ISSN 1341-562X

JOURNAL OF FOREST PLANNING

Vol.18 No.2 Special Issue
"FORCOM 2011"
March, 2013

Japan Society of Forest Planning

JOURNAL OF FOREST PLANNING

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Subscription Information

JOURNAL OF FOREST PLANNING is published half yearly. The subscription for 2013 is 5,000 yen and the single issue price is 2,500 yen. Subscription orders can be sent to following office.

JOURNAL OF FOREST PLANNING is published by
Japan Society of Forest Planning
Lab. of Forest Management, Faculty of Agriculture, Kyushu University, 6-10-3 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan

JOURNAL OF

FOREST PLANNING

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Japan Society of Forest Planning

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Foreword

Special Issue "FORCOM 2011"
The second IUFRO International Conference on Sustainable Forest Resource Management

Organizing Committee of FORCOM 2011

The second International Conference on FORCOM was held at Mie University, Japan, on 25-30 September 2011. It was attended by 63 participants, including researchers overseas, and two keynote addresses, 12 oral presentations, and 19 poster presentations were given during the conference. The in- and post- conference debates and excursions were also fruitful. The nine papers included in the present special issue are revised versions of the addresses and principal presentations at the conference. This special issue has as its main purpose the prospect of enabling a wider audience to share the philosophy and techniques for forest resource management, especially on follow up and new challenges for coming generations, which were lively discussed in the conference. The records of the conference were previously reported in the following journals:

Matsumura, N. (2011) Report on the Second International Conference on FORCOM 2011 – Followup and new challenges for coming generations. Jpn .J. of For. Plann. **45**:9-15 (in Japanese)

Matsumura, N. (2012) Abstract Proceedings of FORCOM 2011. J. For. Plann. **17**:59-70

Matsumura, N. (2012) IUFRO-J News **No.106**:1-4 (in Japanese)

Matsumura, N., Yurugi, Y. and Numamoto, S. (2013) Report on the Second International Conference on FORCOM 2011 – Follow up and new challenge for coming generations. Bull. Graduate School of Bioresources, Mie Univ. **No.39**:51-54 (in Japanese)

Editorial

Reviewer Acknowledgements

Naoto Matsumura *

The Chief Editor of this special issue “FORCOM 2011” of the Journal of Forest Planning would like to thank the following reviewers for their hard work and contributions to the special issue “FORCOM 2011”.

The high quality of this special issue couldn’t have achieved without their efforts.

Naoyuki Furuya	Eiji Kodani	Yasushi Mitsuda
Motoe Miyamoto	Kyoei Nishikawa	Satoshi Tatsuhara
Hirokazu Yamamoto	Shigejiro Yoshida	Atsushi Yoshimoto

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Review

Philosophy and Techniques for Forest Resource Management: Follow up and New Challenges for Coming Generations

Naoto Matsumura *, Yutaka Yurugi * and Shinya Numamoto *

ABSTRACT

Ensuring the sustainability of forest resources for future generations has been a central concern for scientists and managers who have been engaged with the science and practice of forest management. Forest resources provide innumerable ecosystem services that benefit society and the environment. Effective and innovative scientific and practical methods have been developed and implemented to protect important ecosystem functions while meeting increased demands for forest products. Changing societal values demand innovative and/or integrated approaches to forest management that meet social, ecological, and economic goals. New monitoring approaches involving continuous evaluation of harvest-induced and human-induced changes in the forest structure and/or function are needed. Additionally, new approaches to forest management, as well as innovative political measures and people's involvement, are needed to encourage the most efficient and effective use of resources.

The objective of this review is to gather state-of-the-art research results and techniques relating to the management and analysis of forest resources. The organizers of FORCOM2011 would like to welcome and invite those who intend to share their ideas and thoughts about current problems in forest management with others from different regions and research areas.

Keywords: sustainable forest management, inventory, monitoring, database, e-forest

INTRODUCTION

The science and practice of forest management has been one of the main concerns traditionally for forest management scientists and managers to ensure sustainability of forest resource uses. Forest resources are multi-functional and productive to the society as well as the ecosystem. Effective and innovative scientific and practical methods have been developed and implemented in various ways to benefit society though continuous additional consideration on the use of forest resources is demanded by society. Changing societal values demand innovative and/or integrated approaches to forest management that meet social, ecological, and economic goals. New monitoring approaches involving continuous evaluation of harvest-induced and human-induced changes in forest structure and/or function are to be developed with new assessment techniques. This further requires new thoughts on management methods and political measures for the most efficient and effective use of the resources.

The gathering of state-of-the-art research results and techniques relating to the management and analysis of forest resources is an urgent concern relating to both global and local contexts.

On behalf of the organizers of FORCOM2011, the authors would like to report this seminar as a follow up of FORCOM2004 for the sake of developing of the outputs of FORCOM2004 and reviewing the quality concerning philosophy and techniques for forest resource management.

FORCOM 2004 UTSUNOMIYA DECLARATION

Technical developments, greater complexity of decision-making, and an increasing awareness of climatic and societal changes have brought about a remarkable surge of activities in the research discipline known as Forest Management, which provides an important scientific basis for policy and management decisions. These decisions relate to natural forests which represent a highly valued remnant wilderness, as well as to man-made forests which are a renewable source of raw materials essential to human life.

Scientists involved in Forest Management research are responding to political, social and stakeholder demands that forest-use should be based on validated research results, conform to acceptable environmental standards, and be transparent to the public.

This conference has demonstrated ways of how these

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objectives can be achieved, using examples from different parts of the world. Scientists from Asia, the Americas and Europe participated in the proceedings which featured three days of oral and poster presentations, including contributions in forest assessment using large scale laser scanning and satellite data (Danilin, Matsue, Sawada, Kajisa, Murakami); growth modeling, biometrics and silviculture (Kitahara, Dobbertin; Garcia, Takashima, Gaffrey, Ang Lai, Trifkovic, Yamamoto); social and community forest management (Makanji, Nur Mohammed, Kamimura, Sri Nugroho Marsoem); carbon stock assessment and accounting (Valsta, Kim Phat, Nakajima, Abe, Nobori); philosophical questions related to forest use including educational aspects (Tanaka, Osawa, Ito, Kohsaka, Inoue, Katoh) and forest design using decision support tools techniques (Yoshimoto; Paredes, Boston; Feng; Gadow; Mizoue; Mitsuda). The contribution of the various components of the conference towards multiple benefits and improved decision making has shown how the scientific discipline known as Forest Management provides the technical support for policy decisions, the scientific "bread and butter" in the areas of assessment, forecasting and design of a forested landscape.

In theory, involving the different disciplines directly in the management of wooded ecosystems appears to be logical, but the practical implementation of this idea is not a trivial task. This important question was also addressed at the conference, but more research and thinking is needed for workable solutions (Naito, 2005).

THE MOVEMENT CONCERNING THE SUSTAINABLE FOREST MANAGEMENT

National level – Criteria & Indicators, Montreal Process and European Process

One of the international initiatives concerning the promotion of a sustainable forest management, compiling criteria and indicators for intercontinental levels has been proceeding since Earth Summit 1992 in Rio de Janeiro, Brazil (UNCED). The Japanese government has committed to the Montreal Process, the temperate forest zone group excepting Europa. The process involved the twelve countries of Argentina, Australia, Canada, Chile, China, Japan, Korea, Mexico, New Zealand, Russia, Uruguay and the U.S.A. and agreed on 7 criteria and 67 indicators in San Tiago, Chile 1995.

The Montreal Process has revised the criteria and indicators in 2006 and 2008 and reduced the total number of indicators from 67 to 54. The main purpose of revision is to simplify the indicators(Fig. 1).

The European group has worked as the Pan European Process (former Helsinki Process) group since 1990 and agreed on 6 criteria and 27 indicators in 1994. This group has 36 member countries.

REDD (Reduced Emission from Deforestation and Forest Degradation)

The United Nations Framework on Climate Change Convention (UNFCCC) has required developed countries to reduce the emission of carbon produced in their countries. On the other hand, developing countries could also be involved in the program of the mitigation of carbon emission. Several schemes of carbon emission mitigation have been adopted, e.g. Afforestaion/Reforestation Clean Development Mechanism (A/R-CDM) under Kyoto Protocol and Reducing Emission from Deforestation and Forest Degradation (REDD).

The COP of the UNFCCC also discussed the issue of "reducing emissions from deforestation and forest degradation in developing countries" (REDD-plus). As a framework for mitigating the impacts of climate change, REDD+ is perceived as one of the policy mechanisms that has a huge potential to reduce emissions from deforestation and forest degradation through its roles in conservation, sustainable forest management and enhancement of forest carbon stocks. One of the important components for the implementation of REDD+ is the application of a transparent, comparable, coherent, complete and accurate MRV (measurement, reporting and verification) system. The challenge in implementing such a system is enabling society and concerned parties to understand their role in attaining targets for reducing emissions and increasing carbon stocks. At a most basic level, the tools for the calculation of carbon stocks and the monitoring of changes should be prepared in order to calculate the emissions level in all ecosystem types and land uses.

Under the REDD+ mechanism, the method for determining the Reference Emission Level most appropriate to the specific local conditions is imperative. For this, specific allometric models that are appropriate to the location, ecosystem type and tree species are necessary. Currently, the guidelines or references related to the use of allometric models for estimating biomass and carbon stock as well as for determining the local (specific) emission factor are now available in each country, e.g. Krisnawati et al. (2012) for Indonesia and Hosoda & Iehara (2007) for major Japanese species.

National Forest Inventory (NFI)

The National Forest Inventory is a large-scale survey of forest status and forest production potential using a uniform procedure for the entire territory (METLA 2012).

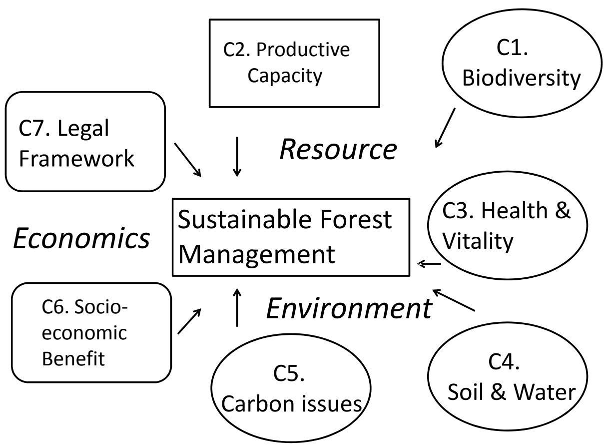

Fig. 1 Criteria & Indicators of Montreal Process

The National Forest Inventory is a monitoring system that produces information concerning national and regional:

forest resources - volume, growth and quality of growing stock
land use structure and forest ownership
forest health
biodiversity of forests
forest carbon stocks and their changes.

Forest resource information produced by NFIs are based on extensive field measurements. In the first inventories, lines through the country were surveyed, but in recent inventories systematic sampling and field plot measurements have been used. The field plots are located in clusters that form a regular network over the whole country, e.g. BMELV(2006).

The forest statistics and other information produced by the NFI are widely used in:

Forest policy making at national and international levels
Regional and national forest management planning
Planning of forest industry investments
Assessing sustainability of forestry and in forest certification
Evaluation of greenhouse gas emissions and changes in carbon storage
Research

Nowadays many international statistics (e.g. FAO and Eurostat), processes (e.g. Ministerial Conference on the Protection of Forests in Europe, MCPFE) and agreements (e.g. Kyoto protocol) require information about the development of forest resources.

In addition to field measurements, the multi-source national forest inventory (MS-NFI) method employs remotely sensed data and other digital data sources such as land-use maps and elevation models. With the aid of satellite images, the forest characteristics can be estimated for areas lying between the relatively sparse network of NFI sample plots.

At the European level, the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) was launched in 1985 under the Convention on the Long-range Transboundary Air Pollution of the UNECE because of the growing public awareness of the possible adverse effects of air pollution on forests (ICP, 2009).

To respond to the needs for harmonized European information, representatives of the European NFIs established an information network called the European National Forest Inventory Network (ENFIN) in Vienna, Austria in 2003. ENFIN applied for common research funding with the aim of investigating techniques leading to comparable European forest resource estimates. The European programme, Cooperation in Science and Technology (COST, 2009) provides funding for large consortia such as the combined NFIs of European countries (Tomppo *et al*., 2010).

The Japanese forest inventory system was reported by Hirata *et al*. (2010) in the above mentioned book (Tomppo *et al*., 2010).

Accounting and reporting methods of forest sinks were discussed under the Kyoto Protocol. A conceptual structure of an accounting and reporting system was designed with consideration to Japan's forest inventory system and rules for Kyoto reporting under the Marrakech Accords and IPCC Good Practice Guidance. The main information of the system consists of forest registers and forest planning maps, and is verified by the forest stand's information and geographic information. Forests were defined by characteristics such as minimum height: 5m, minimum coverage: 30%, minimum area: 0.3ha and minimum width: 20m. An accounting method of Afforestation, Reforestation and Deforestation using an interpretation of grid points on orthophotos was developed for Article 3.3, and an accounting method of forest sinks using ratios of forest management lands were developed for Article 3.4. Including the methods described above, the National Forest Resources Database managing various pieces of forest information was developed for Kyoto reporting and other statistical reports of forest resources (Matsumoto *et al*., 2007, Sasaki, 2012).

Model Forest and International Model Forest Network

Model Forests are based on an approach that combines the social, cultural and economic needs of local communities with the long-term sustainability of large landscapes in which forests are an important feature. By design, they are voluntary, broad-based initiatives linking forestry, research, agriculture, mining, recreation, and other values and interests within a given landscape (www.modelforest.net).

Model Forests are as much about the people who sustain themselves from the forest as they are about trees and forest products—they're a fully working landscape of forests, farms, protected areas, rivers and towns.

In a Model Forest a variety of people with differing interests and perspectives form a neutral partnership based on the following goal: to manage their own natural resources in a way that makes the most sense to them given their historical, economic and cultural identities and in a way that does not jeopardize future generations.

The partnership defines what sustainability means in their own context, develops a common goal, governance structure and strategic plan, then works collaboratively to achieve the goals set out in that plan.

These goals typically strive to harmonize economic and non-economic priorities and to focus, for example, on education, research, or developing local level indicators (LLI) to monitor progress toward sustainability within the Model Forest area. In addition, Model Forest partnerships are very effective in identifying economic opportunities that are not based on timber alone. In that light, a Model Forest is best thought of as a long-term process rather than a project.

Model Forests are unique in several ways: the comprehensiveness of their approach, the scale of operation, the breadth of their partnerships, the level of policy they aim to effect and the importance placed on networking. Geographically, the Model Forest must represent a wide variety of uses and values at play within a particular landscape, such as a watershed (www.modelforest.net).

The International Model Forest Network (IMFN) is a global community practice whose members and supporters work toward a common goal of the sustainable management of forest-based landscapes through the Model Forest approach. The IMFN is comprised of all Model Forest members around the world.

Model Forests are based on a flexible approach to landscape and ecosystem management that combines the social, environmental and economic needs of local communities with the long-term sustainability of large landscapes in which forests are an important feature. By design, they are broad-based initiatives linking a broad mix of stakeholders and sectors and other values and interests within a given landscape.

Three aspects central to a Model Forest are a large landscape, broad partnerships and a commitment to sustainability.

Landscape: A large-scale biophysical area representing a broad range of forest values, including environmental, social, cultural and economic concerns

Partnership: Each Model Forest is a neutral forum that welcomes the voluntary participation of representatives of stakeholder interests and values on the landscape.

Sustainability: Stakeholders are committed to the conservation and sustainable management of natural resources and the forest-based landscape

Since 1996 the Forest Agency of Japan has led discussions in Asia on Model Forests for Field Level Applications of Sustainable Forest Management: Kochi in 1996, Tokyo in 1998, Mie in 1999, Gunma in 1999, and Yamanashi in 2000. To identify indicators that are measurable enough by technical skills and that are not transparent, the ten year project was conducted by Forestry and Forest Products Research Institute (FFPRI) with a field level inventory in the Japanese Model Forest in Kochi and Hokkaido for selecting and arranging suitable local level indicators (LLIs) from 1996 to 2005.

The Kyoto Model Forest Association was the first group in Japan to promote the Model Forest Movement and was established on November 21, 2006. They are looking for people who want to make the forest healthy (www.kyoto-modelforest.jp).

Fig. 2 Regional model forest network in Asia (www.imfn.net)

Forest certification system (FCS)

Forest certification is widely seen as the most important initiative of the last decade to promote better forest management at the forest management unit (FMU) level and forestry sector level. Responsible forest management is a key component of sustainable forest management for a future in which people live in harmony with nature.

The sustainable use of renewable forest products can provide people with shelter, fuel, medicine and other services, while providing essential habitats for plants and animals. WWF understands the threats facing forests today. But trying to prohibit the use of forest resources isn't a viable solution. What can work is a system of certification that ensures sustainable management of these vital resources (wwf.panda.org).

Forest management is a long-term process. The results of good practice can often only become apparent after decades. PEFC Sustainable Forest Management certification provides forest owners and managers with independent recognition of their responsible management practices. As consumers, businesses and governments become more concerned with their environmental footprints, markets for certified paper and wood products continue to grow. PEFC certification provides forest owners and managers – families, communities and companies – with access to the global marketplace for certified products (www.pefc.org).

PEFC sets the highest standards for forest certification and sustainable forest management in line with society's ever evolving understanding and expectations. PEFC's Sustainability Benchmarks are based on a broad societal consensus expressed in international, intergovernmental, multi-stakeholder processes and guidelines involving thousands of interested parties.

Obtaining the PEFC Sustainable Forest Management certification demonstrates that management practices meet requirements for best practice in sustainable forest management, including that:

The biodiversity of forest ecosystems is maintained or enhanced

The range of ecosystem services that forests provide is sustained

Forests provide food, fibre, biomass and wood

Forests are a key part of the water cycle, act as sinks capturing and storing carbon, and prevent soil erosion

Forests provide habitats and shelter for people and wildlife; and they offer spiritual and recreational benefits

Chemicals are substituted by natural alternatives or their use is minimized

Workers' rights and welfare are protected

Local employment is encouraged

Indigenous peoples' rights are respected

Operations are undertaken within the legal framework and following the best practices

The Earth Summit produced no legally- binding commitments on forest management, but it did result in Agenda 21 and the non-legally binding Forest Principles. Also, it crucially provided a forum for many non-governmental organizations to come together and gather support for the innovative idea of a non-governmental, independent and international forest certification scheme. Following intensive consultations in ten countries to build support for the idea of a worldwide certification system, the FSC Founding Assembly was held in Toronto, Canada in 1993.

The FSC Secretariat opened in Oaxaca, Mexico and the FSC was established as a legal entity in Mexico in February 1994. The FSC Secretariat relocated to Bonn, Germany in 2003. The world's forests meet the social, ecological, and economic rights and needs of the present generation without compromising those of future generations.

The Forest Stewardship Council A.C. (FSC) shall promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests (www.fsc.org).

The FSC Principles & Criteria (P&C) describe the essential elements or rules of environmentally appropriate, socially beneficial and economically viable forest management. There are ten principles setting out this vision; each principle is supported by several criteria that provide a way of judging whether the principle has been met in practice.

FSC defines a small producer in terms of the area of their forests or the volume of timber they harvest each year. A small or low-intensity managed forest, or SLIMF, can qualify for streamlined auditing procedures that reduce the cost of the audit by, for example, reducing the sampling in the audit. The procedures also allow for desk-based audits in years where a small producer has not harvested. FSC has eligibility guidelines for SLIMFs that certification bodies use to determine if a forest is eligible or not.

To minimize erosion and stream sedimentation from forestry practices the Georgia Forestry Commission (GFC) has an agreement with the Environmental Protection Division (EPD) of the Georgia Department of Natural Resources to educate the forestry community and promote the use of forestry Best Management Practices (BMPs). Under the same agreement with the EPD and through an understanding with the U.S. Environmental Protection Agency (EPA) and the Army Corps of Engineers, the GFC also monitors BMP implementation and investigates and mediates water quality and wetland complaints resulting from forestry practices (www.gatrees.org).

The forest certification system, local level indicators and guidelines like Best Management Practices are expected to be the most important activities for promoting better forest management at the forest management unit (FMU) level and forestry sector level. Responsible forest management is also a key component of sustainable forest management for a future in which local people are willing to participate in forest management activities and keeping in touch with the life of a richer forest.

FOREST SCIENCE AND TECHNOLOGY

Evaluation of ecosystem service and monitoring

On the aim and scope of the book series Managing Forest Ecosystems, Gadow *et al.* (2000) describe as follows:
Well-managed forests and woodlands are a renewable resource, producing essential raw material with minimum waste and energy use. Rich in habitat and species diversity, forests may contribute to increased ecosystem stability. They can absorb the effects of unwanted deposition and other disturbances and protect neighbouring ecosystems by maintaining stable nutrient and energy cycles and by preventing soil degradation and erosion. They provide much-needed recreation and their continued existence contribute to stabilizing rural communities.

Forests are managed for timber production and species, habitat and process conservation. A subtle shift from multiple-use management to ecosystems management is being observed and the new ecological perspective of multi-functional forest management is based on the principles of ecosystem diversity, stability and elasticity, and the dynamic equilibrium of primary and secondary production.

Making full use of new technology is one of the challenges facing forest management today. Resource information must be obtained with a limited budget. This requires better timing of resource assessment activities and improved use of multiple data sources. Sound ecosystems management, like any other management activity, relies on effective forecasting and operational control (e.g. Gadow, 2006).

Techniques for forest zoning

Ecological Site Classification (ESC) will help forest managers to select tree species, and to make related decisions based on an appreciation of the ecological potential of sites. The classification focuses on the key factors of the site that influence tree growth, and that are important to the rest of the ecosystem. This site-orientated approach to tree species selection will assist users in practicing sustainable forestry. For example, by selecting species suitable to a site, it will discourage the approach of selecting a species and then altering site conditions by excessive ground preparation and fertilizer applications (Pyatt *et al.*, 2001).

The large-scale application of new silvicultural systems has become a political reality in many parts of the world. This involves a gradual transformation of traditional silvicultural practices towards *Continuous Cover Forestry*, also known as *near-natural* forest management, favouring mixed uneven-aged stands, site-adapted tree species and selective harvesting. Selective harvesting systems have a long tradition. Specific *CCF*-related resource assessment, forecasting and sustainable harvest control techniques have been developed, but details about their use are not widely known (Gadow *et al.*, 2002).

Using a very simple classification based on the development of timber volume over age or time we may distinguish two types of sustainable forest management systems:. rotation forest management (RFM) systems, characterized by standard silvicultural treatments and repetitive cycles of clearfelling, followed by planting and continuous cover forestry (CCF) systems which are characterized by selective harvesting and natural regeneration, resulting in uneven-aged structures and frequently also in multi-species forests. The distinction is usually the result of decisions relating to the cost of timber harvesting, simplicity of management, or various intangible benefits.

The oldest and most perfect examples of CCF systems are the so-called plenter selection forests found in France, Switzerland, Slovenia and Germany.

In a forest managed under the selection system, the stand age is undefined. Forest development does not follow a cyclic harvest-and-regeneration pattern. Instead, it oscillates around some "ideal" level of growing stock. The mean annual increment is not appropriate for measuring productivity and the Normal Forest concept and the traditional sustainability criteria are not applicable. CCF systems are encountered in many parts of the world, but forest managers often lack the technical support for generating and evaluating treatment options for complex forest structures.

Using GIS analysis, the relationship between environmental factors and suitability for plantation are reported by Mitsuda *et al.* (2010) and Kodani *et al.* (2011). The assessment of forest functions and problems for forest planning is reviewed by Miyamoto (2010).

Status of Japan

Since World War II, all of Japan's forest resources are reaching the highest maturity stage, mainly in plantation forests. However, domestic forestry in Japan is facing severe management conditions because of the lack of labor and the decline of log prices. In 2012, the "Forest Law" was revised to introduce: 1) the assurance system of proper forest management in forests whose owners are unknown, 2) the administrative order system to halt logging without permission and oblige those loggers to replant, 3) the mandatory notification system for new forest owners, and 4) the "Collective Forest Management Plan System" to promote coordination and consolidation of forestry practices among small private forest owners (MAFF, 2013).

As the role of municipalities in forest and forestry policy becomes more important, the Forest Agency intends to train technical experts who can support local governments and local forest management by working as "Foresters." The Forest Agency is also training technical experts in the planning and construction of forest roads. During the training course, these experts are expected to show the vision and missions of local forest management in a neutral position with wide-scale and long-term viewpoints and to lead the local forestry.

Forest information system (FIS)

Digital forestry is the science, technology, and art of systematically acquiring, integrating, analyzing and applying digital information to support sustainable forests (Zhao *et al.*, 2005). Although many forest scientists and forest professionals are already applying a wide variety of digital technologies in forestry, the gap between contemporary forestry and the concepts embodied in digital forestry is significant. Digital forestry can function as bridge that links the producers and users of digital technologies in forestry (Shao and Reynolds, 2006).

Data management of the National Forest Inventory and monitoring aims to provide a database or data bank and it is currently widely recognized as a digital archive, or on-line database. These databases are directed to decision-makers and the public (e.g. Vibrans *et al.*, 2010). With web service-based architecture, the system can enable interoperability, integrate web services from other application servers, reuse codes, and shorten the development time and cost. Using open source software to develop spatial forest information systems can greatly reduce the cost while providing high performance and sharing spatial forest information (LI *et al.*, 2007).

The agroforestry database is a tree reference and selection guide for 670 tree species that can be used in agroforestry systems in tropical and subtropical regions around the world. Version 4 of the database introduces new searching facilities that allow the selection of tree species that provide specific products, specific environmental services and/or climatological requirements (Oballa *et al.*, 2010, Orwa *et al.*, 2010).

"e-TANZAWA" is a website and a database station for a project team working for the regeneration and conservation of the TANZAWA forest area. They have data archives supported by Web-GIS and provide their activity report to the public (www.e-tanzawa.jp) .

"e-forest" is the term for our five year project going under consortia (Nonoda, 2012, Nonoda *et al.*, 2012, Chiba, 2012, Shiozawa, 2012, Mochizuki, 2012). Research topics are: (1) Construction of forest resource database, (2) Development of a forest diagnostic system using a small-sized laser scanner, etc. Four major functions to be involved in the "e-forest" system are shown in Figure 3 as *4-S*, i.e. sampling, simulation, scheduling, and steering. The image of the end user and functions of "e-forest" are also illustrated in Fig. 4.

DISCUSSION

A review of philosophy and techniques for forest resource management reveals an extensive range of forest science and practices. Managing forest ecosystems maybe characterized by two broad and related categories:

(1) resource inventory and monitoring

(2) analysis, modeling, and simulation to support decision making

With these two types of broad activities under consideration with the ongoing movement concerning the sustainable forest management and state-of-the-art research results, this review provides a recent status of managing global forest ecosystems and proposes knowledge and tools for adaptive ecosystem management. The basic concept is how to maintain a sound forest ecosystem for sustainable forest management and to consider a wise use of forest resources and services using intelligent forest information system, e.g.

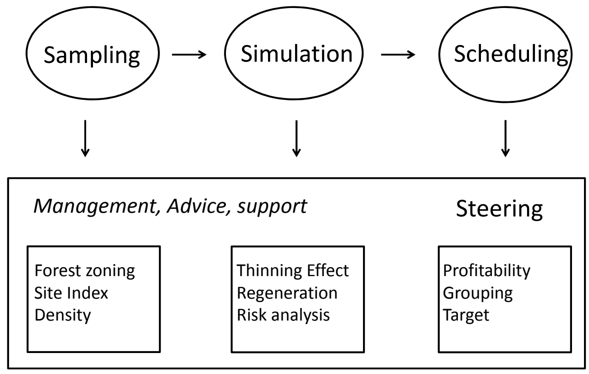

Fig. 3 Major function "4-S" of e-forest system

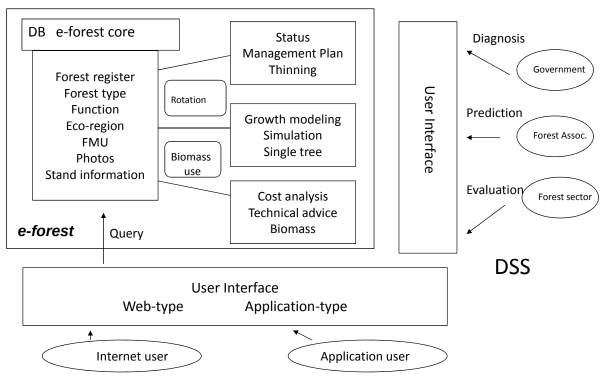

Fig. 4 Database and function of e-forest system

forest database and GIS applications.

The acquisition of basic inventory and monitoring data is fundamental to forest management as well as efforts to conserve a sound forest ecosystem. Furthermore, these data might be updated over time and space, and changes should be recorded and analyzed to compare threshold indicators for checking sustainability.

Applications of resource management in forestry deal with not only single management issues, such as forest zoning, 3D sampling, risk analysis, and optimal harvesting, but also how a mix of management concerns could be integrated through results of scientific research. Nishikawa (2004) introduced the applicability of ecosystem management using an expert system for forest planning. Building an appropriate knowledge database and sharing the results of good practices are the keystones to approaching and evaluating sustainable forest management.

ACKNOWLEDGEMENTS

To compile this review, we would like to thank many Japanese and foreign colleagues, especially for their advice: Sloboda, B., Gadow, K.v., Saborowski, J., Nagel, J., Polley, H., and Marx, K.H. in Germany, Tomppo, E. in Finland, Brassel, P. in Switzerland, and Mason, W.L., and Ray, D. in U.K.

This study was partly funded by the Japan Society for the Promotion of Science Grants-in-Aid for Scientific Research 22405025 and research and development projects for application in promoting a new policy of agriculture, forestry and fisheries 22033.

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* The English title is tentative translation by the authors of this paper from original Japanese title.

(Received 29 October 2012)
(Accepted 30 January 2013)

Article

A Perspective on the Next-Generation Forest Register in the Era of GIS

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ABSTRACT

This paper points out some defects of the current forest register and proposes a concept of next-generation forest register from the view point of GIS application to forest management. Since the fundamental purpose of the GIS is to conduct spatial analysis of multiple thematic maps, one of the basic requirements for the next-generation forest register is the management of forest information on a thematic map basis by using the spatial analysis function of the forest GIS. The main proposals are as follows. The forest register information should be divided into multiple pieces according to thematic maps and their attribute information should be managed separately. The administrative data is an accumulation of thematic maps created every year. Data on forest management should be shared with forestry cooperatives and updated by forestry cooperatives electronically. The issue of personal information can be resolved by dividing the forest register information and managing it separately. Detailed historical information of stands is not necessarily contained in the database; rather, utilizing hyperlinks to the Forest Karte (record). The minimum information of forest GIS may be the thematic map of the forest physiognomy. A forestry experiment station-type forest GIS which is equipped with advanced spatial analysis functions is needed, and analysis and research results obtained from the full use of these functions are provided to the forest GIS used by administrative offices and forestry cooperatives.

Keywords: forest register, GIS, spatial analysis, thematic map

INTRODUCTION

All prefectures have already introduced the forest GIS in Japan, and staffs of not only prefectures but also forestry cooperatives are now starting to use forest GIS. The forest GIS will be recognized as an indispensable system for forest management in the near future. With the spread of the forest GIS, both usage of forest GIS and needs for forest GIS have been changing. It is getting clear that there are new problems on the effective use of forest GIS such as how to gather and update the attribute information, how to apply the function of spatial analysis, how to provide the fundamental thematic maps of forest GIS to users. In addition, we are still having some difficulty in discovering how an ideal next-generation forest register should be. Here, forest register is an account book for forest management in which present condition and related information of each forest stand are recorded.

In this paper, I point out some defects of the current forest register and propose a concept of next-generation forest register from the view point of GIS application to forest management.

DEFECTS IN THE CURRENT FOREST REGISTER

The forest register prepared by prefectures is used as attribute information for the forest GIS. However, the forest register has some structural defects as explained below.

First, the forest register originally designed to show the current state of forest stands. However, the attribute information used for the present-day forest GIS should be more than just its current state. A next-generation forest register which includes the management history needs to be established.

Second, the gap between the information in the forest register and actual stand condition is growing larger, and that gap is sometimes too big to be ignored. For example, the register says there is an area of artificial forest in a certain place but in fact there is only a poor afforested land where trees do not grow well, and there are numerous cases such as this. Accurate information should be prepared in the forest register in order to make efficient use of the register.

Third, the forest register focuses on information about timber production and includes little information about various public benefits that the forests provide. Workers in the field need information about how the forest functions in a way that

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preserves water and protects the soil, as well as in maintaining biodiversity and the ecosystem, and furthermore, they need information about damage to wildlife and damage by disease or insect pests. It is expected that forests features which provide public benefits should be fully used, but the contents of the current forest register are definitely not enough. A next-generation forest register needs to be created.

Fourth, administrative offices and on-site workers do not agree on how to use the forest register and when it should be updated. Some prefectures believe the forest register should only be updated every five years, but forestry cooperatives need to update the forest register more frequently depending on how the forest is managed. Old information does not help them use the forest GIS effectively.

Lastly, the forest register cannot be disclosed because it contains some personal information. This causes another problem, that is, manufactures in the log production industry, who support local forestry activities, cannot obtain the required information. This also obstructs the introduction of healthy competition in the local log production marketplace.

The above-mentioned issues about the current forest register should be solved in order to establish a next-generation forest register that uses GIS as its core and a system that enables continuous updating of data as soon as possible.

DEVELOPING PHASES OF THE FOREST GIS

So far, the forest GIS is thought to have five developing phases.

The first-generation GIS is a system where sub-compartment polygons are created and the polygons are linked to the information from the forest register, which is used as attribute information. Most forest GISs used by prefectures are first-generation.

The second-generation forest GIS is a system where vector data created from existing geographic information such as paper maps are input, and the GIS analyzes that information to make a new thematic map according to the object. This is used when a forest function assessment sectional map based on existing materials is created, for example.

The third-generation forest GIS can analyze monitoring results such as remote sensing information and new forest information, and the fourth-generation forest GIS uses the Internet to collect information about local forests and provides a system to share such information with locals who are involved in the issues.

The fifth-generation forest GIS can analyze various types of forest information collectively and conduct scenario analyses according to possible future events so that the results can be applied to policy making and consensus building.

The first-generation forest GIS is just information of the forest register used as attribute information for sub-compartment polygons, and this simply makes it easier to display and search for forest information and create sectional maps. In addition, the information contained in the forest register is basically the current forest state, so there still remains the issue of maintenance and accumulation methods for each stand's history.

As the fifth-generation forest GIS is used for policy making and consensus building, this type of forest GIS is required to collect various types of information from external sources and make thematic maps or materials according to every single request. Accordingly, we have to review what kind of attribute information should be installed to the forest GIS as the minimum level of information necessary. Also, the forest register must have a flexible structure so that any external data can be taken into the register in various formats.

FUNCTIONS OF THE FOREST GIS

Before thinking about the next-generation forest register based on the forest GIS, we should understand the characteristics of GIS functions to build a structure that allows full use of the GIS functions. This is why we have to reconsider what functions the GIS provide.

The GIS generally provides the following four functions: database function, spatial analysis function, information sending and sharing function, and decision-making support function. Among these functions, the most important function that is essential to the GIS is the spatial analysis function (TANAKA and YOSHIDA, 2005).

Some people think the GIS is a database with map information, which is not correct. Since those who only know the first-generation forest GIS are told that the forest GIS is a system where sub-compartment polygons linked to the information from the forest register, which is used as attribute information, this misunderstanding may be inevitable. However, this way of understanding is only about a rough view of the way the next-generation forest register should be.

Think about how to hold geographic information with the GIS, and compare that with a paper map. One commercial paper map shows all types of geographic information on it. However, the GIS does not hold geographic information in that way. The GIS creates different geographic information for every thematic map and keeps it as a file. For example, it creates a thematic map of a water system consisting of information about rivers and other inland waters, or it creates a thematic map of road networks, collecting geographic information only on roads and streets. After that, it calls only thematic maps needed for the analysis, and conducts spatial analysis dealing with these maps as a layer (Fig. 1). Information such as a paper map on the market is used for background images as raster data.

The key to the GIS is the spatial analysis using multiple thematic maps. Each thematic map has its own attribute information, and by using an overlay function called union, such attribute information is automatically inherited to finer polygons created by the overlay.

POINT DATA WITH GPS INFORMATION, THE MAIN STREAM OF NEW FOREST INFORMATION: CALCULATION OF PLANES FROM POINTS

When thinking about the way the next-generation forest register should be, needless to say, prior consideration of updating the forest register data is also needed. It is necessary

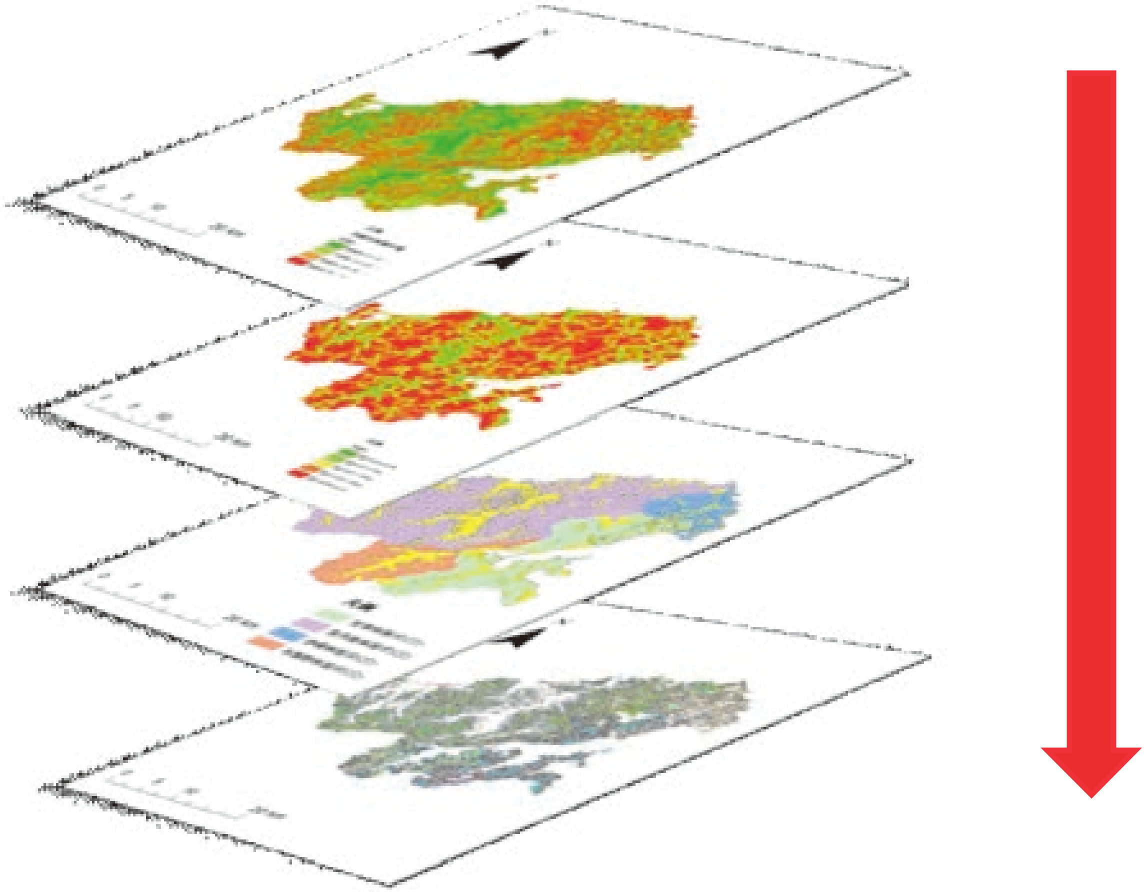

Fig. 1 Image of overlay
The GIS creates different geographic information for every thematic map and conducts spatial analysis dealing with these maps as a layer. From the top, reclassified inclination map, distance sectional map from forest road, administrative district map, age class map of plantations in the area of Tango Promotion Administration Office in Kyoto Prefecture. By using overlay function, we can visualize the geographical advantage condition of each forest stand.

and important to set up fewer steps for manual data updating. In this section, we will consider future ways to obtain GIS data. We have already seen the five development phases of the forest GIS, and since the first and second-generation forest GIS uses drawing data, polygons can be used. GIS in the newer phases, however, are provided with different data obtaining methods.

The third-generation forest GIS uses remote sensing data. Remote sensing data is raster data, so the spatial analysis with GIS means raster data analysis in many cases. Additionally, the analysis results will be integrated into sub-compartment polygons when necessary.

The fourth-generation forest GIS has a system where various observations or research results are analyzed and it also provides a function to distribute the analysis results to relevant local people through the Internet, and the observation or research results basically consist of point data with some GPS information in the future. The major method of analysis using the GIS will be the calculation of planes from points, utilizing the spatial analysis function.

The fifth-generation forest GIS utilizes external digital geographic information in various formats for policy making. This means the system uses not only the data from a database created by the users. You may realize that the establishment of a database consisting of many items is not so significant in this sense. Additionally, since the proper external responsible division will update each external database, people concerned with forests and forestry should discuss what types of data they update as the forest GIS data.

As mentioned above, the fundamental purpose of the GIS is to conduct spatial analysis of multiple thematic maps. The thematic maps used for the analysis must have a reliable source and assured accuracy and reliability, and the users should take responsibility to update the data provided by them. Most data updating according to ground surveys will basically use point data with the GPS information, and planes calculated with points by using the spatial analysis function will be released to other divisions.

DIVISION OF THE FOREST REGISTER

Forests functions in a way that provide public benefits, and such information should be open to the public, in principle. Various forest conservation activities such as model forest movements have been developing in many places throughout the country, and by sharing the forest information, mutual understanding with stakeholders should be encouraged and forest planning which involves ordinary citizens should be established. Municipal forest improvement plans, in particular, require the disclosure of forest information in order to improve transparency and accountability. Since the forest register includes some personal information, however, it has not been disclosed yet.

Prefectural governments supervise the forest register, and its contents slightly vary depending on prefectures. Some prefectures have nearly 200 items registered in the register. However, it is thought that only a small part of the items are related to personal information, although this is not for certain because the register is not open to the public. In other words, since the forest register partially contains personal information, information that has nothing to do with personal information is also not disclosed.

In order to solve this problem, the current forest register information should be divided into different groups. Considering relationships with the forest GIS, it makes sense to divide the forest register information according to the contents of multiple thematic maps. One of those thematic maps will be about forest owners, which contains the personal information. It is appropriate for the thematic map containing personal information and its attribute information not be open to the public.

Division of the forest register according to thematic maps makes it easier to access needed data when users analyze information with the forest GIS, and additionally, it enables them to set up different data updating systems and timing according to the thematic map. Also, updating forest management data can be committed to forestry cooperatives or manufactures in the log production industry, and updated data can be collected in an electronic format.

WHAT WILL THE NEXT-GENERATION FOREST REGISTER BE LIKE?

Now we can envision the outline of the next-generation register centered around the GIS. When the forest GIS is applied to policy making or consensus building, related information should be collected from inside and outside the organization, and geographic information should be processed with the GIS's spatial analysis function (Fig. 2). Accordingly, the fundamental form of the data consists of a thematic map and its attribute information. In addition, the spatial analysis function of the GIS can deal with various data formats of the thematic maps handled, including polygon data which has been used for the traditional forest GIS, raster data which can be obtained by remote sensing, point data which comes from field studies with GPS measurements, digital elevation models (DEM) and digital surface models (DSM) which are created through laser profiling from a plane. Information in the forest register is also divided into different sections according to multiple thematic maps, and each section of information is processed in the same way, with the spatial analysis function of the GIS. In terms of these methods, information in the forest register should be information that can be created or updated by people concerned with forests and forestry under their responsibility.

Since various thematic maps are used for the forest GIS as stated above, we need to think about what types of attribute information should be provided with the forest GIS as a minimum. The minimum attribute information may be ID numbers of sub-compartments created by prefectures and some other related information. The thematic map of the forest physiognomy sectional map, that is, forest stand map, should correspond to this.

Historical information can be treated in the following way from a practical point of view.

First of all, each thematic map needs to be placed on a proper position in the current of the time. Prefectural official forest information as statistical data can be a series of the thematic map as of April 1st, or October 1st of every year. A national census used for the demographic statistics is carried out on October 1st every five years, and the thematic map prepared on a specific day such as October 1st will be kept after the example of this. The thematic map of each year kept in this way becomes historical information used by prefectures and municipalities as administrative materials.

Secondly, there is another issue about each stand's historical information. To solve this issue, it might be practical to hyperlink it to the "Forest Karte (record)." Creating the Forest Karte with a spreadsheet program such as MS Excel helps because the users can use another sheet for a new fiscal year. Some advanced forestry cooperatives already create the Forest Karte, so using hyperlinks will be a better way to respect their formats and contents. Accordingly, the forest GIS extract stands that the users want to see by searching data, and detailed historical information of each stand can be accessed through hyperlinks. In other words, detailed historical information of every single stand is not kept on the forest GIS, but the forest GIS just narrows down and extracts a certain group of stands by a search condition, according to this manner of use.

The remaining issue is about the treatment of historical information about each stand. This is about the historical information on forest land; for example, the current artificial forest land has been an artificial forest land for a long time, or it used to be a natural forest. The accumulation of thematic maps on a specific day such as April 1st enables us to use such information in the future, but ideally, we have to prepare such information on past situations using the results of aerial photographic analyses. In the case of a mountain disaster, wind damage, and snow damage, a damage map should be prepared for all such occasions. Eventually, the accumulation of historical information on stands in 10-meter mesh would be good enough.

NEED FOR FORESTRY EXPERIMENT STATION-TYPE FOREST GIS

We have seen a draft proposal of the next-generation forest register based on the GIS, and its basic concept is that forest information is created, managed, and updated on a basic thematic map basis. Here, basic thematic map means the thematic map of basic data. It solves issues and meets

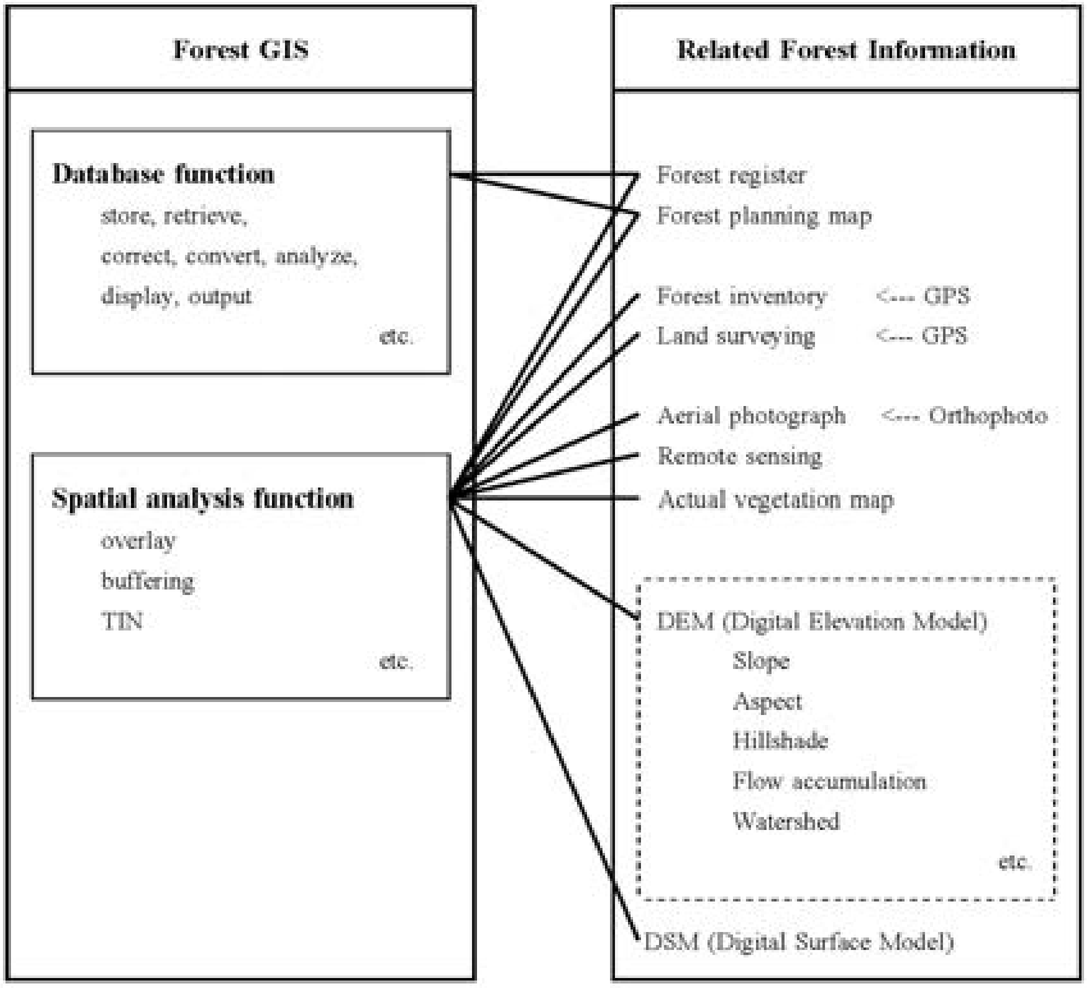

Fig. 2 Functions of forest GIS and related forest information
When the forest GIS is applied to policy making or consensus building, related information should be collected from inside and outside the organization, and geographic information should be processed with the GIS's spatial analysis function.

requests by using the spatial analysis function of the forest GIS to pick and use various thematic maps at the same time. Such a flexible structure enables the forest GIS to be developed as desired according to various needs.

However, groups of specialists of the highly advanced spatial analysis are required because administrative offices and forestry cooperatives cannot have a perfect command of the advanced spatial analysis function of the GIS. In this section, we call this kind of forest GIS which conducts advanced analyses "forestry experiment station-type forest GIS."

A forestry experiment station-type forest GIS is equipped with advanced spatial analysis functions, and analysis and research results obtained from the full use of these functions are provided to the forest GIS used by administrative offices and forestry cooperatives. This means this type of GIS is expected to create and provide new forest GIS information in each region, using the latest IT technologies such as remote sensing, GPS, and the Internet.

As social needs for local forest information increase, it is thought that only technical experts at forestry experiment stations can analyze various types of forest information collectively, conduct scenario analyses based on expected future events, and create geographic information which is suitable for applying to policy making and consensus building. Proper facilities and groups of experts who have advanced knowledge should be established or developed immediately.

People concerned with forests and forestry do need some IT help and support for their business because they have to deal with complicated, diversified and extensive nature, and the forest GIS is an indispensable system. Also, the forestry experiment station-type forest GIS is expected to provide the newest forest information in a proper way.

CONCLUSION

The next-generation forest register should be developed based on the assumption that it is used for the forest GIS, and consequently, the forest register information should be divided into multiple pieces according to thematic maps and their attribute information should be managed separately. This means the forest GIS is used as a tool for spatial analysis, not a database. The administrative data is an accumulation of thematic maps created every year. Data on forest management should be shared with forestry cooperatives and updated by forestry cooperatives electronically. The issue of personal information can be resolved by dividing the forest register information and managing it separately. Detailed historical information of stands is not necessarily contained in the database; rather, utilizing hyperlinks added to the Forest Karte improves the flexibility of the Forest Karte. The most important thing in the improvement based on the PDCA cycle is originality and ingenuity of on-site workers, so the management of the Forest Karte is entirely left up to on-site workers. Although data updating is always a significant issue to any system, the method of separately managing forest registries enables us to establish a system of taking responsibility of data updating for each thematic map.

This structure of the next-generation forest register can reduce the number of functions of the forest GIS used by on-site workers and the number of tasks they perform. This is because they only have to download the forest register information they need in a thematic map format. When they want new thematic maps or new data, they can ask an expert of the forestry experiment station-type forest GIS to create such new items. Although we call this system forestry experiment station-type forest GIS, they can ask proper external consultants to take care of this instead.

As I've mentioned repeatedly, I'm against the idea of creating a huge database consisting of so many items as a next-generation forest register. Creating such a database requires a great deal of labor, and additionally, updating the data is also laborious work. In addition, a database with an inflexible structure may have quite a bit of trouble when used in the future.

One of the basic requirements for the next-generation forest register is the management of forest information on a thematic map basis by using the spatial analysis function of the forest GIS. I hope these ideas are a starting point for considering the next-generation forest register.

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(Received 16 September 2012)
(Accepted 29 January 2013)

Article

Developing a National-level System for Simulating the Carbon Dynamics of Hinoki (*Chamaecyparis obtusa*) Planted Forests in Japan

Yasushi Mitsuda [*1] Hidesato Kanomata [*2] and Mitsuo Matsumoto [*3]

ABSTRACT

The objectives of this study were to develop a national-level system for simulating the carbon dynamics of planted forests of hinoki, which is the second most important plantation species in Japan, and to discuss the effects of forestry on the carbon dynamics of hinoki planted forests at a national scale. We developed a simulation system consisting of a 1-km-grid national-level forest database and a stand-level carbon cycle model. We simulated the forest carbon dynamics for 2005 to 2050 at a national scale using the developed simulation system with estimated climatic values and harvested timber volumes. The results of simulations indicated that the promotion of forestry leads to a decrease in both total carbon stocks and total carbon sequestration for hinoki planted forests in Japan. Longer-term simulation is required to evaluate the effects of clearcutting and subsequent replanting on the carbon dynamics of Japan's forests.

Keywords: carbon cycle model, carbon sequestration, climate change, effect of forestry on carbon dynamics

INTRODUCTION

A system for simulating carbon dynamics at the national scale would provide valuable support for making decisions on climate change policy. Article 3.4 of the Kyoto Protocol recognizes appropriate forest management as an effective method for facilitating carbon removal (SEDJO *et al.*, 2002; IPCC, 2003; HIROSHIMA and NAKAJIMA, 2006). After World War II, the Japanese government intensively promoted the planting of marketable coniferous species, such as sugi (*Cryptomeria japonica*) and hinoki (*Chamaecyparis obtusa*), to fulfill the high domestic demand for timber. Consequently, approximately 40% of the forests in Japan are planted forests established for timber production. Thus, forest policies to promote appropriate management of the large areas of planted forests are essential for facilitating carbon sequestration in the future.

To ensure the implementation of effective forest management policies, it is necessary to have a system for simulating forest carbon dynamics at a national scale. The system must be able to compare the effects of alternative forest policies on future forest carbon sequestration so as to allow the optimum choice from among the alternatives. For reporting carbon stocks and its flux under the Kyoto Protocol, yield tables for each major species are used to estimate the carbon stocks for each stand of a specific species and age (MINISTRY OF THE ENVIRONMENT, JAPAN *et al.*, 2011). Yield tables are age-dependent stand-level stand simulators consisting of empirical models such as age-dependent tree height models and tree height/diameter correlation models. A stand simulator based on empirical relationships can provide a robust estimate of stand volume and carbon stocks; however, robustness cannot be assured under the future conditions with global climate change and changes in forestry operation regime, such as abandonment, longer rotation periods, and line thinning. Therefore, it is necessary to develop a system for predicting forest growth and also the forest carbon dynamics for a changing future.

The objectives of this study were to develop a national-level system for simulating the carbon dynamics of planted forests of hinoki, which is the second most important plantation species in Japan, and to discuss the effects of forestry on the carbon dynamics of hinoki planted forests in Japan.

SIMULATION SYSTEM

We developed a simulation system consisting of a national-level forest database and a stand-level carbon cycle

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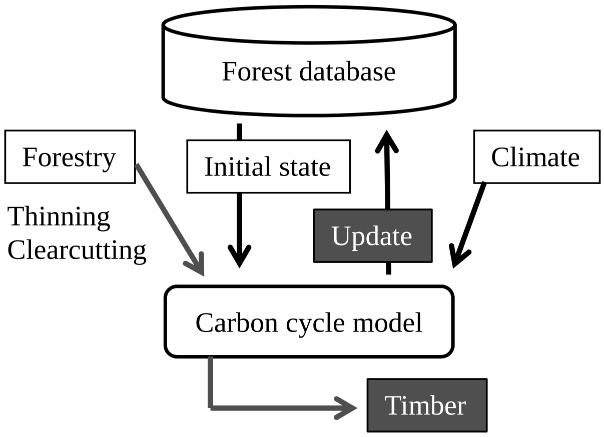

Fig. 1 Overview of national-level simulation system for carbon dynamics of hinoki planted forests.

model (Fig. 1). The forest database gives stand information for the carbon cycle model as initial values of the stand state. Based on predicted forestry activities and climatic values, the carbon cycle model estimates the carbon flux for each stand based on plant growth and forestry operation. Then, the forest database is updated by future values of the stand state estimated by the carbon cycle model and harvested timber, and the system provides information about the changes in carbon stocks in hinoki planted forests throughout Japan.

National-level Forest Database

Our database is a 1-km-grid forest database, derived from forest maps and registers available for all private and national forests in Japan (HIRATA *et al.*, 2010). Forest registers contain information on the forest stands, such as species, age, land area and owner. All forest stands are located on the forest map. We had already developed a national-scale forest database in a geographic information system (GIS), where stand information derived from the forest register and stand location derived from the forest map are linked (MATSUMOTO *et al.*, 2007). We reconstructed the national-level forest database at 1-km resolution for feasibility of computation and resolution of climatic data. Using the GIS function, we extracted vectors of forest stands by 1-km grid, and summarized the forest information within each 1-km grid, grouped by species and 5-year interval age class (Fig. 2). Thus, we defined cohorts by tree species and stand age class as the unit of the national-level forest database and simulation of forest carbon dynamics. As illustrated in Fig. 2, there are a number of cohorts within each 1-km grid.

First, we developed the forest database using the cohorts with information on the species, age class and area for each 1-km grid for all of Japan. The stand structure of each cohort, such as average tree size, tree number, and stocking biomass of each living woody biomass pool (stems, branches, foliage and roots), was estimated using the National Forest Inventory (e.g. KITAHARA *et al.*, 2008; 2010a;b). We divided the trees in each cohort into five strata by each 20 percentile of diameter at breast height (DBH), and defined this as the DBH class. We also estimated the tree size, number of trees, and stocking biomass for each DBH class. Furthermore, we defined five layers in the canopy structure, and estimated the foliage biomass of each layer for each DBH class (Fig. 3).

Stand-level Carbon Cycle Model

We developed a carbon-cycle based stand-level growth model. Process-based models (PBMs) include physiological interactions between plants and their environment, and are thus suitable for use with predicted future climate conditions; they are also suitable for simulating the effects of various management regimes (e.g., combinations of timing and intensity of thinning) on stand growth (e.g. MAKIPPÄÄ *et al.*, 1999; MÄKELÄ *et al.*, 2000; LASCH *et al.*, 2005). A number of process-based forest growth models have been developed to better understand the carbon cycle of forest ecosystems (e.g. GERTNER *et al.*, 1996; LANDSBERG and WARING, 1997; CHIBA,

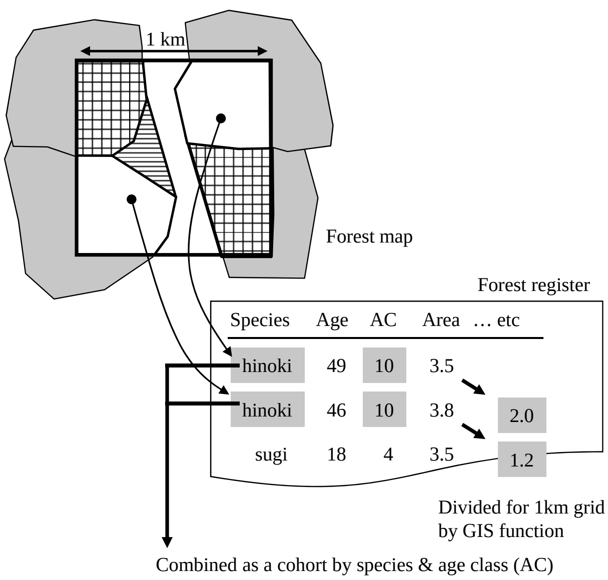

Fig. 2 Illustration of the procedure for constructing the 1-km-grid forest database.

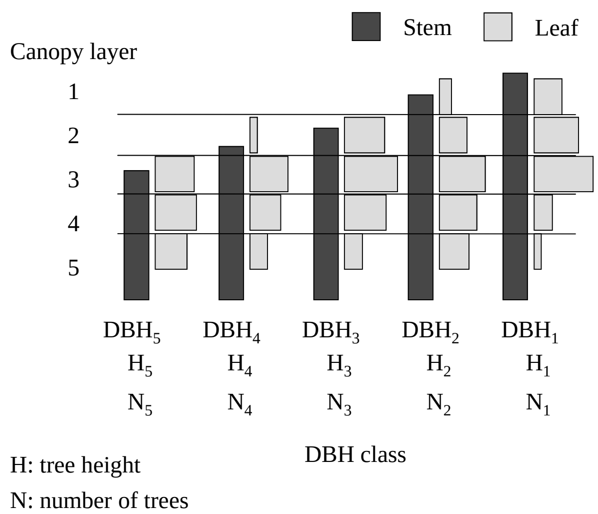

Fig. 3 Illustration of the stand structure of a cohort.

1998; Kurz and Apps, 1999; Mäkelä *et al*., 2000; Dufrêne *et al*., 2005), and we selected the 3-PG developed by Landsberg and Waring (1997) as the basis of our growth model.

Here, we briefly explain our stand-level carbon-cycle model. We modified the 3-PG model to a simpler version having only six processes: (1) photosynthetically active radiation absorption; (2) photosynthetic production; (3) constraints on photosynthesis by environmental factors; (4) respiration; (5) litterfall and root turnover; and (6) biomass partitioning (Fig. 4). The photosynthesis part of the 3-PG model, which includes processes (1) and (2), is based on the Monsi-Saeki canopy photosynthesis model. We used a monthly time-step for calculating photosynthesis and respiration, a yearly time-step for calculating litterfall and biomass partitioning. Dry matter weight per unit area of four living woody biomass pools (i.e., foliage, stems, branches, and roots) was used as the basis for calculating the carbon balance.

We further modified the original 3-PG model in the following points. We simplified the model so as to have only two climatic factors restricting the potential gross photosynthetic rate in process (3). At the same time, we modified the calculation method for the potential gross photosynthetic rate in process (2). At the photosynthetic production process, absorbed solar radiation is converted to gross primary production using canopy quantum efficiency, which was set to be constant in the original 3-PG model. However, we used a light-response curve to express the nonlinear relationship between the photosynthetic rate and the intensity of absorbed radiation (e.g. Hirose and Werger, 1987). Furthermore, we introduced five leaf strata to the canopy structure, and then we calculated the intensity of radiation, related photosynthetic rate, and gross primary production for each leaf stratum. This modification allowed us to evaluate the aftereffects of different thinning scenarios on stand growth. A detailed representation of our model is provided in Mitsuda *et al*. (2010). The parameters of our model were derived from long-term repeated measurements at the permanent plots for a yield study located in the National Forest.

Our model includes some ecophysiological interactions between plants and their environment, and therefore may be

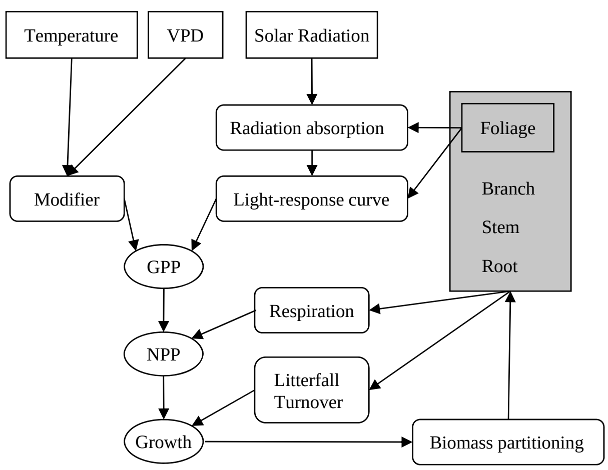

Fig. 4 Flow diagram of the carbon cycle model developed in this study.

more suitable for predicting the future forest carbon dynamics at a national scale with climate and forestry regime changes compared to the yield table approach. Although our model reflects some ecophysiological processes, it contains some empirical relationships as well. As stated in Korzukhin *et al*. (1996), all models can be placed somewhere on a continuum from purely mechanistic to purely statistical. Finding a balance between model complexity, structural and temporal resolution and costs for parameterization, data requirements, and computational feasibility should be considered.

SIMULATION

Using the system developed here, we ran simulations to investigate the effect of forestry on carbon dynamics of hinoki planted forests at a national scale. For each hinoki cohort throughout Japan, the initial stand status was assigned from the 1-km-grid national-level forest database developed in this study. As the forest database was prepared using the forest registers and maps of 2005, the starting year of the simulation of carbon dynamics was set as 2005, to continue until 2050, thus covering 45 years. The stand-level carbon-cycle model developed in this study estimated the stand growth for each hinoki cohort using 1-km-resolution monthly time-step climate data derived from MIROC-hi 3.2, which was developed by K-1 Model Developers (2004) and interpolated into 1-km-resolution by the Agro-Meteorology Division, National Institute for Agro-Environmental Sciences. Timber volumes to be cut by thinning and clearcutting were assigned for each age class of each prefecture. Until the harvested volume reached the volume estimated in the forestry scenarios (see later), cohorts to be thinned or clearcut were chosen according to the suitability of forestry operations evaluated by road density and topography for each 1-km grid. The 1-km-grid national-level forest database was updated by simulated stand growth information and harvest information, and then we summarized the carbon stocks and carbon flux in hinoki planted forests for all of Japan. Natural disturbances caused by strong wind, heavy rain and insects, were not considered.

We set two forestry scenarios identified based on the estimated value of harvest timber volume by clearcutting and the replanting ratio after harvesting. The first scenario was based on the current trend in forestry. We assumed that the current annual volume of timber harvest by clearcutting for each prefecture would be constant. The volume to be harvested by clearcutting for each age class was proportional to the area of the respective age class. It should be noted that stands targeted for harvesting by clearcutting were all over 40-years-old. In the case of thinning, we assumed that current annual thinned timber volume per unit area, which was calculated as thinned volume divided by total area (not thinned area) for each age class for each prefecture, would also be constant. The volume to be harvested by thinning was estimated by that value and total area for each age class for each prefecture. Thus, we estimated timber volume to be harvested by clearcutting and thinning for each age class for each prefecture for every year in the simulation period. As mentioned earlier, we chose cohorts to be clearcut and thinned to fulfill those estimated volumes in simulations.

When a cohort was clearcut, we decided whether it would be replanted or not using a certain probability, which is called the replanting ratio in this study. The replanting ratio after clearcutting was set to be constant at 50%, which reflects the current value. We derived the second scenario from the first one. In Scenario 2, annual timber volume to be harvested by clearcutting for each prefecture was doubled, assuming that harvesting was promoted by forest policy. Additionally, the replanting ratio was increased to 80%, assuming that replanting after harvest was also promoted.

RESULTS AND DISCUSSION

Fig. 5 shows the results of simulation based on Scenario 1. The solid line shows the carbon stocks of total living woody biomass in hinoki planted forests of Japan. The black broken line shows the carbon flux and the gray solid line shows the smoothed carbon flux. Under the conditions of Scenario 1, the total carbon stocks in hinoki planted forests in Japan continued to increase until 2050. The carbon flux took positive values throughout the simulation period, which indicated that the hinoki planted forests would remain a carbon sink until 2050. The hinoki planted forests will capture carbon in the air until 2050; however, the annual rate of carbon sequestration will decrease gradually. This may be due to the current age distribution of hinoki planted forests. As mentioned earlier, the government had promoted the planting of marketable coniferous species; however, after Japan's rapid economic growth, timber prices dropped and forestry activity decreased. Therefore, as shown in Fig. 6, the current age distribution of hinoki planted forests is biased, showing fewer younger stands and a sharp peak in age class 8 (up to 40 years). This biased age distribution did not change during the simulation period; it simply shifted to older, hence the proportion of area of older-aged stands, where the carbon sequestration rate was low, gradually increased. As a result, the simulation indicated that the carbon flux of planted hinoki forests would decrease gradually until 2050.

Fig. 7 shows the spatial distribution of carbon stocks and its changes between 2005 and 2050. One-km grids with higher carbon stocks in hinoki planted forests are shown in a darker color. Nagano and Gifu Prefectures are famous regions for hinoki forests, large areas of which have been managed for many years. Hinoki might be the preferred planting species in Wakayama, Ehime, and Kochi Prefectures. Reflecting the historical trends in planting, the spatial distribution of hinoki carbon stocks varies across Japan.

Time series of carbon stocks and its flux simulated using the two forestry scenarios are compared in Fig. 8. The solid lines represent the dynamics of carbon stocks and the broken lines are the smoothed dynamics of the carbon flux. Promotion of harvesting caused a decrease in both total carbon stocks and total carbon flux of hinoki planted forests in Japan. In older-aged stands, as mentioned above, the growth rate decreased as stand age increased; however, volume growth would continue at a certain rate (e.g. IEHARA *et al.*, 2001). As hinoki is not a fast-growing species, the annual volume growth of a stand just after replanting is often lower than that of older-aged stands. On a national scale, the regeneration effect on carbon sequestration derived from clearcutting and subsequent replanting could not compensate for the amount of carbon absorbed by harvested older-aged stands.

Our simulation of the forest carbon dynamics for 45 years indicates that the promotion of forestry would result in a decrease in both total carbon stocks and total carbon sequestration of hinoki planted forests in Japan, although the carbon sequestration rate decreased in both forestry scenarios. This trend must be examined with a longer simulation period (over 45 years) for both forestry scenarios. In Scenario 1, forestry activities were assumed to be at a quite low level, so the carbon sequestration rate would continue to decrease into the future. In Scenario 2, however, regenerated stands would grow into mature stands which absorb much more carbon than older-aged stands, suggesting that the carbon sequestration rate would recover in a longer term simulation. To help support decision-making in forest policy, the regeneration effect of clearcutting and replanting should be examined with longer-term simulations.

Thus, the developed national-level system for simulating the carbon dynamics of hinoki planted forests was able to evaluate the effect of forestry promotion at a national scale. A comparison of simulations based on several forestry scenarios would help us to evaluate the effects of forestry promotion on forest carbon dynamics at a national scale, and then to select the desirable forest policy. Hence, our system can be an efficient tool for supporting decisions in the policy-making process.

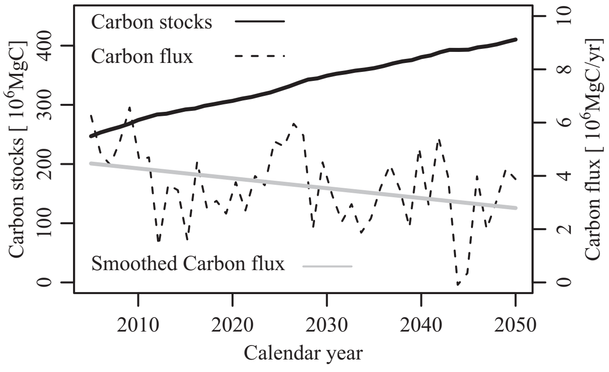

Fig. 5 Simulated dynamics of carbon stocks of total living woody biomass and its flux in hinoki planted forests for all of Japan.

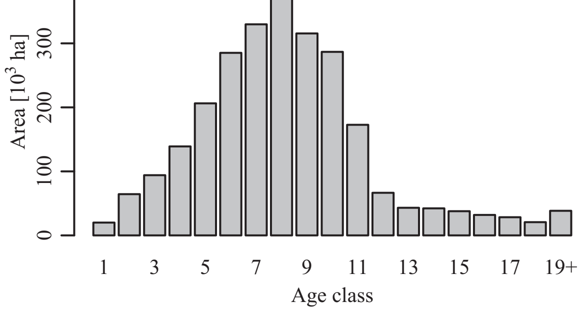

Fig. 6 Age distribution of hinoki planted forests in 2007.

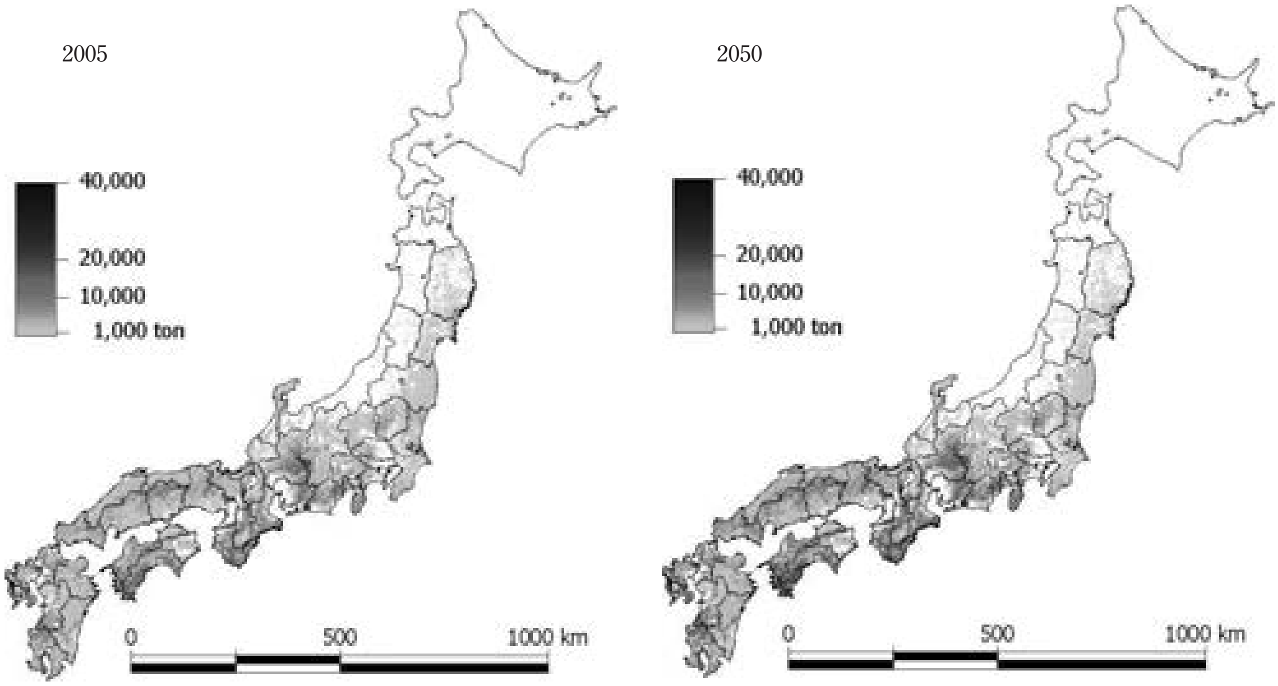

Fig. 7 Spatial distribution of carbon stocks in hinoki planted forests. Islands were excluded.

ACKNOWLEDGEMENT

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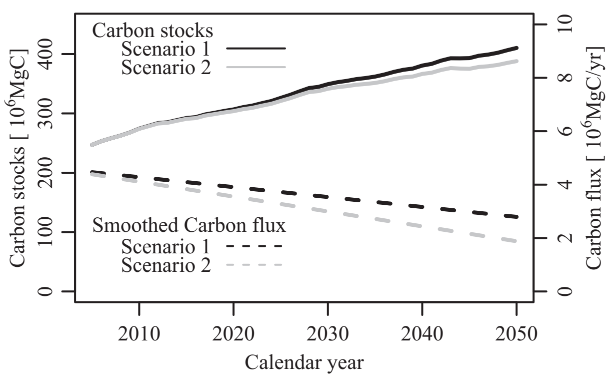

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(Recieved 12 February 2012)
(Accepted 20 July 2012)

Article

Classification of Natural Forest Types for Forest Resource Monitoring Survey Data

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ABSTRACT

The Forest Resource Monitoring Survey (FRMS) started to satisfy not only national requirements but also international ones such as the Montreal Process in 1999. Forest type is an important component from which many indicators of forest biodiversity can be estimated, and the country reports of the Montreal Process must include the forest characteristics of forest types. The current data from FRMS is expected to classify natural forest, but there was almost no data on natural forest types in the second country report of Japan. There are several methods of defining, classifying and identifying forest types and the results differ depending on the method used. Most definitions or classifications of species assemblages and identification of indicators are subjective. This study aimed to classify the forest types of natural FRMS stands and to develop a reproducible classification method. As a result, we classified 74.1% of natural stands which corresponded to climatic area and better than classification of recent country reports, but we could not classify all natural stands.

Keywords: Forest Resource Monitoring Survey (FRMS), forest type, indicator species index, SIMPROF test

INTRODUCTION

In Japan, the forest register records information on the stand status of all private and national forest land including species, age, stand DBH and height (TOMPPO *et al*., 2010). However, natural forests (not planted forests) are recorded as “mixed” in the forest register. The Forest Resource Monitoring Survey (FRMS), which carried out as Forest ecosystem and biodiversity survey from 2009, was started in 1999 with the aim of understanding the state and dynamics of various aspects of forests such as wood production and biodiversity throughout the country. FRMS plots have been established on a systematic 4-km grid across the forests of Japan with about 14,000 plots in total, and are measured every 5 years (KITAHARA *et al*., 2010). Current data from the FRMS is also expected to satisfy international requirements such as the Montreal Process. Forest type is one of the important components from which many indicators of forest biodiversity can be estimated (ALBERDI *et al*., 2010) and some indicators of the Montreal Process must be reported for each forest type. In the second country report of the Montreal Process, the forest type defined from the summed basal area ratio of dominant species accounted for more than 30% of stands, therefore forests in which no single species accounted for more than 30% of a stand were classified as unknown forest types (JAPAN FOREST AGENCY, 2009). Especially, the most broad-leaved natural forests were classified as deciduous, evergreen and mixed broad-leaved forests, and there are no suggested classification methods for FRMS.

The identification of forest characteristics or indicator species is a traditional activity in ecology and biogeography, and most researchers classify and identify subjectively. Regarding National Forest Inventories, there are different methods for each country. HANSEN and HAHN (1992) reported the detailed procedure for classifying forest type of the Forest Inventory and Analysis (FIA) program of the USDA Forest Service. The forest type of FIA is based on definitions published by the Society of American Foresters (SAF) (EYRE, 1980). Forest type is determined by the SAF algorithm using summed stocking volume for each species group. Two-way indicator species analysis (TWINSPAN) classification and the CCA or DCA ordination technique were applied in successive stages of the Finnish National Forest Inventory data analysis for determining the types of forest sites (TONTERI *et al*., 1990). TWINSPAN is a widespread method for classifying species assemblages and identifying indicator species. However, DUFRÊNE and LEGENDRE (1997) pointed out the following

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problems: (1) TWINSPAN assumes the existence of a strong gradient dominating the data structure, and so may fail to identify secondary gradients or other types of structure in data sets; and (2) the cutting points along the dominant axis are rather arbitrary; instead of selecting large gaps in the data, sites that may be close in species composition may be separated. Cluster analysis is another popular method for classification in ecology, but users of cluster analysis usually decide the number of clusters and classify and identify species assemblages subjectively. There is a need for the identification of characteristics or indicator species in the fields of nature monitoring, conservation, and management. The objectives of this study were to classify the forest types of natural FRMS stands to obtain information for the next country report for the Montreal Process and to develop a reproducible classification method.

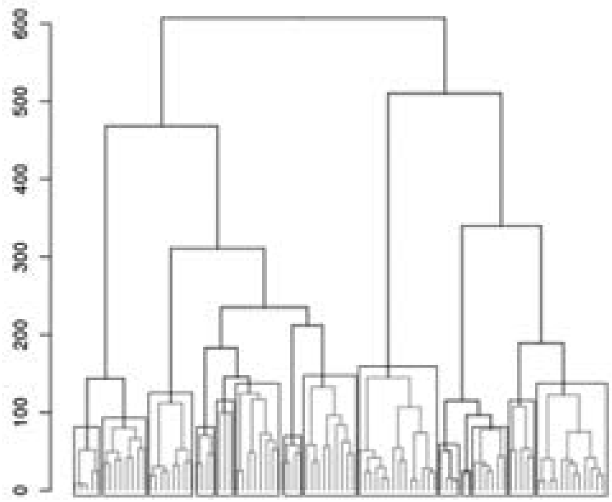

Fig. 1 An example of cluster analysis dendrogram.
Note: Encircled branches denote the significant clusters ($\alpha < 0.05$).

MATERIALS AND METHODS

We used the data of 15,877 forest stands which were measured in the second FRMS from 2004 to 2008. Dominant analysis (Ohsawa, 1984) was used to determine non-planted stands. This method compares the distribution of dominance of the data with the distribution of dominance in the models, adopts the number of dominant species that minimizes the deviation, and decides the dominant type. In this study, there were one or two dominant species stands with dominant planted species. Here, the stem volume per species was defined as dominance, and we determined the following four categories of planted stand. Coniferous planted stands (e.g. *Cryptomeria japonica*, *Chamaecyparis obtusa*, *Larix kaempferi*) accounted for 46% of all stands, broadleaved planted stands (e.g. *Quercus serrata*, *Quercus acutissima*) for 22%, and bamboo stands (*Phyllostachys pubescens*, *Phyllostachys bambusoides*) for 4%, and we defined the remaining stands as natural forest stands. There is no volume equation for bamboo in the Japanese common volume equation (Japan Forest Agency, 1984; 1985), therefore bamboo stem volume was estimated using the equation of Inoue *et al.* (2011) and Suga *et al.* (2011).

To classify the species group, the cluster analysis with similarity profile routine (SIMPROF) test (Clarke *et al.*, 2008) was applied to FRMS stand data. The SIMPROF test is a permutation test for determining the number of significant clusters ($\alpha < 0.05$) produced using hierarchical cluster analysis with the assumption of no *a priori* groups (Clarke *et al.*, 2008). This test randomizes each species separately, across the stands, and recalculates the profiles 1000 times. Thus, we classified species assemblages without arbitrariness. Fig. 1 shows an example of a cluster analysis dendrogram; encircled branches denote significant clusters ($\alpha < 0.05$) with the SIMPROF test. We calculated the similarity matrix for cluster analysis from the whole-country dataset, however, the SIMPROF test failed because of the redundancy of the similarity matrix. Therefore, the classification was applied to each watershed which was set as a forest planning area. The 158 forest planning watersheds were decided for each prefecture and forest management is performed in each of them. When there were not enough datasets in one watershed, we classified by combining the data with the data of the nearest watershed. From the full species list for each of watersheds, the frequent species, defined as those occurring in more than 95% of the species list in the watersheds, were selected for classification.

To identify the indicator species of each cluster (species assemblage), we tried to find the indicator species and species assemblages characterizing the group of clusters by using the indicator value index (Dufrêne and Legendre, 1997; Cáceres *et al*., 2010). The statistical significance of the species indicator values was evaluated using a randomization permutation procedure. We identified indicator species having a significant value ($\alpha < 0.05$).

RESULTS AND DISCUSSION

Fig. 2 shows the ratio of natural stands and Fig. 3 shows the distribution of species richness for each watershed from north to south of Japan. As a result of dominant analysis, there were 4342 natural stands. The ratio of natural stands has decreased, otherwise the number of species has increased from north to south, excluding the Okinawa region. This result depends not only on the plantation ratio or watershed area, but also on the climatic zone (Takyu *et al*., 2005).

The cluster analysis with SIMPROF test classified 690 significant groups in all watersheds and 511 groups (74.1%) were identified as indicator species by indicator value index. Fig. 4 shows the distribution of Japanese forest zones by climate index without minor islands and Fig. 5 shows the distribution of leaf-type, which were identified by indicator species index, of FRMS stands. Overall, 70.4% of deciduous shrub leaf-type stands appeared in the Boreal and Temperate Zone, 78.7% of deciduous tree stands appeared in the Temperate Zone and 71.8% of evergreen stands appeared in the Warm Temperate Zone. Hence, this result shows that the classification and identification corresponded to the climate. The 179 groups (1,280 stands) were not identified in this

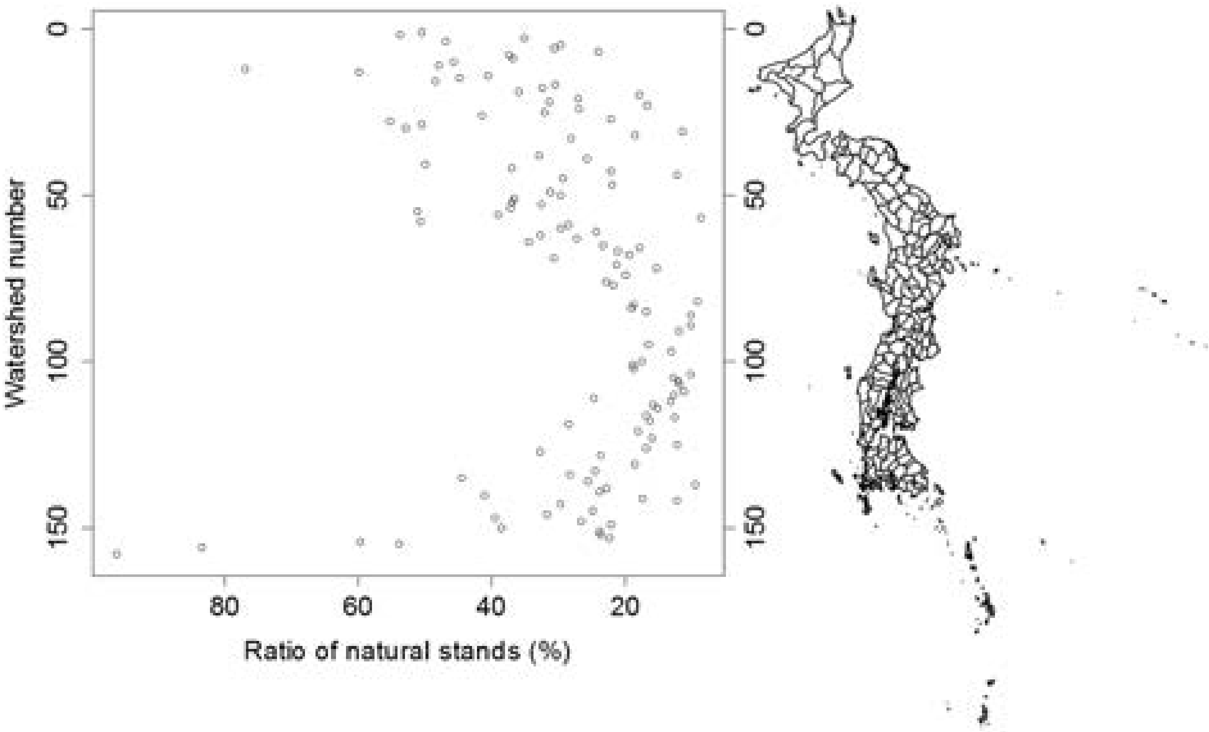

Fig. 2 Relationship between the ratio of natural stands and the data of each watershed from north to south of Japan.

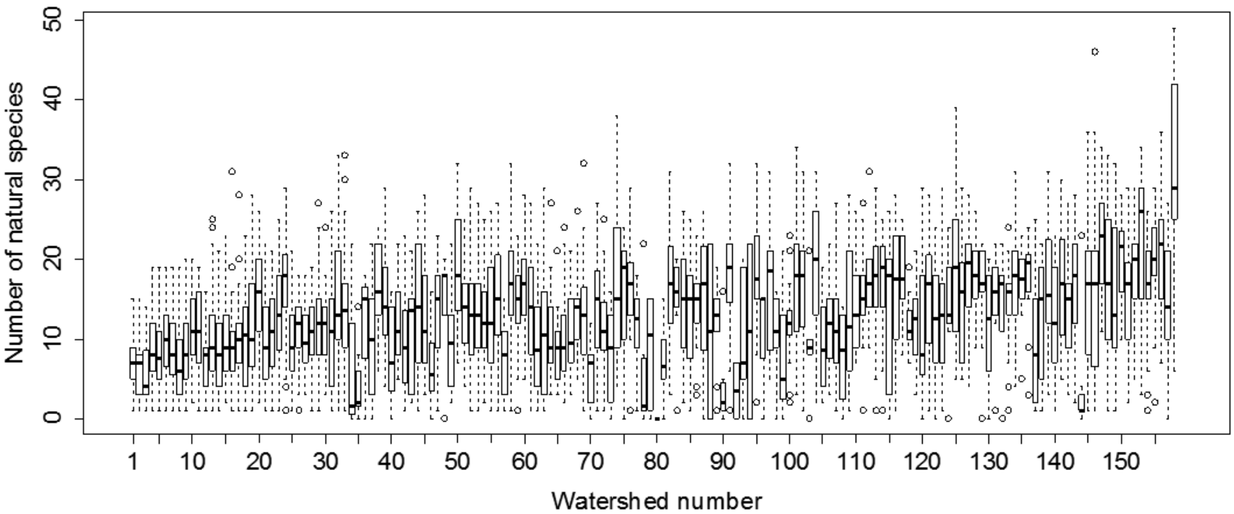

Fig. 3 Relationship between the distribution of species richness and the data of each watershed from north to south of Japan.

study, because these stands contained so many species or were only a small stand volume or small stand area. In the second country report of the Montreal Process, unknown natural forest types accounted for 25% of all stands, which were defined as mixed forest (Japan Forest Agency, 2009). It is difficult to define all stands by forest type because the complicated composition of species depends on the area of stands or measurement errors.

Fig. 6 shows the distribution of stands which were re-characterized by indicator species in Shikoku Island. There

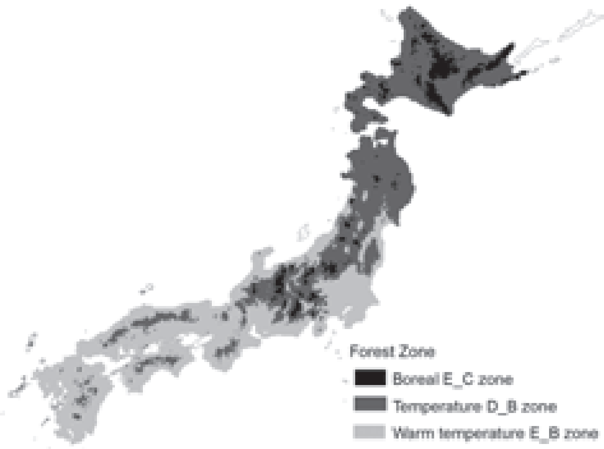

Fig. 4 The distribution of forest zone.
Note; E: Evergreen, D: Deciduous, C: Coniferous, B: Broad-leaved.

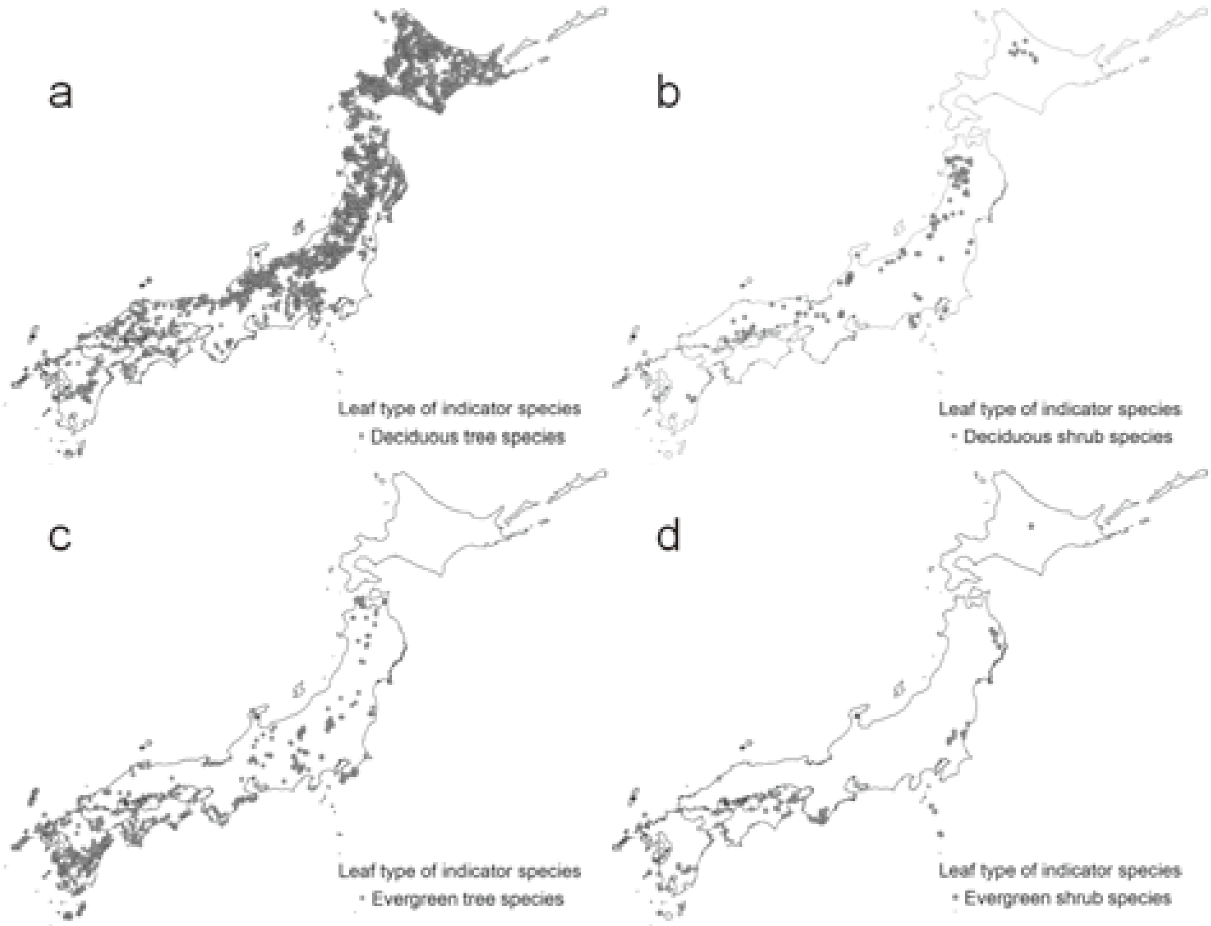

Fig. 5 The distribution of leaf-type of identified indicator species.
Note; a: Deciduous tree species, b: Deciduous shrub species, c: Evergreen tree species, d: Evergreen shrub species.

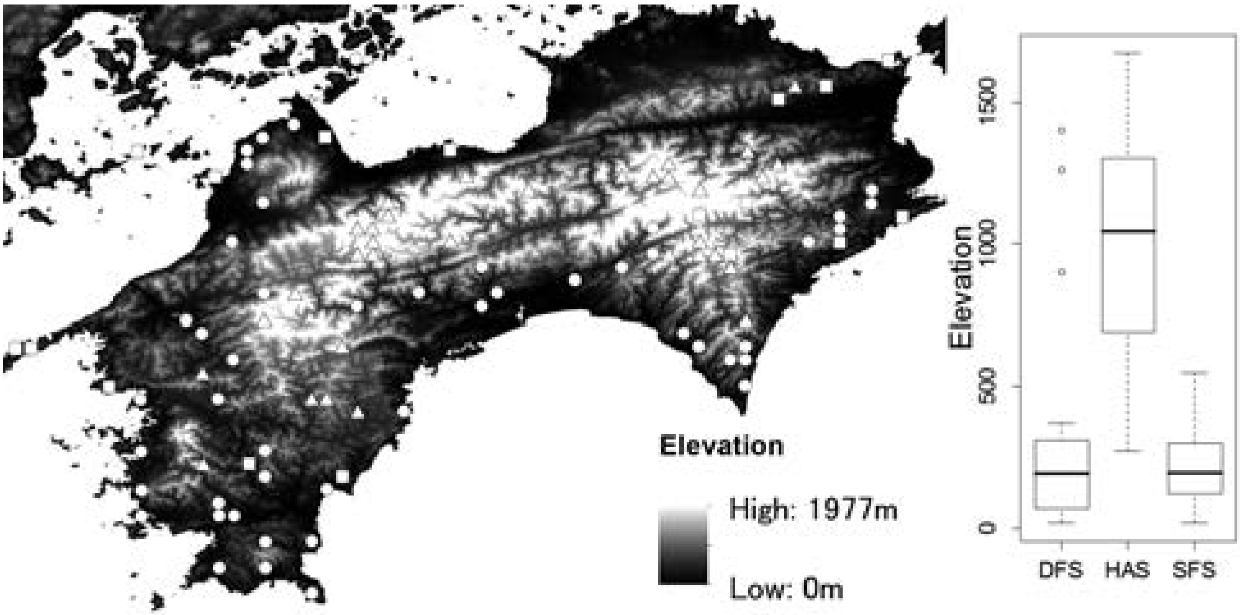

Fig. 6 The distribution of stands that were characterized by indicator species in Shikoku Island.
Note; Square: Disturbed forest species group (DFS), Triangle: high altitude species group (HAS), Circle: secondary forest species group (SFS).

are some secondary forest species groups (e.g. *Quercus glauca*, *Castanopsis sieboldii*, *Castanopsis cuspidata*) at low elevations (< 500 m) where people live, and some high altitude forest species groups (e.g. *Fagus crenata Blume*, *Abies homolepis*, *Quercus crispula*) in mountainous places. The disturbed forest species groups of *Mallotus japonicus*, *Eurya japonica*, *Zanthoxylum ailanthoides* showed no topological characteristics. There were significant differences between high altitude species groups and the other two type groups. It seems that indicator species could be explained by environmental factors such as altitude, human activity and disturbance, but we need to re-characterize stands using identified indicator species. In this study, we classified stands into groups for each watershed, because it was difficult to classify by clustering using the all-stands dataset of Japan as the similarity matrix will be redundant. When using the natural forest type of this result, re-categorization for the user's purpose is needed, but the stands with identified species could provide useful information.

CONCLUSION

We classified and identified natural forest stands of the Forest Resource Monitoring Survey data in a reproducible way without arbitrariness and found that natural stands indicated climatic information. However, we still need to re-categorize indicators for country-level usage. The stands of FRMS which were classified and identified were useful information for the next country report of the Montreal Process. On the other hand, Japan's national-level system for simulating the forest carbon dynamics of planted forests was developed in the project "Development of mitigation and adaptation techniques to global warming in the sectors of agriculture, forestry, and fisheries" (Mitsuda *et al.*, 2011), and this system contains no information on natural forest type with positional data. Therefore, this result from FRMS may also be applied to the carbon stock model of natural forests. Finally, further research on ecological classification is needed.

ACKNOWLEDGEMENTS

This study was supported by "Development of mitigation and adaptation techniques to global warming in the sectors of agriculture, forestry, and fisheries" sponsored by the Ministry of Agriculture, Forestry and Fisheries, Japan. The authors thank Dr. Mahoko Noguchi and Ms. Natsu Sannomiya from Shikoku Research Center, Forestry and Forest Products Research Institute for their valuable advice and support.

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* These English titles are tentative translations from the Japanese titles by the authors of this paper.

(Received 12 March 2012)
(Accepted 20 July 2012)

Article

Monitoring of peat swamp forest using PALSAR data
- A trial of double bounce correction -

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ABSTRACT

When synthetic aperture radar (SAR) is used to obtain remote sensing images of forests, the images can be degraded by double reflections of the radar beam, e.g., by reflecting off water surface and then tree stems or by reflecting off a fallen tree and then by other fallen stems, which together act as a corner reflector. Here, we developed a method for correcting for this effect, called the double bounce effect. To demonstrate the method, we monitored changes in a peat swamp forest around Palangka Raya in Central Kalimantan, Indonesia using ALOS/PALSAR data. Biomass surveys were executed in plots of grass, shrub and forest and above ground biomass (AGB) was calculated. Five Fine Beam Double Polarization PALSAR images, which were obtained between July 2007 and December 2010, were used. The backscattering coefficient (BSC) increased asymptotically to the saturation level with increasing AGB. BSC of HH changed linearly with BSC of HV in areas with different biomass and without double bounce. The linear relationship between the BSC of HH and BSC of HV showed plant succession, and the change ratio of HH BSC to HV BSC show a contribution of vertical stems on BSC, since stem biomass was the main part of AGB in L-band. However, in areas such as riverside forests and fire scars where BSC suffered from double bounce (DB areas) no such relationship was observed. Because signal of HH returns much stronger than that of HV by double bounce, we assumed that the double bounce changes the ratio of HH BSC and HV BSC inversely. The double bounce effect on HV BSC was corrected using a linear combination of two vectors which showed the contribution of vertical stems and the contribution of double bounce. In contrast to AGB, the original BSC was higher in DB areas than in high biomass forests. However, when we applied the above correction in DB areas, the BSC anomaly in HV disappeared. Curvilinear regression models were developed to estimate AGB using the corrected HV BSC of an image acquired in July 2007. The estimated AGB was not accurate when it exceeded 100 Mg ha^{-1} due to saturation of BSC, although it was reasonable in DB areas except in the case of an image acquired in December 2010. The method for correcting AGB should be suitable for monitoring of deforestation, regeneration and regrowth of trees in areas with low biomass in peat swamp forest.

Keywords: Central Kalimantan, biomass, double bounce, PALSAR, peat swamp forest

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INTRODUCTION

About 20% of anthropogenic carbon dioxide emission is caused by land use changes in the tropics dominated by tropical deforestation (IPCC 2007). Because of this situation, protection of forests in the tropics has been an important world-wide political problem. Therefore efforts and actions to reduce deforestation, maintain, and conserve forest carbon stocks in developing countries are mandatory (Reducing Emissions from Deforestation in Developing countries, REDD) (UNFCC 2007). Implementation of policies to reduce emissions from deforestation require effective deforestation monitoring systems that are reproducible, provide consistent results, meet standards for mapping accuracy, and can be implemented at the national level (DEFRIES *et al.* 2007).

Remotely sensed data supported by ground observations are key tools for effective monitoring of forest change. Because forests occupy huge areas in the tropics and elsewhere in the world, it is difficult to monitor them by field surveys. Therefore satellite images which cover large areas would reduce survey efforts and costs, if the images are used properly. Detecting deforestation and forest degradation is essential to understand the status of a forest and to make plans for protecting forests in the tropics for REDD or Reducing Emissions from Deforestation in Developing countries plus (REDD plus). Optical sensor images are most commonly used for land cover classification, although cloud cover is a problem (AKIYAMA and KAWAMURA, 2003). Synthetic aperture radar (SAR) is well suited for observing cloud-covered forests in the tropics because it uses longer wavelengths that pass through clouds (OUCHI, 2009). Therefore SAR images are worth to use to monitor forests in the tropics (ROSENQVIST *et al.*, 2003, ALMEIDA-FILHO *et al.*, 2007).

Estimating decrease of forest biomass is important to understand the impacts of deforestation on carbon emissions. SAR, which observes land surface using a longer wavelength, such as the L-band (15-30 cm), has a higher capability of detecting biomass in forests than X-band (2.4-3.75 cm) and C-band (3.75-7.5 cm) SAR due to scattering of the emitted signal from SAR within canopies (OUCHI, 2009). Phased Array type L-band Synthetic Aperture Radar (PALSAR) on the Advanced Land Observing Satellite (ALOS) is expected to be useful for biomass estimation of forest (ROSENQVIST *et al.*, 2007). The relationship between forest biomass and signal (backscattering coefficients) of L-band SAR was examined by many scientists for these two decades (SENOO *et al.*, 1995; LUCKMAN *et al.*, 1997; LUCKMAN *et al.*, 1998; CASTELA *et al.*, 2002; LUCAS *et al.*, 2006). Although the longer wavelength of L-band among space-borne SAR has an advantage in higher saturation levels to biomass than X-band or C-band SAR, signals are saturated at dry biomass between 50 and 150 Mg ha^{-1} (LUCKMAN *et al.*, 1998, CASTELA *et al.*, 2002, LE TOAN *et al.*, 2004; LUCUS *et al.*, 2006). Forest structure causes variation in backscattering coefficients and its saturation level (CASTELA *et al.*, 2002). In addition, wood materials on the ground after deforestation function as corner reflectors and cause an initial increase in the L-band SAR backscatter, which then subsequently decreases over time as the wood decays (ALMEIDA-FILHO *et al.*, 2007).

Double bounce

Input microwave signal scatters isotropically in canopies by leaves, branches and stems which locate randomly. Therefore microwaves scattered to various directions and a small part of input energy returns to SAR (Fig. 1). This type of scattering is called volume scattering. Backscattering is dominated by the scattered signal from branches and stems but not forest floor in mature forest in L-band SAR. Reflection of the like polarization with that of input signal (HH or VV) dominates for the case of natural objects, however cross polarization (HV or VH) signal occurs, which is called depolarization, in canopies (IGUCHI, 1992). HV indicates the horizontal transmit (H) and vertical receive (V) radar channel and so on.

On the contrary, specular reflection is major at flat smooth surface, and it results in return signals of the same polarization. When a microwave is reflected by a smooth surface such as still-water surface and then by a smooth objects such as tree stems (or vice versa), it is called double bounce (IGUCHI, 1992, Fig. 1). Since the direction of the reflected signal is focused, the backscattering amplitude is greater than that of volume scattering. Double bounce by the interaction of trees and ground is the greatest where trees with large stems grow on flat smooth ground like still-water surface. The return signal of the same polarization such as HH is increased by double bounce, since specular reflection dominates (IGUCHI, 1992). For example, the HH signal is increased by fallen tree stems after forest fires as well as after

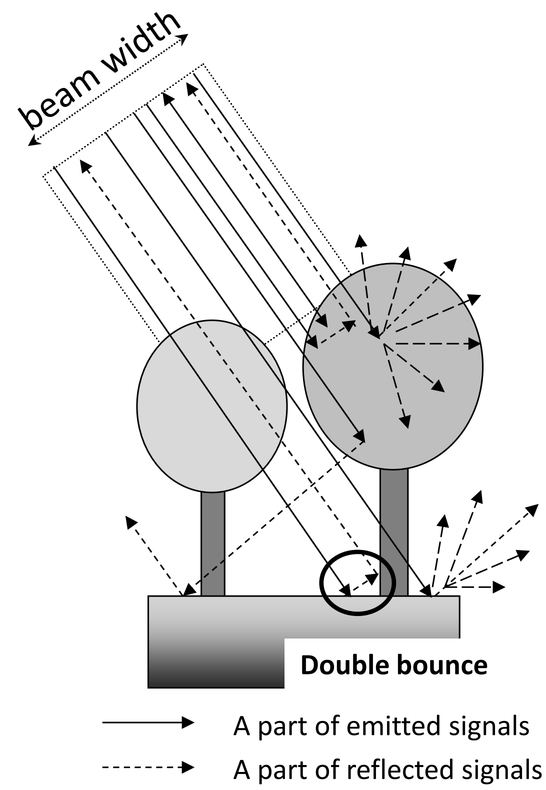

Fig. 1 Schematic description of scattering of SAR signal. Double bounce is returned signal reflected by both the ground or water surface and tree stems.

deforestation (ALMEIDA-FILHO *et al*., 2007), and the HH signal is also increased by open swamp forest under submerged conditions (AZIZ and WHITE, 2003). Areas with double bounce have relatively greater BSC in HH than HV compared with areas without double bounce. On the other hand, double bounce is negligible for dense forests even under submerged conditions, because BSC of HH and HV was quite stable through dry and submerged conditions, and because BSC was smaller than it was in open canopy forests, as described below.

The objective of this study was to evaluate the usefulness of PALSAR imagery performance of backscatter signals for biomass estimation to monitor peat swamp forests. A simple method was developed to reduce the effects of double bounce on the backscattering coefficient (BSC), and above ground biomass (AGB) estimation models were developed using the original and corrected BSC using a curvilinear regression method. AGB was estimated using the original and corrected BSC, and the two results were compared to evaluate the usefulness of the correction for monitoring seasonal and inter-annual forest changes in a peat swamp forest.

STUDY SITE AND DATA

The study site was the south of Palagka Raya, Central Kalimantan, Indonesia. The natural vegetation of the area is peat swamp forest. In 1995, 1.7 million hectors of the forest was chosen to be developed as paddy fields by the Mega Rice Project (MUHAMAD, 2001) to increase domestic rice supply. The project was to start at the end of 1995 and to be completing in 2005. Many drainage channels were dug between 1996 and 1999. Then the project was abandoned for various reasons including the Asian economic crisis and forest fire. However, the drainage is continuing and the peat swamp is drying. In addition, the channel allowed easy access, resulting in illegal deforestation. The dried peat burns easily and much time is needed to extinguish the fires. Thus the peat swamp forest was in critical condition.

A field survey was conducted between 2008 and 2010 and thirty-one plots with an area of 40 meters by 30 meters were set in shrublands and in open and closed forests. Stem diameter at breast height (1.3m, DBH) of all trees were measured with a tape measure. Tree height was measured with a Vertex (Haglöf, Sweden). A DBH-Height curve was derived in each plot and tree height was estimated using the DBH-Height curve for all trees. The above ground biomass of each tree was computed with the equation (modified from KIYONO *et al*., 2006).

$$AGB = 2.17 \times BA^{1.02} \times WD^{0.978} \times H^{0.631} \quad (1)$$

where AGB is above ground biomass (kg), BA is basal area (m^2), WD is wood density ($Kg\ m^{-2}$) and H is tree height (m). The basal area was computed using DBH assuming circular stems. The plot locations were measured using a handheld GPS (Model 60CSX, Garmin International, Inc. KS, USA). AGB per hector in each plot was computed using the measurements.

For this study, we used five PALSAR images of Fine Beam Double Polarization mode that were taken on five days (July 9, 2007, October 9, 2007, May 26, 2008, October 14, 2009 and December 2, 2010). Hereafter, these dates are referred to 0707, 0710, 0805, 0910 and 1012, respectively. For example, PAL0707 shows the PALSAR image of July 9, 2007, and HV0710 is the horizontal transmit (H) and vertical receive (V) radar channel (HV) of image obtained on October 9, 2007. In general, the radar backscatter is modulated by the terrain height variation. Among the radar backscattering coefficients, gamma-naught, which is the normalized-radar-cross-section divided by the cosine of local incidence angle is the most insensitive parameter to the terrain effect as well as to the off-nadir angle. Thus, we adopted gamma-naught for this analysis and used the slope-corrected, ortho-rectified, and geo-coded PALSAR images by JAXA (SHIMADA, 2010). All PALSAR images were averaged by an average filter with a 7 by 7 pixel kernel to reduce speckle noise.

METHODS

We found that the effect of double bounce was outstanding in submerged forest and fire scars with fallen trees during a preliminary study. Therefore, correction of double bounce effect was attempted for HV images and the results were compared with the original HV images. AGB was estimated using the original and corrected PALSAR images and the results were compared. The procedure was as follows.

Correction of Double Bounce Effect

Assumption and correction

While double bounce is dominant in submerged forests and burnt forests, multiple scattering is dominant in dry land forests. Since backscattering is greater in submerged and burnt forest than in peat swamp forest, HH and HV BSC disperses in a scattergram as shown in Fig. 2 using PAL0707.

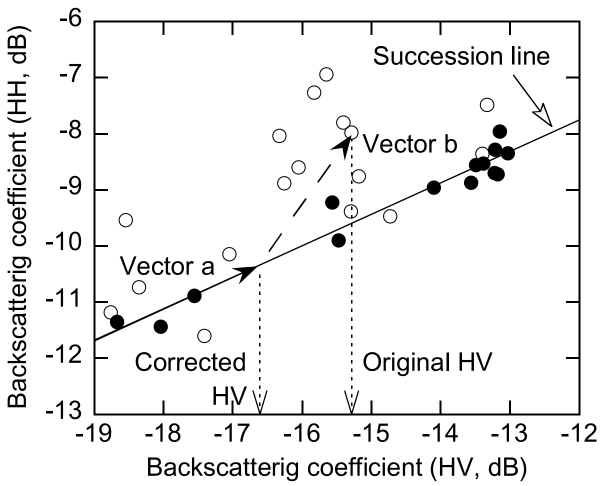

Fig. 2 Scatter diagram of HH and HV backscattering coefficient in plot areas on PAL0707.
Black circles are plots commonly appeared along the succession line in all PALSAR images, which suggests the vegetation condition is similar within 4 years. Most plots with open circles have relatively greater backscattering coefficient (BSC) of HH than the plots with black circle. The higher BSC in HH was probably caused by the double bounce by the surface condition.

Black circles are plots commonly appeared at the bottom of plots' distribution, which have lower BSC of HH among plots with similar BSC of HV, in all PALSAR images. This suggested that the vegetation condition was similar within 4 years in these plots. Areas suffered by double bounce show greater HH BSC than HV BSC as shown in Fig. 2 with some of open circles. On the contrary, a linear relationship would exist between HH and HV BSC among wildland and forest plots with black circles. Plots with smaller biomass have smaller BSC, and plots with greater biomass have greater BSC in the linear relationship. The relationship can be expressed by a line, and intensity of BSC would show succession stage of wild vegetation (succession line). The succession line (2) can be determined by a linear regression analysis using BSC of 14 plots with black circles which were located at the lower-right edge in Fig. 2. These plots also had similar BSC in other images.

$$HH_{org} = -1.023 + 0.5611 \times HV_{org} \quad R^2 = 0.951 \qquad (2)$$

where HV_{org} and HH_{org} are BSC of HV and HH in the original PAL0707, respectively.

The regression line shows that BSC of HV, which is caused by depolarization (IGUCHI, 1992), increased by canopy growth. The slope shows BSC of HV increased about twice of BSC of HH.

Double bounce, which is specular reflection of SAR signal twice (IGUCHI, 1992) on the flat water surface or fallen tree stems at first and next on stems in the test site, dominates and returns strong signals to SAR. Specular reflection doesn't cause depolarization, therefore BSC increases much greater in HH polarization than HV polarization. Thus specular reflection, by which most signals are reflected to one direction without depolarization (IGUCHI, 1992), is dominant in submerged forests and open areas with fallen stems. On the contrary, Lambertian reflection, by which signals are scattered isotropically and depolarization occurs (IGUCHI, 1992), is dominant in dryland forests.

As for ground condition, if the ground surface is smooth like still-water under swamp forest, specular reflection is dominant on the ground (YAMAGUCHI, 2001) and causes strong double bounce. On the other hand, if the ground surface is rough like soil ground with bush, Lambertian reflection is dominant (YAMAGUCHI, 2001) and double bounce is very small. This means that contribution of double bounce changes in the peat swamp forest due to changing water level.

As described above, the dominant reflection is different in submerged forest and fire scars from dryland forest, we assume that the submerged water and fallen tree stems (smooth elements) yields contribution on BSC inversely to dry land forest, since BSC of HH is enhanced by double bounce greatly. It is expressed as the ratio of HH and HV BSC to be 1.782 to be the inverse of the regression slope of 0.5611 in equation (2).

$$HH_{org} = 1.782 \times HV_{org} + C \qquad (3)$$

where C is a constant which is determined by BSC of each pixel.

We considered two vectors, one caused by stems (vector a) and the other caused by the double bounce (vector b, Fig 2.). Since BSC caused by the double bounce is a noise factor when we analyze biomass using BSC, we reduced the double bounce effect as follows.

1. We supposed the succession line showed changes of BSC by an ideal tree growth. If biomass was greater, BSC became greater along the succession line (succession vector a).
2. On the other hand, smooth water surface and fallen stems cause changes in BSC inversely to the succession line due to the double bounce effect (disturbance vector b).
3. We assume that BSC was a linear combination of the succession and disturbance vectors. Therefore intersection of the succession line and disturbance vector of each pixel shows a HV BSC value which was contributed mainly by canopy elements. We define the HV BSC at the intersection as the corrected HV BSC from the double bounce effect.

The corrected HV was computed for all images using the succession line (vector a) in equation (2) and vector b (3) for the filtered images.

Comparison of Seasonal Trend of BSC

Five reference areas representing four categories of land were selected: two mature forests with high AGB (High AGB forest 1 and 2), a forest along Kahayan river (Riverside forest), a fire scar burnt around 2003 (Fire scar) and mature forest burnt in 2009 (Burnt forest) (Table 1). We visited all areas in 2008, 2009 or 2010, however we couldn't measure biomass in Riverside forest and Burnt forest before the fire in 2010. Therefore biomass of these categories is based on our visual inspection with stand height etc. BSC values were picked up from the five images, and seasonal trend of BSC was

Table 1　Description of selected reference areas

Category	Description
High AGB forest 1	This forest was located within a peat swamp forest with AGB between 180 and 300 Mg ha^{-1} without serious disturbance. Crown closure varies area by area.
High AGB forest 2	Location was very close to High AGB forest 1 within the same forest.
Riverside forest	This forest located along Kahayan river. AGB might be less than 150 Mg ha^{-1} by our visual inspection.
Fire scar	Tree stems were laid down on the ground and aliving biomass was about 6 to 20 Mg ha^{-1} in 2008. The fire scar was clearly identified on PAL0707.
Burnt forest	Forest near High AGB forest 1 was burnt in October 2009. AGB might be about 150 Mg ha^{-1} less than that of High AGB forest before the fire . Tree stems fell over after the fire.

compared among the five categories for original HH, original HV and corrected HV on figures.

Biomass Estimation and Monitoring

Field plots were separated into two groups according to the succession line (Fig. 2). Plots for succession line were used for creating a biomass estimation model and others are used for validation. Regression models were developed between above ground biomass (AGB, Mg ha^{-1}) and original or corrected HV BSC by a curvilinear regression method using AGB of 14 plots and the filtered PAL0707 as follows.

$$AGB_{org} = 3.585\times10^{5} \times e^{0.5994HVorg} \quad R^2 = 0.4923 \quad (4)$$

$$AGB_{cor} = 3.204\times10^{5} \times e^{0.5918HVcor} \quad R^2 = 0.4746 \quad (5)$$

The performances of these two models were validated using data from the 17 plots that were not used for modeling. Equation (4) was applied to the original HV images and the equation (5) was applied to the corrected HV images.

ERDAS IMAGINE version 9.3 (ERDAS Inc., USA) was used for image processing and KaleidaGraph version 4.0 (Synergy Software, USA) was used for statistical analysis.

RESULTS AND DISCUSSION

Temporal Change of Backscattering Coefficient (BSC)

Data range of HH BSC (ca. 5 dB) was wider than that of HV BSC (ca. 3.5 dB) of the original images regarding the selected categories (Fig. 3 a, b, Table 1). BSC was obviously greater in Fire scar than that in High AGB forest 1 and 2 in all HH images. On the other hand, Fire scar had low biomass (about 6 to 20 Mg ha^{-1}), while High AGB forests had a much greater biomass (about 180 to 300 Mg ha^{-1}) than that. The difference in BSC and AGB was apparent in Burnt forest with about 150 Mg ha^{-1} of AGB between before and after a forest fire (Fig. 3a). Fallen stems without burning overlapped each other and few trees stood on the ground in Burnt forest after the fire. The sharpe increase of BSC (about 6 dB) suggests that fallen stems had a greater influence on BSC than tree canopies in HH. While BSC dropped about 1.5 dB as a result of the fire and increased about 2dB later in the original HV (Fig. 3b). The change was rather small comparing with the change in HH. BSC of the original HV images in Fire scar was greater than that in High AGB forests by May 2008, then it became smaller than High AGB forests (Fig. 3b). Similar changes were reported in the case of forest logging (ALMEIDA-FILHO *et al.*, 2007). The original BSC of HH and HV images changed considerably with season in fire scars suggesting that BSC in fire scars were easily affected by environmental conditions such as water content as described in AKIYAMA *et al.* (2007).

The trees in Riverside forest were short and Riverside forest would have less biomass than High AGB forests by our visual inspection, although BSC was greater in Riverside forest than High AGB forests in the original HH and HV images. The difference was greater in HH images than HV images. This is consistent with the finding that the double bounce effect is greater in HH signals than HV signals (AZIZ and WHITE, 2003).

Water level change would cause seasonal or inter-annual variation of BSC especially at the time of high water level under flood conditions as occurred in December 2010. Unlike

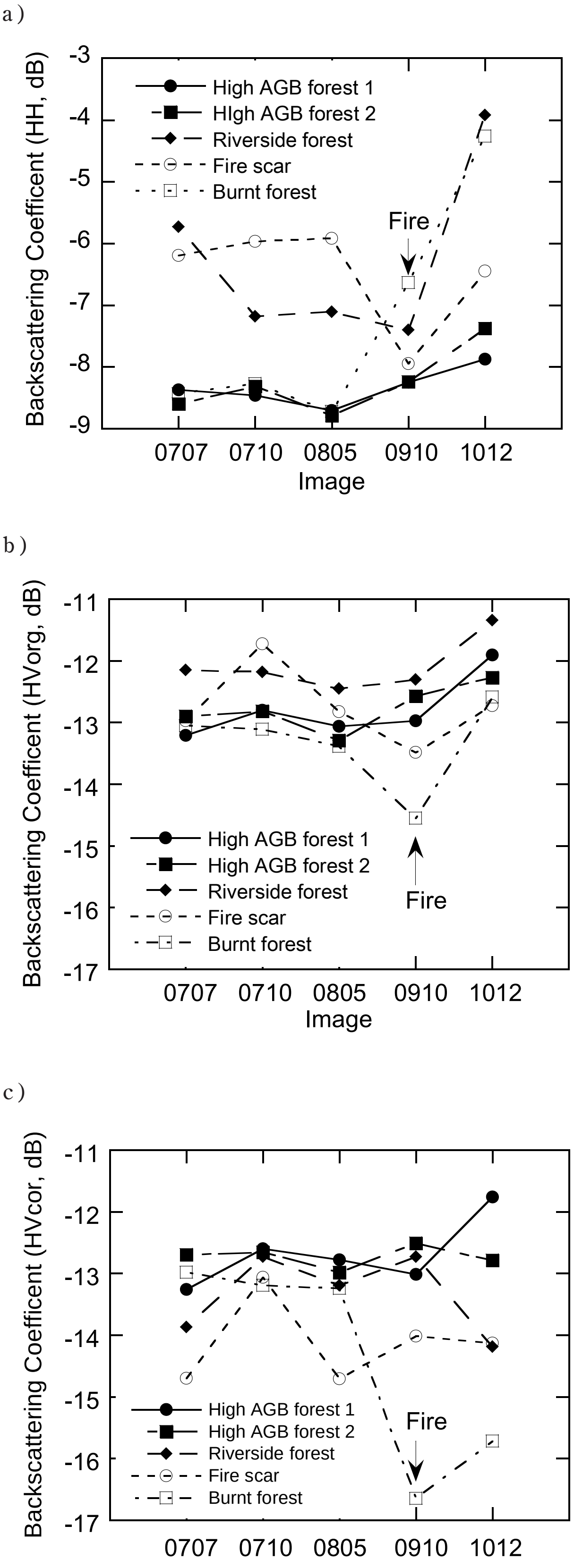

Fig. 3 Seasonal trend of BSC
Seasonal changes of BSC are drawn for the selected categories in Table 1.

Riverside forest, BSC of HH was most stable in High AGB forests among the land cover categories in all images. These evidences were caused by the difference of double bounce effects on these two forest types caused by whether dense forest with large biomass or not (AZIZ and WHITE, 2003).

The double bounce correction reduced this inconsistency in HV images especially for Riverside forest, and the order of BSC intensity coincided with AGB quite well (Fig. 3b). However, the correction may not work well on HV1012, since the data range of forest categories (High AGB forest 1 and 2, Riverside forest) became wider than that of original HV. The succession line was determined using PAL0707 alone and was applied to all images, although the succession line might change due to environmental conditions in each image.

Relationship between AGB and BSC

Although a curve-linear relationship has been reported between BSC and above ground biomass in the literature (LUCKMAN *et al.*, 1997; LUCKMAN *et al.*, 1998; CASTELA *et al.*, 2002; LE TOAN *et al.*, 2004; LUCAS *et al.*, 2006), the relationship was not clear if all plots are considered in Fig. 4. In Fire scars, standing AGB was low although BSC was greater than that of closed forests due to double bounce by fallen trees (Fig. 3), similar to the case of deforestation (ALMEIDA-FILHO *et al.*, 2007). Therefore Fig. 4 doesn't show a general relationship between standing AGB and BSC, which is expected under ordinary conditions as shown in the literature (LUCKMAN *et al.*, 1997; LUCKMAN *et al.*, 1998; CASTELA *et al.*, 2002; LE TOAN *et al.*, 2004; LUCAS *et al.*, 2006). Therefore, plots along the succession line (Fig. 2), which are shown as black circles in Fig. 4, were selected for the regression analysis to develop an AGB estimation model. The curve shows the relationship between AGB and BSC in the original HV images of the selected plots (Fig.4). BSC tended to become saturated with increasing AGB (Fig. 4), which caused inaccurate biomass estimation in high biomass forests.

Biomass estimation models were developed using the selected 14 plots for original and corrected HV0707 (Fig. 5). The models were barely different between the original HV (Fig. 5a) and the corrected HV (Fig. 5b), probably because the double bounce effect in the selected plots was small. The models diverged when BSC was greater than about -14 dB. The estimated biomass exceeding 100 Mg ha^{-1} wouldn't be reliable due to the divergence.

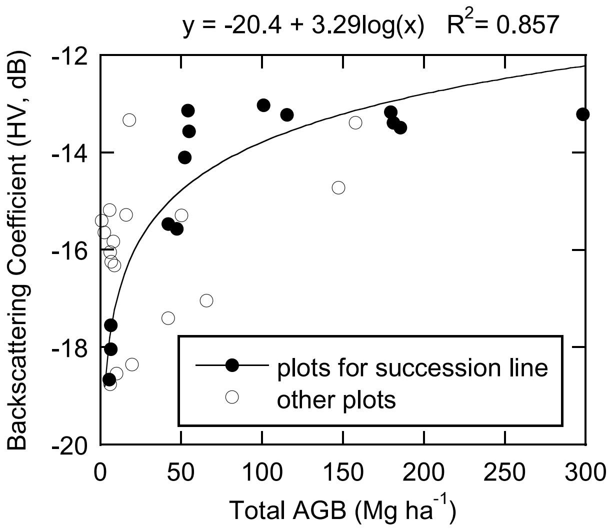

Fig. 4 Relationship between AGB and BSC
Relationship between AGB and BSC was examined using the original HV0707.

AGB estimation

The relationship between measured and estimated AGB

a)

b)

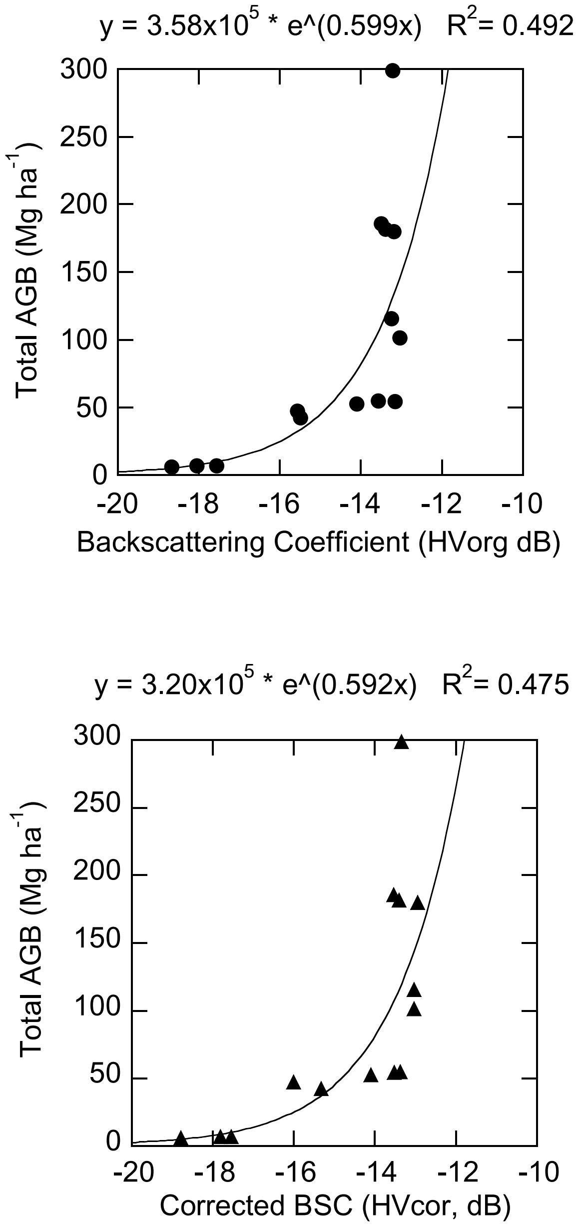

Fig. 5 Biomass estimation models
Two Biomass estimation models were determined by a curviliner regression fitting, one for the original HV image (a) and the other for the corrected HV image (b) using HV0707.

is shown in Fig. 6. Correlation coefficients adjusted for the degree of freedom were 0.439 (t=1.893, insignificant at 5%) for the original HV and 0.728 (t=4.111, significant at 1%) for the corrected HV. The root mean square errors (RMSE) between the field and estimated AGB were 31.3 Mg ha^{-1} and 22.0 Mg ha^{-1} for the original and corrected HV, respectively. As appeared in RMSE, plots concentrated along the regression line after the double bounce correction (Fig. 6). Thus the double bounce correction improved AGB estimation, however the slope was quite smaller than 1 due to saturation of the backscattering.

The biomass estimation models in equations (4) and (5) were applied for the original HV and corrected HV images, respectively. Fig. 7 shows the estimated AGB for the selected categories in Table 1. AGB was estimated greater consistently in Riverside forest than that in the two High AGB forests using the original HV (Fig. 7a). AGB changed drastic in Fire scar especially at October 2010. On the other hand, AGB was estimated smaller consistently in Riverside forest than High AGB forest 2 using the corrected HV (Fig. 7b). Although the estimated AGB was quite stable for High AGB forest 2, AGB changed greatly in December 2010 for High AGB forest 1. The difference suggests non-uniform BSC in forests in HV1012 and the effect of divergence in Fig. 5. BSC was probably influenced in a large area by submerging in PAL1012, therefore, the succession line would be determined using BSC of PAL1012. The steady estimated AGB of High AGB forest 2 in all cases (Fig. 7b) probably suggests, if the succession line determined properly for each scene, accuracy of AGB estimation would

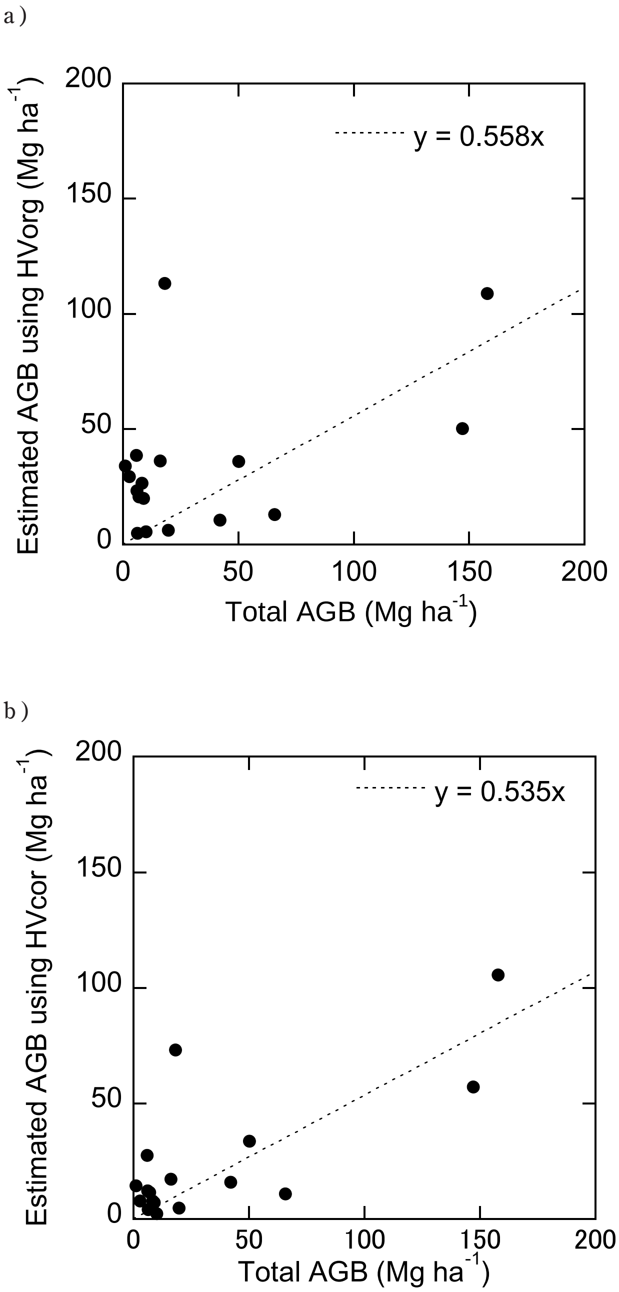

Fig. 6 Validation of biomass estimation
Relationship between field and estimated AGB was examined for the original HV image (a) and the corrected HV image (b) using HV0707.

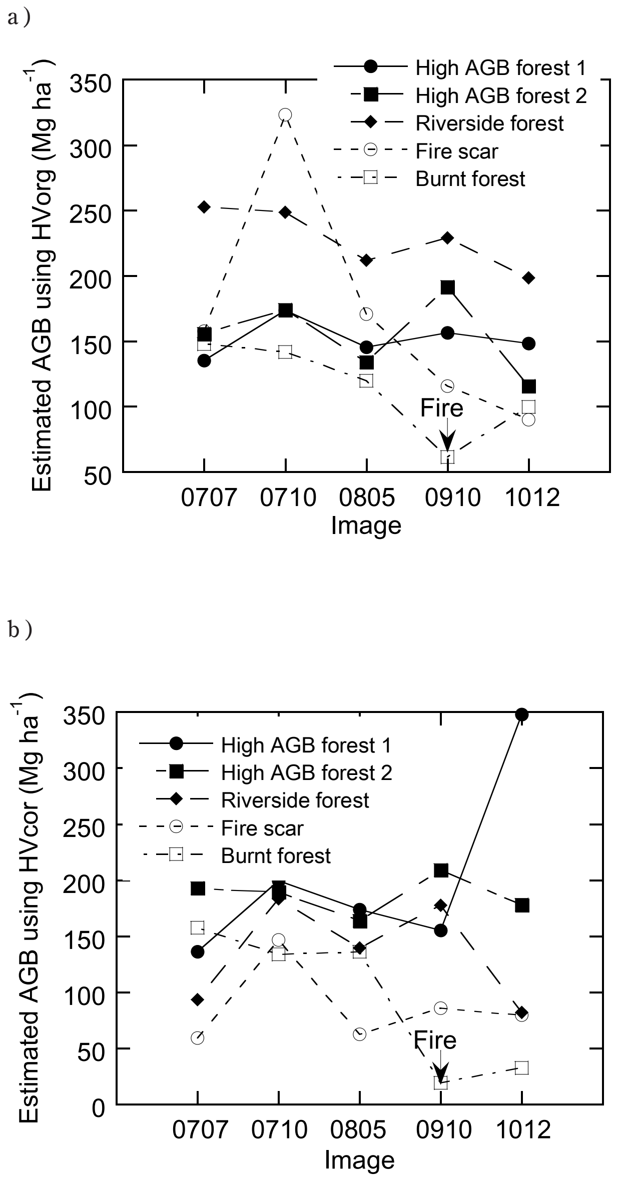

Fig. 7 Seasonal trend of estimated AGB
Estimated AGB was compared seasonally for the selected categories in Table 1 for the original HV images (a) and the corrected HV images (b).

improve. As for Burnt forest, the AGB was estimated reasonably in October 2009 and December 2010. Thus the double bounce correction reduced the overestimation of AGB in Fire scar and Riverside forest.

Spatial distribution of AGB appeared differently between the results using the original HV (Fig. 8a) and the corrected HV (Fig. 8b). AGB appeared properly in shrub or grass areas where AGB was less than 50 Mg ha^{-1} in all images with or without the double bounce correction. PAL0910 was obtained under dry conditions when forest fire occurred, and some fire scars appeared in the middle of image in red on PAL0910 (Burnt forest, Fig. 8a). Double bounce by fallen stems caused the overestimation of AGB. PAL1012 was obtained under wet conditions when the ground filled with water in a large part of forest, bush and grass. The submerged condition greatly increased the double bounce effect and overestimation of AGB using the original HV especially in areas over 300 Mg ha^{-1} of estimated AGB. According to our forest survey, AGB rarely exceeded 300 Mg ha^{-1} in the forest which appeared in the middle bottom in each plate of Fig. 8. Therefore, in a large part

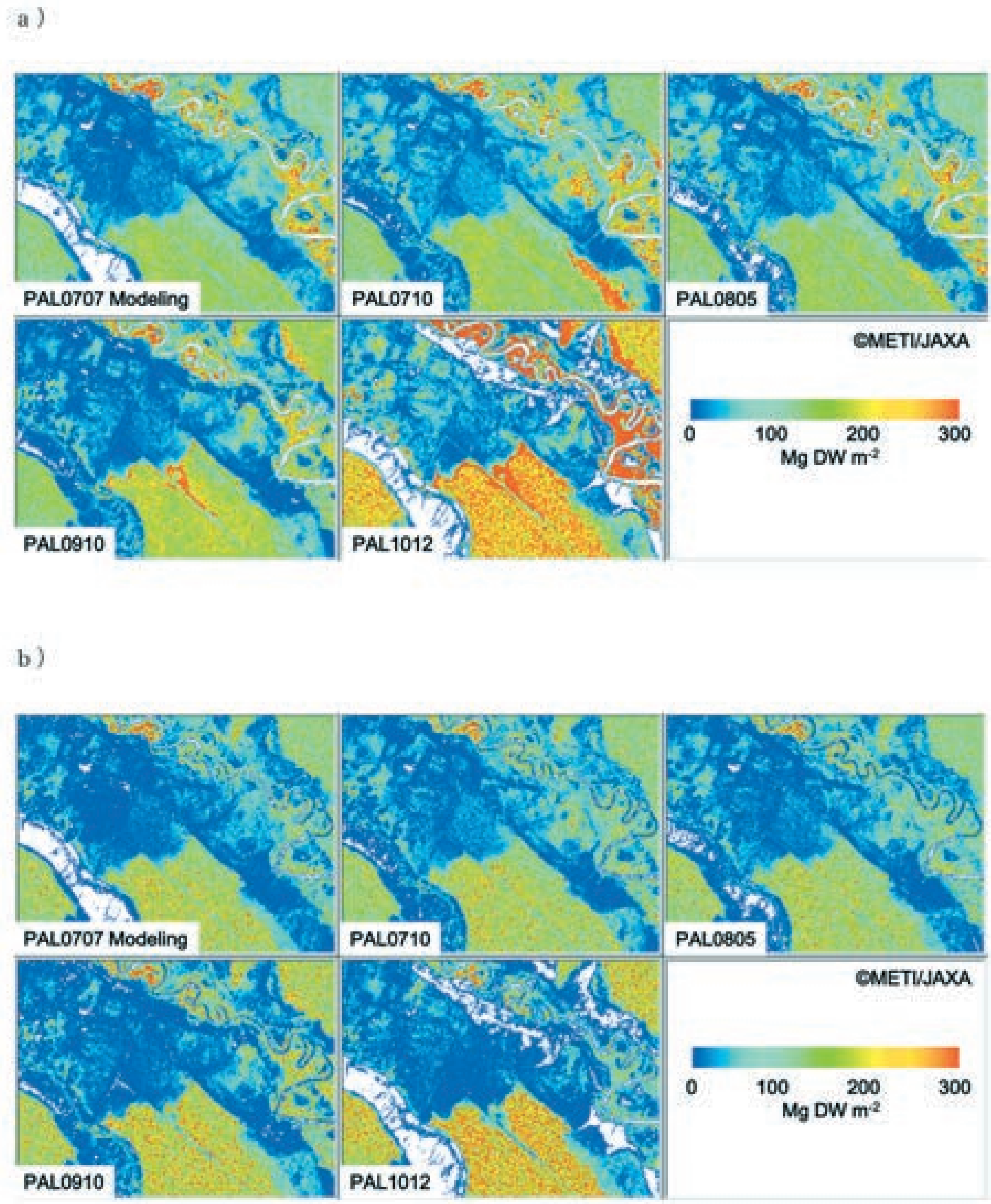

Fig. 8 Distribution of estimated AGB in different seasons
Estimated AGB was mapped and its seasonal change was examined for the original HV images (a) and for the corrected HV images (b).

of the areas with AGB over 300 Mg ha^{-1} (Fig 8a), the AGB was overestimated as a result of double bounce and the divergence of biomass estimation model (Fig. 5a).

The white areas in Fig. 8 are areas of open water, where AGB was not estimated. Of the five images, PAL1012 had the largest the open water area. As for riverside of Kahayan at the upper right corner (Fig. 8), AGB was estimated rather steadily except PAL1012. AGB was estimated at over 300 Mg ha^{-1} in forests along the river (Fig. 8a), however the double bounce correction reduced the overestimation and was successful in this area (Fig. 8b). Regarding natural forest in the middle bottom (High AGB forests), AGB also appeared similarly among the images except PAL1012. As for fire scars, the corrected HV improved AGB estimation in areas with fallen trees by reducing double bounce in October 2009 and December 2010 (Fig. 8b). However, the estimated AGB using HV1012 was higher than those in other images in natural forests at the bottom. The reason for the higher estimation of AGB in December 2010 was not clear. As described previously, large parts of the forest would be submerged and double bounce might be the cause of overestimation of AGB even after the correction.

Although the AGB distribution maps using original HV images (Fig. 8a) showed high AGB in fire scars with fallen trees and riverside forests under submerged condition especially in PAL1012, such anomalies were reduced greatly using the corrected HV images. The AGB distribution pattern became quite similar among maps and the overestimation of AGB was corrected reasonably as described previously (Fig. 8b). The improvement demonstrates the usefulness of the double bounce correction in fire scars with fallen trees and open forest under submerged condition.

CONCLUSIONS

Effect of double bounce, which was caused by smooth water surface in submerged forest and fallen tree stems in burnt forest, is greater on BSC of HH than that of HV of PALSAR imagery. Biomass is overestimated for these areas due to double bounce even using HV data. The method of reducing double bounce effects developed in this research greatly reduced the overestimation of AGB. Comparisons of estimated AGB among five PALSAR images showed that the estimated AGB became more accurate. However estimates of AGB in mature forests were not so accurate when AGB exceeded 100 Mg ha^{-1} due to the saturation of BSC in High AGB forests. The double bounce correction can be used to monitor growth or regrowth of disturbed forest or deforestation in peat swamp forest using PALSAR imagery.

ACKNOWLEDGEMENTS

The field works were conducted by a team of Centre for International Co-operation in Sustainable Management of Tropical Peat (SIMTROP), University of Palangka Raya, and Forestry and Forest Products Research Institute (FFPRI) approved by the State Ministry of Research and Technology (RISTEK), Indonesia. The authors appreciate for the support of field surveys by the staff members of University of Palangka Raya. The study was executed as part of the research program (A-0802) supported by the Global Environment Research Fund of the Ministry of the Environment, Japan.

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(Received 14 March 2012)
(Accepted 5 November 2012)

Article

Vegetation Map Using the Object-oriented Image Classification with Ensemble Learning

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ABSTRACT

Vegetation mapping provides basic information for forest management and planning. In remote sensing research, the process of creating an accurate vegetation map is an important subject. Recently, there has been growing research interest in the object-oriented image classification techniques. The object-oriented image classification consists of multi-dimensional features including object features and thus requires multi-dimensional image classification approaches. For example, a linear model such as the maximum likelihood method of pixel-based classification cannot characterize the patterns or relations of multi-dimensional data. In multi-dimensional image classification, data mining and ensemble learning have been shown to increase accuracy and flexibility. This study examined the use of the object-oriented image classification by Random Forest classification for vegetation mapping. Vegetation maps were also created using the Nearest Neighbor method and the Classification and Regression Tree method for comparison of classification accuracy. The study area was Sado Island in Niigata Prefecture, Japan. SPOT/HRG imagery (June 2007) was used and classified into the following seven classes: broad-leaved deciduous forest, Japanese cedar, Japanese red pine, bamboo forest, paddy field, urban/road, and bare land. We employed eCognition software for the object-oriented image classification. We selected 18 object features: the mean, standard deviation, ratio, shape, length, and compactness for each band and normalized difference vegetation index value. High accuracy was found for the vegetation maps produced using the Random Forest and Nearest Neighbor methods. The accuracies of these two methods were significantly different from that of the Classification and Regression Tree method, as shown by kappa analysis. Among the three techniques, the Random Forest method showed the highest classification accuracies when class accuracies such as user's accuracy and producer's accuracy were considered. This study demonstrates that the Random Forest classification is effective for vegetation mapping by multi-dimensional image classification.

Keywords: accuracy assessment, classification and regression tree, nearest neighbor, object-oriented image classification, random forest, SPOT/HRG

INTRODUCTION

Earth observation is an important requirement for global environmental research. This includes studies of global climate change, land-cover or land-use change, sustainable forest management, natural resources management, and disaster management (Committee on Global Change Research, National Research Council, 1999). Vegetation provides the base for an ecosystem and plays a critical role in climate change by influencing terrestrial CO_2 (Wofsy *et al.*, 1993; Falge *et al.*, 2002; Xiao *et al.*, 2004). Thus, the evaluation of forest ecological structures and functions is necessary worldwide. As many case studies have shown (*e.g.*, DeFries *et al.*, 2007; Berterretche *et al.*, 2005; Healey *et al.*, 2006; Zhang *et al.*, 2004), remote sensing is an effective tool for global environmental research. Vegetation mapping, in particular, provides valuable information for evaluating natural and artificial environments by quantifying the vegetation structure at various landscape levels, either at a specific time point or over a continuous period (Xie *et al.*, 2008; Hirata, 2009).

Remote sensing and image interpretation have been employed in forestry management for many years (He *et al.*, 2005; Xie *et al.*, 2008; Hirata, 2009). Remote sensing observations can be used to differentiate types of forest cover on the basis of forest structure and species composition and are especially useful for studies of large areas (Franklin, 2001; Nordberg and Evertson, 2003). In Japan, vegetation maps

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have been produced by the Ministry of the Environment since 1973. However, these maps depend on detailed analyses of aerial photographs and substantial field surveying, a process requiring huge amounts of time and effort. The accuracy of these maps also depends on the skill of the researcher. For efficient vegetation mapping, a consistent and accurate classification algorithm is essential (KAMAGATA and HARA, 2010). Thus, classifying and mapping vegetation is an important technical subject for remote sensing research.

Conventional image classification techniques include supervised classification by the maximum likelihood method or unsupervised classification of ISODATA. As optical sensors and classification techniques have advanced, various types of satellite imagery and classification algorithms have become available for vegetation mapping. Examples of such advances include the imaging of hyperspectral data and the development of the object-oriented image classification techniques. Hyperspectral data include multi-dimensional features such as multiple wavelength ranges (DATT, 1998; JONES and VAUGHAN, 2010). The object-oriented image classification have multiple object and textural features (BAATZ and SCHÄPE, 2000; MALLINIS *et al.*, 2008). Some research has suggested that the image patterning and relational aspects of multi-dimensional data are not properly characterized by traditional methods, such as the maximum likelihood method, because of complexity caused by factors such as the variability of features in each vegetation cover type, the cause of the multidimensionality as the large number of observed bands, and possible correlation among features to be classified (MELGANI and BRUZZONE, 2004).

In the classification of multi-dimensional data, data mining and ensemble learning are considered effective approaches (GISLASON *et al.*, 2006). Many ensemble methods have been proposed (HANSEN and SALAMON, 1990; BENEDIKTSSON and SWAIN, 1992), with the most widely used being boosting (SCHAPIRE, 1999) and bagging (BREIMAN, 1994). These methods are based on training many classifiers, which has been shown to reduce the variance of the classification. However, drawbacks of these methods include slowness, overtraining, and sensitivity to noise (BRIEM *et al.*, 2002). Another ensemble method, called the Random Forest (RF), is a decision tree type of classifier (BREIMAN, 2001). RF is a bootstrap aggregation operation that produces multiple classifications of trees, each based on a random subset of training data observations (BREIMAN, 2001; LAWRENCE *et al.*, 2006).

We applied the RF method to classify multi-dimensional features as a case study of the object-oriented image classification using object features. For comparison, we also applied the Nearest Neighbor method (NN) and the Classification and Regression Tree model (CART) for image classification. Our primary objective was to identify an effective technique for multi-dimensional image classification for vegetation mapping. The multi-dimensional features in this study were object features based on the digital number (DN); textural features such as the gray-level co-occurrence matrix were not used.

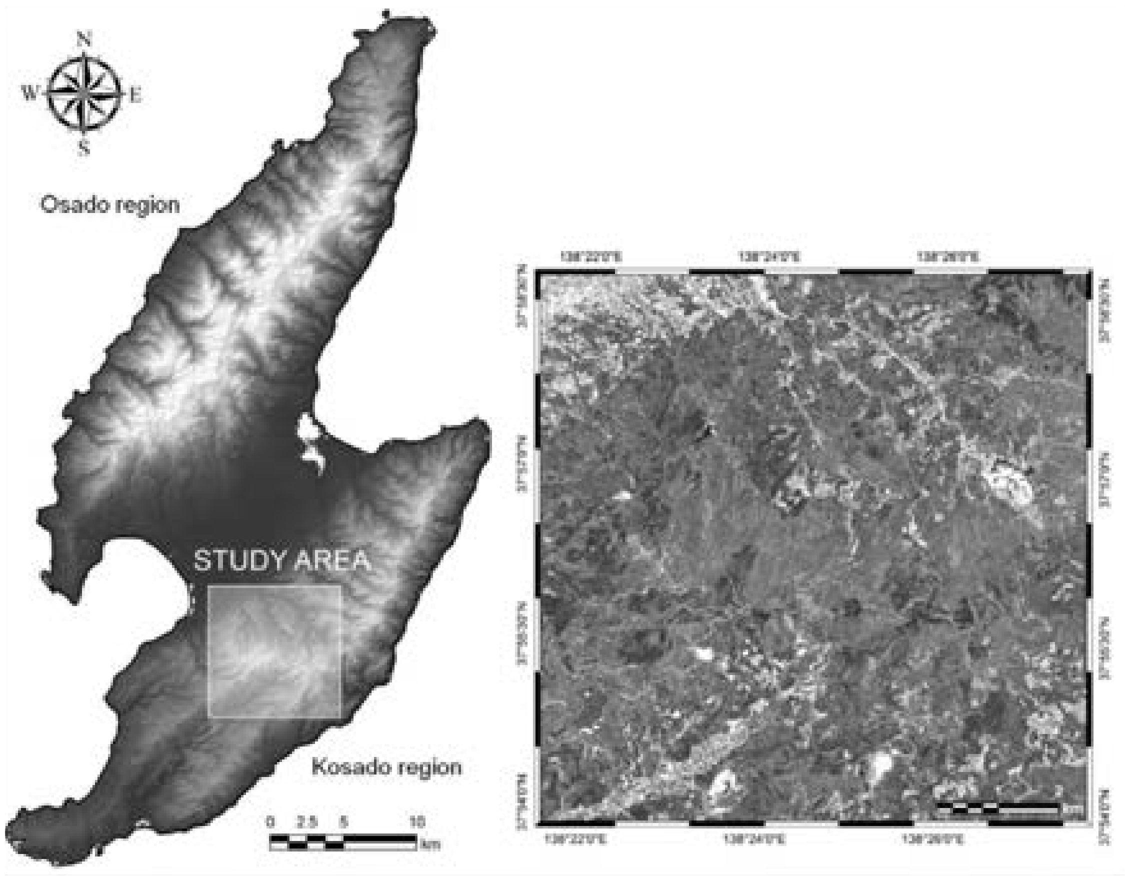

Fig. 1 Study area and SPOT/HRG (acquired in 2007/06/03) imagery within test site

MATERIALS AND METHODS

Study Area and Data Correction

The study area was Sado Island, located in Niigata Prefecture, Japan (37°50'-38°20'N, 138°10'-138°33'E; Fig. 1). The island covers 855.26 km^2 and has a population density of 74 people per square kilometer. Elevation ranges from 1 to 1,165 m above sea level. Sado Island is divided into two regions: the Osado region and the Kosado region (Fig. 1). The Osado region has high mountains and small settlements with paddy fields. The Kosado region has low mountains and gently sloping valleys with paddy fields. Forest covers 76% of the island and is composed mostly of secondary forest dominated by oak (*Quercus* L.) and conifer plantations of Japanese cedar (*Cryptomeria japonica*) and Japanese red pine (*Pinus* L.). The mean annual temperature is 14.3°C, and the mean annual precipitation is 1301.3 mm. We established a test site (size: 9 km×9 km) in the Kosado region and performed a field survey (Fig. 1) in which we collected vegetation data and located the data using a Global Positioning System device (GPS: GPSMAP60Cx, GARMIN, Inc.). Location data were used for training samples and validation of the vegetation mapping. Image classification was conducted for this test site.

SPOT/HRG satellite imagery, acquired on 3 June 2006, was used for vegetation mapping. The SPOT data were geo-referenced to the Universal Transverse Mercator system using ERDAS IMAGINE 9.3 (ERDAS, Inc.) with a root mean-square error within one pixel. Shade caused by topographic relief (*i.e.*, topographic effect) can create serious obstacles for the analysis of remote sensing data. A dual partitioning regression method was applied to offset topographic effects (Sakamoto *et al.*, 2009). We used DNs for the observed wavelength bands [band 1: green, band 2: red, band 3: near infrared (NIR), band 4: shortwave infrared (SWIR)] and the normalized difference vegetation index (NDVI; Asrar, 1989), which shows the vegetation quantity, to classify vegetation cover within the study area. NDVI is defined as

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

where RED and NIR are the DNs of the visible red and near-infrared bands, respectively.

Image Classification and Accuracy Assessment

The object-oriented image classification was applied for vegetation mapping. We used the commercial software eCognition ver. 4 (Definiens Imaging, Inc.) to conduct the object-oriented method. Using this method, the object-oriented classification can be performed in lieu of traditional methods, such as pixel-based classification. Segmentation represents the first step of any object-oriented classification. In this segmentation technique, individual pixels are considered the initial regions. A region-growing procedure for segmentation was used for image classification. In eCognition, the segmentation is a bottom-up, region-merging technique, where the smallest object contains one pixel. In this process, adjacent pixels in image objects are totaled by considering spectral and shape features. This process stops when the smallest growth exceeds the threshold defined by the scale parameter (Benz *et al.*, 2004). Segmentation analysis, at fine and coarse scales, is important in the object-oriented image classification to extract the boundaries of dominant objects occurring at corresponding scales (Hall *et al.*, 2004).

The SPOT data were then segmented into homogeneous objects. In the segmentation process, the object-amount, object-form, and object-size features were used. The parameters were scale (10), shape (0.3), and compactness (0.4). Total number of segmented object was 35,051. For the image classification features, we selected 18 object features: the mean, standard deviation, ratio, shape, length, and compactness for each band and NDVI. In mapping the vegetation, we defined seven classes: broad-leaved deciduous forest, Japanese cedar, Japanese red pine, bamboo forest, paddy field, urban/road, and bare land. RF, NN, and CART techniques were employed for image classification (details of these techniques are described in later sections). Classification training data were extracted from the area in which land cover could be checked using an aerial photograph from 2006, combined with field verification as reference data (Table 1).

The accuracy of vegetation maps was assessed using an aerial photograph and field survey data (Table 1). The error matrix, producer's accuracy, user's accuracy, overall accuracy, and kappa coefficient were used for accuracy assessment. In addition, the standard error of class accuracy in each class was calculated. Some studies have suggested that the overall accuracy and kappa coefficient are not applicable for accuracy assessments that take into consideration variation in sample size (Stehman and Czaplewski, 2003; Nusser and Klaas, 2003). To resolve this problem, evaluation of standard error in each class was proposed to assess accuracy (Nusser and Klaas, 2003). Significance testing was performed to evaluate the usefulness of the ensemble learning method. The significance of the accuracy difference between two maps, with independent kappa coefficients $\hat{K}_1$ and $\hat{K}_2$, can be evaluated with the normal curve deviate:

$$Z = \frac{\hat{K}_1 - \hat{K}_2}{\sqrt{\hat{\sigma}_1^2(\hat{K}) + \hat{\sigma}_2^2(\hat{K})}} \quad (2)$$

where $\hat{\sigma}_1^2(\hat{K})$ and $\hat{\sigma}_2^2(\hat{K})$ represent the estimated variances in the derived coefficients. Comparing the value of Z calculated from Equation 2 against tabulated values then assesses the significance of difference between the two kappa coefficients. To simply examine the difference between two kappa

Table 1 Data for image classification: Information classes and samples.

Information class	Training samples	Test samples
Broad-leaved decidious forest	74	166
Japanese cedar	61	41
Japanese red pine	53	31
Bamboo	40	9
Paddy field	62	39
Urban land/Road	68	43
Bare land	43	25
Total samples	401	354

Training samples were equally acquired to reduce the bias of image classification. Test samples were acquired according to the whole area ratio, in order to evaluate the accuracy of the study site.

coefficients, the null hypothesis was rejected at the widely used 5% level of significance if |Z| > 1.96, and at the 1% level of significance if |Z| > 2.58 (CONGALTON *et al.*, 1983; FOODY, 2004). The error matrix, producer's accuracy, user's accuracy, overall accuracy, kappa coefficient, standard error, and significance test were computed using R-2.8.1 (R DEVELOPMENT CORE TEAM, 2008; ROSSITER, 2004).

Random Forest Classification Technique

The Random Forest method, as proposed by BREIMAN (2001), is an ensemble classifier that consists of numerous decision trees; the output class is the mode of the classes for the individual trees. In training, the RF algorithm, like CART, creates multiple trees, each trained on a bootstrapped sample of the training data. It then searches only across a randomly selected subset of input variables to determine a split. In this study, we developed RF models with 500 classification trees. Eighteen features were included as multi-dimensional variables for the RF model. The number of features used at each tree split was optimized based on out-of-bag estimates of error (LIAW and WIENER, 2002). The out-of-bag estimates were developed using the one-third of the data that was randomly excluded from the contraction of each of the 500 classification trees. The RF model was developed using training data and the accuracy was evaluated using test data. We used the Random Forest package in R (LIAW and WIENER, 2002) for the RF image classification.

Nearest Neighbor Classification Technique

The NN algorithm is the non-parametric classifier since no Gaussian distribution is assumed for the data model (HUBERT-MOY *et al.*, 2001). In this technique, the Euclidean distance from the observation to be classified to the nearest training sample observation is calculated (DUDA and HART, 1973). The whole classification process can be improved by the selection of optimal object features. We used a function of feature space optimization in eCognition software (DEFINIENS IMAGING, 2004). This technique is a basic function in eCognition software for the object-oriented image classification. The eCognition program contains two image classification methods: NN supervised classification and user-defined fuzzy classification (BAATZ and SCHÄPE, 2000). In this study, NN supervised classification using a training data set was employed for comparison with RF and CART based on supervised classification.

Classification and Regression Tree Classification Technique

BREIMAN *et al.* (1984) developed CART, a classification tree technique based on binary recursive splitting. CART divides data into homogeneous groups. In the classification tree analysis, the predicted outcome is the class to which the data belongs. The tree is developed initially having one node. The training data are divided into two groups and these nodes are each split into two child nodes. In this study, Gini impurity (BREIMAN *et al.*, 1984) is a measure of how often a randomly chosen element from a set would be incorrectly labeled if it were randomly labeled according to the distribution of labels in the subset. We used the rpart package in R (THERNEAU and ATKINSON, 1997) for CART image classification.

RESULTS AND DISCUSSION

Vegetation maps produced by the three classification methods are presented in Figure 2. Most of our test site was composed of broad-leaved deciduous forests and Japanese cedar, and other vegetation types and land covers were distributed in a mosaic pattern. Notably, there was low coverage by Japanese red pine and bamboo forest. Simple visual comparison of the classified images suggested that the RF and NN classifications were similar. However, the CART method overestimated the coverage by bamboo forest. The error matrixes and accuracies of three vegetation maps are presented in Tables 2, 3, and 4. The most accurate classification technique for multi-dimensional features was the RF classifier based both on overall accuracy and the kappa coefficient. The CART method had the lowest accuracy of the three classification techniques. The estimated overall accuracies were 94% for the RF method (kappa = 0.90), 89% for the NN method (kappa = 0.85), and 82% for the CART method (kappa = 0.75) using training samples of image classification as the accuracy assessment. Using test samples as the accuracy assessment, the estimated overall accuracies were 80% for the RF method (kappa = 0.73), 76% for the NN method (kappa = 0.67), and 69% for the CART method (kappa = 0.57). The overall accuracy and kappa coefficient are traditional indices for accuracy assessment. However, some previous studies have suggested that the overall accuracy and kappa coefficient may not be appropriate accuracy assessments because of variation in sample sizes (STEHMAN and CZAPLEWSKI, 2003; NUSSER and KLAAS, 2003).

In this study, we also evaluated class accuracies included in the standard error of each class. The user's accuracies ranged from 0.54 to 0.94 for RF (standard error ranged from 0.003 to 0.056), from 0.22 to 0.94 for NN (standard error ranged from 0.003 to 0.046), and from 0.08 to 1.00 for CART (standard error ranged from 0.000 to 0.116). The producer's accuracies ranged from 0.48 to 0.89 for RF (standard error ranged from 0.003 to 0.056), from 0.22 to 0.89 for NN (standard error ranged from 0.003 to 0.046), and from 0.12 to 0.86 for CART (standard error ranged from 0.003 to 0.049). The standard errors of the RF and NN methods were lower than that of CART. Furthermore, class accuracies also showed wide variations in the NN and CART methods. RF was highly accurate in all classes, and there was little variation between class accuracies. Thus, the RF method was most accurate from the perspective of the user's accuracy and producer's accuracy included in the sample variation of each class.

Table 5 presents the results of the kappa analysis, which compares error matrices, two at a time, to determine if they are significantly different. This method is based on the standard normal deviate and the fact that, although remote sensing data are discrete, the kappa statistic is asymptotically normally distributed (CONGALTON, 1991). The difference in classification accuracy between CART and the other two techniques was significant (at the 99% confidence level for RF and 95% confidence level for NN). Although the overall accuracy of the RF method was 4% higher than that of the NN method, the kappa results indicated that this difference was

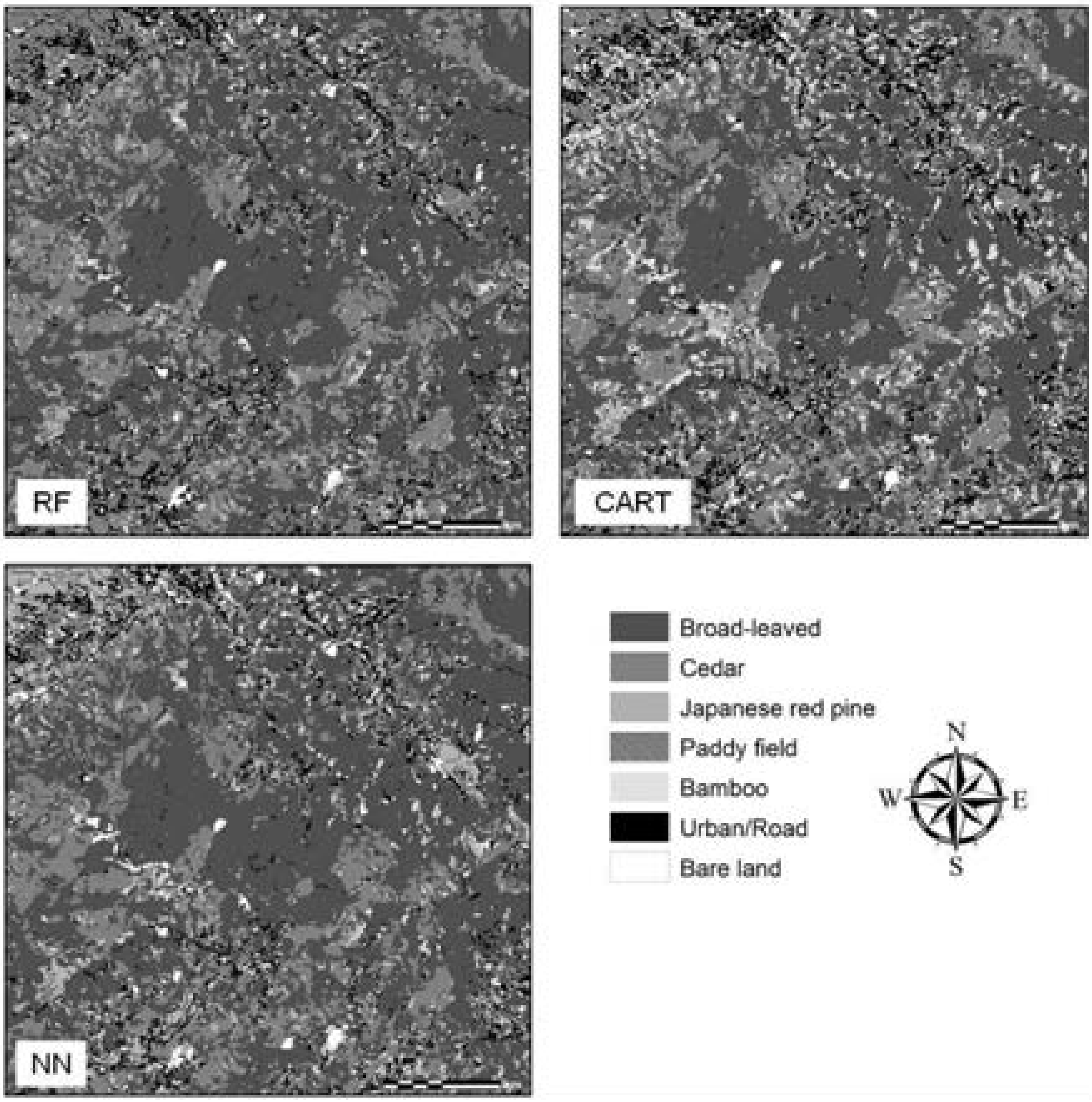

Fig. 2 Results of vegetation mapping by three classification techniques.

not significant.

Our accuracy assessments suggest that the RF method was the most accurate of the three classification techniques. Overall and class accuracies of both the NN and CART methods were less than those of the RF method, suggesting that the ensemble learning method was effective for multi-dimensional classification. However, kappa analysis of RF and NN accuracies did not show a significant difference. This result indicates both the NN method and RF method are effective for multi-dimensional classification. The NN method is a standard classification technique in eCognition software (Definiens Imaging, 2004). In the NN method of eCognition, feature selection can be applied as a function of feature space optimization under multi-dimensional classification. The optimal variables for image classification are detected by performing a feature selection.

The classification accuracy of the NN method appeared to be similar to that of the RF method with optimization of the variable. However, verification of feature selection techniques is required to treat many variables, including textural features. In the classification of hyperspectral data, which have more than 50 bands (variables), principal component analysis, decision tree, and other feature selection techniques have been employed instead of feature space optimization in case studies using eCognition software (Yu *et al.*, 2006; Addink *et al.*, 2007). Therefore, the limitations of feature space optimization should be examined. The kappa accuracies of error matrices were significantly different between RF/CART and NN/CART, and the CART method was found to be unsuitable for multi-dimensional classification. Although the CART method is based on the RF method, the patterning or relation of multi-dimensional data is not characterized by one decision tree (Gislason *et al.*, 2006). Furthermore, although the accuracy of the RF and NN methods was not significantly different, in vegetation mapping, whole class accuracy, rather than accuracy for a specific class, is expected. From this perspective, the RF method is more accurate than the NN method for multi-dimensional classification, when class accuracies such as the user's accuracy (>54%) and producer's accuracy (>48%) are taken into consideration. In summary,

Table 2 Error matrix and classification accuracy of Random Forest method.

	Broad	Cedar	Pine	Bamboo	Paddy	Urb/R	Bare	U.A.	S.E.	P.A.	S.E.
Broad	147	5	3	0	0	0	2	0.94	0.003	0.89	0.003
Cedar	6	33	19	2	5	0	0	0.54	0.009	0.76	0.012
Pine	3	1	8	4	0	2	0	0.68	0.021	0.68	0.016
Bamboo	4	1	1	2	0	1	0	0.56	0.056	0.56	0.056
Paddy	0	0	0	0	33	1	2	0.91	0.009	0.79	0.011
Urb/R	6	1	0	1	1	38	12	0.69	0.009	0.84	0.010
Bare	0	0	0	0	0	1	9	0.86	0.032	0.48	0.020

Overall accuracy= 0.80, Kappa= 0.73, 95% confidence limits for kappa: 0.67…0.78.
U.A.: User's accuracy, P.A.: producer's accuracy, S.E.: Standard error, Broad: Broad-leaved deciduous forest, Cedar: Japanese cedar, Pine: Japanese red pine, Bamboo: Bamboo forest, Paddy: Paddy field, Urb/R: Urban area and Road, Bare: Bare land.

Table 3 Error matrix and classification accuracy of Nearest Neighbor method.

	Broad	Cedar	Pine	Bamboo	Paddy	Urb/R	Bare	U.A.	S.E.	P.A.	S.E.
Broad	147	4	2	0	0	2	2	0.94	0.003	0.89	0.003
Cedar	9	31	8	2	6	1	0	0.51	0.008	0.80	0.012
Pine	4	5	21	1	0	0	0	0.44	0.022	0.26	0.014
Bamboo	2	0	0	5	0	0	2	0.22	0.046	0.22	0.046
Paddy	0	0	0	0	31	2	1	0.92	0.009	0.85	0.010
Urb/R	4	1	0	1	2	36	8	0.64	0.009	0.88	0.009
Bare	0	0	0	0	0	2	12	0.90	0.027	0.36	0.019

Overall accuracy= 0.76, Kappa= 0.67, 95% confidence limits for kappa: 0.62…0.73
U.A.: User's accuracy, P.A.: producer's accuracy, S.E.: Standard error, Broad: Broad-leaved deciduous forest, Cedar: Japanese cedar, Pine: Japanese red pine, Bamboo: Bamboo forest, Paddy: Paddy field, Urb/R: Urban area and Road, Bare: Bare land.

Table 4 Error matrix and classification accuracy of Classification and Regression Tree method.

	Broad	Cedar	Pine	Bamboo	Paddy	Urb/R	Bare	U.A.	S.E.	P.A.	S.E.
Broad	138	4	1	0	0	0	1	0.96	0.003	0.83	0.003
Cedar	6	31	16	2	3	1	1	0.52	0.009	0.76	0.012
Pine	8	0	9	2	0	1	0	0.45	0.026	0.29	0.015
Bamboo	6	4	5	2	3	3	2	0.08	0.011	0.22	0.049
Paddy	0	0	0	0	20	0	0	1.00	0.000	0.51	0.013
Urb/R	8	2	0	3	13	37	18	0.46	0.006	0.86	0.010
Bare	0	0	0	0	0	1	3	0.75	0.116	0.12	0.012

Overall accuracy= 0.69, Kappa= 0.57, 95% confidence limits for kappa: 0.51…0.63
U.A.: User's accuracy, P.A.: producer's accuracy, S.E.: Standard error, Broad: Broad-leaved deciduous forest, Cedar: Japanese cedar, Pine: Japanese red pine, Bamboo: Bamboo forest, Paddy: Paddy field, Urb/R: Urban area and Road, Bare: Bare land.

Table 5 Results of Kappa analysis for comparison between error matrices in three classification techniques.

Comparison	Z-statistic	Result
Random Forest vs. Nearest Neighbor	1.496	NS
Random Forest vs. CART	3.947	S[a]
Nearest Neighbor vs. CART	2.429	S[b]

[a] At the 99% confidence level, and [b] at the 95% confidence level.
S = significant, NS = not significant.

we propose that the RF method is an accurate technique for vegetation mapping by multi-dimensional image classification from the perspectives of the overall accuracy, kappa coefficient, and class accuracy.

CONCLUSIONS

We compared three techniques for classifying remotely sensed data with multi-dimensional features for vegetation mapping. The object-oriented image classification was applied to the multi-dimensional features. Among the three classification methods used, the RF method was the most accurate. Tests of significant difference between error matrices showed that RF and NN were suitable for classification of remotely sensed multi-dimensional data, whereas CART was unsuitable. The whole class accuracies of user's accuracy and producer's accuracy indicated that the RF method was more accurate than the NN method. On the basis of these results, we recommend the RF method for multi-dimensional classification of remotely sensed data for vegetation mapping. However, this is only one case study. More verification is required to determine the usefulness of ensemble learning for image classification. Future works should examine other classification techniques, such as support vector machine, neural network analysis, boosting, bagging, and the Bayesian classifier. Moreover, systematic techniques should be established to examine image classification for other areas, other remotely sensed data, and seasonal variability.

ACKNOWLEDGEMENT

We are grateful to Mr. Kyohei NAKAGAWA, Mr. Kentaro AIZAWA, and Mr. Shota MATSUZAWA for their helpful of field survey. We thank anonymous reviewers for making helpful suggestions. This work was supported by Grant-in-Aid for JSPS Fellows (KAKENHI No. 23-5907).

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(Received 10 February 2012)
(Accepted 25 July 2012)

Article

Analysis of High School Students' Perceptions of the Functions Served by Forests

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ABSTRACT

This study examined first-year high school students' perceptions of "forests" in general, "artificial forests," and "natural forests" and investigated factors associated with their knowledge of forests, experience of visiting forests, and gender. A questionnaire was administered in a high school in Kobe, Japan, in 2009. The valid response rate was 97.6% (boys 146, girls 139). There were three main findings: carbon storage was less expected in forests in general and natural forests by those who knew the item "substitute for wood products," but more expected in natural forests by those who knew "management by people"; the factor "experience visiting forests" increased students' expectations regarding rare species protection in natural forests, but decreased their expectations regarding carbon storage in the three types of forest; and boys perceived timber production as a function of artificial forests more than girls did.

keywords: questionnaire, high school students, function of forests, knowledge of forests, visit to forests

INTRODUCTION

An understanding of young people's perceptions of the functions of forests is important in developing forest-management strategies. Kawase (2012) studied first-year high school students (age 15-16 years old) and showed that the respondents expected particular functions for particular types of forest; that is, both "artificial" and "natural" forests functioned for carbon storage, artificial forests functioned for timber production, natural forests functioned for rare species protection, and "forests" in general functioned for carbon storage. Detailed information on these results will help to elucidate their perceptions precisely.

Therefore, this study examined the respondents' perceptions of the following three forest types that had been analyzed separately in previous studies: "forests" in general, "artificial forests," and "natural forests" (The Cabinet Office Poll, 2007; Ogasawara *et al*., 1990). Specifically, this study quantitatively investigated factors associated with students' perceptions of the functions of forests. We analyzed factors as they related to the respondents' knowledge of forests, experience visiting forests, and gender.

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Two groups have investigated the perceptions of the public and of young people regarding the functions served by forests: the Japanese government (*e.g.*, Cabinet Office Poll, 2007) and forestry researchers (*e.g.*, Ogasawara *et al*., 1990; Ikeda *et al*., 1994; Yasumura *et al*., 1997; Kraxner *et al*., 2009). However, no study had analyzed factors related to expected forest functions. To address this issue, we referred to two studies focusing on the natural environment and applied concepts discussed in them to forest functions. Misaka and Koike (2006) analyzed factors related to residents' perceptions of flood control and river environments and identified important factors that included knowledge and experience of floods. Doi (2011) reviewed papers on environmental education and suggested a correlation between perceptions and gender.

We did not consider the factor "experience with forest disasters" but did use the factor "experience visiting forests." This was because our respondents were first-year high school students, who may not have experienced forest disasters or might not have remembered disasters that happened when they were very young. We assumed that "experience with floods" discussed by Misaka and Koike (2006) could be included in "experience concerning river environments." Although we eliminated the disaster factor, we considered that "experience visiting forests" could serve as one experience concerning forests.

SAMPLES AND METHODS

Study Site

We wanted to investigate students from an urban area because few of them would have experienced the forest industry in daily life. We selected Kobe, an ordinance-designated city with a population of 1,525,000 according to the 2005 Census, as it was likely that few respondents' knowledge of forests and experience visiting forests would be influenced by contact with the forest industry. A comparison of respondents' perceptions between urban and rural areas was beyond of the scope of this study.

The focal study group in this study was 15-16-year-old first-year students at one public high school. The high school does not have a special course on forests and the forest industry, and all of the respondents took a general curriculum that consisted of the same subjects.

Survey

A questionnaire was administered to first-year students at a high school in Kobe in 2009. Teachers distributed the questionnaires, which the students completed in the classroom; the teachers then collected the completed questionnaires (collection rate 100%). Seven questionnaires with six or more invalid answers out of the 31 questions were excluded. Therefore, the valid response rate was 97.6% (146 boys, 139 girls). This paper analyzed the respondents who completed Questions F1, A1, N1, K, E1, E2, E3, E4, and S (Table 1) (134 boys, 134 girls).

Questions F1, A1, and N1 were examined in Kawase (2012). The letters F, A, and N denote forests in general, artificial forests, and natural forests, respectively. These questions concern carbon storage in forests in general, artificial, and natural forests, timber production in artificial forests, and rare species protection in natural forests (Fig. 1). The explanatory variables affecting the respondents' prioritization were analyzed.

The remaining questions were used to find candidate explanatory variables associated with their perceptions of the functions of forests. Each choice in the questions corresponded to a candidate explanatory variable. As shown in Table 1, Question K is related to the respondents' knowledge of forests. The choices for Question K can be divided in three categories: 1) management by people (site preparation, planting, weeding, pruning, and thinning); 2) harm caused by nature (pine death, bark beetles, damage by bears, and damage by deer); and 3) substitutes for wood products (biofuel and kenaf).

Questions E1 to E4 are associated with the respondents' experience visiting forests. Question S divides the respondents by gender.

Procedure of Analysis

The candidate explanatory variables were analyzed using logistic regression analysis, which enabled us to examine cause-and-effect relationships. We used univariate and multiple logistic regression analysis, which has three advantages when evaluating factors: 1) multiple logistic regression analysis adjusts the effects among variables and the significant variables selected through this analysis are independent; 2) the significant variables selected in the univariate analysis, but not in the multiple logistic regression analysis, are considered to be fake variables; and 3) the significant variables selected in the multiple logistic regression analysis, but not the univariate analysis, are considered variables that would be missed without multiple logistic regression analysis.

The analysis followed processes 1 to 3 of Hamada (2006, p152) using R ver. 2.12.1. These three processes were adapted to our case and were 1) an examination of the distribution of each explanatory variable, 2) univariate analysis of each candidate explanatory variable, and 3) multiple logistic regression analysis using stepwise selection for variable selection. These processes involved the following:

1. The distribution of each explanatory variable was shown.

2. Univariate logistic regression analysis was conducted for each candidate explanatory variable. The model used for the univariate analysis was shown as the probability of the respondents' expectation of each function p, expressed using parameters β_0 and β_1, for variable X, as follows (see Hamada, 2006, p153):

$$\log(p/(1-p)) = \beta_0 + \beta_1 \cdot X \quad (1)$$

Table 1 Questions and choices

Questions	
F1	Choose one function that you feel is important for forests.
A1	Choose one function that you feel is important for artificial forests.
N1	Choose one function that you feel is important for natural forests.
K	Do you know each word?
E1	Did you visit forests before entering elementary school?
E2	Did you visit forests when you were an elementary school student?
E3	Did you visit forests when you were a junior high school student?
E4	Do you visit forests now?
Choices	
F1 A1 N1	producing timber (timber production), producing mushrooms and other non- wood forest products, storage of water resources, protection from flooding and preserving land, cleaning air and muffling noise, absorbing carbon dioxide to reduce global warming (carbon storage), place for leisure and recreation, place for teaching people to commune with nature, protecting rare species
K	site preparation, planting, weeding, pruning, thinning, pine death, bark beetles, damage by bears, damage by deer, biofuel, kenaf
E1~E4	before entering elementary school (bfelementary), elementary school (elementary), junior high school (juniorhigh), high school

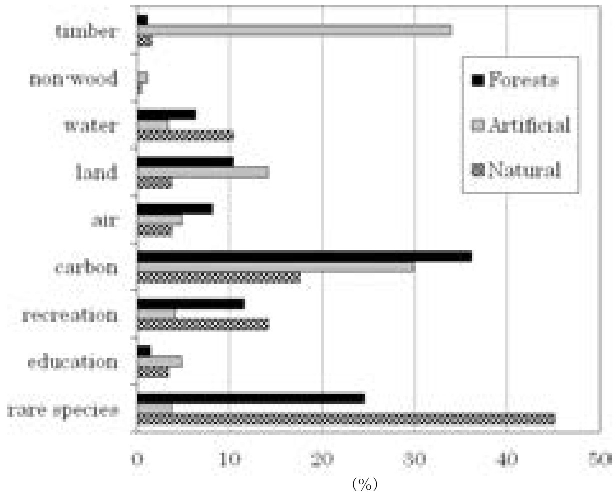

Fig. 1 The rate of respondents who chose each function

An odds ratio shows the expectations of one group compared to another group. Univariate analysis calculates non-adjusted odds ratios as exp(β_1). The probability of the expectation by the respondents who knew each word or term, had visited forests, or were male (P_y) and the probability of the expectation by the remaining respondents (P_n) were calculated as follows (see HAMADA, 2006, p140):

$$\exp(\beta_1)=1,\ P_y = P_n \quad (2)$$

$$\exp(\beta_1)>1,\ P_y > P_n \quad (3)$$

$$\exp(\beta_1)<1,\ P_y < P_n \quad (4)$$

3. Multiple logistic regression analysis using the step-down procedure with stepwise selection was conducted. Variable selection was conducted when there were numerous variables. Stepwise selection helps to select explanatory variables. This analysis excludes influence among variables and adjusts the relations of variables. The model of this analysis is shown as the probability of the respondents' expectation of each function p, with parameters β_0, β_1,…, and variables X_1, X_2 …, as follows:

$$\log(p/(1-p)) = \beta_0 + \beta_1 \cdot X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots \quad (5)$$

Each adjusted odds ratio is calculated as exp (β_1), exp (β_2), and exp (β_3), using Akaike's information criterion (AIC) as the standard for stepwise selection. The model with the smallest AIC value was selected. The formula for AIC is as follows (see also FUJI, 2010, pp. 93–94):

AIC= −2 (maximum log likelihood) + 2 (the number of parameters) (6)

RESULTS

The distributions of each explanatory variable are shown in Figs. 2 and 3. Fig. 2 shows the rate of respondents who knew each term concerning forests and forest management. As shown in Fig. 2, planting and biofuel had high scores of approximately 90%. More than 60% of the respondents were familiar with pruning and thinning. These were followed by pine death, damage by bears, kenaf, and damage by deer. Weeding, bark beetles, and site preparation had the lowest scores.

Fig. 3 shows the proportion of respondents who remembered visiting forests in each period. Approximately 50% remembered visiting forests before entering elementary school, and 60% remembered visiting forests when they were elementary school students (the highest rate). The rate decreased to approximately 20% when they became junior high school students. The rate was 8% when in high school. This indicates that the respondents visited forests when elementary students and tended to lose the opportunity to visit forests after entering junior high school.

A univariate logistic regression analysis was conducted for each candidate explanatory variable. Table 2 shows the non-adjusted odds ratios and 95% confidential interval of the significant variables (p<0.05). The letters F, A, and N denote forests in general, artificial forests, and natural forests, respectively. As shown in Table 2, significant variables were identified only for the function of carbon storage. The variables were pruning, biofuel, kenaf, and "juniorhigh" for forests; pine death for artificial forests; and pruning, thinning, kenaf, and "bfelementary" for natural forests.

The finding that the odds ratios of all the variables in Table 2 are less than one means $P_n > P_y$ for these variables. Therefore, the respondents who knew the words pruning, biofuel, and kenaf and who remembered visiting forests when in junior high school had lower expectations for the function of carbon storage in forests. The respondents who knew the term pine death had lower expectations for the function of

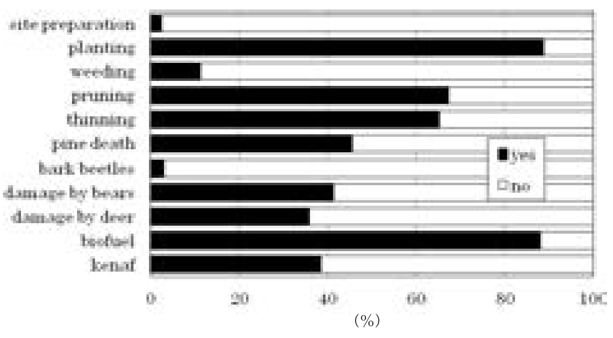

Fig.2 The rate of respondents who knew each term concerning forests and forest management

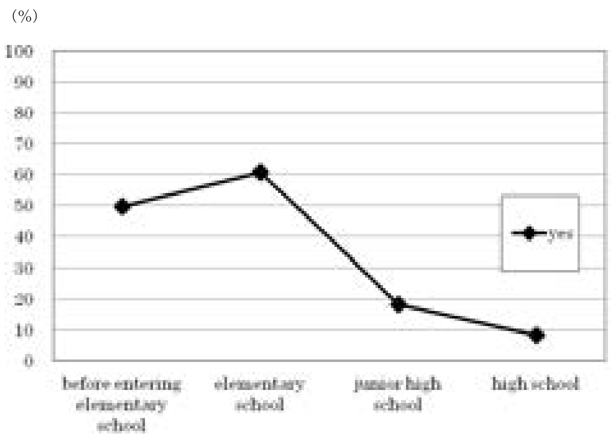

Fig.3 The rate of respondents who remembered visiting forests in each period

Table 2 The univariate analysis: ** $p<0.01$, * $p<0.05$. The letters F, A, and N denote forests in general, artificial forests, and natural forests, respectively.

Variables		*p*-value	Odds ratio	95% Confidential interval
F CO_2				
	pruning	0.014*	0.518	0.306–0.875
	biofuel	0.014*	0.391	0.185–0.828
	kenaf	0.008**	0.482	0.282–0.825
	juniorhigh	0.013*	0.389	0.185–0.820
A CO_2				
	pine death	0.048*	0.581	0.339–0.995
N CO_2				
	pruning	0.027*	0.484	0.255–0.919
	thinning	0.026*	0.484	0.255–0.916
	kenaf	0.022*	0.428	0.207–0.886
	bfelementary	0.044*	0.513	0.268–0.983

carbon storage in artificial forests. The respondents who knew the words pruning, thinning, and kenaf and who remembered visiting forests before entering elementary school had lower expectations for the function of carbon storage in natural forests.

Multiple logistic regression analysis using a step-down procedure for stepwise selection was conducted. Table 3 shows the adjusted odds ratios and 95% confidential interval of the significant variables (p<0.05). As shown in Table 3, the significant variables were kenaf and juniorhigh for the function of carbon storage in forests; elementary for the function of carbon storage in artificial forests; weeding, kenaf, and bfelementary for the function of carbon storage in natural forests; gender for the function of timber production in artificial forests; and bfelementary for the function of rare species protection in natural forests. These variables are independent variables.

The following variables were also selected in the multiple regression analysis, but they were not significant ($p<0.05$) and are not shown in Table 3: pruning and biofuel for the function of carbon storage in forests; site preparation, weeding, juniorhigh, and gender for the function of carbon storage in artificial forests; site preparation, planting, pruning, thinning, and bark beetles for the function of carbon storage in natural forests; site preparation and damage by bears for the function of timber production in artificial forests; and planting, elementary, and juniorhigh for the function of rare species protection in natural forests.

The result that the odds ratios of weeding for carbon storage in natural forests, gender for timber production in artificial forests, and bfelementary for rare species protection in natural forests are >1 means $P_y > P_n$ for these variables, while the finding that the odds ratios of the remaining variables in Table 3 are <1 means $P_n > P_y$ for these variables.

The respondents who knew of weeding expected more carbon storage in natural forests. Male students expected more timber production in artificial forests than did female students. The respondents who remembered visiting forests before entering elementary school expected more rare species protection in natural forests.

The respondents who knew the word kenaf or who remembered visiting forests when they were junior high school students expected less carbon storage in forests. The respondents who remembered visiting forests when they were elementary school students expected less carbon storage in artificial forests. The respondents who knew the word kenaf or who remembered visiting forests before entering elementary school expected less carbon storage in natural forests.

The univariate and multiple logistic regression analyses categorized the variables as follows. Fake variables, which

Table 3 Multiple logistic regression analysis

Variables		*p*-value	Odds ratio	95% Confidential interval
F CO_2				
	kenaf	0.028*	0.539	0.310–0.937
	juniorhigh	0.029*	0.428	0.200–0.917
A CO_2				
	elementary	0.031*	0.478	0.245–0.935
N CO_2				
	weeding	0.037*	2.852	1.065–7.637
	kenaf	0.019*	0.401	0.187–0.858
	bfelementary	0.038*	0.485	0.245–0.962
A timber production				
	(Intercept)	0.000***	0.317	0.200–0.501
	gender	0.031*	1.771	1.053–2.979
N rare species protection				
	(Intercept)	0.026*	0.382	0.164–0.890
	bfelementary	0.026*	1.899	1.079–3.342

Table 4 Categorization of explanatory variables

Group	Management	Substitutes	Experience	Gender
FCO_2		kenaf No	juniorhigh No	
A CO_2			elementary No	
NCO_2	weeding Yes	kenaf No	bfelementary No	
A timber				male
N rare species protection			bfelementary Yes	

were selected only in the univariate analysis, were pruning and biofuel for carbon storage in forests, pine death for carbon storage in artificial forests, and pruning and thinning for carbon storage in natural forests. The variables missed in the univariate analysis but found in the multiple logistic regression analysis were elementary for carbon storage in artificial forests, weeding for carbon storage in natural forests, gender for timber production in artificial forests, and bfelementary for rare species protection in natural forests.

Table 4 categorizes the independent factors using the odds ratios in Table 3. Factors are not categorized into "harm caused by nature." Multiple logistic regression analysis was necessary because variables that related to the respondents' perceptions of functions other than carbon storage were not revealed in the univariate analysis.

DISCUSSION

This study investigated factors associated with high school students' perceptions of the functions served by forests as related to their knowledge of forests and experience visiting forests. Regarding their knowledge of forests, those who knew of kenaf expected less carbon storage in both forests and natural forests, whereas those who knew the term weeding expected more carbon storage in natural forests.

MISAKA and KOIKE (2006) surveyed residents regarding flood control and river environments and indicated that the factor knowledge was the basis of their interest in river environments and flood control. If this concept can be extended to our study, then the respondents' interest in forests depended on the type of knowledge they had.

Since kenaf is a "substitute for wood products," these respondents may place more importance on decreasing carbon dioxide by using substitutes for wood products rather than by managing forests. Weeding was included in "management by people." The respondents may have thought that weeding is important for helping natural forests to store carbon; that is, weeding does not harm trees and helps to preserve natural forests.

Regarding experience visiting forests, those who remembered visiting forests when they were elementary school students expected less carbon storage in artificial forests, and those who remembered visiting forests when they were junior high school students expected less carbon storage by forests in general. Moreover, those who remembered visiting forests before entering elementary school placed greater importance on rare species protection, but placed less importance on carbon storage in natural forests. Visiting forests may decrease expectations regarding carbon storage. Visiting forests before entering elementary school may influence perceptions of natural forests.

MISAKA and KOIKE (2006) found that people who had experienced floods were very conscious of flood control, although their study differed from ours in terms of the subject of focus and the respondents' age and place of residence. In our study, the factor "experience visiting forests" increased the respondents' expectations regarding the function of rare species protection in natural forests, but decreased that for the functions of carbon storage in forests, artificial, and natural forests. Experience visiting forests may increase expectations regarding functions other than carbon storage.

We also found that boys preferred timber production as a function in artificial forests. DOI (2011) inferred that gender is one of the factors that affects students' attitudes and behavior regarding environmental issues. Our result indicates the need to compare responses by gender regarding students' perceptions of forests.

The factors examined here are not comprehensive and other factors may relate to students' perceptions. We found that all of the factors examined were negatively related to the function of carbon storage, except knowledge of weeding in natural forests. This suggests that students' perceptions of the function of carbon storage differ from their perceptions of the remaining functions. Consequently, it may be difficult to evaluate perceptions of carbon storage in the same manner as the remaining functions. Future studies should include other factors associated with students' perceptions of forests.

CONCLUSION

This study examined factors related to first-year high school students' perceptions of the functions served by forests. It investigated the relationships between factors related to students' knowledge of forests and experience visiting forests and their perceptions of the carbon storage function of forests in general and of artificial and natural forests, the function of timber production in artificial forests, and the function of rare species protection in natural forests. Regarding knowledge of forests, we found that students who had knowledge of "substitute for wood products" expected less carbon storage in forests and natural forests, whereas students who had knowledge of "management by people" expected more carbon storage in natural forests. Regarding experience visiting forests, students who had visited forests expected less carbon storage in forests in general and in artificial and natural forests, although the students visited during different periods in their lives. Conversely, students who visited forests before entering elementary school expected more rare species protection in natural forests. We also found that boys expected more timber production in artificial forests. Finally, we found that all of the factors examined were negatively related to the function of carbon storage, except knowledge of weeding in natural forests. This suggests that the students' perceptions of the function of carbon storage differed from their perceptions of the other functions. Future studies should include other factors associated with students' perceptions of forests.

ACKNOWLEDGMENTS

The author thanks the high school for allowing her to administer the questionnaire and thanks Associate Professor Koji MATSUSHITA of Kyoto University for providing helpful comments on the manuscript.

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*The English title is a tentative translation by the authors of this paper from the original Japanese title.

(Received 3 March 2012)
(Accepted 3 August 2012)

Article

Forests and Human Development: An Analysis of the Socio-Economic Factors Affecting Global Forest Area Changes

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ABSTRACT

This study examined the impacts of socio-economic factors on forest area change by human development level of countries. Cluster analysis and panel data analysis were combined to solve the problem of heterogeneity in panel data analysis and the problem of data availability to some extent. The results show that many socio-economic factors have negative impacts on forest area in countries at low levels of human development, but their impacts become positive in countries at higher levels of human development, such as rate of rural population, adult literacy rate, and GDP per capita. The findings of this research remind decision makers to pay attention to increasing countries' level of human development when attempting to prevent deforestation, because people in higher human development index countries tend to be more protective of forests.

Keywords: human development, socio-economic factors, deforestation, cluster analysis, panel data analysis

INTRODUCTION

People treat forests differently at different stages of human development. These differences can be seen throughout thousands of years of human history and in changes in forest area over the past two decades in countries at different stages of development.

Global forest area has been decreasing. Although the pace of this decline has slowed, 83 million ha of forest disappeared from 1990 to 2000, and 52 million ha of forest were eliminated between 2000 and 2010, according to FRA2010 (FAO, 2010). The countries with the largest decreases in forest area in the past two decades include Brazil (55.3 million ha), Indonesia (24.1 million ha), Nigeria (8.2 million ha) and Tanzania (8.1 million ha). Of the 233 countries and regions listed in FRA2010, forest area decreased in 88 countries and increased or remained stable in 136 countries (forest area data are not available for remaining countries). Numerous studies have examined the relationship between forest resources and socio-economic factors, from macro-level analyses utilizing multinational data to micro-level analyses based on field investigations. In particular, poverty (or economic level) and population growth have been examined as the underlying causes of deforestation (Miyamoto, 2010).

Since the late 1980s, the idea that "poverty is the cause and result of environmental degradation" has spread through international organizations (Wced, 1987; World Bank, 1992; Jalal, 1993). As a result, many studies have been conducted to investigate whether poverty accelerates deforestation or not. These studies have identified a number of influential factors and have concluded that the relationship between poverty and the environment is complex (Duraiappah, 1998; Deininger and Minten, 1999; Wunder, 2001; Angelsen and Wunder, 2003).

Since the 1980s, population growth has been considered one of the most likely causes of deforestation. However, a number of studies have identified diverse results regarding the impact of population growth. Angelsen and Kaimowitz (1999) reviewed the economic research on deforestation and concluded that although many empirical studies have found a positive correlation between deforestation and population density, the evidence for population growth as a cause of deforestation is weak, because the impact of population might be dependent on other factors, such as infrastructure, soil, and non-agricultural work opportunities. Geist and Lambin (2002) reviewed case studies on deforestation from 150 regions and found many cases in which population factors were not the cause of deforestation. Even in cases in which population was a cause, population growth or population density alone did not cause deforestation.

Jha and Bawa (2006) analyzed the relationship between population growth, the Human Development Index (HDI), and deforestation using statistical data from 30 countries. It showed that 1) when population growth is high and the HDI is low, the deforestation rate is high, and 2) irrespective of

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population growth, when the HDI is high, the deforestation rate is low. This research may be the first study to include the HDI in an analysis of the impact of socio-economic factors on forest resources, but models reflecting the relationship between forest and HDI factors are not specified.

The aim of this research is to analyze the impact of socio-economic factors on global forest area changes, from a viewpoint of the relationship between forest and human development level through combining statistical and econometric approaches, cluster analysis and panel data analysis.

Firstly, socio-economic factors include three variables reflecting levels of human development, life expectancy at birth, adult literacy rate and gross domestic product (GDP) per capita, as found in the HDI prepared and issued by the United Nations Development Programme (UNDP) in its Human Development Reports (UNDP, 2011a). UNDP defines human development as "about creating an environment in which people can develop their full potential and lead productive, creative lives in accord with their needs and interests" (UNDP, 2011b). Secondly, because the population size, living area and the extent of development of primary sector (agriculture, forestry, and fishery) are also important, this study also analyzes the impacts of total population, rate of rural population and the gross production value of agriculture. Thus, these six variables cover the level of human development, population size, humans' geographical relationship with forests, and the development of agricultural production.

The analysis was conducted in two stages. In the first stage, the 205 countries (and regions) were grouped into five clusters using cluster analysis. FRA2010 lists 233 countries, but this study used 205 countries as research objects and excluded the rest due to data availability or small forest area. Our research might deal with the most countries in clarifying the impacts of socio-economic factors. In the second stage, the impacts of the socio-economic factors on changes in forest area were analyzed through a panel data analysis of each of the five clusters. The free software R (R 2.13.1, 2011) and the software TSP (TSP INTERNATIONAL, 2010) were used in the analysis.

As discussed in MICHINAKA *et al.* (2011), by introducing cluster analysis before implementing panel data analysis, the problems of choosing or grouping countries arbitrarily and heterogeneity in panel data analysis can be solved to some extent compared with previous researches; therefore, better results can be obtained.

Research by introducing cluster analysis before panel data analysis has not been found in researches to the impacts of socio-economic factors on deforestation, and some researches are found in other fields, like RICHARDS (2000), MICHINAKA *et al.* (2010 and 2011), VASILESCU *et al.* (2011), ABRAMS *et al.* (2012). RICHARDS (2000) analyzed the household decisions on purchasing apples in six local markets in USA; MICHINAKA *et al.* (2010 and 2011) estimated the demand elasticities for forest products in multiple countries; VASILESCU *et al.* (2011) analyzed the factors affecting earnings for E.U. members; ABRAMS *et al.* (2012) analyzed the price elasticity of demand for water in Sydney.

CLUSTER ANALYSIS

Cluster analysis is described as "the art of finding groups in data" (KAUFMAN and ROUSSEEUW, 1990, p. 1) and has been used by biologists and social scientists for over half a century (KAUFMAN and ROUSSEEUW, 1987). Cluster analysis is also used in forest science (ATTA-BOATENG and MOSER, 1998; YEHA *et al.*, 2000, MICHINAKA *et al.*, 2010, 2011). For example, ROOS *et al.* (2001) examined differences in Swedish sawmill production strategies using cluster analysis.

There are three reasons for the implementation of cluster analysis prior to the analysis of the impact of socio-economic factors on global forest area changes in this study. Firstly, cluster analysis can produce a general overview that addresses both differences and similarities among countries. That is, by cluster analysis, countries with similarity are grouped together, while countries with less or few similarity are grouped into different groups. Secondly, there are no available and suitable time series data for some countries. It is difficult to undertake an analysis of these countries. Cluster analysis groups countries into clusters based on their similarities across a number of variables, i.e., countries in a cluster based on the cluster analysis have similarity. Therefore, the results of panel data analysis on some countries within a cluster could be extended to all of the member countries in the cluster, which could counter the problem of data availability. Third, some studies have used ad hoc criteria for grouping countries, whereas cluster analysis can identify similarities and group objects scientifically.

Data and their Standardization

Three variables, rate of rural population (%), GDP per capita, and forest change (change in forest area), are used in the cluster analysis to group countries and analyze the impact of socio-economic factors. GDP per capita is one of the most important indices reflecting human development. HDI is not used in this study due to data availability; the number of countries in the UNDP report is much lower than the number of countries whose GDP per capita is known. The rate of rural population is used because we contend that people who live in rural areas and urban areas have different relationships with forests. Data on the rate of rural population (%) and GDP per capita (US$, purchasing power parity) are for 2008 and sourced from FRA2010. The third variable is forest change. By comparing the forest area data for 1990 and 2010 in FRA2010, it is evident that forest area decreased in some countries, whereas it increased or remained stable in other countries. We allocate the number "1" to those countries with decreased forest area and "0" to the rest. This factor is adopted in the analysis because we contend that countries with similar forest change (decreasing or otherwise) have similarities.

When data are used in the cluster analysis, they are usually standardized. Observations for different variables have different means and variances. If standardization is not performed, large numbers will have more weight in the calculation of distances among objects. In this research, the percentage of the rate of rural population and forest change (1 or 0) is too small compared with the GDP per capita in US dollars without standardization. Data standardization allows variables to contribute equally. Standardization converts the original data to normalized variables.

The most commonly used standardizing function is z-scores:

$$Z_{ij} = \frac{X_{ij} - \overline{X}_i}{S_i} \quad (1)$$

where X_{ij} is the original data, $\overline{X}_i$ is the mean for the ith variable, and S_i is the standard deviation (SD) for the ith variable. In the partitioning around medoids approach, described in the next section, the mean absolute deviation is used instead of the standard deviation to disperse the impacts of outliers.

Cluster Analysis Approaches and Determination of the Number of Clusters

The partitioning around medoids (PAM), or k-medoids method, a nonhierarchical approach to cluster analysis developed by Kaufman and Rousseuw (1987), finds k clusters with k representative objects (called medoids, a kind of center for the cluster) in the data and attempts to assign each object in the data set to the proper representative object. Compared with the k-means method, which aims to partition n objects into k clusters in which each object belongs to the cluster with the nearest mean (centroid), PAM is robust to noise and outliers because the centroid is easily affected by outliers, whereas the medoid is not. Under PAM, a silhouette statistic is calculated that shows how well an object lies within the cluster and it is used to determine the number of clusters. When the silhouette average reaches the maximum, the number of clusters is determined as the best choice. Table 1 shows the results of the cluster analysis. When the number of clusters is five, the silhouette average reaches 0.46, the largest value, as shown in Table 1. Therefore, 205 countries are grouped into five clusters. Usually, the structure of a cluster is said to be stable when the silhouette average is larger than 0.50. Here, 0.46 is also acceptable because it is not far below 0.50. The silhouette averages for the five clusters are 0.62, 0.53, 0.39, 0.42, and 0.34 (Fig. 1). For Clusters 3, 4 and 5, the silhouette averages are not high, meaning that a few countries (2, 3 and 4 countries, respectively) with weak similarities are included in that cluster.

Table 1 Silhouette averages for cluster analysis

Number of Clusters	2	3	4	5	6	7	8	9	Others
Silhouette Averages	0.38	0.42	0.42	**0.46**	0.44	0.40	0.39	0.39	≤0.38

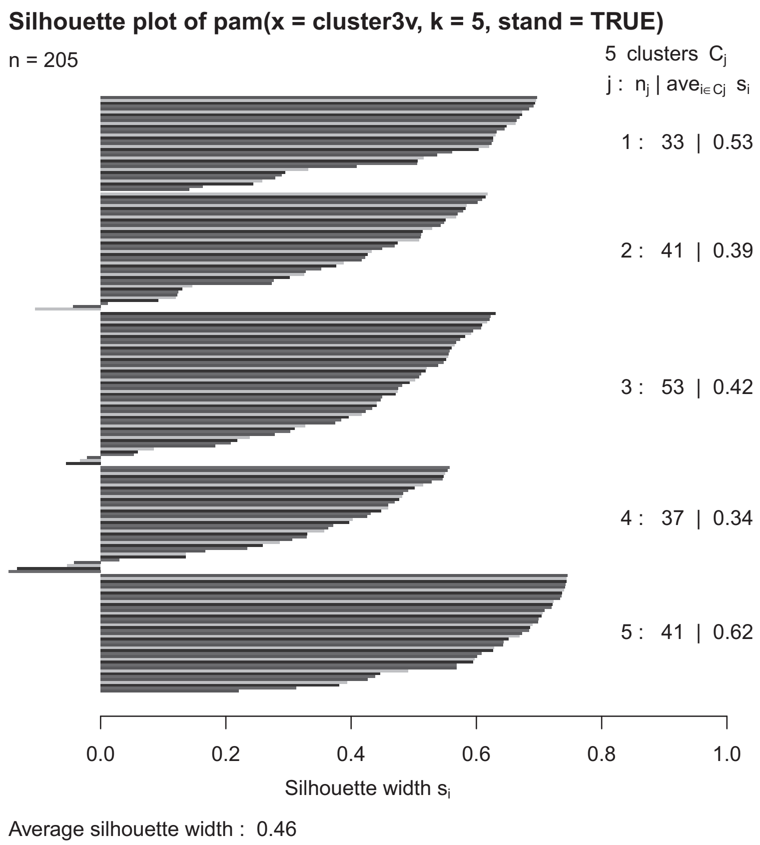

Fig. 1 Silhouette plot for cluster analysis results
Note: the order of clusters shown in the figure is changed in the paper for convenience

Results of Cluster Analysis

Not in black on the left same as othersBy using PAM, 205 countries are grouped into five clusters according to the distances to their medoids, as shown in Fig. 2 and Table 2. Fig. 2 shows the plot of pairs of any two of the three variables. Countries in the same cluster are shown in the same color in Fig. 2. Table 2 shows the detailed results of the cluster analysis. Cluster 1 has the highest mean rate of rural population (72%), the lowest mean GDP per capita (2232 US$), and decreased forest area. Bangladesh, Cambodia, Lao P.D.R., and Papua New Guinea (PNG) are some examples in this group. Thailand is also included in this cluster due to its high rate of rural population (67%) and decreased forest area. The rate of rural population in Cluster 2 is slightly lower and the GDP per capita is slightly higher compared with Cluster 1, but the forest area did not decrease from 1990 to 2010. China, India, and Viet Nam belong to this cluster. The other three clusters have low rate of rural population. The GDP per capita in Cluster 3 is low, although it is higher than in Clusters 1 and 2. It is also important to note that the countries in Cluster 3, including Brazil, Cameroon, Indonesia, and Malaysia, have decreased forest areas. Clusters 4 and 5 have low rate of rural population and non-decreased forest areas, and the countries in Cluster 5 have the highest GDP per capita. Chile, Gabon, Portugal, and Russian Federation are some of the countries in Cluster 4. Cluster 5 is mainly composed of developed countries, such as Japan, New Zealand, the United Kingdom (UK), and the United States (US). The countries in Clusters 1 and 3 have decreased forest areas, whereas the countries in Clusters 2, 4 and 5 have forest areas that are unchanged or increased, with two exceptions.

Although the first stage of analysis examines 205 countries, due to data availability, only some countries are included in the model specification in panel data analysis in the second stage. The countries that are included in the analysis of the impact of socio-economic factors on forests in the next stage are shown in bold type in Table 2. According to the theory of cluster analysis, countries in the same cluster have similarity. Therefore, the results obtained by the panel data analysis based on some of the countries can represent the entire cluster.

Tests for Cluster Analysis Results

A one-way analysis of means (not assuming equal variances) was tested. This technique compares the means of two or more samples using the F distribution as a variable. The null hypothesis is that the samples in all groups are drawn from the same population. By using R software, the following results are obtained: for GDP per capita, $F = 96.92$, $p\text{-value} < 0.001$ and for rate of rural population, $F = 129.90$, $p\text{-value} < 0.001$. These results show that some clusters have different means-that is, they are not from the same population. For forest change, a one-way analysis of means cannot provide adequate results due to its quantity characteristics. It is evident that some clusters have the same values for forest change, but other clusters have different values. Multiple comparisons between clusters were performed using Tukey's HSD (Tukey's honestly significant difference test, a single-step

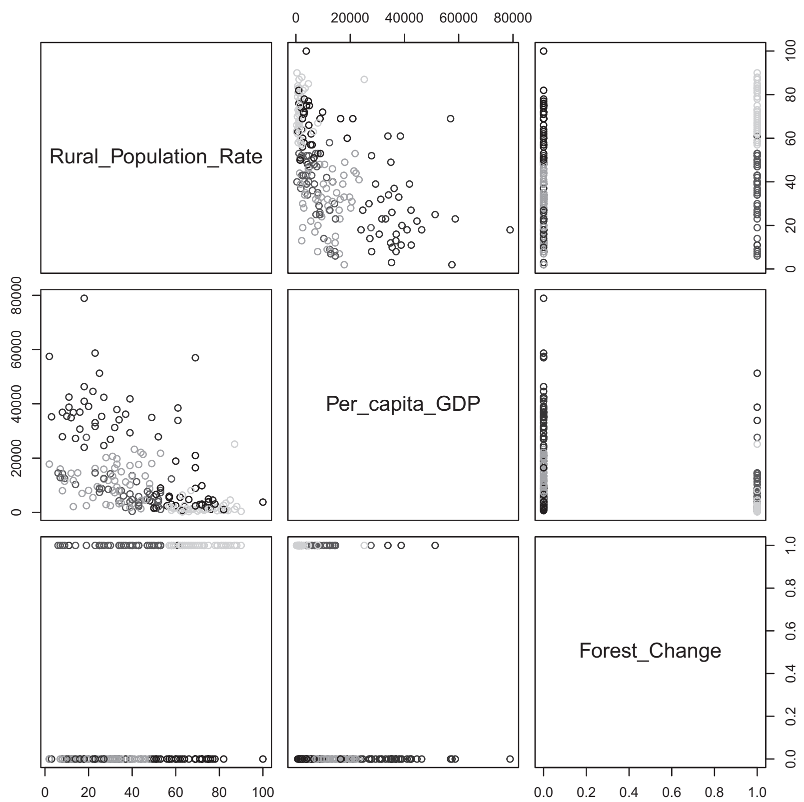

Fig. 2 Pair plot of five clusters for three variables

Table 2 Results of cluster analysis

Clusters	Statistics	Rural Population Rate (%)	Per Capita GDP (US$)	Forest Change (1 or 0)	Countries in the cluster
1	Min	57	200	1	**Bangladesh**, Benin, Burkina Faso, **Burundi**, Cambodia, Central African R., Chad, Comoros, D. R. Congo, Eritrea, Ethiopia, Guinea, Guinea-Bissau, **Kenya**, **Lao P. D. R.**, **Madagascar**, **Malawi**, **Mali**, Mauritania, Montserrat, *Mozambique*, Myanmar, Namibia, Nepal, Niger, **Pakistan**, PNG, Senegal, Sierra Leone, Solomon Islands, Somalia, Sri Lanka, **Sudan**, Thailand, Timor-Leste, **Togo**, **Trinidad and Tobago**, Uganda, Tanzania, Zambia, Zimbabwe
	Mean	72	2232	1	
(41)	Max	90	25173	1	
	SD	10	3985	0	
2	Min	48	658	0	Afghanistan, Antigua and Barbuda, Barbados, Bhutan, **China**, **Côte d'Ivoire**, Egypt, **Fiji**, Grenada, **Guyana**, **India**, Kiribati, **Kyrgyzstan**, **Lesotho**, Maldives, Micronesia, **Moldova**, **Rwanda**, Saint Helena, Ascension and Tristan da Cunha, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, **Swaziland**, **Tajikistan**, Tonga, Turkmenistan, Tuvalu, Uzbekistan, Vanuatu, **Viet Nam**, Wallis and Futuna Islands, Yemen
	Mean	67	5205	0	
(33)	Max	100	20970	0	
	SD	11	4948	0	
3	Min	6	388	1	**Albania**, Algeria, Angola, **Argentina**, **Armenia**, Belize, Bolivia, Bosnia and Herzegovina, **Botswana**, **Brazil**, **Cameroon**, **Colombia**, **Congo**, D. P. R. Korea, Dominica, **Ecuador**, **El Salvador**, Georgia, **Ghana**, **Guatemala**, Haiti, **Honduras**, **Indonesia**, **Jamaica**, **Kazakhstan**, Liberia, **Malaysia**, **Mauritius**, **Mexico**, **Mongolia**, **Nicaragua**, Nigeria, Niue, Northern Mariana, **Panama**, **Paraguay**, **Peru**, **S. Korea**, Suriname, Virgin, **Venezuela**
	Mean	37	7813	1	
(41)	Max	58	27658	1	
	SD	14	5229	0	
4	Min	2	1363	0	Samoa, Aruba, Azerbaijan, Belarus, **Bulgaria**, Cape Verde, **Chile**, Cook, **Costa Rica**, **Croatia**, Cuba, Djibouti, **Dominican R.**, **Estonia**, F. Polynesia, **Gabon**, **Gambia**, **Hungary**, **Iran**, Iraq, Jordan, **Latvia**, Lebanon, Libyan. **Lithuania**, Marshall, Montenegro, **Morocco**, Antilles, New Caledonia, Palestinian, Oman, Palau, **Philippines**, **Poland**, **Portugal**, Puerto Rico, **Romania**, **Russia**, Pierre and M., Sao T. P., Serbia, Seychelles, **Slovakia**, **S. Africa**, **Syrian**, Yugoslav, **Tunisia**, **Turkey**, Turks and Caicos, **Ukraine**, **Uruguay**, Western Sahara
	Mean	31	11522	0	
(53)	Max	53	23254	0	
	SD	13	6163	0	
5	Min	2	23991	0	Andorra, **Australia**, **Austria**, Bahamas, Bahrain, **Belgium**, British Virgin, **Brunei Darussalam**, **Canada**, **Cyprus**, **Czech**, **Denmark**, Equatorial Guinea, **Finland**, **France**, **Germany**, **Greece**, Iceland, **Ireland**, Isle of Man, **Israel**, **Italy**, **Japan**, Jersey, Kuwait, Luxembourg, **Netherlands**, **New Zealand**, **Norway**, Saudi Arabia, **Slovenia**, **Spain**, **Sweden**, **Switzerland**, **UAE**, **UK**, **USA**
	Mean	26	38431	0	
(37)	Max	69	78922	1	
	SD	16	10963	0	
	Min	2	200	0	
	Median	43	7716	0	
All	Mean	45	12762	0.4	205 countries
	Max	100	78922	1	
	SD	23	14127	0.5	

Note: 1. Some names are shortened for convenience.
2. Numbers in brackets are the number of countries included in the cluster.
3. Countries in **bold** type are included in the panel data analysis in the next step.
4. For forest change, "1" implies a decrease in forest area and "0" implies otherwise.

multiple comparison procedure) with multiple comparisons of means at a 95% family-wise confidence level. The results show that the differences in some pairs are not significant on an individual variable basis. By determining whether a pair with no significant difference appears simultaneously in three dimensions of variables, it can be concluded that a difference in any two clusters is significant in at least one dimension. For example, compared with Cluster 1, Cluster 2 has a lower but similar rate of rural population, a higher but similar GDP per capita, and an opposite forest change. Therefore, the difference between Cluster 1 and Cluster 2, at least for one of the three variables, is verified by multiple comparisons.

IMPACTS OF SOCIO-ECONOMIC FACTORS ON FOREST AREA

Models and Data

"A longitudinal, or panel data set is one that follows a given sample of individuals over time, and thus provides multiple observations on each individual in the sample" (Hsiao, 2003). Panel data analysis has the following advantages: (a) it can solve problems that cannot be solved by either time-series data or cross-sectional data alone; (b) it can increase the degrees of freedom when using a large number of data points; and (c) it can improve the efficiency of estimations (HSIAO, 2003). Panel data analysis is a useful tool, especially when the sample is short and wide, such as when the sample contains a large number of cross-sectional individuals or units over a small number of time periods. The model for panel data analysis takes the following form:

$$y_{it} = \alpha_i + \boldsymbol{\beta}'\mathbf{X}_{it} + u_{it},\ i = 1, \ldots, N \text{ and } t = 1, \ldots T \qquad (2)$$

Usually, there are three basic kinds of econometric models by panel data analysis: the pooled OLS model, the fixed effects (FE) model, and the random effects (RE) model. For pooled OLS models, the intercept and slopes are same for all the individuals, without considering the individual effects. For FE models, the intercepts α_i are fixed and different for different individuals, but the slopes (coefficients) remain the same for all individuals, treating the effects α_i as fixed. RE models are similar to FE models except treating the effects as unobserved random variables by a generalized least squares procedure. For the above model, in this research, the function uses the natural logarithm and takes the following empirical form:

$$\ln(y_{it}) = \beta_0 + \beta_1 \ln(LE_{it}) + \beta_2 \ln(ALR_{it}) + \beta_2 \ln(GDP_{it}) + \beta_2 \ln(POP\ \mathrm{it}) + \beta_2 \ln(RRP_{it}) + \beta_2 \ln(GAP_{it}) + e_{it} \quad (3)$$

where y_{it} stands for the forest area in country i = 1,…, N during year t = 1,…,T, LE is life expectancy at birth (years), ALR is the adult literacy rate (%), GDP is GDP per capita, POP is the total population (persons), RRP is the rate of rural population (%), GAP is the gross production value of agriculture, and e_{it} is the error term. For a logarithm function, the slope coefficients represent the rate of change, or elasticity. For example, β_1 indicates that when LE changes 1%, the forest area will change β_1 percent.

FRA2010 provides data for forest area in 1990, 2000, 2005 and 2010. Because we need data for the same time interval to conduct a panel data analysis, forest area data for 1995 are interpolated by obtaining the average of the data in 1990 and 2000. Life expectancy at birth (years), adult literacy rate (%), and GDP per capita (constant 2008 PPP US$) are sourced from UNDP. The gross agricultural product (constant 2004-2006 US$), total population and rural population data are from FAO (2011).

Results

In this study, some tests are implemented in order to get unbiased results, shown as in Table 3. (1) F test is implemented for panel data poolability, individual effect, to compare FE models versus pooled OLS models. The F test results show that FE model estimations are better than pooled OLS models in all clusters. (2) Breusch-Pagan Lagrange Multipliers are calculated to compare RE models with pooled OLS models (Breusch and Pagan, 1980). It is found that all the RE models are superior to pooled OLS models. (3) Hausman test is implemented to compare FE and RE models. The results show that FE models are better than RE models in all clusters except Cluster 1. (4) Testing for serial correlation is undertaken by using Breusch-Godfrey/Woodridge test (Baltagi and Li, 1995, Woodridge, 2002, Croissant and Millo, 2008). It shows that all the clusters have serial correlation in idiosyncratic errors. (5) Testing for heteroskydasticity is undertaken by studentized Breusch-Pagan test (Breusch and Pagan, 1979). It is found that all the clusters have the problem of heteroskydasticity at the different levels of significance, 1%, 5%, or 10%, except Cluster 2, which is not heteroskydastic. (6) Testing for cross-sectional dependence, or contemporaneous correlation, is undertaken by using Pesaran CD test (Pesaran, 2004). It is found that there is no cross-sectional dependence in Clusters 1 through 4, with an exception for Cluster 5.

For Clusters 1, 3, and 4, to deal with the problems of both serial correlation and heteroskydasticity, general feasible generalized least squares models are estimated, as estimations of general feasible generalized least squares are “robust against any type of intragroup heteroskedasticity and serial correlation” (Croissant and Millo, 2008). For Cluster 2, serial correlation exists, but not heteroskedastic and no cross-sectional dependence; AR(1) is implemented in order to correct serial correlation errors. For Cluster 5, robust covariance matrix of parameters was estimated for dealing with cross-sectional dependence and serial correlation by using Pesaran CD approach (Beck and Katz, 1995).

Panel data analysis was applied to every cluster, and the results are shown in Table 4. We will now discuss which

Table 3 Test results for 5 clusters

Items	1	2	3	4	5	Remarks
(1) Testing for poolability (comparing FE models vs pooled models, F test)	p-value < 0.001	p-value < 0.001	p-value < 0.001	p-value < 0.001	p-value < 0.001	FE models are better than pooled models for all clusters
(2) Testing for poolability (Breusch-Pagan Lagrange Multiplier for RE models)	p-value < 0.001	p-value = 0.002	p-value < 0.001	p-value < 0.001	p-value < 0.001	RE models are better than pooled model for all clusters
(3) Comparing models: RE vs FE (Hausman test)	p-value = 0.967	p-value = 0.008	p-value < 0.001	p-value < 0.001	p-value = 0.020	FE models are better than RE in 1 to 4
(4) Testing for serial correlation (Breusch-Godfrey/Wooldridge test)	p-value = 0.020	p-value < 0.001	p-value < 0.001	p-value < 0.001	p-value < 0.001	Serial correlation exist in all clusters
(5) Testing for heteroskedasticity (Breusch-Pagan test)	p-value = 0.034	p-value = 0.411	p-value = 0.062	p-value = 0.025	p-value = 0.001	Clusters 1, 3, 4 and 5 are heteroskedastic; cluster 2 is not heteroskedastic
(6) testing for cross-sectional dependence (Pesaran CD test)	p-value = 0.752	p-value = 0.286	p-value = 0.220	p-value = 0.861	p-value = 0.007	No cross-sectional dependence except in Cluster 5

Note: for (6), p-values from FE models are shown here, even though RE models have similar results.

Table 4 Results for panel data analysis for 5 clusters

Variables	1	2	3	4	5
Life expectancy at birth (years)	0.01	0.19	**-0.31*** **	0.08	0.50
Adult literacy rate (%)	**-0.72*** **	-0.21	**-0.41*** **	0.13	**1.60*** **
GDP per capita	0.09	0.05	**-0.04* **	**0.05*** **	**0.23** **
Total population	0.27	0.03	**-0.19*** **	-0.12	-0.27
Rural population rate (%)	0.75	**-0.45*** **	-0.02	**-0.16** **	**0.08** **
Gross production value of agriculture (US$)	0.01	**0.15** **	-0.01	0.01	0.00

Note: ***: significant at 1% level by t values; **: significant at 5% level; *: significant at 10% level.

factors affect forest area changes, significantly or otherwise.

In Cluster 1, only adult literacy rate is significant; it has a negative impact on forest area. This means that as people obtain more education and literacy, they tend to cause forest area to decrease in the countries in Cluster 1. Other factors, including GDP per capita and population, do not affect forest area significantly, which may be due to the data quality in countries with high rate of rural population and low per capita income.

In the countries in Cluster 2, the rate of rural population and gross production value of agriculture are significant, while other factors are not. The rate of rural population has a negative impact on forest area, but the increase in gross production value of agriculture can cause forest area to increase. The rate of the rural population shows a decreasing trend globally, from 57% in 1990 to 49% in 2010. For most countries (with some exceptions, such as Sri Lanka and Zambia), the rate of rural population has decreased due to urbanization. Although the rate of rural population has a negative impact on changes in forest area, the pressure of the increase in rate of rural population on forests decreases. As for the second significant factor, agriculture includes forestry, hunting, fishing, the cultivation of crops and livestock production (WORLD BANK, 2009). The countries in this cluster, such as Viet Nam and China, have increased forest areas, possibly because of the important role of the development of agriculture, although the rural population counteracts this increase in forest area.

In Cluster 3, all the countries have decreased forest areas; all factors except the rate of rural population and agricultural gross production value had negative impacts on forest area. It seems that people tend to cause forest area to decrease when their income increases and their life situations improve.

In Cluster 4, the rate of rural population have negative impacts on forest area, while GDP per capita has a positive impact on forest area, but other factors do not have significant impacts. The countries in Cluster 4 have lower rate of rural population and higher GDP per capita than those in Clusters 1, 2 and 3. Although the rural population imposes pressure on the increase in forest area, the decreases in the rate of rural population alleviate this pressure.

In Cluster 5, the adult literacy rate, GDP per capita, and rate of rural population are significant and have positive impacts on forest area. This cluster is composed of the highest human development countries with the lowest rate of rural population and the highest GDP per capita. It shows that the increase in income can further contribute to the afforestation in the countries in Cluster 5. Positive impacts from the rate of rural population imply that the rural population is important to maintain or increase forest area. In other words, the decreased rate of rural population places pressure on maintaining the forest area in countries at high level of human development.

Now let us check the results in the light of factors. Life expectancy at birth and total population have significant and negative impacts in Cluster 3 but not significant in other clusters. The adult literacy rate has negative impacts in Clusters 1 and 3, both of which are at lower levels of human development, but it has a positive and significant impact in Cluster 5, which has the highest level of human development. The elasticities of adult literacy rate have also decreased from 0.72 in Cluster 1 to 0.41 in Cluster 3. GDP per capita is significant in the last three clusters, but their sign are different, changing from negative to positive, as their levels of human development increase. Rural population has a significant and negative impact in Clusters 2 and 4, and a significant and positive impact in Cluster 5, but not significant in Clusters 1 and 3. The elasticity for rate of rural population has decreased from 0.45 in Cluster 2 to 0.16 in Cluster 4 and 0.08 in Cluster 5. Gross production value of agriculture is significant only in Cluster 2. Cluster 2 is composed of countries with high rate of rural population, but an increasing forest area. It seems that the development of agriculture helps afforestation and reforestation in these countries. These impacts indicate that the impact of some factors change from negative to positive, such as adult literacy rate, GDP per capita and rate of rural population, as the level of human development increases; some other factors changed their significant negative signs to not significant, such as life expectancy at birth, total population.

CONCLUSIONS AND DISCUSSION

This research combines cluster analysis and panel data analysis. Five clusters were obtained by cluster analysis. Through cluster analysis, countries with similarity are grouped into one cluster, while countries with less similarity are gathered in different clusters. Panel data analysis is implemented to countries in each cluster, and better results were obtained because the heterogeneity issue in panel data analysis is improved as member countries in each cluster have similarity (MICHINAKA *et al.*, 2011). In a cluster, for some countries, suitable data for econometrics analysis are available, while for other countries there are no suitable data. Results by panel data analysis to those countries in which data are available could represent the whole cluster and extend the results to all the countries in the same cluster due to existence of similarity among countries in the same cluster according to the cluster analysis theory. In this way, the problem of data availability is solved, to some extent.

JHA and BAWA (2006) associates forest area changes with the HDI index and calculates the correlation coefficients, paving the way for this quantitative analysis of their impacts. Our study may be the first to analyze the impacts of socio-economic factors, including three HDI variables, using econometric analysis, especially combining cluster analysis with panel data analysis.

This study found that many factors have negative impacts on forest area in countries at low levels of human development, but that the impacts become positive or not significant in countries at higher levels of human development. This finding implies that the relationship between forests and people changes when the level of human development changes.

The rate of rural population, rather than agricultural population or the rate of agricultural population, is used as a factor in this analysis. When people live in rural areas, it is easier for them to access forests. This close relationship with forests is reflected in the construction of homes, the use of fuel wood and timber in daily life, and the extension of their farmland or the development of new farmland by converting forests to agriculture fields, which may cause forest degradation and deforestation. The rate of rural population not only reflects changes in the rural population and the share of the rural population in the total population, but it also reflects urbanization and the development of human society. The differences between the rate of rural population and the rate of agricultural population might be caused by the speed of urbanization and the development of non-agricultural industries, such as the manufacturing and service industries, as well as the development of agriculture. Both seem to be possible causes of deforestation. It is difficult to determine their priority due to the data quality, especially for developing countries.

Total population is used as a factor in this research, but population density is not. For a country, population density is the total population divided by its land area; the land area is stable during the entire period of analysis, with some exceptions. The logarithm form is used in the estimation of coefficients, and the coefficients of factors reflect rates of change related to these factors and forest area. The coefficients of factors do not change if land areas are added to the total population (i.e., if population density is used), although this process will change the intercepts.

One of the most frequently discussed theories in recent years concerning the relationship between environment and economic development is the "Environmental Kuznets Curve" (EKC), which presents the relationship between economic level and environmental degradation as an inverted-U shape. This theory states that as the economic level increases, environmental degradation also increases; once a certain level is reached, however, environmental degradation decreases. GDP, GNI and income are used as indicators of economic level. According to Stern's review (2004) of studies on the EKC, there have been many attempts to verify the EKC, but empirical evidence is weak, and a consensus has not been reached. In this research, the change in elasticities in GDP per capita, from negative 0.04 to positive 0.05 and 0.23, as the levels of human development rise, implies the course that income is a negative factor in some countries with low levels of human development, whereas in countries at a high level of human development, income changes to a positive factor. This finding seems to be in accordance with the Environmental Kuznets Curve and the U hypothesis of forest resources (STERN, 2004; NAGATA *et al*., 1993, *etc*.).

Previous researches have also dealt with the deforestation version of the EKC. One affirmative report from BHATTARAI and HAMMIG (2001) analyzed the relationship between deforestation and income for 66 tropical countries from 1972 to 1991 and found strong evidence in support of the EKC in Latin America, Africa and Asia. In contrast, BARBIER and BURGESS (2001) presented a critical report using panel data for tropical countries from 1961 to 1994 and found that the relationship between agricultural land expansion and income varied by region. These authors concluded that this relationship is not necessarily an inverted-U curve. VAN and AZOMAHOU (2007) analyzed panel data for 59 developing countries from 1972 to 1994, but their study failed to find evidence supporting the EKC in relation to deforestation. Another way of discussing the deforestation version of the EKC is "Forest Transition", a theory by MATHER (1990, 1992) of the historical development of forest resources based on the cases of developed countries. Mather hypothesized that as economies develop, forests initially decline but eventually begin to increase. The debate on this concept continues to this day (NAGATA *et al*., 1993; MATHER *et al*., 1999; RUDEL *et al*., 2005).

Life expectancy at birth and adult literacy rate have negative impacts to countries at low level of human development, but not significant in high level countries. It seems that these two factors in the human development also follow the similar course with income in the light of the relationship with forest. If this is true, it is not enough to link only income with environment as in EKC or the U hypothesis of forest resources without adding life expectancy and an education factor as reflected in HDI.

The findings of this research can remind decision-makers to pay attention to increasing countries' level of human development when attempting to prevent deforestation in countries at low level of human development, i.e., forest policy should considered with policy on human development comprehensively. Policies that attempt to increase the levels of HDI in these countries are needed because people in higher HDI countries tend to be more protective of forests. The introduction of the HDI index is also a reminder of the importance of life expectancy and education in addition to income level.

This paper introduced cluster analysis before panel data analysis for the first time in this field, by which the problem of heterogeneity in panel data analysis is improved, and tried to avoid biased estimations by solving the problems of serial correlation, heteroskydasticity, and cross-sectional dependence. Maybe due to the reliability of data, some of the coefficients are not significant as expected, such as the rate of rural population in Clusters 1 and 3, which are consist of countries with deforestation. As the data availability and quality get improved in the future, the results from cluster analysis and panel data analysis might be expected to get improved too.

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(Received 13 January 2012)
(Accepted 21 August 2012)

Article

Determinants of Spatially Explicit Classification Decisions in Natural Forest Management in Central Hokkaido, Japan

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ABSTRACT

Spatially explicit classification is an essential planning technique in managing natural forests having structural heterogeneity on a landscape scale. Operationally, forest planners demarcate classification boundaries on-site, based on their empirical knowledge. This study examined factors affecting spatially explicit classification decisions by expert planners in natural forest management in central Hokkaido, Japan. A case analysis was conducted at the University of Tokyo Hokkaido Forest to identify the criteria used for classification decision-making. We examined a total of 930 inventory plots within four major management types ('softwood selection harvest,' 'hardwood selection harvest,' 'pre-harvest,' and 'regeneration activity required') during 2005 to 2009. We calculated tree basal area (BA) and density, species composition, and diameter distribution in each management type. 'Softwood selection harvest' had high abundance and density of conifers (*Abies sachalinensis* in particular) at marketable size classes [diameter at breast height (DBH) $\geq$ 13 cm]. In 'hardwood selection harvest,' a large BA of broad-leaved trees (mainly *Tilia japonica* and *Acer mono*) was observed at middle- and large-size classes. 'Pre-harvest' had high densities of both coniferous and broad-leaved trees (mainly *A. sachalinensis* and *Betula ermanii*) of small diameter. The BA and tree density were relatively low in 'regeneration activities required.' Results from the classification and regression tree analysis indicated that the amount of marketable timber (25 cm $\leq$ DBH < 59 cm) had the primary effect on spatially explicit classification decisions in natural forests.

keywords: central Hokkaido, classification and regression tree, natural forest management, spatially explicit classification, stand structure

INTRODUCTION

Forests are spatially heterogeneous in nature, and a mosaic of patches at different developmental phases can be observed on a landscape scale (Watt, 1947). The spatiotemporal structure is largely influenced by site conditions and disturbance history (Lertzman *et al.*, 1996), and is further complicated by management practices such as logging and planting (Hiura, 2005). To manage natural forests with spatial complexity and heterogeneity, the forests can be classified into several management types according to stand characteristics and management objectives. In each type, an appropriate silvicultural treatment or a combination of treatments (e.g., harvesting, thinning, scarifying, planting) can then be determined in an adaptive manner (Boncina, 2011).

Multi-aged mixed forests of coniferous and broad-leaved trees are widespread in Hokkaido, northernmost Japan (Tatewaki, 1958). The stand structure is particularly diverse and provides a patch-mosaic of spatial arrangements (Kubota, 2000). As a natural forest management practice in central Hokkaido, the stand-based silvicultural management system (SSMS; "rinbun segyo ho" in Japanese) has been used at the University of Tokyo (UT) Hokkaido Forest since the late 1950s (Watanabe and Sasaki, 1994). The idea behind the SSMS is that management should be adaptive to the conditions of each stand to maximize the multiple public and economic functions of the forest ecosystems (Takahashi, 2001). Spatially explicit classification is one of the essential planning techniques in the SSMS (Shibata, 1988). Natural forests are classified into several management types following the qualitative guidelines described in the management plan (The Tokyo University Forest in Hokkaido, 2007). Operationally, forest planners make classification decisions on-site, based on their empirical skills and expertise gained through long-term work experience. Although previous studies such as those

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by Yamamoto *et al.* (1996) and Owari *et al.* (2007) examined the stand characteristics of management types quantitatively, there is still little knowledge on how classification decisions are actually made by experienced planners.

The purpose of this study was to determine factors affecting spatially explicit classification decisions by expert forest planners under the SSMS. To identify the operational criteria used to make classification decisions in natural forest management in central Hokkaido, this study examined several management types classified during the latest planning period at the UT Hokkaido Forest. We first investigated the general characteristics of stand structure (tree basal area and density, species composition, diameter distribution) observed in major management types. Then, the underlying rules of spatially explicit classification decisions by forest planners were determined using a statistical classification technique.

MATERIALS AND METHODS

The UT Hokkaido Forest is located in the central part of Hokkaido, with an area of 22,715 ha. The mean annual temperature and precipitation at the Arboretum (230 m a.s.l.) during 2001–2008 were 6.3°C and 1,250 mm, respectively (The University of Tokyo Hokkaido Forest, 2012). Snow (max. 83 cm in depth) typically covers the ground from late November to early April. The typical substrate and soil type are welded tuff (Geological Survey of Japan, 2003) and dark and brown forest soil (Asahi, 1963). Natural mixed forests with coniferous and broad-leaved tree species are the main land cover. The forest floor is often occupied by dwarf bamboo *Sasa senanensis* or *Sasa kurilensis*.

Our study site (Fig. 1) was the area managed during the 12^{th} planning period (2006–2010) (43°10–19'N, 124°24–39'E; 190–930 m a.s.l.; 6,008.14 ha). Spatially explicit classification was conducted by technicians of the UT Hokkaido Forest, based on careful on-site observations with intensive ground surveying. Among the management types classified, this study investigated four major types with a total area of 3,104.35 ha (Fig. 1). The largest types was 'softwood selection harvest' (1,650.67 ha), hereafter abbreviated as SS, in which coniferous trees were dominant and a selection system was applicable. The rate of removals was limited to 10–17% of the growing stock, which was less than the growth rate (The Tokyo University Forest in Hokkaido, 2007). 'Hardwood selection harvest' (HS; 450.83 ha) was a type, in which broad-leaved trees were dominant and a selection system was applicable. The rate of removals was limited to 10–16% of the growing stock. 'Pre-harvest' (PH; 490.59 ha) was a type in which harvests were postponed to nurture existing young growth. 'Regeneration activity required' (RA; 512.26 ha) was a type in which silvicultural activities were required due to lack of natural regeneration.

We used a total of 930 inventory plots that had been established and measured at the study site 1 year before management (2005–2009; Fig. 1). The plot size was typically 0.25 ha (50 m × 50 m), and the species and diameter at breast height (DBH: 1.3 m) for all live trees with DBH ≥ 5 cm were recorded in each plot. The number of juveniles (height ≥ 1.3 m; DBH < 5 cm) by tree species was also counted.

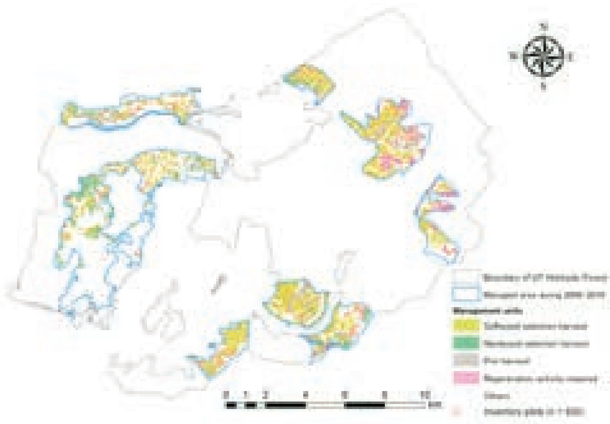

Fig. 1 Location of management types and inventory plots

In each management type, tree basal area (BA), tree density, and juvenile density were examined by calculating the mean and standard error of inventory plots. A non-parametric Kruskal Wallis test with Scheffe's test for multiple comparisons was performed to examine differences between the types. Species composition was analyzed by listing observed tree species with BA, tree density, and juvenile density. Diameter distribution was investigated by calculating BA and tree density according to the DBH classes (2-cm intervals).

A classification and regression tree (CART) analysis was performed to derive the decision rules for spatially explicit classification administered by the technicians. CART is a non-parametric, binary, recursive partitioning technique (Breiman *et al.*, 1984), and has been widely applied in forestry (Fan *et al.*, 2006). On the basis of interviews with chief technicians, the following attributes of each species group (conifer or broad-leaved) were included as predictor variables: the amount of marketable timber (represented by the BA of middle- and large-sized trees; 25 cm ≤ DBH < 59 cm) and the number of young growth trees (represented by the density of juveniles and small-sized trees; height ≥ 1.3 m and DBH < 25 cm). The mvpart package (De'ath, 2012) in the statistical program R 2.14.1 (R Development Core Team, 2011) was used for computation. The best-fit model was identified using cross-validation, with the final tree that fell within 1 standard error of the minimum cross-validated error (De'ath, 2002).

RESULTS

Tree Basal Area and Density

Figure 2 shows the mean BA in the four management types. We found a significant difference among the types with regard to total BA ($p < 0.01$), which was significantly larger in SS (31.1 m^2 ha^{-1}) than in the other types (22.9–25.7 m^2 ha^{-1}). The BA of coniferous and broad-leaved trees also differed significantly among the management types ($p < 0.01$). The conifer BA was significantly larger in SS (18.8 m^2 ha^{-1}) and smaller in HS (5.8 m^2 ha^{-1}). In contrast, broad-leaved trees dominated in HS (19.9 m^2 ha^{-1}) and showed lower dominance in SS (11.9 m^2 ha^{-1}). In the other two types, PH and RA, there

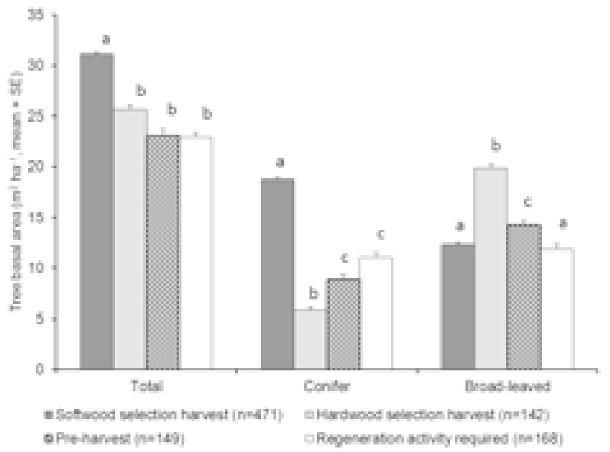

Fig. 2 Mean tree basal areas by management type
All live trees with DBH ≥ 5 cm were included in the calculation. Means followed by different letters differ significantly according to Scheffe's test for multiple comparisons (p < 0.01).

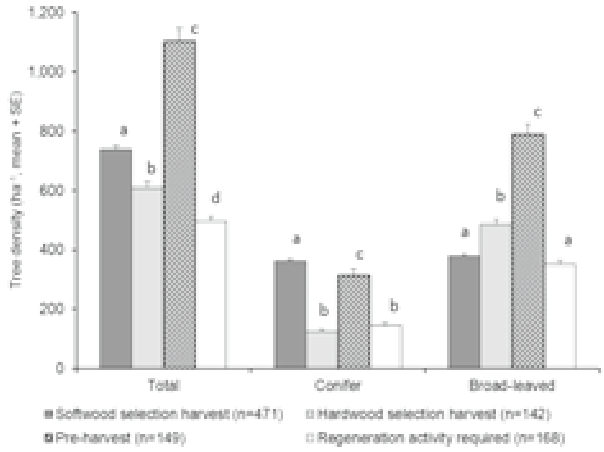

Fig. 3 Mean tree densities by management type
All live trees with DBH ≥ 5 cm were included in the calculation. Means followed by different letters differ significantly according to Scheffe's test for multiple comparisons (p < 0.01).

were relatively small BAs of both conifers and broad-leaved trees.

Figure 3 shows the mean tree density in each management type. A significant difference was observed among the types in terms of total tree density ($p < 0.01$), which was significantly higher in PH (1,102 individuals ha^{-1}), followed by SS (739 individuals ha^{-1}). The densities of both conifers and broad-leaved trees also differed significantly among the management types ($p < 0.01$). The conifer density was significantly higher in SS (361 individuals ha^{-1}) and lower in HS (125 individuals ha^{-1}). The density of broad-leaved trees was significantly higher in PH (789 individuals ha^{-1}) and lower in SS (379 individuals ha^{-1}). In the management type of RA, both conifers and broad-leaved trees had relatively low densities.

Figure 4 shows the mean juvenile density by management type. There were significant differences among the types in terms of total juvenile density ($p < 0.01$), which was

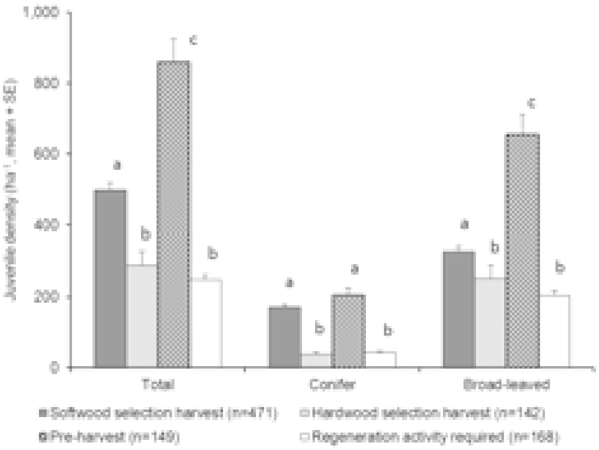

Fig. 4 Mean juvenile densities by management type
All live trees with height ≥ 1.3 m and DBH < 5 cm were included in the calculation. Means followed by different letters differ significantly according to Scheffe's test for multiple comparisons (p < 0.01).

Table 1 Observed tree species by management type

Species	Trees								Juveniles			
	Mean dominance m² ha⁻¹				Mean density individuals ha⁻¹				Mean density individuals ha⁻¹			
	SS	HS	PH	RA	SS	HS	PH	RA	SS	HS	PH	RA
Abies sachalinensis	11.7	3.7	6.0	4.0	276	93	253	83	151	33	177	34
Picea jezoensis	6.4	1.9	2.5	6.7	69	27	43	60	15	5	19	9
Tilia japonica	2.7	3.5	2.2	2.1	73	86	106	61	45	35	76	25
Acer mono	1.9	3.4	1.9	1.5	53	92	91	39	39	37	83	11
Kalopanax pictus	1.0	1.1	0.6	0.7	14	13	13	8	3	1	5	1
Quercus crispula	0.9	1.4	1.1	0.5	11	13	36	7	4	2	15	2
Betula ermanii	0.8	0.3	1.5	2.1	16	4	114	51	11	1	137	36
Ulmus laciniata	0.7	1.7	0.4	0.9	15	30	13	16	3	3	2	2
Betula maximowicziana	0.5	1.0	1.2	0.2	8	12	47	4	1	4	8	1
Tilia maximowicziana	0.3	1.6	0.4	0.6	10	35	17	14	4	18	8	5
Other spp.	4.1	6.2	5.3	3.6	196	204	369	155	221	151	328	123
Total	31.1	25.7	23.1	22.9	739	609	1,102	497	498	290	860	248

SS: softwood selection harvest; HS: hardwood selection harvest; PH: pre-harvest; RA: regeneration activity required Tree: DBH ≥ 5 cm; Juvenile: Height ≥ 1.3 m and DBH < 5 cm.

significantly higher in PH (860 individuals ha^{-1}) than in the other types (248–498 individuals ha^{-1}). The densities of both coniferous and broad-leaved juveniles also differed significantly among the management types ($p < 0.01$). The conifer densities were significantly higher in PH (205 individuals ha^{-1}) and SS (171 individuals ha^{-1}). The density of broad-leaved juveniles was significantly higher in PH (656 individuals ha^{-1}). HS and RA, which had significantly lower densities of both coniferous and broad-leaved juveniles, were not significantly different.

Species Composition

In total, 45 tree species were recorded. The major species observed in the management types are listed in Table 1. The type SS had a relatively high dominance of *Abies sachalinensis* (11.7 m^2 ha^{-1}) compared to the other three types (3.7–6.0 m^2 ha^{-1}). *Tilia japonica* and *Acer mono* were dominant broad-leaved tree species in HS. PH had relatively high tree and juvenile densities of *A. sachalinensis* and *Betula ermanii*. Although RA had small BA and low density for most tree species, *Picea jezoensis* showed relatively high dominance in this type.

Diameter Distribution

Figure 5 shows the mean BAs of conifers and broad-leaved trees by DBH class. Mono-modal distributions were observed in both species groups and in all management types. SS had the largest conifer BA at 13 cm ≤ DBH < 59 cm, whereas HS had the largest BA of broad-leaved trees at 21 cm ≤ DBH < 73 cm. Both species groups were mostly in small-size classes in the PH type, whereas the RA type had a relatively large BA of conifers in large-size classes.

Figure 6 shows the mean tree densities of conifers and broad-leaved trees by DBH class. Inverse J-shaped diameter distributions were observed in both species groups, although curve shapes differed by management types. Among the types, PH and SS had the highest densities of conifers at 5 cm ≤ DBH < 13 cm and 13 cm ≤ DBH < 59 cm, respectively. PH had the most broad-leaved trees at 5 cm ≤ DBH < 21 cm. The diameter distributions of HS and RA were similar and had relatively low densities of small-size classes.

Decision Rules for Spatially Explicit Classification

Figure 7 shows the derived classification tree model of spatially explicit classification decisions. The CART analysis produced a tree having three splits and four terminal nodes (management types), with a relative error of 0.601 and a cross-validated error of 0.647. Table 2 shows the correspondence between the observations and predictions of spatially explicit classification. Of 930 inventory plots, 654 (70.3%) were successfully classified into the correct management types. The rate of correct classification was fairly high for SS (85.6%) and HS (71.1%), whereas it was relatively low for PH (57.0%) and RA (38.7%).

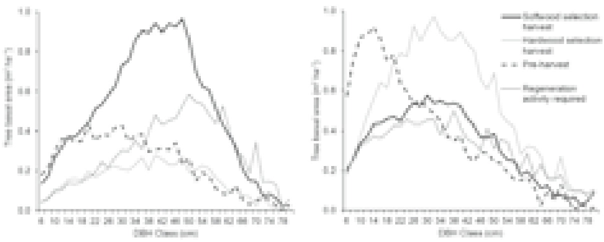

Fig. 5 Mean basal areas of coniferous and broad-leaved trees by diameter class*
* 2-cm intervals.

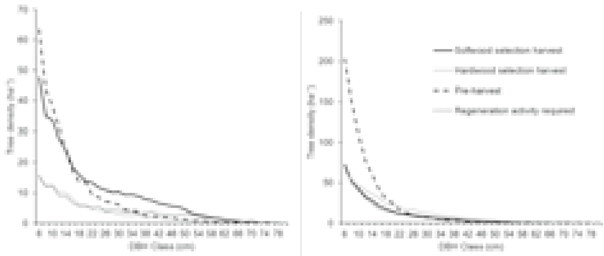

Fig. 6 Mean densities of coniferous and broad-leaved trees by diameter class*
* 2-cm intervals.

The amount of marketable softwood timber was the primary splitter, creating a division at 8.237 m^2 ha^{-1} of middle- and large-sized conifers (Fig. 7). In total, 502 plots above the threshold underwent SS. The second splitter was the amount of marketable hardwood timber, subdividing samples at 10.34 m^2 ha^{-1} of middle- and large-sized trees, with 171 plots above the split value transitioning to HS. The amount of broad-leaved young growth was the third splitter, with a partition at 790 trees ha^{-1} of juveniles and small-sized trees. In total, 123 plots above the limit were transitioned at PH, while 134 plots below the limit were categorized as RA. The amount of coniferous young growth was not selected as a significant splitter.

DISCUSSION

The results depict the general features of stand structure in the 4 management types investigated in this study. High abundance and density of conifers (*Abies sachalinensis* in particular) may be essential to the management type of SS.

Table 2 Correspondence between observed and predicted classification of inventory plots into management types

Number of observed plots	Number of predicted plots				
	SS	HS	PH	RA	Total
Softwood selection harvest (SS)	403	27	13	28	471
Hardwood selection harvest (HS)	8	101	12	21	142
Pre-harvest (PH)	27	17	85	20	149
Regeneration activities required (RA)	64	26	13	65	168
Total	502	171	123	134	930

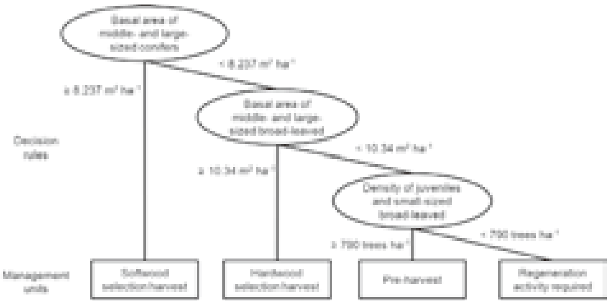

Fig. 7 Classification tree model of spatially explicit classification decisions

The mean BA and density were consistent with findings by OWARI *et al.* (2011), who reported 17.5 m^2 ha^{-1} and 373 trees ha^{-1} of conifers in selection stands (equivalent to SS), on average, based on 1,382 inventory plots that were established in the UT Hokkaido Forest during 1995–2004. YAMAMOTO *et al.* (1996) also obtained a similar result, showing a mean growing stock of 254 m^3 ha^{-1} and a mean density of 380 conifers ha^{-1} in selection stands from 888 inventory plots during 1986–1995. Conifers were most abundant in the marketable size classes (DBH $\leq$ 13 cm) in this type. An inverse J-shaped diameter distribution, which may be a desirable size structure for selection forests (O'HARA and GERSONDE, 2004), was maintained in tree density. Because adequate amounts of marketable softwood timber and young growth were maintained, technicians would probably consider a selection system to be applicable.

The results suggest that a high abundance of broad-leaved trees (mainly *Tilia japonica* and *Acer mono*) may be vital for HS. We observed large amounts of broad-leaved trees at middle and large diameter classes. Whichever tree species groups consists of, an adequate amount of marketable timber is probably a prerequisite for selection harvests in natural forests. An inadequate amount of young growth was observed, indicating a lack of succeeding trees in this type. Stand degradation after recurrent selection harvests would be a matter of concern, and silvicultural operations for promoting regeneration would be necessary to avoid degradation.

Despite its low tree abundance, PH had significantly high densities of both coniferous and broad-leaved trees (mainly *A. sachalinensis* and *Betula ermanii*). The diameter distribution was skewed to small-size classes. This may be partly due to repeated selection harvests, which may have resulted in the loss of marketable timber at some sites (THE TOKYO UNIVERSITY FOREST IN HOKKAIDO, 2007). Another reason for the stand development would be scarification operations formerly conducted at wind-damaged sites, where even-aged pure stands of *B. ermanii* dominated. The amount of marketable timber was inadequate and abundant natural regeneration may be necessary in this management type.

Natural forests with low degrees of regeneration and marketable timber were principally stratified into RA. Thick floor vegetation of *Sasa* spp. likely hindered the emergence of seedlings and juveniles. Thus, silvicultural activities, such as scarification and enrichment plantation, would probably be required to enhance regeneration. In this type, a relatively high amount of conifers (especially *Picea jezoensis*) was observed at middle and large diameter classes. *Picea jezoensis* regenerates only on coarse woody debris and rarely on the ground (NAKAGAWA *et al.*, 2001). Due to the difficulty of natural regeneration, the abundance of *P. jezoensis* has been decreasing at the UT Hokkaido Forest (TATSUMI *et al.*, 2010). Forest planners probably aimed to protect the species by removing areas in which it grew from selection harvesting.

Results from the CART analysis indicated that the amount of marketable timber was the primary factor on spatially explicit classification decisions. Although consecutive regeneration is a necessary condition for sustainable selection harvests (ZINGG *et al.*, 1999), the number of young growth trees seemed to be a secondary deciding factor. This is consistent with the classification guidelines under the 12^{th} forest management plan (THE TOKYO UNIVERSITY FOREST IN HOKKAIDO, 2007), stating that stands should be classified into 'selection harvest' (either softwood or hardwood) if they are assumed to be harvestable again after one rotation period (15 or 20 years). Regeneration status was not explicitly described as a critical attribute. While the results confirmed that forest planners had been faithful to the guidelines, it is uncertain whether these practices will guarantee sustained yield in the long run.

CONCLUSIONS

This study sought to quantitatively identify the criteria used to spatially classify natural forests for management in central Hokkaido, Japan. Although this study focused on the structural differences among major management types, other site-specific factors, such as topographic conditions and disturbance history may have affected classification decisions. Additionally, the continuous shift in stand structure caused by management practices may have resulted in decision rule modifications within the SSMS. Comparative studies between management planning periods are therefore needed to more fully understand spatially explicit classification decisions in natural forest management.

ACKNOWLEDGEMENTS

We thank current and former technical staffs at the UT Hokkaido Forest for their continuous and great efforts collecting field data. This study was partly supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (A), 19208015, 2007–2009.

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