfall intensity and runoff or sediment yield (Data not shown).

The hill slope treatments affected mean runoff and sediment yields of the runoff plots ($F_{4,250}$ = 9.12, P < 0.001 and $F_{4,250}$ = 4.84, P = 0.001, respectively). The mean runoff of the PVA control plots was greatest in September 2003 and August 2004, due to the high rainfall caused by the typhoons. Mean runoff was greater in the PVA control plots than in the other plots (Fig. 3). LEBs and seeding did not significantly reduce runoff, being only 7% and 6% lower than the PVA control plots, respectively. However, wood-chip mulching significantly decreased the runoff by 42%, and runoff in the DVA plots was 81% lower than in the PVA control plots.

Mean sediment yields of the PVA control plots were also greater than other plots (Fig. 3). However, mean sediment yields of LEBs and seeding plots were only 2% and 7% lower than PVA control plots, respectively, and not statistically different. The mean sediment yield of the mulched plots was 51% lower and of the DVA plots 79% lower, than the PVA control plots. The hill slope treatments had a significant effect on mean runoff coefficients (runoff/rainfall) ($F_{4,250}$ = 17.12, P < 0.001). Mean runoff coefficients of mulched plots were significantly lower than PVA control plots (Fig. 3).

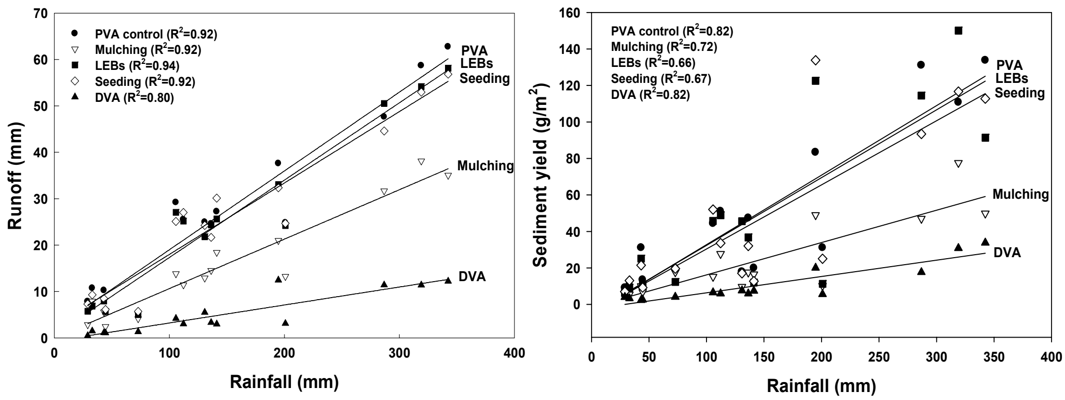

Fig. 2. Relationship between rainfall (mm) and runoff yield (mm) and sediment yield (g/m^2) at the runoff plots from August 2003 to October 2004.

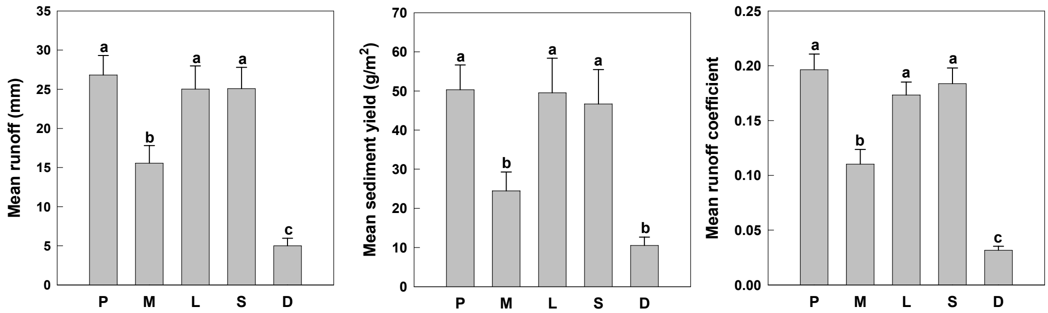

Fig. 3. Mean runoff yield (mm), sediment yield (g/m2) and runoff coefficient (runoff/rainfall) in runoff plots. Data are means + standard errors. Values followed by the same letters are not significantly different (LSD test, P < 0.05). P: PVA control, M: mulching, L: LEBs, S: seeding, D: DVA

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