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Interacting Science, People, and Natural Resources in Amazonian Rainforests

by

Matti Salo

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From

Section of Biodiversity and Environmental Science
Department of Biology
University of Turku
FIN-20014 Turku, Finland

Supervised by

Professor Pekka Niemelä and professor Jukka Salo
Department of Biology
University of Turku, Finland

Professor Risto Kalliola
Department of Geography
University of Turku, Finland

Professor Teivo Teivainen
Department of Political Science
University of Helsinki, Finland

Reviewed by

Dr. Timothy R. Baker
School of Geography, University of Leeds
Leeds, UK

Dr. Antti Otsamo
Finnish Forest Industries
Helsinki, Finland

Dissertation opponent

Dr. Matti Nummelin
Ministry for Foreign Affairs of Finland
Helsinki, Finland

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Knowledge Meets Landscape: Interacting Science, People, and Natural Resources in Amazonian Rainforests

Thesis

Matti Salo

This thesis is based on the following articles which are referred to in the text by their Roman numerals.

I Schulman, L., Junikka, L., Ruokolainen, K., Sääksjärvi, I.E., Salo, M., Juvonen, S.-K., Salo, J. & Higgins, M. 2007. Amazonian biodiversity and protected areas: do they meet? *Biodiversity and Conservation 16: 3011-3051.*

II Salo, M. & Pyhälä, A. 2007. Exploring the gap between conservation science and protected area establishment in the Allpahuayo-Mishana National Reserve (Peruvian Amazonia). *Environmental Conservation 34: 23–32.*

III Salo, M. & Toivonen, T. 2009. Tropical timber rush of Peruvian Amazonia: spatial allocation of forest concessions in an uninventoried frontier. *Environmental Management 44: 609–623.*

IV Salo, M., Helle, S. & Toivonen, T. The small and the local first? Localism and allocation of forest concessions in Peruvian Amazonia. *Manuscript.*

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Introduction

Natural resources are being used, conserved, managed, plundered, sold, bought, wasted, saved, and lost, every single day, and across land and sea. Similarly, the planet's biological diversity constantly interacts with human societies.

Tropical forests harbour and maintain some of the most important of the world's natural resources and ecosystem services, as well as are home to a disproportionate share of its biodiversity (Dirzo & Raven 2003). Decisions concerning forests are being made at multiple levels, from individual households dependent on cutting and selling timber (Amacher et al. 2009), to international organisations, such as World Bank, capable of shaping complete forestry sectors across national borders (Hajjar & Innes 2009).

The knowledge and the information indispensably catalysing the decisions these actors make originate in an infinite variety of sources and are managed in myriad ways (Parker et al. 2008). The amount and quality of biodiversity-related information produced worldwide are steadily increasing. Meanwhile, public debates on biodiversity issues, and associated political decision-making processes, use a wide array of information sources, as well as a diversity of fora and media.

In the Global South biological diversity reaches its peaks, and is usually accompanied by extreme pressures for economic growth and social change. In such circumstances, biodiversity information and related knowledge-power can assume controversial roles (Escobar 1998). In one hand, while scientific or other exogenous knowledge can be seen, for instance, as a valuable resource for capitalising natural resources (Sears et al. 2007), in the other it is also a potential tool for enforcing environmental programmes along the development frontier (Rodriguez et al. 2007), where local interests and views may diverge greatly from international priorities.

The role of science in the management of environment and natural resources is far from being straightforward. Brunner (2005) highlights the need to move from 'scientific management' in which science is aspired to take its place above politics, to 'adaptive governance' that integrates distinct forms of knowledge into decision-making processes. It is doubtful, if science has ever prevailed over politics in decision-making concerning the use of natural resources. It is similarly important to notice that scientific information is not value-free (Kincaid et al. 2007), and its use is far from being a panacea. Nevertheless, science has an important role to play in adaptive governance, and scientists should have an active role in that process (Giller et al. 2008).

Access to, and control of, natural resources are issues of primary importance for all societies (Ribot & Peluso 2003). Many natural resources are linked to land, and land-use may well be the single human activity with the most significant impact on biological diversity and renewable natural resources worldwide (Foley et al. 2005). While humans have seized the vast majority of global biomes (Hoekstra et al. 2005), simultaneously almost 13 per cent of Earth's terrestrial surface has been designated as protected areas or nature reserves (Jenkins & Joppa 2009), i.e. sites where human activities have been legally restricted in favour of other living organisms and environmental processes.

Amazonian rainforests are among the last relatively well preserved large natural ecosystems remaining on Earth; a fact that, at least in theory, should allow proactive conservation efforts in the region (Mittermeier et al. 2003). Areas included in reserve networks, however, are excluded from many other land-use designations. Thus, although it is theoretically possible to approach the goal of assuring the conservation of viable populations of all Amazonian species by complementing the protected areas networks *ad infinitum*, a pragmatic observer may already note that the Amazonian landscape is limited, whereas the needs of different land-use forms seem limitless.

Malhi et al. (2008) argue that the next few years may be critical if more sustainable management of natural resources, improved maintenance of biological diversity and ecosystem services, in addition to enhanced mitigation of climate change, are to be achieved in Amazonia. Indeed, the fate of Amazonian rainforests is increasingly seen as a critical global environmental issue, which draws international attention to local efforts and solutions to improve forest management in the region. Although both, development of protected areas networks, and efficient land-use planning are of utmost importance for this goal, also the legitimacy of the means applied, their enforcement, as well as scientific and policy foundations of these processes have to be constantly assessed and monitored.

Peruvian Amazonia extends over more than 750,000 square kilometres east of the Andean Cordillera. The vast rainforests found in this mostly sparsely populated part of the country are home to one of the most diverse biotic systems of the world (Finer et al. 2008). Simultaneously these forests are a patchwork formed by a diverse array of formal and informal land-use patterns and usufruct areas (Arce-Nazario 2007). Although the weight of politics and economic issues cannot be underestimated in Amazonian land-use planning, the role of science has been substantial in the recent decades that have witnessed the almost complete division of Peruvian Amazonian lands to different formal land-use assignments and informal usufruct areas. Although scientific understanding of Amazonian environments has evolved considerably during the same period, it is justified to ask whether there has been a corresponding evolution in the processes that are applied in order to determine the suitability of different land-use assignments in particular areas and contexts.

The approaches used to allocate land-areas for different uses should be able to critically adjust to the information accumulated and knowledge built. Decision-makers should ask whether the information they are provided with is correct, and the level of knowledge sufficient for informed decisions. Furthermore it is elementary that the decision-making systems applied allow available information to infiltrate into the different levels of administration involved.

After all, decision-making systems should be capable of interacting with science and adjusting to feedback, when changes occur in the paradigms related to the ecological processes that shape Amazonian landscape. Active-adaptive management should anticipate different future scenarios that depend on environmental and social uncertainties, using scientific methods and testing the possible outcomes of different policies as hypotheses (Jacobson et al. 2009).

One of the most recent trends in Amazonian Peru is the enhanced incorporation of both already accumulated and new environmental knowledge into the decision-making processes that ultimately affect biodiversity (Juvonen & Tello Fernández 2004). Along with this process, biodiversity information is increasingly finding its way into public debates and policies. However, detailed studies on the integration of scientific knowledge and environmental issues in such context are lacking.

The main aim of this thesis, consisting of four original articles, is to explore this complex issue. The papers deal with the use of scientific, and other kinds of information in decision-making processes involving a variety of stakeholders, and ranging from continental-scale systems of protected areas to local forest concessions designated for timber production. The outlines of the four articles are the following, and hereafter I refer to these articles with their respective Roman numerals in superscript$^{\text{I–IV}}$:

I The first article presents a continental Amazonian assessment of the role of natural scientific theory and criteria used for planning nature reserve networks, and asks whether Amazonian biodiversity and protected areas meet. This article reviews the development of natural scientific understanding of the processes behind Amazonian biodiversity patterns, as well as explores the ways in which the knowledge on these patterns has contributed to conservation planning and to its potential success.

II The second paper identifies links between the biological basis of conservation and broader context within which protected areas are embedded, and asks how conservation can be brought from maps into the field. The article presents a case study from Peruvian Amazonia illustrating the gap that exists between the natural sciences' contribution to finding priority sites for conservation in one hand, and the socio-economic and socio-cultural settings in which political decisions concerning conservation are made.

III The third article analyses the implications of forest allocation for both conservation and management of natural resources, and asks what can be done to force spatial planning to take more interactive forms. The article explores the criteria used, the process applied, and the outcome achieved in allocating Peruvian rainforests for timber production, and for other land-use assignments, including protected areas.

IV The fourth article explores access to forest resources in Peruvian Amazonia, and asks whether there are local and outsider interests related to natural resources, and if there are, how can they be articulated and what are their implications. The paper discusses the roles different actors and their perceptions of local realities take when important natural resources are at stake.

Study area and background

Amazonia: local exclusion and global inclusion

Amazonia is the world's largest tropical forest biome, covering an area the size of extra-Russian Europe (figure 1). In addition to harbouring maybe a quarter of all biological diversity on Earth, the continent-wide rainforest biome is also important for the planet's climate systems and other biogeochemical processes (Malhi et al. 2008). Similarly, while Amazonia is mostly sparsely populated, and frequently called one of the last large wilderness areas in the world (Mittermeier et al. 2003), it is also home to a growing human population including a great diversity of indigenous peoples (BID/PNUD/TCA 1991; Turnbull 2009). Nine different countries have parts of their territory in AmazoniaI, and all of these countries have their own and distinct Amazonian policies (Perz et al. 2005).

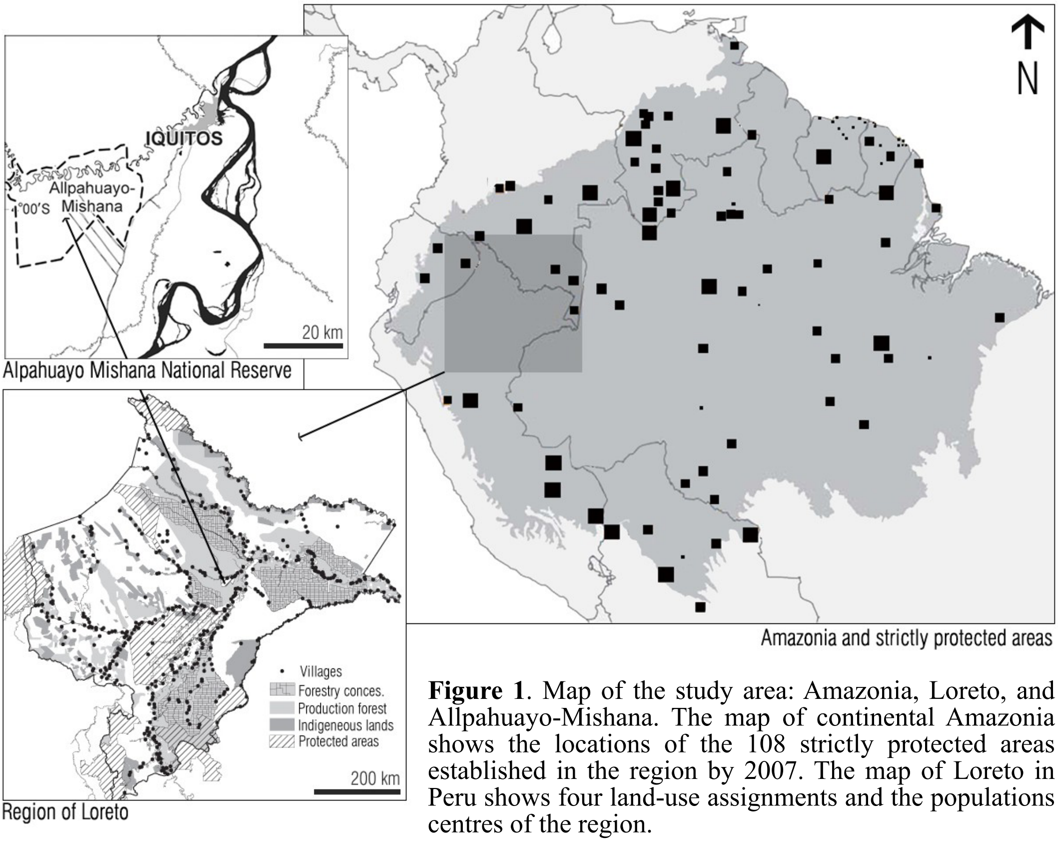

Figure 1. Map of the study area: Amazonia, Loreto, and Allpahuayo-Mishana. The map of continental Amazonia shows the locations of the 108 strictly protected areas established in the region by 2007. The map of Loreto in Peru shows four land-use assignments and the populations centres of the region.

A large part of Amazonian rainforests are still standing, and there are not many known examples of animal or plant species that modern people would have driven to extinction. However, the region's natural ecosystems are increasingly under pressure, and many extinctions may have occurred without anyone even knowing those species existed; possibly the majority of Amazonian species remain undiscovered to science.

Although predicting extinction rates is extremely difficult (Feeley & Silman 2008; Hubbell et al. 2008), the area's natural resources and the ecosystem services it provides are ever more vulnerable because of mounting anthropogenic stress. Multiple development frontiers penetrate and run alongside the natural ecosystems of the region, both in space and in time (Browder et al. 2008; Hecht 2005; Rodrigues et al. 2009). However, Amazonia is a unique region in the sense that, at least in theory, both conservation and land-use have there been planned in a relatively free space, and systematically using scientific information. Although it is true that a significant part of the region is in fact occupied by indigenous peoples with or without legally recognized land titles (Finer et al. 2008; García & Álvarez 2007), Amazonia has been used as a living laboratory for conservation and land-use planning.

Likewise, it can be said that Peruvian Amazonia harbours extreme biological and cultural diversity in a common property landscape. The majority of Amazonian lands in Peru belong to the state, and the natural resources Amazonian ecosystems provide have been in practice governed as common property resources. Many of the current social and environmental conflicts and problems in the region are related to land ownership, access, and usufruct (García & Álvarez 2007). All these issues link land not only to property rights issues, but also to knowledge. Different kinds of knowledge and different information systems interact when land and resources are governed and managed (Escobar 1998).

If sparsely populated Amazonia with complicated accessibility is sometimes seen as South-American periphery, the Peruvian region of Loreto may be called Amazonian periphery. In Amazonia equalling to the surface area of extra-Russian Europe, Loreto's size surpasses that of Germany, while its population is less than one million. However, despite its few inhabitants, and maybe precisely because of its isolated location, Loreto has a strong regional identity (Chirif 2002).

During the last three decades the region has also witnessed a considerable scientific effort aiming at exploring the links between the region's environmental conditions and its biological diversity. This effort has involved both foreign and local scientists, and during the last ten years there has been an increasing tendency for applying the available information in the planning processes concerning Peruvian Amazonia and Loreto (Juvonen & Tello Fernández 2004).

Whose property? Whose usufruct?

Land tenure underlies all efforts to improve the sustainability of forest management and conservation of biological diversity. Security and stability of land tenure regimes, and associated investment in sustainability, have been studied extensively in environmental science. At least land use comprehensiveness (diversity of use rights granted), duration of ownership or usufruct, economic compensation, exclusiveness, transferability, and level of capacitation involved are among issues that are important in land use governance (Owubah et al. 2001). All these issues are thus central when land-use decisions are made, either in order to enhance the exploitation of natural resources or to restrict human activities.

Peruvian rainforests extend over a surface area larger than any European country, except for Russia. These vast natural ecosystems mainly consist of publicly owned lands, and public land ownership of Peruvian forest land has its historical background as well as its current consequences for both land-use and conservation.

Through the colonial times and during the first decades of Peruvian independence (since 1821), Amazonia was a distant part of the country, and hardly integrated to the economic and political systems of the emerging nation (García & Álvarez 2007). At those times, Amazonia was merely perceived as an empty space that had to be colonised. This view ignored completely the existence of a considerable indigenous population inhabiting the region (García & Álvarez 2007).

However, only the successive economic booms based on the exploitation of valuable natural resources, such as raw rubber c. 1860–1920 (Coomes & Barham 1994) and oil, mostly in the latter part of the 1900s to present (Finer et al. 2008), have contributed to the modern demographic expansion in the region. The boom and bust style economic cycles, that Peruvian Amazonia has witnessed, have involved private land ownership associated to activities such as rubber extraction and agriculture (García & Álvarez 2007).

As a result of the deliberate lack of regulatory mechanisms, however, the Amazonian indigenous population has been left without legally recognised rights to its traditional lands, and also has been frequently displaced (García & Álvarez 2007). Although general Juan Velasco's military government initiated a radical land reform in Peru in 1969, its effect did not reach Amazonian lowlands (García & Álvarez 2007).

The military government further implemented a series of legislative reforms that have had far-reaching environmental outcomes. In 1975, a forestry law was issued, laying normative context for the country's forestry regime for coming decades, and initiating the development of a system of protected areas in the country (García & Álvarez 2007; Moore 1992; Solano 2005). The forestry law, that has later been criticised from almost all possible viewpoints[IV], was at its time actually seen as modern and innovative (Moore 1992).

Among the novel premises of the law was the territorial division of Peruvian forests between free access forests, national forests, protection forests, and units of conservation. The first two forest categories were designated for resource exploitation by private actors and future state companies, respectively, but in practice only private actors have been using Peruvian forests.

The two second categories restricted the use of forests. While protection forests were designated mainly in areas with high risk of erosion, the establishment of the national system of units of conservation, SINUC (Sistema Nacional de Unidades de Conservación) would later form the basis for the national protected areas network SINANPE (Sistema de Áreas Naturales Protegidas por el Estado). The early system of protected areas pursued to protect a representative sample of environmental variation at a very coarse resolution; all three macro-ecologic regions of the country, coast, mountains, and rainforest, were to be included (Solano 2005). The National Park of Manu was established in 1973 in order to protect Amazonian rainforest biome.

Although yet the forestry law of 1975 considered forest resources public domain, the new constitution of Peru, that entered into force in 1979, had even more far-reaching implications for the country's forest biome. The new constitution determined that all natural resources found in Peru are national patrimony, and inalienably under the sovereignty of the state (Moore 1992). This interpretation has been maintained in the current Peruvian constitution from the year 1993 (García & Álvarez 2007), and its consequences can clearly be seen in the Amazonian landscape.

As a result of the state's sovereignty over natural resource base, in Peruvian Amazonia neither the numerous indigenous peoples nor the recent colonists have been able to acquire legal ownership of land areas that are assigned for forestry production (García & Álvarez 2007; Solano 2005). In those areas only usufruct can be granted for the different natural resources forest ecosystems provide.

The land ownership regime for agricultural land has been somewhat more relaxed, and in Peruvian Amazonia a substantial number of small privately titled land areas with varying legal state can be found. The situation is mostly result of the agricultural expansion promoted in the 1980s through zero-interest loans from the Agrarian Bank (García & Álvarez 2007; Maki et al. 2001). Neither the state nor the colonists, however, emphasised the formalisation of these land properties, a fact that led to an irregular land ownership pattern in the agricultural frontier (García & Álvarez 2007).

The distinction between agricultural and forest land is in theory justified by soil characteristics. The classification of soils according to their main use potential

(INRENA 2002; ONERN 1982), and the maps resulting from this classification have been used in delimitation of different land-use areas. Furthermore, forest land has been interpreted as inseparable part of the forest resource, and thus all land that is classified having mainly forestry potential, has been and still is, publicly owned. According to Agrawal (2007) three quarters of Peruvian forest and other woodland is public, while the remaining quarter is communal property. Private individuals and companies do not own production forest land in Peru.

From classifying to governing

This kind of approach to land-use management is essentially tied to the criteria used in defining the link between soils and vegetation, but also related to soil protection. These relationships have been established by applying a classification that categorises soils according to their main use potential, and to the associated risk of erosion (INRENA 2002; ONERN 1982). This has had profound social and environmental consequences regardless the serious limitations of the scientific basis of the methodologies applied in the soil classification process.

As a result more than 460,000 square kilometres of Peruvian Amazonia are considered primarily suitable for forestry, and thus state property. If the interpretation is sustained, these lands cannot be legally converted to other land-cover types. If the land areas categorised primarily suitable for soil protection are added to the productive forest land, 87 per cent of Peruvian Amazonia is permanently considered public property.

Although rights to land occupation and resource use have been granted to private actors and communities also on forest land, the resource base itself cannot be sold or privatised (García & Álvarez 2007). However, legal sovereignty over forest land has not enabled Peruvian state to effectively enforce its ownership of forest resources.

Throughout the 1980s and 1990s and until present, Peruvian forests have been used for extractive timber production with little efforts for forest management or sustainable harvesting (Dourojeanni 1990; Smith et al. 2006). The lack of control, combined with the abundance of land and many resources, has in practice led to the use of Peruvian forests as if they were a common property resource. This in turn has caused serious governance difficulties.

Illegal logging and trade on illegally harvested forest products is a worldwide phenomenon, and although the magnitude of the problem has not been accurately estimated in Peru, according to Chirinos and Ruiz (2003) around 80 percent of all timber harvested in Peru is to some degree illegal. The revenues annually lost by the Peruvian government as a consequence of informal forestry, and other indirect negative effects this situation causes for the society in general, have also been estimated considerably high (Gutierrez-Velez & MacDicken 2008).

From the beginning of the 1990s, and after the United Nations Conference on Environment and Development (Rio de Janeiro, 1992), both the Peruvian authorities and the civil society in the country began to show interest in problems associated with biodiversity and forest management[III,IV] (García & Álvarez 2007).

In the 1990s Peru constituted two new institutions with environmental agenda. The National Instutute of Natural Resources (INRENA) and the National Council of Environment (CONAM) had an administrative and a normative role (García & Álvarez 2007). The country also issued a general law of environment, and various other environmental laws, that brought its legislation better in line with the obligations of the UN Convention on Biological Diversity. These laws regulated issues such as protected areas, sustainable use of natural resources, environmental impact assessment, and use of biological diversity (García & Álvarez 2007; Solano 2005).

The 1990s also saw several propositions of a new forestry law, presented by environmental NGOs, but only by the end of the decade a Peruvian congress committee drafted a new forestry law in a process that was criticised for its lack of transparency (García & Álvarez 2007). The law was then modified, and it entered into force in 2000, with its regulations issued in 2001. The stated objective of the reform was to implement more sustainable forest management practices, while promoting the sector economically and improving its social impacts. The new forestry law contained important reforms in three aspects: spatial planning, access to forests, and forest management. According to Smith et al. (2006), however, the implementation of the new law has not particularly changed the forestry practices in the country.

Because of the policies promoting public land tenure, the Peruvian state has had the option of using scientific knowledge to determine which forest areas are available for timber production and management, as well as for the management of other forest resources. Although the Peruvian definition of forest land has a scientific basis, the main criteria used, namely soil characteristics and topographic features, have neither been used rigorously in the field throughout the country, nor documented sufficiently. This forest classification is based on the potential of different environments, but does not commit itself on determining whether a given location actually is forested.

Therefore, a new definition has recently been proposed for Peru in order to determine areas eligible for interventions under the Clean Development Mechanism linked to the Kyoto Protocol, and for monitoring the country's forest cover. According to the proposal made by the National Environmental Fund (FONAM) forest is an area that must have 1) a canopy coverage of at least 30 per cent, 2) a natural height of at least 5 meters, and 3) a stand surface of at least 0.5 hectares. The legal status of this definition is still vague in comparison to the legally binding categorisation of forest land based on the use potential of soils.

The lack of well documented and consistent methodologies in the delimitation processes, that have been applied in order to identify forest areas, render it doubtful whether the current land-use assignments can be defended as scientifically justified. However, they have served as a buffer against opportunistic private land-use and speculation, at least thus far. A recent modification proposed for the Peruvian forestry law (Legislative Decree 1090) actually comes up with an exception for the rule according to which forest land is public property. If the proposed change takes place, a vaguely expressed 'national interest' could justify the conversion of land classified principally suitable for forestry to other land-use categories.

In the current situation, at least mining, hydrocarbon exploration, cash-crop cultivation, and plantation forestry might aspire being of 'national interest'. Independently from the definitions forest may have in the future, however, both sustainable forest management and conservation require substantial investment in producing sound scientific understanding of how Amazonian forest biome has became what it is today, and how the dynamic Amazonian environment generates, maintains, and regenerates its diversity.

Understanding Amazonian diversity

Amazonian forest ecology, as well as taxonomic issues, have been studied extensively during past decades, and the region's rainforests are known to be amongst the most species-rich places on Earth (Dirzo & Raven 2003). However, there is much less consensus about the individual factors that have generated this diversity, and continuously determine its distribution. Lowland rainforests can be structurally relatively similar over vast distances, and actual differences between environmental patterns are costly to detect over extensive areas. However, there is a widely recognised need for fine resolution classification of Amazonian environment types both at country level and across national borders. Amazonian environmental history and processes, as well as landscape dynamics, have to be understood if such transboundary and transdisciplinary undertakings are to be carried out successfully.

The long-term continental evolution of the whole Amazonian region is based on tectonic activity (Rasanen et al. 1987; Räsänen et al. 1992; Räsänen et al. 1990). The Andean Cordillera is the result of the plate of Nazca sliding under the continental plate of South America. This process is still active, and has a constant effect on the Andean forelands where, as a result of tectonic forces, some areas elevate while others subside.

Simultaneously erosion and weathering produce material that river systems subsequently transport and deposit in different areas in the Amazon basin (Kalliola et al. 1993; Salo et al. 1986). The geological history of Western Amazonia also involves various marine, brackish water, and lacustrine/estuarine phases linked to the development of the Pebas megalake and wetland biomes in the Miocene, with their implications on sediment deposit patterns (Roddaz et al. 2005; Wesselingh et al. 2002; Wesselingh & Salo 2006). Furthermore, the development of the Amazon river itself, through periods of connection to the north to the Caribbean until the current outfall in the Atlantic, has also formed Amazonian landscape and soils (Wesselingh & Salo 2006).

Finer resolution processes further modify Amazonian landscape and its biotic communities. These factors include disturbance regimes driven by river system dynamics (Salo et al. 1986), other natural forces such as extreme climatic events related to El Niño-Southern Oscillation, convectional storms, natural fires, seasonal flooding, and anthropogenic disturbance, amongst others (Malhi & Phillips 2005).

The disturbance factors can be described hierarchically in spatial and temporal scales, and their effects can be seen in soils and vegetation, as well as in the regeneration potential of ecosystems at varying scales. Therefore, identification of forest types and mapping them is of primary importance for land-use, including conservation and forest management. Understanding geological processes and their outcomes is also particularly important for forestry planning.

Although environmental dynamics are now widely considered as a central explanation for Amazonian diversity, this scientific understanding is actually of quite recent origin. Only in 1969 did Jürgen Haffer's famous paper in Science challenge the, until then dominant, view of the Amazonian rainforests as stable environments. Haffer's 'Pleistocene refuge' hypothesis postulated that climate history was largely behind both the generation of species diversity and the distribution of taxa. The Pleistocene is known to have had cooler and drier periods, and according to the advocates of the Pleistocene hypothesis Amazonian forests would have cyclically reduced forming isolated speciation centres, and then expanded again enabling species dispersion (Haffer 1969, 2008; Haffer & Prance 2001).

A number of studies have tried to prove the hypothesis, but although Haffer (2008) has complemented his theory, and some new evidence has been suggested (Solomon et al. 2008), the Pleistocene hypothesis remains highly controversial (Colinvaux et al. 2000). The proposed refugia are not congruent for different taxa, and also severely biased collecting effort complicates the analyses (Nelson et al. 1990; Schulman et al. 2007). Furthermore, based on pollen data and climate–vegetation models the evidence is mounting that Amazonia remained generally forested during the Pleistocene[I] (Maslin 2005; Mayle & Bush 2005). Other historical dispersal-limitation factors have been also suggested to play a role in explaining Amazonian diversity patterns. Rivers can form physical barriers and limit the dispersal of organisms, but their role as biogeographical borders for different taxa is not uncomplicated (Tuomisto & Ruokolainen 1997).

Many Amazonian animal and plant species have huge geographical ranges, but especially Western Amazonia is demonstrated to harbour a fine-scale environmental mosaic (Kvist & Nebel 2001; Tuomisto et al. 1995). On the other hand, Pitman et al. (1999) have argued that most Western Amazonian tree species are widespread generalists across the landscape, and thus challenged the view of Western Amazonian vegetation as a small-scale heterogeneous environmental mosaic.

Obviously, the common tree species may not grow as dense stands but they are present in a wide range of habitats. However, Pitman et al. (2001) argue that there are common species that grow both with high frequency and high local abundance, and constitute oligarchies dominating large areas, and question the assumption that higher diversity necessarily means lower densities (Pitman et al. 2002). Oligarchic dominance in palms was also found by Vormisto et al. (2004). The issue remains debated (Condit et al. 2002; Ruokolainen & Tuomisto 2002; Tuomisto & Ruokolainen 2006) and it is probable that existing oligarchies are not in contradiction with the mosaic nature of western Amazonian environment.

Independently of the floristic patterns, forest ecosystems have an important role in global climate and carbon cycle, which has drawn a considerable scientific interest to Amazonian forests during the last decade. A number of studies have tried to detect differences in forest productivity at different temporal and spatial scales. For example, the accumulation of carbon in the forest biomass has been assessed along different environmental gradients (Baker et al. 2004; de Castilho et al. 2006; Phillips et al. 2002). In a continental analysis ter Steege et al. (2006) studied both species composition and forest functions finding two principal gradients for trees: the forests varied according to soil fertility and length of dry season. Increasing soil fertility is found to boost forest productivity and individual tree turnover. As to this gradient, Phillips et al. (2004) demonstrate that individual tree turnover increases two-fold from eastern Amazonian poor soils to the rich soils in western Amazonia. For the second gradient, the longer the dry season, the lower is the average alpha diversity (ter Steege et al. 2006).

These studies may not contribute to conservation planning from a species-centred perspective. However, they are of considerable use when forest management and use are planned on a scientifically sound basis. Regardless floristic composition, it is known that soil richness is an important variable for tree growth speed and thus for both timber quality and stock regeneration (Grogan et al. 2003; Malhi et al. 2004; Montes et al. 2003). Forestry professionals could also find it useful to know how rainfall seasonality, for example, affects not only alpha diversity, but also the stand density (ter Steege et al. 2003).

In addition to the density of tree individuals, the density of timber, or wood specific gravity, is an important attribute of timber quality. There is evidence suggesting a tendency for lower wood density in fast growing trees (Suzuki 1999) and trees growing in highly dynamic environments (ter Steege & Hammond 2001). Western Amazonian rainforest is frequently a highly dynamic environment. Thus forest classification that both recognises the deterministic production potential of distinct ecological units, and takes into account the disturbance factors, should be advocated.

Environmental determinism and heterogeneity

The importance of edaphic factors in determining floristic composition across landscape has been widely studied over the last decades. Although Clinebell et al. (1995) found that 'tropical forest species richness is surprisingly independent of soil quality', a substantial number of studies have found evidence for environmentally deterministic floristic patterns.

Yet Gentry (1988), and Tuomisto et al. (1995), suggested edaphic determinism as an explanation for the distribution of Amazonian biodiversity. Fine et al. (2005) found soil specialization in their study of 35 Burseraceae species in three western Amazonian regions. Also in the case of plant family Melastomataceae and ferns soil characteristics play a significant role as an explanation of floristic differences between sites (Tuomisto et al. 2002). Tuomisto et al. (2003) have also analysed a large dataset from western Amazonia including ferns and Melastomataceae plants. Their results support the idea of environmental determinism.

A controversy remains as to whether the available data on distribution and species turnover of trees and other plant groups is congruent. Ruokolainen et al. (2007) have found evidence of such correlation between trees, ferns, and Melastomataceae plants. Furthermore, recent evidence supports the idea of bottom-up deterministic distribution patterns, not only for plants but also for taxa on higher trophic levels (Saaksjarvi et al. 2006).

The processes through which Amazonian forest regenerates have to be understood for management recommendations to be successful. The seasonal floods, fluvial dynamics, and rapid weathering in tropical climate are associated to soil formation. Where and how these soils end up in the transportation and deposition cycles taking place through millions of years probably explain a large part of the current environmental variation in western Amazonia. The Andean tectonic activity is also an ongoing phenomenon, and even rapid changes in the fluvial systems are possible (Pärssinen et al. 1996). These in turn have an effect on the location of floodplains and tierra firme ecosystems as well as on peatland formation (Lahteenoja et al. 2009).

Amazonia is a particularly dynamic and heterogenic environment, in which the full array of different phases of processes shaping landscapes can be seen. Soil nutrient content, humidity, and slope characteristics vary across Amazonian landscape, and interact with climatic conditions, topographic features resulting from denudation processes, flooding regimes, and sedimentation. All this is reflected in the structure of biotic systems, habitats, biotopes, and communities. The heterogeneity of western Amazonian forests is undoubtedly a result of processes taking place across different spatial and temporal scales, and thus the magnitude of heterogeneity also varies at different scales.

It is not enough, however, to establish a relationship between edaphic factors and floristic patterns or forest productivity. Thus far, in land-use planning the systematic contribution of scientific understanding has been primarily seen in the development of reserve networks, while other processes determining land-use assignments have largely been based on simpler procedures.

More than a decade has passed since Tuomisto et al. (1995) 'dissected Amazonian biodiversity', and argued that only in Peruvian Amazonia natural biotope types far exceed one hundred. However, thus far neither conservation nor other land-use planning processes have been able to reach that resolution. Because of the vast extension and extreme complexity of Amazonian landscape, combined with difficult access, the region's biodiversity escapes classifications.

Materials and methods

This thesis is a part of the constantly evolving academic work carried out by the interdisciplinary University of Turku Amazon Research Team (UTU-ART). During the last three decades the group has produced a considerable body of publications exploring interactions between environmental dynamics, biological systems, and human societies in Amazonian landscape. These studies have contributed significantly to the current natural-scientific understanding of Amazonian environments.

The work I present in this thesis has been carried out in close collaboration with other members of the UTU-ART, representing various disciplines including biology, geography, and geology. Several other Finnish and Latin American scientists, with backgrounds ranging from natural to social and political sciences, have also participated in the present work. In addition to academic co-operation, I have also had the opportunity to accumulate practical experience supporting this dissertation, while working in international environmental development co-operation in Peruvian Amazonia.

The four articles constituting my thesis are based on a diverse set of materials from a wide array of sources. I have been visiting Peruvian Amazonia yearly between 1999 and 2009, and although a major part of the materials used in this dissertation were collected during the three principal study visits to Peru in 2004, 2005, and 2006, all the time I have spent in the country during the last ten years has supported the process.

The materials used in this work contain informal[I–IV] and taped semi-structured interviews[II], published and grey literature[I–V], database searches[I,IV], press media articles[II,IV], and spatial data sets[III,IV].

Because of the varying nature and reliability of these different sources of information, I have had to put special emphasis on source criticism and data triangulation. Each of the articles presented here contains a detailed description of materials and methods used therein, and here I only present an overview.

I have conducted innumerable informal and dozens of taped semi-structured interviews, and I cannot overestimated their role in forming me a picture of what kind of problematics are linked to land-use planning, conservation, and management of natural resources in Peruvian Amazonia.

Another priceless body of data providing multifaceted insight into Amazonian realities has been an article collection containing press media articles published in Peruvian Amazonia, counting in hundreds, and resulting from surveys in the archives of local Iquitos-based print press and in Peruvian libraries. This data set is supported by a thorough literature review, consisting of both published articles and books, and unpublished so called grey literature produced locally by Amazonian institutions.

Amazonian countries' environmental administrations also handle a great body of information that is available either publicly through the institutions' internet pages, or can be provided on request, for the purposes of academic research. I have used the internet-based databases of governmental institutions related to conservation, forestry, and taxation, as well as databases managed by environmental non-governmental organisations (NGOs). Some of these databases also provide spatial data, and the spatial data sets provided by Peruvian institutions, international cooperation agencies, and different NGOs, linked to data from other sources, have enabled an analysis that uses multiple overlapping and interrelated thematic data layers.

The present dissertation consists of articles that apply methodologies from both natural and social sciences. Literature review and database analysis have a particularly important role in the article I. Article II is based on interviews, media analysis, and literature review. In addition, in the articles III and IV I have applied geographic information systems, and in the article IV statistical analysis is combined to the use of a geographical information system (GIS) application.

All the articles I–IV contain a detailed description of the methods used, and here I only want to particularly emphasise the future challenge there is for finding meaningful ways to apply internet-based open-access GIS for control, monitoring, and management activities related to forestry, and the use of other natural resources related to biological diversity.

Results and discussion

Though incomplete, science has left its marks in the Amazonian landscape

Amazonian rainforests have witnessed and persisted more than 10,000 years of human presence (Roosevelt et al. 1996). Even the last few decades' mounting pressures have left around 85 per cent of the forest's original extent standing (Malhi et al. 2008; Soares-Filho et al. 2006).

However, penetrating road networks (Maki et al. 2001; Perz et al. 2008), cattle ranching (Kirby et al. 2006), industrial cash-crop cultivation (Morton et al. 2006), slash-and-burn-agriculture (Fujisaka et al. 1996), selective logging (Asner et al. 2005), and advancing urban sphere (Padoch et al. 2008), among others, have left their cicatrices in the Amazonian landscape.

Scientific information has contributed to some of these processes, but nowhere has its role been as straightforward as in their counter-measure, in conservation planning. Systematic use of scientific criteria has had an important role behind the establishment of complete networks of protected areas in different Amazonian countries[I].

Systematic conservation planning is a relatively straightforward procedure including priority-setting, analysis of existing reserve networks, complementing site selection, and subsequent management and follow-up activities (Margules & Pressey 2000). In practice the process, nonetheless, frequently suffers from the problem that planning stagnates where it should only get more complex. Once protected areas have been legally established, and the basic management documentation has been completed, the mission is often considered accomplished, or at least there are no blueprint guidelines for implementing the conservation measures in practice[II].

This is frequently due to the chronic lack of financial resources local authorities suffer, but it is also a real 'implementation problem' (Knight et al. 2006; Knight et al. 2008); compared to site selection, conservation science has had much less success in finding links between the protected areas' biological diversity, associated natural resources, ecosystem services, local human populations, and monitoring of conservation success[II].

All protected areas worldwide experience some degree of human influence. The International Union for Conservation of Nature (IUCN) has classified protected areas in six categories according to the level of protection they legally offer for biological diversity in one hand, and to the level of land and resource use they grant for humans in the other. The IUCN categories I–IV are frequently considered strictly protected, whereas sites in the categories V and VI also incorporate more explicit development goals, and may even state human activities as necessary for the original conservation values to be maintained (Locke & Dearden 2005).

Although all six IUCN categories (Ia: strict nature reserve; Ib: wilderness area; II: national park; III: natural monument; IV: habitat/species management area; V: protected landscape/seascape; VI: managed resource protected area) provide protection for natural ecosystems, many conservation scientists consider only the strictly protected areas sufficiently robust measures for effective biodiversity conservation (Locke & Dearden 2005).

If strictly protected areas are effectively enforced, they protect biological diversity and simultaneously stringently restrict human use of land and natural resources. This double effect renders it all the more important that the scientific foundations of these long-term (practically permanent) land-use allocations are well understood and assessed[I,III]. Currently more than 10 per cent of Amazonia is designated as strictly protected[I]. Three quarters of this area has been systematically selected using natural scientific theory in order to sample species diversity, thus maximising protected areas network's representativeness[I]. Therefore, scientific criteria have had, conversely, implications also on the areas that have been left outside the reserve networks[III].

Whether the knowledge used in site selection processes is sufficiently documented, let alone in accordance with current understanding of the Amazonian diversity, is another question. Systematic conservation planning involves initial analysis, in which the knowledge on the biodiversity patterns in the chosen region is assessed. Due to the complex nature of biological diversity in most contexts, surrogates predicting the distribution of desired components of biodiversity are practically always needed for this task to be completed (Margules & Pressey 2000). Similarly, distribution data is not available for the vast majority of Amazonian species, not even for those that are known to exist (Hopkins 2007; Schulman et al. 2007). Thus surrogates have had a central role in the search of protected areas representativeness in most Amazonian countries[I].

However, any of the surrogates used thus far can not be considered sufficiently reliable, or adequately documented, for safely assuming that the Amazonian protected areas network represents the full array of species diversity found in the region[I]. On the other hand it is safe to assume that even if the network of strictly protected reserves is complemented, the area that stays outside reserves will have a vital role for both biodiversity conservation and human development.

Pierce et al. (2005) argue that the outcomes of systematic conservation planning have not been efficiently incorporated to other land-use planning processes partly because conservation planning has not included analysis instruments, which would be directly useful for land-use planning. Instead the emphasis has been in finding priority sites for conservation.

Yet a number of spatial planning processes applied in Amazonia have involved use of surrogates for prediction of land-use potential in varying environments, the methodologies and exact criteria used are rarely adequately documented[I–IV]. This renders it difficult to analyse their scientific basis. For example, Peruvian Amazonia has been divided between several major land-use assignments, of which particularly protected areas[I] and production forests[III], covering considerable areas, have been delimited on the basis of environmental surrogates. However, both of these important undertakings have been carried out without systematic and published documentation. Production forests and protected areas network also harbour substantial internal variability, which has not yet been described in detail neither for management purposes nor for monitoring timber flows[III], or evaluating success of conservation goals[I].

It is clear that environmental heterogeneity and landscape dynamics should be better taken into account when protected areas networks are planned[I], but finding high resolution tools for an analysis contributing to efficient land-use planning might actually be at least as urgent as complementing the existing conservation priority schemes[III, IV]. Due to protected areas not being known as particularly flexible land-use assignments, conservation decisions are usually considered irreversible (Costello & Polasky 2004; Strange et al. 2006). Thus it is important that the scientific basis, and the criteria used in their designation, should be well documented and justified[II], as well as the spatial scales on which the success is measured should be determined.

Expert power has contributed to ‘anecdotic conservation’

Although Manolis et al. (2008) argue that conservation science may lack leadership, and inspired by the concept of adaptive governance by Brunner (2005), claim that ‘adaptive leadership’ is needed, many leading conservation scientists have had an important role in the development of priority-setting processes (Brooks et al. 2006).

Sometimes scientists have also contributed directly to decisions creating new reserves[II]. In these cases they most probably have had the state-of-the-art science at their disposal. Still, if a nationwide conservation priority map is drawn by a hundred scientists in a workshop[I], can that procedure be considered systematic use of scientific criteria? Although expert-knowledge is usually biased towards well-known taxa and areas (Knight & Cowling 2007), there is certain basis for considering biological priority-setting methods value-free. However, the outcomes of such undertakings never are disconnected from the values people have. Thus there also is a risk of applying scientific information as value-free, where it, in fact, cannot be considered so.

The values scientists advocate, and their perceptions of the relationships between biological and other criteria define also their choices when priorities are articulated in maps[I] and in management planning[II]. Scientists and experts have had, and still have, a substantial role in the development of conservation criteria, but the role of international NGOs, in which many experts work, has grown steadily (Rodriguez et al. 2007). This has partly happened at the expense of traditional academic institutions that apply time-consuming scientific publishing procedures[I].

This development may have streamlined the priority-setting processes in conservation, but has also caused criticism. For example the Rapid Assessment Processes (RAP) and Rapid Biological Inventories (RBI), may have their success stories (Hayden 2007), but rapid processes have frequently a limited reliability precisely because in a short time sample sizes and scopes are limited (Stem et al. 2005). This can lead to the perception of nature conservation as something anecdotic.

In fact, the analysis of how scientific information has been historically used in land-use or conservation planning, and what other types of information have been used alongside, is currently surprisingly difficult to undertake[I–III]. Although rapid processes have directly contributed to reserve establishment[I,II], and sometimes urgent measures are needed, the scientific base of such approaches can also be criticised. In some cases conservation priorities actually are predetermined by experts on the basis of their personal knowledge, but the hard and appealing facts have to be teased out in the field in order to justify the political conservation decisions.

This is far from the ideal goal of conserving sites that have been selected as priorities in transparent and scientifically sound procedures that incorporate more than mere biological criteria, let alone individual species occurrence data. Indeed, this could be seen as an example of ends justifying the means used, when ideally in conservation science means should justify the ends.

A challenge for spatial analysis: how to promote forest management?

In all circumstances interactions between protected areas and surroundings should be inherently incorporated in the planning methodologies applied (Hansen & DeFries 2007). Similarly the management of natural resources outside protected areas has to be carried out in coordination with the conservation measures enforced within reserve boundaries.

For example, illegal logging of mahogany *(Swietenia macrophylla)* in the vast Pacaya Samiria National Reserve, in Peruvian Amazonia, is currently likely to be linked to the implementation of forest concessions on the opposite side of the Ucayali river (Álvarez 2005). Studies explicitly addressing the interactions between concession management, timber laundering, law enforcement, and environmental dynamics determining the production potential and regeneration of mahogany populations are thus urgently needed.

Frameworks have been proposed for incorporating the outcomes of systematic conservation planning also into other land-use planning processes (Pierce et al. 2005). Conservation planning still seems to be more reactive than proactive in its approach. Thus land-use planning schemes inherently searching positive outcomes, instead of looking for places where restrictions are imposed, will be needed. These contributions could be, for example, the identification of areas specifically suitable for agroforestry, timber production, or other productive activities, or combinations of them. Planning conservation and land-use should not be unidirectional[I], and once land-use assignments have been delimited, follow-up should be always carried out.

For example, ecosystem services provided by a protected area[II], or timber flow originating in forest concessions, should be quantified and related to environmental variables that can be spatially analysed[III].

After Brazil, Peru has the second largest forests in Latin America, of which around 90 percent are in Amazonia. Forestry is an important activity in Peruvian Amazonia both in economic and socio-political terms (Tello Fernández et al. 2004), but demanding bureaucratic processes for securing logging rights, high level of poverty, and widespread unemployment have contributed to the current situation in which logging is frequently carried out without legal authorisation (Chirinos & Ruiz 2003).

An estimated magnitude of 80 per cent of Peruvian logging is to some degree illegal (Chirinos & Ruiz 2003), and Smith et al. (2006) point out that decades of failures in governance and norms in Peru complicate the improvement of forestry practices in spite of radical reforms in legislation. The lack of efficient control has enabled small-scale individual loggers to extract timber practically from anywhere for decades, and the formal contracts they have subscribed, have only worked for legalising the timber at some point in the transportation and production chains (Dourojeanni 1990).

According to a World Bank (2006) report, among 17 countries with extensive forests the percentage of timber logged illegally varies between 10 and 90 percent (50 per cent of the total), and causes the annual loss of around 15 billion dollars worldwide. A number of global initiatives such as FAO's Tropical Forestry Action Programme, ITTO Process, Amazonian Process, CIFOR Process (Owubah et al. 2001) and the Tarapoto Process (Elías 2004) as well as several forestry legislation reforms (Silva et al. 2002; Smith et al. 2006) have addressed the problem. Meanwhile, the root causes and mechanisms of illegality and informality in forestry vary across contexts, and thus there is no blueprint solution applicable in all countries with forests. Rather local solutions have to be found taking into account the external conditions that also drive illegality.

According to Grieser Johns (1997) there is a clear gradient in Amazonia, showing up to 60 timber species commercially logged in the eastern parts of the region, whereas in the isolated Western Amazonia only few species can be commercially logged. In Peru usually no more than a few of the most valuable species are logged, and these normally are light-weight species that can be floated (Smith et al. 2006). Thus it is common that only the most valuable timber is skimmed off the forests, an activity that still causes collateral damage to the rest of the vegetation (Schulze & Zweede 2006) and pressure to the fauna in the affected localities (Peres 2001).

In Peruvian Amazonia practically all transport of timber involves river network at some stage, and timber has to be floated or shipped with corresponding transport documents. These papers are supposed to tell the origin and destination of the timber transported. Controlling the river transport is possible at least at watershed level, if control posts are located in the river mouths. Meanwhile, timber laundering (Smith et al. 2006) can be performed using a combination of forest inventories, logging records, and transport documents, each of which can be truthful, slightly modified, or completely fabricated.

Although ground truthing is the only accurate way to detect infractions, also the lack of actualised information on the species composition and volumes in the concession forests renders it difficult for the authorities to control timber extraction. Because no substantial investment in improved control and enforcement is likely to appear in the near future, enhancing the monitoring of logging, timber transport, and commercialisation may be the most feasible solution, at the moment, for improving the situation.

A real-time GIS-based monitoring system could detect at least significant changes in the forestry regime immediately after they occur, which would facilitate the allocation of limited controlling efforts, and would also help focusing further studies on the underlying reasons for these changes in the timber flow. An open-access system managing the constantly accumulating official logging record, and linking it to environmental information, access related variables, transport documentation, and data generated in the control posts, could facilitate the control, and simultaneously contribute to the feasibility studies and management planning of forestry. The analysis could be carried out at chosen spatial scales (e.g. individual concession or watershed) depending on the accuracy of the input data. Although there are serious problems in sharing biodiversity related data for monitoring purposes worldwide (Bertzky & Stoll-Kleemann 2009), the public nature of many environmental and production related data in Peru would enable interesting innovations (Kalliola et al. 2008).

The use of traditional GIS applications often requires specific skills, but recent development of internet-based GIS services can increase the use and public access to such systems (Butler 2006; Karnataka et al. 2009). The open-access nature of a monitoring system would enhance mutual control, involve scientists and NGOs. It would neither violate the rights of the concession holders, since many of the data is already public, although difficult to access. Links between environmental data, and records dealing with use, management, control, and commercialisation of natural resources, such as timber, could thus be cost-effectively established at different resolutions.

Amazonian landscape still evolves through the small and the local

Contrasting to many other tropical countries (Perez et al. 2005; Wunder 2005), Peruvian forest concessions are almost exclusively in the hands of small to medium-sized private sector domestic and usually local actors[IV] (Putzel et al. 2008). While Peruvian forest legislation is based on international environmental standards and focused on promoting private incentive, forestry practices, in turn, are regulated by local norms and locally enforced governance systems (Smith et al. 2006). Similarly local knowledge still plays a substantial role in the production chain, and investment in scientifically justified management practices is low.

However, there are Amazonian examples of local population successfully importing and transforming exogenous knowledge and technology for local use (Sears et al. 2007). Amacher et al. (2009) have found, that in Brazilian Amazonia smallholders selling timber for intermediary merchants are responsible for a considerable part of actual timber extraction, although forest concessions are too expensive for them to acquire and manage. Also in Peru a large part of logging takes place outside of forest concessions, and is carried out by individual loggers supplying timber to forestry industrialists through middlemen.

Although available scientific knowledge would be useful when decisions are made concerning the use and management of natural resources, the resolutions frequently do not meet; the spatial resolution of environmental data cannot be cost-effectively applied at scales small enough. In one hand, existing scientific information in Peru is not available for all stakeholders[IV], and in the other, management recommendations and planning required are based on scientific knowledge that actually does not exist in a useful format. The same is likely to be true for agriculture, agroforestry, non-timber forest resources, and logging. Similarly, many small and local actors have substantial roles shaping Amazonian landscape, but their needs and the scientific information do not meet.

There is also a reverse problem; small and local actors possess direct information on the resource stocks, regeneration potential, and other such variables, but this knowledge is not reflected in larger scale spatial planning. For example, according to Rocha et al. (2006) uncertainty over timber volume within Brazilian forest concessions decreased the concession value by 10 per cent.

In the Peruvian case, however, it can be argued that uncertainty can also pay. Without good knowledge on the volumes of valuable timber species such as mahogany within the concessions, it is easier to overestimate the stocks in order to fabricate false documents for laundering timber that has been logged elsewhere (Smith et al. 2006). Thus there might often be a gap between the resolutions at which the small and the local actors operate in one hand, and authorities manage the official data on resource stocks in the other.

Soils determine land tenure and use, but data quality and resolution do not meet

In Peru several recently created protected areas have been established in sites that have been identified as conservation priorities[I]. For example, the National Reserve of Allpahuayo Mishana in north-east Peru was created in 1999 in a site identified as belonging to the national priority areas for conservation[II] (Rodriguez & Young 2000). The reserve's history is an illustrating example of the implications different land-use allocations and land tenure issues may have, when they are based more on political necessity than on serious planning. Allpahuayo Mishana's biological diversity, soils, and socio-economic setting are actually relatively well known on Amazonian standards[II], but no efficient land-use planning was implemented in the area prior to the recent conservation efforts.

Allpahuayo Mishana mostly consists of public lands, of which a part have been titled to state institutions (Plan Maestro 2005). However, prior to the reserve creation parts of the site had also been parcelled out as private properties, and furthermore, the forests of Allpahuayo Mishana had been used for decades by resident population with traditional communal usufruct, but no legal land titles[II]. These different stakeholders had distinct interests in terms of the land itself, the natural resources it provided, and the ecosystem services it generated[II].

Peruvian authorities have identified a part of the soils found in the area as suitable for agriculture or grazing. And because those land-use categories enabled the selling of land, a conflict-prone land-use pattern had emerged in the area. At least some of the lands that were classified for agriculture or use for pasture, however, cannot be considered appropriate for those activities.

When the scientific paradigm explaining Amazonian diversity started to change in the 1960s and 1970s, in Peru also the ways in which land and natural resources were treated started to change (García & Álvarez 2007). That in turn, had implications on the basis of land-use planning. Soils began to have an important role, but the lack of high-quality data played down the efforts to really reach a satisfactory understanding of the use potential of soils in different parts of the country at a sufficient resolution.

Because high-resolution classification according to soil characteristics has not been available for the whole extent of Peruvian Amazonia, but there has been an urgent need to respond to the soaring pressures for agricultural expansion, land-use decisions have been taken without considering all the necessary preconditions (Maki et al. 2001).

Amazonian landscape is a rich patchwork of interrelated formal land-use assignments and traditional usufruct areas[III]. In this kind of challenging context, it is all the more important that conservation science assumes tasks more complex than merely predicting species distributions and assessing gaps in protected areas coverage[II]. All the more so, because the final step from mapping priority sites for conservation to effectively establishing protected areas involves several multifaceted issues such as legislative frameworks, multi-scale politics, and socioeconomic realities, that must be taken into account when conservation is brought from maps to the field[II].

These issues cannot be reliably dealt with, if interactions between protected areas and other land-use assignments are not seen as a part of the Amazonian human and natural landscape. Land-use conflicts related to ownership, entitling, and usufruct are probably the subjects that cause the most acute and urgent problems when different land-use areas are currently delimited. Identifying and quantifying ecosystem services, spotting, predicting and resolving land-use conflicts, assuring and regulating resource access and use, and addressing multi-scale political and power relations, are among the key issues when Amazonian protected areas networks are complemented in the future[II].

Ecosystem services divide and connect stakeholders at different scales

There is evidence that conservation projects explicitly emphasising ecosystem services attract more financial resources than projects that only stress biodiversity issues, without simultaneously compromising protected area establishment (Goldman et al. 2008). Local and regional level ecosystem services have also been used as justification for decisions creating protected areas[II]. A Brazilian program promoting payments for ecosystem services (PES) to smallholders has shown limited success (Hall 2008), but overall the PES projects so far have to prove their promises of improved biodiversity conservation (Goldman et al. 2008).

Currently projects proposing and assessing direct valuation of ecosystem services in Peru are mostly related to climate change. Reduction of Emissions from Deforestation and Degradation (REDD) projects pursue both finding direct financing for conservation and indirect benefits through carbon sequestration and biodiversity conservation also outside protected areas networks (Ebeling & Yasue 2008).

Solving the technical problems of establishing deforestation baselines, quantifying the deforestation that REDD projects would prevent, and associated carbon sinks accurately enough, and taking into account the possible leakage (i.e. the deforestation actually not prevented but rather moved elsewhere) (Laurance 2008) are not the only challenge of ecosystem service approaches in conservation. Similarly other land-use and other environmental services should be taken into account.

Forest ecosystems are not mere carbon storages, and when land-use projects are implemented there is a serious risk of compromising the local population's already fragile rights over traditional lands with no legal ownership (Laurance 2008). These allegations may sometimes be exaggerated, but at least in the Peruvian context, with traditional lands poorly recognised, and new private property access regimes proposed (as in the proposed Legislative Decree 1090), the fears are reasonable.

Ecosystem services can be identified at extremely varying scales. The most intangible of these services are future benefits that coming generations will enjoy. For example, climate change mitigation by prevented deforestation and existence value of plants or animals yet unknown to science are such benefits. However, these benefits have been emphasised in public debates concerning conservation[II].

Many other ecosystem services are much more concrete, yet maybe not much easier to quantify. For example, forests can provide timber and non-timber products, protect soils from erosion, regulate hydrological cycles, and provide clean water for urban population[II]. Although involved actors range from local households to future generations at global level, the benefits protected areas generate can be articulated in concrete terms if ecosystem services are quantified. Techniques are constantly being developed to assess this complex issue (Chopra & Dasgupta 2008; Krishnaswamy et al. 2009; Naidoo & Ricketts 2006).

Management and monitoring can contribute to scientific understanding

In many parts of the world human-saturated land-use patterns have evolved (Ellis & Ramankutty 2008) resulting from centuries of agricultural and urban development. In such a setting science inevitably has to adjust to the existing land-use patterns rather than to shape them. In Amazonia land-use planning is carried out in a landscape that, compared to most other places on Earth, can well be called wilderness.

The use and the conservation of Amazonian forests are so intertwined, that the relatively intact forest cover Peruvian lowland Amazonia still presents, allows interlinked conservation planning and management efforts. Respecting and promoting the ancestral rights of the indigenous population of Amazonia forms a constant and ever more urgent challenge for Peruvian government authorities. Even so, there is a particularly ample room for manoeuvre when land-use is planned in Amazonian rainforests, particularly due to the public land ownership that reigns in the region. Thus science potentially has a profound role providing guidance for decision-making processes.

Science can contribute to the development of active-adaptive decision-making systems for land-use planning in Peru and in Amazonia. The challenge is substantial, given the extreme environmental and cultural diversity, the acute development needs, the multiple socio-economic pressures, the political plurality, and the high level of uncertainty that all these issues inherently entail in the region. Nevertheless, instead of putting all faith in the traditional “trial and error management”, active-adaptive management (Jacobson et al. 2009) can find possible solutions to problems before they even emerge.

Although human-nature systems are always complex and context-specific, solutions are available for testing different future scenarios of natural resources management and conservation. There is no time to lose; it is urgent to start constructing open-access information systems linking spatial data to accumulating environmental and biodiversity information, as well as to the record concerning use and management of natural resources.

In Amazonia there is an urgent need for internet-based GIS applications that continuously collect and organise information from empirical studies, museum specimens, and, very importantly, from production chains monitored by state authorities. Current technology for remote sensing, georeferencing, and dealing with data in (geographical) information systems, in addition to the development of algorithms designed for evaluating land-use options, enables very complicated spatial analyses (Ducheyne et al. 2006; Malczewski 2006; Sante-Riveira et al. 2008), and the integration of GIS applications and algorithms in land-use planning has been extensively studied at least since early 1990s (Malczewski 2006). Moreover, open-access GIS services are technically feasible, and enhance the use of the produced information by different stakeholders (Guralnick & Neufeld 2005).

Knowing enough is not enough

Although technically advanced methods and tools are increasingly available for land-use planners and scientists alike, there are noteworthy examples illustrating the complicated relationship between scientific knowledge and land-use management. Finnish forests are large in European standards, but compared to Amazonian or Peruvian forests their environmental variation and species composition are exceptionally well known.

Even so, Finland has neither been able to conserve its forest biota adequately, nor to manage its forests in a way that all stakeholders would consider even nearly sustainable. Finnish forests have been studied and scientifically managed for a century now (Siiskonen 2007), but serious discrepancies still exist between different stakeholders both regarding forest conservation (Hanski 2005) and sustainable management (Siiskonen 2007).

Although boreal forests differ greatly from Amazonian rainforests in their biotic, edaphic, and socio-economic characteristics, there are important lessons to be learnt from our forests and from their management, as well as from their conservation. A considerable part of Finnish forests belong to private smallholders, and forest production has been based in Finland on strict enforcement of management recommendations (Siiskonen 2007).

However, all the recommendations forest science has provided, and forestry authorities subsequently enforced, have not been readily accepted by the majority of conservationists, or even by all the small forest owners preferring traditional lower impact management (Siiskonen 2007).

Finnish forests have been managed mostly on the basis of criteria, that link edaphic factors and productive potential of forest land, and in fact the main goal of forest management has been to maximise timber production. Indeed, in Finnish forests timber production has been considerably successful, but has also prevailed over biodiversity and other non-timber values for decades. Even the definition of forest itself is conditional to the growth of trees; only areas with a forest growth potential exceeding the average annual increment of 1.0 m^2 per hectare are considered productive forest land. Finnish forests are currently growing faster than perhaps ever, but simultaneously they are losing biological diversity at an alarming pace (Hanski 2005).

Thus the impressive scientific effort Finnish forests have received has not solved all problems related to their use, management, and conservation. Nonetheless, this does not mean that scientific information does not have use in the pursuit of finding solutions, but rather that quality information alone is not enough. The same is obviously true both in Finland and in Amazonia.

Science is a never ending endeavour to know and explain better the things that we experience. However, knowing when we know enough is only a part of the problem. The modest success science has had in modifying land-use management in Amazonia compared to the success-story of Finnish bulk production of timber can be seen from an alternative viewpoint if we also contrast the possible future scenarios available for scientific management in these two forest environments.

Compared to the well studied Finnish forest environments that are basically all in intensive use, Amazonia is still in many aspects an uninventoried and pristine frontier. Amazonian rainforests are amongst the most diverse and complex ecosystems on Earth, and while we increasingly understand their composition and functions, the failures to communicate this understanding (Pitman et al. 2007) and to apply it in land-use are as serious as ever.

Nevertheless, in Amazonia, if somewhere, there are still open options for a major shift in paradigms considering the role of science and scientists in decision-making processes. This however, may entail more than just fine-tuning the science–policy interphase. In Amazonia the gap between scientific knowledge available, and the actual information used as a basis for decisions with environmental repercussions is very real, and there is no certainty whether the leap from theory to practice is getting shorter.

One of the key bottlenecks in Amazonian land-use planning is the fact that a large part of the primary data collected and managed by both environmental authorities and scientists remains inaccessible for most users. This may well be called lost effort, and it hinders the participation of scholars and civil society in general in the search of better management of natural resources and ecosystems. In the end, improved access to data and information would also enhance the process of democaritisation of science. Similarly, scientists should maybe better acknowledge that science itself has a very limited capacity to force changes in policies, let alone in land-use practices.

This precicely is why scientists should be much more sensitive and open-minded in their interactions with the diverse actors they wish to help to make better, and better informed land-use decisions. Likewise, more emphasis should be placed on seriously studying the needs of the end users of scientifically produced information and knowledge.

The practical value and usefulness of scientific information should be seriously assessed using the same standards of rigurous scrutiny, that we expect from science itself. This is a great challenge for scientists addressing local phenomena with global repercussions, and facing the environmental crisis.

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