REVIEW ARTICLE

Emerging issues in forest science

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Abstract

Major issues in forest science, such as climate change, bio-energy, biodiversity, and water, were assessed by IUFRO responsive to the broader scientific and policy communities to tackle more complex global environmental, social, and economic issues impacting forests. Other issues highlighted in this paper are forest health and forest genetics; forest modeling and operations engineering; challenges for mitigation and adaptation; public participation on decisions, research, and distribution of benefits; estimating ecosystem services, biofuels and biodiversity; societal issues, including health, food, poverty, urbanization, and lifestyle; educational change in structure and topics; and information and research administration. As forest science faced various challenges in the last few years, there is a need for interdisciplinary approaches and cross-sectoral collaboration. These interrelated and emerging key-issues, particularly climate change, biodiversity, bio-energy and water, are of strong interest to policy makers and groups inside and outside the forest sector. These will all be of high relevance to forest science and to IUFRO in the coming years, primarily for global collaboration.

KEY WORDS

biodiversity, climate change, IUFRO, forest products, water resources

Introduction

Forest science, as with all other sciences, has to be constantly renewed. The Board of IUFRO regularly assesses the most important issues in forest science. This paper is based upon the most recent of these discussions in the IUFRO Board and the views from the Divisions and Task Forces of IUFRO.

For a long time, the greatest tasks and challenges in forestry have been related to meeting the basic needs of people, including wood, water, food, bio-energy, biodiversity, and recreation (Westoby 1987; Sands 2005; Calder 2007; Stupak et al. 2008; IUFRO 2009a). The forest science framework for these tasks exists, although there is a clear need for re-thinking the basic forestry paradigm to better meet these chal-

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lenges (Mery et al. 2005). Furthermore, they now have to be dealt with in the increasingly important context of climate change and the related increase in natural and social disturbances.

Climate change and forestry

Challenges for adaptation and mitigation

Reports of current impacts of climate-mediated events on forests include diebacks, mass mortality and changes in tree physiology, forest biodiversity, forest growth and productivity. These changes are affecting the livelihoods of populations around the world (Innes and Hickey 2006; Betts et al. 2008; Seppälä et al. 2009). Climate change will undoubtedly cause many social changes to the world's population, with the effects being most severe amongst the most vulnerable. This creates the potential for considerable inequity, and a major role for forest research will be ensuring that adaptation and mitigation strategies do not further inequity or generate social injustice (Adger et al. 2006). Research is also needed to ensure that mitigation and adaptation strategies are both scientifically justifiable and socially appropriate. The debate over reducing emissions form deforestation and forest degradation (REDD) has revealed just how controversial some strategies can be (Angelsen 2008). Research priorities include the design of effective mitigation strategies involving forests, the most appropriate management strategies for adaptation, the ability of and optimum strategies for vulnerable groups to adapt, and the institutional barriers facing both mitigation and adaptation.

The adaptation of forests and forestry to climate change can be regarded as a major challenge for forest research and the forest sector in general (Collaborative Partnership on Forests 2008). Future forestry will have to focus on a change from non-intervention or reactive adaptation to planned adaptation. Some consider that this would represent a paradigm shift away from sustainable forest management, which is largely based on past conditions (Ferguson 1996; McDonald and Lane 2004) to the management of uncertainty and the goal of sustainable livelihoods. Others would argue that the proper implementation of sustainable forest management within an adaptive framework would enable the uncertainty to be addressed and the requirement for sustainable livelihoods to be met (Collaborative Partnership on Forests 2008; Seppälä et al., 2009). Whatever it is termed, the requirement is for the development of more adaptive, flexible silvicultural and agro-forestry systems, adjusted to include new risks and realities. Stand-scale and landscape-scale adaptation approaches must include consideration of uncertainty and replace deterministically based practices (Kimmins 2008; Schultz 2008).

Strategies to meet climate change challenges

A range of potential strategies exist to help managers meet these future challenges (Innes et al. 2009). The optimum mix of strategies will depend on the location, the nature of the forest, the potential future climate and institutional factors. Due to the large amount of forest degradation (10 mil ha/yr), reforestation of degraded areas or the establishment of suitably adapted plantations is urgently needed. However, large areas of single species plantations continue to be established, and these may be vulnerable to pests, diseases and fire under future climates. Monitoring for impact and risk assessment are core components in planned adaptation and new knowledge, new methods, and new fields of expertise have to be incorporated into management systems. As Gujit (2007) has argued, there is a need to go far beyond the traditional monitoring approaches that have been used to date in forestry.

The likelihood that the costs of risk in forestry will increase and affect net revenues presents a major challenge. A particular concern is that many countries lack the resources and expertise to support monitoring of forest health and damage assessments, or to implement adequate early responses to the likely impacts of climate change. While some assume that this problem is most acute in the least-developed countries, it is becoming clear that many developed countries are failing to maintain adequate monitoring programmes. Climate change clearly involves equity issues that need to be better addressed by the global community (Adger et al. 2006). Developing and testing new, highly streamlined monitoring techniques and adaptation approaches are major challenges for research, but ironically are often not seen as being a part of research by traditional scientific funding agencies. In forestry education, the adaptation of forests and people to climate change must be integrated in the undergraduate and graduate school levels.

One of the biggest problems faced by the forestry communities in individual countries attempting to deal with the potential effects of climate change is the extent of regulation of activities. This regulation was often designed to ensure that particular values were maintained, such as the maintenance of stand diversity. However, such regulations may actually hinder adaptation to climate change, with seed transfer restrictions being a particularly good example. Regulation needs to be much more flexible than is currently the case in most countries.

Emerging issues in the forest products industries

Sustainable forest product

The world continues to lose natural forests at a significant rate. At the same time, a large proportion of the global population is dependent on forest products. While ecologically sustainable forest management practices are becoming more acceptable than traditional forestry methods in many parts of the world, international organisations need to place increased emphasis on the international benefits of forests and forest products (carbon sequestration, protection of water quality, prevention of erosion, provision of recreation, provision of habitats for endangered plant and animal species, supply of wood and natural products (including energy)) in their public materials so that the drive for changes comes from the general public rather than from forest owners. For instance, low impact timber harvesting (Lansky 2002; McEvoy 2004) and the use of environmentally acceptable wood processing practices reduce environmental degradation while protecting the health and safety of consumers of forest products. The benefits and values of non-wood forest products to large populations of the world also need to be accepted, realized and properly accounted for.

To rectify the negative image of foresters, wood technologists/industrialists and wood products, it is important to develop new products and environmentally acceptable, energy conserving/efficient processing practices. Fundamentally, the paradigm of what is a forest product and what defines the forest products industry needs to be expanded to include all products that come from the forest. Greater efforts are needed to educate people that forest products can be produced sustainably. However, the successful adoption of advances in forest products research depends on a number of other factors. The main challenges are:

– The loss of forest area must be reversed;
– The supply of wood and non-wood forest products must be sustained;
– To achieve this, efforts need to be made to improve the public knowledge of the positive benefits of forestry and all forest products;
– The image of "forestry" as a profession needs to be bolstered to ensure the recruitment of innovative staff; and
– Local economies must be improved through the use of forests products while providing tangible benefits to the people living in and around forests.

Finally, non-wood forest products need to be fully integrated into management and utilization strategies from the beginning to ensure that the people who benefit from them are included in their management, as well as to ensure that the resources are adequately conserved.

Challenges with bio-energy

With recent fluctuations in the price of fossil fuels there is a renewed interest in bio-energy. Short rotation coppice, short rotation forestry and biodiesel crops are being developed in many countries (USAID 2005; Stupak et al. 2008). With the growing global trend toward fast-wood forestry, it is expected that within 20 years, half of all wood fibre in the world will be sourced from plantations, and more than half of those are in the tropics and subtropics. Moreover, an increasing amount of the world's wood supply is being produced in growing conditions more similar to farming than traditional forestry, in fast-wood forestry systems. The trends towards fast-wood forestry and increased areas of plantations in the tropics need to combined with the other functions that forests can fulfil, including the control of erosion and the rehabilitation of degraded lands and forests. The main challenges are:

– Development of new wood processing processes and products that are environmentally, socially and politically acceptable;
– Resolution of the already observed problem that the higher demand on biomass from forests will create competition for fibre with traditional forest products; and

- Development of more efficient use of material from plantations, involving segregation and allocation technology based on end-user requirements.

Challenges in biodiversity conservation

Globally, an important challenge emerges from the fact that the survival and persistence of many threatened and endangered forest species is in doubt. The restoration of degraded land (Lee 2006, 2007, 2008) provides an opportunity to establish these rare forest species and increase biodiversity of treated areas, provided that ecological information is available. The increased demand for wood and non-wood goods and services has to be managed simultaneously with the increasing demand for biodiversity conservation (Scherr et al. 2004). In the face of current media attention on climate change, one of the great science-policy challenges for the forest sector is to redirect some of the attention and energy away from speculation about the effects of climate change on individual species to a more productive operational focus on biodiversity conservation and the central role of biodiversity. In particular, more attention needs to be paid to how forests have adapted in the past to all forms, degrees, and directions of environmental change.

In the effort to improve the accuracy of the climate and carbon budget models used to examine likely climate change given specific emission scenarios, policy makers may be overlooking important biological concepts about forest resilience and its dependence on biodiversity (species richness and genetic diversity), as the primary means by which forests adapt to change. The relationship between biodiversity and response to disturbance has been a foundation for population, species, community, and ecosystem adaptation to environmental change throughout geological history, and has formed the basis for much forest management (Perera et al. 2000, 2004) and nature conservation planning (Alexander 2008). The geological and fossil records show abundant evidence of both past climate change and adaptation to these changes. A better understanding of how these responses function in complex forest ecosystems, especially those that have involved human influences, will be an important area for future research (Puettman et al. 2009).

A major and growing challenge for biodiversity conservation is the threat presented by invasive species (Lockwood et al. 2007). These represent potential pathogens for forests (see below), but may also affect all other components of the forest ecosystem. Climate change is likely to alter the competitive abilities of many species, and this may make them more, or less, resilient to the adverse effects of invasive species. However, relatively little is known about such changes, and considerable research is needed.

Management of water resources

Particularly critical is our understanding of how forests may influence and modify extreme events such as floods, droughts and mass movement events that can sometimes have devastating societal consequences. The public perception that forests are, in all circumstances, necessarily and always good for the water environment, that they increase rainfall and runoff, regulate flows, reduce erosion, reduce floods, and improve water quality, has long been questioned by some in the scientific community. The evolving scientific perception suggests a more complex and generally less advantageous view of forests in relation to the water environment (Calder 2005), although debate remains vigorous (Alila et al. 2009). Important questions include: How much water will be consumed by growing tree crops compared to other land uses? And will the promotion of bio-energy schemes have serious impacts on catchments which might already be moving towards closure?

The role of forests in relation to the sustainable management of land and water resources remains a contentious issue in many parts of the world. This is despite a significant advance in scientific understanding of forest and water interactions based on almost a century of research in forest hydrology. Problems have often arisen from a failure both to communicate results effectively to policy makers and planners and to challenge entrenched views. New approaches and dissemination tools are required to address this problem. Thus, the importance of increasing our understanding of the interactions between forest and water, and of communicating this to policy makers, is growing. It is important to identify where there is a consensus amongst the forest hydrology community on the key forest and water issues and to highlight those that remain poorly understood as the focus for further research. A future issue will be to develop a framework to allow the overall benefits and costs of forestry schemes to be assessed in relation to timber supply, biodiversity, societal and environmental impacts, particularly where the water impacts relate to the water environment (Calder 2007).

Challenges in forest health and forest genetics

A global perspective on forest tree health

Natural and plantation forests of the world have been seriously damaged by epidemics of alien invasive insects and diseases since the early 1900s. This has intensified as the increase in global trade has facilitated pathways for pests to move among countries and continents. The accidental introduction of these pest species to forests where they have not co-evolved with hosts or natural enemies has often destabilized forest ecosystem processes, occasionally resulting in the total extirpation of the host tree species. Added to this is an increasing number of reports that indicate that climate change is resulting in serious damage to some of the world's forests. There are also increasing numbers of examples of interactions between pests, pathogens, air pollution and climate change and collectively, these factors present a worrying outlook for the future health of forests. In addition to the very negative impact that pests, pathogens, air pollution and climate change are having on natural forests, these factors are also seriously threatening the sustainability of plantation forestry worldwide. The economies of several nations are highly dependent on plantations and there are a growing numbers of threats to this practice.

Plantation forestry often relies on innovative new technologies to improve trees and to avoid health problems, at least those caused by pests and diseases. Forward planning and investment in these technologies will help to ensure long term sustainability. This is not true for natural forests where biodiversity disasters, including extinctions, are likely to increase in years to come. Forest health research deserves significant investment to reduce the negative impact of pests, diseases, air pollution and climate change. Through such research, and the application of the ensuing knowledge, the health of forests will be secured globally.

Emerging issues in forest genetics and tree physiology

Forest genetics and tree physiology research have progressed rapidly from provenance testing to advanced-generation breeding, and resulted in substantial genetic gains in forest plantation for adaptation, productivity, pest resistance and wood quality. Genetically improved plantation trees have had and continue to make significant impacts on forest productivity, wood supplies, and sustainability of forest resources. Although research in the vegetative propagation of rooted cuttings and somatic embryogenesis has made possible the operational deployment of forest clones in plantations, new challenges will revolve around improved productivity, reduced pests and disease susceptibility, and enhanced wood quality in plantations (Strauss and Bradshaw 2004).

With traditional breeding programs being challenged by the overwhelming level of new information in biotechnology and genomics, the new challenges are to explore opportunities on how to incorporate these tools effectively into forest genetics research and tree breeding programs. Key biotechnology challenges include successful transformation systems for major species, gene expression, risk analysis and public acceptance. Genomics research in association mapping, with gene space scan, abundant marker and trait variation and high resolution mapping may be more promising for integration with breeding. Genetic diversity and gene conservation will continue to be a great challenge for forest resources management. New emerging issues in using forest bio-materials for energy and other products have created new research challenges for forest genetics and tree physiology in the future.

Challenges in forest modelling and operations engineering

Forest modelling and management

The challenges in forest modelling and management are intimately related to the global change environment that has modified the way forestry is practised. Climate change is strongly affecting forests and this impact is expected to increase in the future. Extreme droughts, severe storms and fires, and pest and diseases outbreaks are becoming more and more frequent. Such changes are already proving challenging for forest modellers (Böttcher 2008). At the same time societal demands are increasing and changing. For example, forests for recreation are often expected to have a complex structure, with several species and trees of different sizes, requiring more complex forest models.

Traditional forest management plans, periodically reviewed (for instance every 10 years) and focused on one well-defined forest, may not cope well with the rapidity of changes being observed in the physical, social and economic environment (Innes et al. 2005). There is a need for flexible forest management that can be easily adapted to the changing situation of the forest or to the new societal requirements and that focuses not only on the situation of each forest but also of the landscape around it (Voller and Harrison 1998; D'Eon et al. 2000). This flexible forest management requires input from several research areas:

– Continuous forest monitoring that allows early detection and evaluation of the occurrence and impact of hazards – new multisource inventories for forest monitoring
– Forest models able to predict forest development and growth under climate change and after the occurrence of hazards – improved models combining process-based and statistical-based sub-models
– Forest models that are not based on site index can be run using variables usually available in forest inventories – new methods for site quality characterization
– Forest models should be able to predict the impact of genetic material
– Forest models should be able to predict wood quality
– Non-wood products and services need to be taken into account in forest management – new valuation methods for these products and services

The results of the research areas listed above should be integrated into flexible decision support systems that can support forest managers in successively adapting forest management to climate and societal changes. Such systems should be subject to rigorous field testing and should reflect the increasing volume of knowledge coming from large-scale experiments (Peterson and Maguire 2005). The involvement of managers and other stakeholders in the development of these systems is crucial for their usefulness as a support to day to day management decisions.

Forest operations engineering and management

Forest operations engineering and management is a problem-oriented scientific discipline that has been continuously evolving in response to technological, economical, and political forces for change. It is attempting to meet the challenge to continuously adapt forest operations practices and policies to face future challenges. The overarching question is how to reconfigure operating units, firms, and supply networks in order to continuously maintain their adaptability, flexibility and self-learning capability.

Many of the challenges will involve the reconfiguration of current practices, and the evaluation of the legacy of past activities. For example, roads established on slopes considered today to be stable may in future be at risk of slope failure. Bridges designed to allow a specific volume of water to pass at a given return interval may no longer be capable of meeting that requirement. High-latitude areas dependent on harvesting while the ground is snow-covered and/or frozen may find that the operational season is drastically reduced, requiring the development of new operational procedures. All such challenges and uncertainties will need to be addressed.

There is a strong need to strengthen forest operations engineering and management research and promote joint research efforts. Additionally, we have to develop joint activities with international science organizations and institutions (e.g., to industrial engineering and management, industrial ecology, or operations research) and to improve the dissemination of research knowledge according to scientific standards and customs.

Challenges for public participation – decisions, research, distribution of benefits

A growing trend in forest management has been the recognition for the need for the active co-management of forests. This extends beyond forestry to all natural resources (Colfer 2005a; Armitage et al. 2007). Very often, managers will be required to adopt new systems of thinking, as when the US Forest Service adopted ecosystem management (Breen 2008).

Many of the challenges facing forestry relate to governance and tenure. This covers a broad range of subjects, ranging from the development of international forest policy, through national governance issues, to the distribution of forestry benefits to local people. Despite early recognition of possible strategies (e.g., Panayotou and Ashton 1992), global governance has failed so far to halt deforestation, and major new ways are needed to address this issue (Smouts 2003; Humphreys 2006). Such methods will require a far better understanding of the complex relationships between people and forests (Gibson et al. 2000; Menzies 2007), and there is a need to both study from what has happened in the past through historical studies of institutions (Poore 2003) and practices (Dawkins and Philip 1998; Bott et al. 2003), and to be open to learn from such assessments.

In some parts of the world, there are still major issues concerning the distribution of forest benefits to local peoples, including both Indigenous Peoples and others. Research is needed on how to transfer a greater governance role to such people, including policy research, research on the most effective type of institutions and research on potential stumbling blocks to their greater involvement (Howitt 2001; Lawes et al. 2004; Stevenson and Natcher 2009). Further research is also urgently needed on how forests and forestry can contribute to the alleviation of poverty (Parrotta et al. 2008).

Challenges facing forest researchers include conducting research at the boundaries between disciplines and involving local people in research. For example, many research recommendations talk about involving "society" and "community" in research, but with some rare exceptions (Colfer 2005b), there is often a failure to deal with the complexity associated with such terms. Better involvement of the affected communities in research and the application of that research is an urgent priority.

Challenges in estimating ecosystem services, biofuels, and biodiversity

While much progress has been made in the valuation of ecosystem services (Campbell and Luckert 2002; Swingland 2002), there has been a widespread failure to incorporate such values in the day-to-day management of forests. This is an area of rapid growth, but one that has been politically contentious. There remains considerable disagreement over valuation methods, and even greater disagreement over who should pay for the maintenance of public goods. Research is needed on a range of issues related to this topic, from valuation methodologies to the willingness of individuals or groups to pay for services that they have previously received freely.

Forests and perceptions of society

One of the social changes that has occurred in recent years is the way in which people view forests, and there has been growing recognition of the role that forests play in the cultural development of societies (Harrison 1992; Hayman 2003). There is increasing pressure in many parts of Europe, for example, for a form of forestry that is closer to nature (Egli 1998). In some areas, this translates into the conversion of even-aged, single species plantations into multiple-aged multi-species forests. Similar management suggestions have been made for some time in North America (Hammond 1991; Drengson and Taylor 1997), Australia (Lindenmayer and Frankline 2003; Lindenmayer and Fischer 2006) and elsewhere. However, considerable research into this is still needed, as the assumption is often made that the converted forest should look something like an idealized forest, with this forest being based on past experience. Climate change, for example, means that the forests of the future will be very different to the forests of the past, and considerable effort will be needed to determine the nature of these forests, and to convince all stakeholders that the planning of such forests needs to look to the future rather than be based on past concepts of forests.

Europe is exceptional in that most forests have already been heavily impacted by past management. In many other parts of the world, forestry is based on a more natural form of management. However, even in these cases, there is a need for a better understanding of the multiple relationships between society and forests (Drengson and Taylor 2009). Increasingly, the views of the public are being incorporated into forest management (Donoghue and Sturtevant 2008), yet this represents a two-edged sword. On the one hand, the incorporation of public views means that societal requirements are being taken into account. On the other hand, the views of the public as to what represents "good" forest practices may be inconsistent with scientific knowledge on the nature of forests. This represents an important research challenge for the future.

Forests for health, food, poverty, urbanization, lifestyle

Forest science has traditionally been compartmentalized, with a major division between the natural and social sciences. The emphasis in research institutions dealing with forests has tended to lie with natural sciences, but it is increasingly clear that not only are the social sciences critical to the future of forests, but also there is a strong need to integrate natural and social sciences better than hitherto. This is evident in, for example, the debate about the future of old growth forests (Spies and Duncan 2009), concerns about the links between land degradation, population and poverty (Young 1998) and concerns about how modern primarily urban societies can live sustainably in landscapes of high conservation concern (Stork and Turton 2008). Such concerns invite a re-examination of what constitutes the public interest when forests are involved (Woodwell 2001).

With more and more of the world's population living in cities, urban forestry is a growing issue that with few exceptions is inadequately dealt with by traditional research institutions. Related to this are studies of the links between forests and human health (Colfer 2008). Urban forestry represents a major area of potential research with many challenges, ranging from the ecophysiological to the social. Here, more than anywhere, research will need to bridge the divide between the natural and social sciences (Konijnendijk et al. 2004).

Educational change – structure and topics

Education covers many topics, including the training of future foresters and the education of an increasingly urbanized society about the value of forests. Some parts of the world have seen a major drop in the number of people seeking a forestry education; elsewhere there have been significant losses of trained foresters through epidemics such as HIV. Most foresters continue to be trained as natural scientists, acquiring knowledge that is aimed at helping them to manage forests. However, future forest management will be as much about managing people as about managing vegetation, many traditional forestry programs have yet to recognize this. Research is needed on effective recruitment methods for future generations of foresters, on the knowledge needs of these future foresters and on the optimal learning methods that can be utilized (Anon 2004).

Information and research administration – processes, tools, data management

Over the last 10 years, major changes have occurred in the ways that people (including researchers, managers, decision-makers and others) access information. The nature of scientific publishing is changing rapidly, and traditional peer-reviewed journals are being challenged by collective means of knowledge development (Tapscott and Williams 2008). The majority of the academic community has viewed such developments with deep suspicion, yet the success of tools such as Wikipedia is undoubted. Attempts to introduce such methods to the forestry community include the Global Forest Information Service (www.gfis.net) or the Sustainable Forest Management Knowledge Base (www.sfmindicators.org). Research is still needed on the most effective ways to communicate such information to different sectors and cultures within the community.

Conclusions

– Forest science, like many other sciences, has faced major challenges in the last few years. Research has become more complex and many of the issues affecting forests cannot be solved by the forest sector alone. Resolution of these issues is becoming increasingly important as many types of forest decrease in the area to a point where their future viability comes into question (Laurance and Peres 2006). Forests are a part of the broader landscape, and solutions to forestry problems often lie in broader sustainability solutions (Sayer and Campbell 2004; Sayer and Maginnis 2005). This will require a number of changes in approach, including the adoption of broader (landscape) scales of research, and the better integration of natural and social sciences (Vogt et al. 2007).

– Many issues of global importance, such as climate change, biodiversity, bio-energy, and water availability, are of strong interest to policy makers and groups inside and outside the forest sector (IUFRO 2009b). These four, inter-related, emerging key-issues will all be of high relevance to forest science as well as to the cross-sectoral and global collaboration in IUFRO in the coming years.
– Outreach to society and decision makers remains a significant challenge for foresters and forest researchers all over the world. The 'information overload' that the internet and other forms of information access have opened up means that any attempts to communicate and to shape the science-policy interface will require sustained and innovative approaches.

References

Adger W.N., Paavola J., Huq S., Mace M.J. 2006. Fairness in adaptation to climate change. Cambridge, Massachusetts, USA, MIT Press, pp. 317.

Alexander M. 2008. Management planning for nature conservation. A theoretical basis and practical guide. Berlin, Germany, Springer, pp. 425.

Alila Y., Kuras P.K., Schnorbus M., Hudson R. 2009. Forests and floods: A new paradigm sheds light on age-old controversies. Water Resources Research, in press.

Angelsen A. 2008. Moving ahead with REDD. Issues, options and implications. Bogor, Indonesia, CIFOR.

Anon. 2004. Proceedings of International Symposium on "Forest Research and Education for the 21st Century". Seoul Education and Cultural Center, Korea Forest Research Institute, Korean Forestry Society, Seoul National University.

Armitage D., Berkes F., Doubleday N. 2007. Adaptive co-management. Collaboration, learning, and multi-level governance. Vancouver, Canada, UBC Press, pp. 337.

Betts R.A., Malhi Y., Roberts J.T. 2008. The future of the Amazon: new perspectives from climate, ecosystem and social sciences. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363 (1498), 1729–1735.

Bott R., Murphy P., Udell R. 2003. Learning from the forest. A fifty-year journey towards sustainable forest management. Calgary, Alberta, Canada, Fifth House, pp. 242.

Böttcher H. 2008. Forest management for climate change mitigation. Modelling of forestry options, their impact on the regional carbon balance and the implications for a future climate protocol. Saarbrükken, Germany, VDM Verlag Dr. Müller, pp. 168.

Breen R.É. 2008. Approaching ecosystem management. Change and challenge in forest planning in the US Forest Service. Saarbrücken, Germany, VDM Verlag Dr. Müller, pp. 152.

Calder I.R. 2005. Blue revolution: Integrated land and water resource management. London, UK, Earthscan, pp. 208.

Calder I.R. 2007. Forests and water – Ensuring forest benefits outweigh water costs. *Forest Ecology and Management*, 251, 110–120.

Campbell, B.M., Luckert, M.K. 2002. Uncovering the hidden harvest. Valuation methods for woodland and forest resources. London, UK, Earthscan, pp. 262.

Colfer C.J. P. 2005a. The complex forest. Communities, uncertainty, and adaptive collaborative management. Washington, DC, USA, Resources for the Future.

Colfer C.J. P. 2005b. The equitable forest. Diversity, community, and resource management. Washington, DC, USA, Resources for the Future.

Colfer C.J. P. 2008. Human health and forests. A global overview of issues, practice and policy. London, UK, Earthscan, pp. 374.

Collaborative Partnership on Forests 2008. Strategic framework for forests and climate change. Rome, Italy, Collaborative Partnership on Forests.

Dawkins H.C., Philip M.S. 1998. Tropical moist forest silviculture and management. A history of success and failure. Wallingford, UK, CABI Publishing, pp. 359.

D'Eon R.G., Johnson J., Ferguson E.A. 2000. Ecosystem management of forest landscapes. Directions and implementation. Vancouver, British Columbia, Canada, UBC Press.

Donoghue E.M., Sturtevant V.E. 2008. Forest community connections. Implications for research, management, and governance. Washington, DC, USA, Resources for the Future, pp. 280.

Drengson A., Taylor D. 1997. Ecoforestry. The art and science of sustainable forest use. Gabriola Island, British Columbia, Canada, New Society Publishers, pp. 312.

Drengson, A. Taylor D. 2009. Wild foresting. Practising Nature's wisdom. Gabriola Island, British Columbia, Canada, New Society Publishers, pp. 307.

Egli B. 1998. Naturgemäße Waldwirtschaft. *Neujahrsblatt der Naturforschenden Gesellschaft Schaffhausen*, 51.

Ferguson I.S. 1996. Sustainable forest management. Oxford, UK, Oxford University Press, pp. 162.

Gibson C.C., McKean M.A. and Ostrom E. 2000. People and forests. Communities, institutions, and governance. Cambridge, Massachusetts, USA, MIT Press.

Gujit I. 2007. Negotiated learning. Collaborative monitoring in forest resource management. Washington, DC, USA, Resources for the Future.

Guldin R.W., Koch N.E., Parrotta J., Gamborg C., Thorsen B.J. 2004. Forest science and forest policy in Europe, Africa and the Middle East: Building bridges to a sustainable future. *Scandinavian Journal of Forest Research*, 19 (4), 5–13.

Hammond H. 1991. Seeing the forest among the trees. The case for holistic forest use. Vancouver, British Columbia, Canada, Polestar Press.

Harrison R.P. 1992. Forests. The shadow of civilization. Chicago, Michigan, USA, University of Chicago Press.

Hayman R. 2003. Trees, woodlands and western civilization. London, UK, Hambledon and London.

Howitt R. 2001. Rethinking resource management. Justice, sustainability and indigenous peoples. London, UK, Routledge.

Humphreys D. 2006. Logjam. Deforestation and the crisis of global governance. London, UK, Earthscan.

Innes J.L., Hickey G.M. 2006. The importance of climate change in considering the role of forests in the alleviation of poverty. *International Forestry Review*, 8 (4), 406–416.

Innes J.L., Hickey G.M., Hoen H.F. 2005. Forestry and Environmental Change: socioeconomic and political dimension*s*. IUFRO Research Series, 11. Wallingford, UK, CABI Publishing.

Innes J.L., Joyce L.A., Kellomäki S., Loumann B., Ogden A., Parrotta J., Thompson I., Ayres M., Ong C., Santoso H., Sohngen B., Wreford A. 2009. Management for adaptation. In: Adaptation of Forests and People to Climate Change (eds.: R. Seppälä, A. Buck, P. Katila). A Global Assessment Report. IUFRO World Series, 22, 135–185.

IUFRO 2009a. Abstracts for IUFRO symposium – Emerging issues in forest science. Session 6.4 Research, extension and education. XIII World Forestry Congress, 18–25 October 2009, Buenos Aires, Argentina

IUFRO 2009b. IUFRO Review 2009. Panel Report. Management Committee Meeting, 30–31 March 2009, Pretoria, South Africa. pp. 14.

Kimmins J.P. 2008. From science to stewardship: Harnessing forest ecology in the service of society. *Forest Ecology and Management*, 256 (10), 1625–1635.

Konijnendijk C.C., Schipperijn J., Hoyer K.H. 2004. Forestry serving urbanised societies. IUFRO World Series, 14.

Lansky M. 2002. Low-impact forestry. Forestry as if the future mattered. Hallowell, Maine, USA, Maine Environmental Policy Institute.

Laurance W.F., Peres C.A. 2006. Emerging threats to tropical forests. Chicago, Michigan, USA, University of Chicago Press.

Lawes M.J., Eeley H.A. C., Shackleton C.M., Geach B.G. S. 2004. Indigenous forests and woodlands in South Africa. Policy, people and practice. Scottsville, University of KwaZulu-Natal Press., South Africa.

Lee D.K. 2006. Keep Asia Green. Southeast Asia. IUFRO World Series, 20 (1), pp. 242.

Lee D.K. 2007. Keep Asia Green. Northeast Asia. IUFRO World Series, 20 (2), pp. 170.

Lee D.K. 2008. Keep Asia Green. South Asia. IUFRO World Series, 20 (3), pp. 220.

Lindenmayer D.B., Fischer J. 2006. Habitat fragmentation and landscape change. An ecological and conservation synthesis. Washington, DC, USA, Island Press, pp. 352.

Lindenmayer D.B., Franklin J.F. 2003. Towards forest sustainability. Washington, DC, USA, Island Press, pp. 231.

Lockwood J.L., Hoopes M.F., Marchetti M.P. 2009. Invasion ecology. Oxford, UK, Blackwell Publishing, pp. 304.

McDonald G.T., Lane M.B. 2004. Converging global indicators for sustainable forest management. *Forest Policy and Economics*, 6, 63–70.

McEvoy T.J. 2004. Positive impact forestry. A sustainable approach to managing woodlands. Washington, DC, USA, Island Press, pp. 296.

Menzies N.K. 2007. Our forest, your ecosystem, their timber. Communities, conservation, and the state in community-based forest management. New York, USA, Columbia University Press, pp. 264.

Mery G., Alfaro R., Kanninen M., Lobovikov M. 2005. Forests in the global balance – Changing paradigms. IUFRO World Series, 17, pp. 318.

Panayotou T., Ashton P.S. 1992. Not by timber alone. Economics and ecology for sustaining tropical forests. Washington, DC, USA, Island Press, pp. 280.

Parrotta J.A., Liu J., Sim H.-C. 2008. Sustainable forest management and poverty alleviation: Roles of traditional forest-related knowledge. IUFRO World Series, 21, pp. 223.

Perera A.H., Buse L.J., Weber M.G. 2004. Emulating natural forest landscape disturbances. Concepts and applications. New York, USA, Columbia University Press, pp. 315.

Perera A.H., Euler D.L., Thompson I.D. 2000. Ecology of a managed terrestrial landscape. Patterns and processes of forest landscapes in Ontario. Vancouver, British Columbia, Canada, UBC Press, pp. 346.

Peterson C.E., Maguire D.A. 2005. Balancing ecosystem values: Innovative experiments for sustainable forestry. Proceedings of an international workshop. General Technical Report PNW-GTR-635. US Department of Agriculture Forest Service, Portland, Oregon, USA, pp. 389.

Poore D. 2003. Changing landscapes. London, UK, Earthscan, pp. 290.

Puettmann K.J., Coates K.D., Messier C. 2009. A critique of silviculture. Managing for complexity. Washington, DC, Island Press., Canada,

Sands R. 2005. Forestry in a Global Context. CABI Publishing, Wallingford, UK, pp. 272.

Sayer J., Campbell B. 2004. The science of sustainable development. Local livelihoods and the global environment. Cambridge, UK, Cambridge University Press., pp. 123.

Sayer J., Maginnis S. 2005. Forests in landscapes. Ecosystem approaches to sustainability. London, UK, Earthscan, pp. 257.

Scherr S.J., White A., Kaimowitz D. 2004. A new agenda for forest conservation and poverty reduction: Making markets work for low-income producers. Forest trends, Washington, DC, USA, pp. 90.

Schultz C. 2008. Responding to scientific uncertainty in U.S. forest policy. *Environmental Science & Policy*, 11, 253–271.

Seppälä R., Buck A., Katila P. 2009. Adaptation of Forests and People to Climate Change. A Global Assessment Report. IUFRO World Series, 22, pp. 224.

Smouts M. -C. 2003. Tropical forests, international jungle: the underside of global ecopolitics. New York, USA, Palgrave-Macmillan, pp. 266.

Spies T.A., Duncan S.L. 2009. Old growth in a new world. A Pacific Northwest icon re-examined. Washington, DC, USA, Island Press, pp. 344.

Stevenson M.G., Natcher D.C. 2009. Changing the culture of forestry in Canada. Building effective institutions for Aboriginal engagement in sustainable forest management. CCI Press and Sustainable Forest Management Network, Edmonton, Alberta, Canada, pp. 210.

Stork N.E., Turton S.M. 2008. Living in a dynamic tropical forest landscape. Oxford, UK, Blackwell Publishing, pp. 652.

mStrauss S.H., Bradshaw H.D. 2004. The bioengineered forest. Challenges for science and society. Washington, DC, USA, Resources for the Future, pp. 245.

Stupak I., Asikainen A., Jonsell M., Karltun E., Lunnan A., Mizaraite D., Pasanen K., Parn H., Raulund-Rasmussen K., Roser D., Schroeder M., Varnagiryte I., Vilkriste L., Callesen I., Clarke N., Gaitnieks T., Ingerslev M., Mandre M., Ozolincius R., Saarsalmi A., Armolaitis K., Helmisaari H.-S., Indriksons A., Kairiukstis L., Katzensteiner K., Kukkola M., Ots K., Ravn H.P., Tamminen P. 2008. Sustainable utilization of forest biomass for energy – possibilities and problems. Policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries. *Biomass and Bioenergy*, 31, 666–684.

Swingland I.R. 2002. Capturing carbon and conserving biodiversity. The market approach. London, UK, Earthscan, pp. 392.

Tapscott D., Williams A.D. 2008. Wikinomics: How mass collaboration changes everything. London, UK, Atlantic Books.

USAID 2005. USAID Forestry Programs: Technical Notes on Emerging Issues in Global Forest Management, pp. 7.

Vogt K.A., Honea J., Vogt D.J., Andreu M., Edmonds R., Sigurdardóttir R., Patel-Weynand T. 2007. Forests and society. Sustainability and life cycles of forests in human landscapes. Wallingford, UK, CABI Publishing.

Voller J., Harrison S. 1998. Conservation biology principles for forested landscapes. UBC Press, Vancouver, British Columbia, Canada, pp. 244.

Westoby J. 1987. The purpose of forests. Oxford, UK, Basil Blackwell, pp. 343.

Woodwell G.M. 2001. Forests in a full world. New Haven, Connecticut, USA, Yale University Press, pp. 256.

Young A. 1998. Land resources. Now and for the future. Cambridge, UK, Cambridge University Press, pp. 319.