Linking tropical silviculture to sustainable forest management

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Undisturbed tropical montane rain forest in Costa Rica.
Photograph S. Günter.

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RÉSUMÉ

LIER LA SYLVICULTURE TROPICALE À LA GESTION FORESTIÈRE DURABLE

Depuis l'émergence du concept de la « gestion durable des ressources » dans les dernières décennies du XXe siècle, les aspects écologiques, technologiques et socio-économiques constituent les piliers de la gestion forestière durable. Alors que la production de bois et de produits forestiers non ligneux (PFNL) a longtemps été l'objectif premier de la gestion forestière, la demande de services forestiers écologiques s'accroît aujourd'hui en parallèle. Cependant, les systèmes de gestion forestière tropicale ont été conçus pour la plupart il y a fort longtemps, avec pour but principal la production de bois. Cet article présente une approche en six étapes pour passer de la sylviculture tropicale classique axée sur la production de bois à des approches plus globales visant à assurer une gestion réellement durable des ressources forestières. Cet objectif est particulièrement important sous les tropiques, où la production de bois est désormais menacée par un rythme de déforestation alarmant et par l'importance accrue des ressources forestières pour assurer la subsistance des populations locales. L'augmentation des superficies forestières concurrence fortement les autres objectifs d'utilisation des terres, et l'intensification permettant d'accroître la production à l'hectare est donc une approche prometteuse pour résoudre ce problème majeur, par exemple par la mise en œuvre des techniques sylvicoles à rotations courtes, la domestication d'essences ou l'aménagement des sites. La diversification des structures et des services forestiers est une stratégie complémentaire importante visant à remédier à la dégradation éventuelle des forêts et aux pénuries d'autres biens ou services, et de ce fait à contribuer à la gestion durable à l'échelle d'un paysage. Les échelles de gestion, temporelles et spatiales, doivent donc être adaptées aux besoins des exploitants forestiers individuels (pour la production de bois, par exemple) mais aussi à ceux de la collectivité (eau, biodiversité, stockage du carbone…). La gestion forestière durable dépend fortement de son acceptation par l'ensemble des intéressés, et les approches participatives peuvent y contribuer de façon significative. Cet article présente des exemples montrant comment l'intégration de la sylviculture et de la gestion forestière permet, en englobant tous les aspects indiqués ci-dessus, de contrer la gestion de conception purement extractive pour aboutir à une approche sylvicole moderne en termes de gestion adaptive de l'écosystème. L'autonomie des acteurs sociaux et des mécanismes de marché opérationnels pour les produits et services autres que le bois sont des éléments incontournables de la planification sylvicole moderne, mais n'ont aucune utilité pour la gestion forestière durable tant qu'ils ne s'accompagnent pas d'une solide connaissance des fonctions et processus écologiques et d'une bonne compréhension des impacts des interventions humaines. La sylviculture tropicale et la gestion durable des forêts dépendent l'une comme l'autre de la connaissance des écosystèmes et de son application pratique sur le terrain.

Mots-clés : gestion forestière durable, sylviculture, diversification, mitigation, échelles temporelles et spatiales, approches participatives.

ABSTRACT

LINKING TROPICAL SILVICULTURE TO SUSTAINABLE FOREST MANAGEMENT

Since the term "sustainability" appeared in the last decades of the twentieth century, ecological, technological and socioeconomic aspects have been the main pillars of sustainable forest management (SFM). While timber production and NWFPs were the dominant aims of forest management in the past, demand increasingly includes the provision of environmental services. However, most silvicultural systems in the tropics were designed many decades ago with a strong focus on timber production. This paper discusses six steps to bridge the gap between classic tropical silviculture geared to timber production and more comprehensive approaches for sustainability in forest management. This is of particular importance in the tropics, where timber production is faced with alarming rates of deforestation and the increasing importance of forests for subsistence needs. Since forest expansion is in strong competition with other land use aims, intensification to increase timber output per unit area is a promising approach to overcome this major problem, for example through short-rotation forestry, species domestication, site improvement, and other measures. Diversifying forest structures and services is important as an additional strategy to mitigate possible environmental damage and shortages in the provision of other goods and services, and therefore to contribute to sustainable management at the landscape level. Scales of management, both temporal and spatial, therefore have to be adapted to the needs of individual land owners (e.g. for timber production) as well as to the collective needs of societies (e.g. water, biodiversity, carbon sequestration). Sustainable forest management is very dependent on acceptance by all stakeholders involved. Participatory approaches can contribute significantly to sustainability in this context. This article illustrates how the integration of silviculture and forest management, including all the aspects mentioned above, can counteract the frequently applied "timber mining" approach and lead to a modern approach to silviculture in terms of adaptive ecosystem management. Social empowerment, and functional market mechanisms for products and services beyond timber are essential components of modern silvicultural planning, but they are of no use to SFM if they are not accompanied by a sound understanding of ecological functions and processes and the impacts of human interventions. Tropical silviculture and SFM depend on ecological knowledge and on its practical implementation in the field.

Keywords: sustainable forest management, silviculture, diversification, mitigation, temporal and spatial scales, participatory approaches.

RESUMEN

VINCULAR LA SILVICULTURA TROPICAL AL MANEJO FORESTAL SOSTENIBLE

Desde la aparición del concepto de "manejo sostenible de recursos" en las últimas décadas del siglo XX, los aspectos ecológicos, tecnológicos y socioeconómicos constituyen los pilares del manejo forestal sostenible (MFS). Aunque la producción de madera y productos forestales no madereros (PFNM) han sido durante mucho tiempo los objetivos principales del manejo forestal, actualmente la demanda de servicios forestales ecológicos se incrementa de forma paralela. Sin embargo, la mayoría de sistemas de manejo forestal se diseñaron hace muchos años, teniendo como objetivo principal la producción maderera. Este artículo presenta un enfoque en seis pasos para pasar de una silvicultura tropical clásica orientada a la producción de madera a enfoques más globales que persiguen garantizar un manejo realmente sostenible de los recursos forestales. Este objetivo es especialmente importante en los trópicos, en donde la producción maderera se ve ahora amenazada por un ritmo de deforestación alarmante y por la creciente importancia de los recursos forestales para garantizar la subsistencia de la población local. Dado que el aumento de áreas forestales se encuentra en fuerte competencia con los demás objetivos de uso de las tierras, la intensificación que permite incrementar la producción por hectárea es un enfoque prometedor para superar este grave problema mediante, por ejemplo, la aplicación de técnicas silvícolas de rotación corta, la domesticación de especies o la mejora de los sitios. La diversificación de estructuras y servicios forestales es una importante estrategia complementaria para paliar la posible degradación de los bosques y la escasez de otros bienes y servicios y, por consiguiente, contribuye al manejo sostenible a escala del paisaje. Hay que adaptar, pues, las escalas de manejo temporales y espaciales a las necesidades de los propietarios forestales individuales (para producción maderera, por ejemplo), pero también a las necesidades colectivas de la sociedad (agua, biodiversidad, almacenamiento de carbono…). El manejo forestal depende en buena medida del grado de aceptación de todos los interesados y los enfoques participativos pueden contribuir de modo significativo. Este artículo presenta ejemplos que muestran cómo la integración de la silvicultura y el manejo forestal, al incluir todos los aspectos antes mencionados, pueden contrarrestar un manejo de concepción puramente extractiva y dar lugar a un enfoque silvícola moderno en términos de manejo adaptativo de los ecosistemas. El empoderamiento social y la existencia de mecanismos de mercado operativos para otros productos y servicios, además de la madera, son componentes esenciales de la planificación silvícola moderna, pero no son de ninguna utilidad para el manejo forestal sostenible si no van acompañados de un sólido conocimiento de las funciones y procesos ecológicos y una buena comprensión de los impactos de las intervenciones humanas. La silvicultura tropical y el manejo sostenible de los bosques dependen del conocimiento de los ecosistemas y de su aplicación práctica sobre el terreno.

Palabras clave: manejo forestal sostenible, silvicultura, diversificación, mitigación, escalas temporales y espaciales, enfoques participativos.

Introduction

Managing forests without considering the impacts of interventions on an ecosystem is as old as humankind. The increasing human population and pressure exceeding the regeneration capacity of forest ecosystems causes destruction of wilderness and loss of biodiversity, e.g., by overhunting of animals and intensification of agriculture several thousand years ago (EASTWOOD *et al.,* 2007; HORAN *et al.* 2003) or over-exploitation of high timber-value species such as mahogany (*Swietenia* spp.) in Central America starting some 100 years ago (LAMB, 1966). Although early in human history the main aims were collecting non-timber forest products (NTFPs) and hunting, in recent centuries the main focus of forestry was on harvesting timber. The term "sustainability in terms of sustained yields has been introduced to European Forestry already by Hans-Carl von Carlowitz in the 18th century. Since then the requirements and aims of sustainable forest management (SFM) have changed to increasingly meet also social objectives, and to explicitly consider also products other than timber (BENSKIN & BEDFORD, 1995). A comprehensive approach of sustainability has been established by the so called "Brundtland Report" of the World Commission on Environment and Development (WCED, 1987). There is broad consensus among scientists that ecological, technological, and socioeconomic aspects are the main pillars for silviculture and sustainable forest management (BRUENIG, 1996; DAWKINS & PHILIPS, 1998; GÜNTER *et al.*, 2011; PUETTMANN *et al.*, 2009; SMITH *et al.*, 1996; WEBER-BLASCHKE *et al.*, 2005).

Consequently, new challenges arise for forest management and silviculture because of the need to fulfill the demand for products such as timber and NTFPs, and provision of services including water on a local or regional scale and conservation of biodiversity and mitigation of climate change on a global scale. A prerequisite for this more comprehensive approach of silviculture are a suitable political context and markets which allocate appropriate payments for NTFPs and forest services to the land owners and users. Well managed forests are also of particular importance for agriculture: the "presence of well managed forests in critical areas, in certain types of watersheds, is an absolute necessity if tropical agriculture is to flourish, if tropical food supplies are to be sustained in brittle, fragile ecological areas, and if hunger and malnutrition are to be contained" (KING, 1997).

In the context of sustainable forest management, the definition of silviculture has consequently shifted from a focus only on timber production to more comprehensive approaches. The various definitions integrate the requirements of the whole society towards the forests. These more comprehensive definitions explicitly reflect the concern for ecosystem functions and products and services far beyond timber production. Modern definitions link silviculture and sustainable forest management, for example:

- Silviculture is designed to create and maintain the kind of forest that will best fulfill the objectives of the owner and the governing society. The production of timber, though the most common objective, is neither the only nor necessarily the dominant one (SMITH *et al.*, 1996).

Undisturbed tropical low land rain forest in Ecuador. Photograph S. Günter.

- Silviculture investigates the consequences of decisions about the treatment of forest ecosystems in order to fulfill present and future human needs (KNOKE, 2010).

These more comprehensive silvicultural approaches are much more complex and consequently demanding in terms of planning and implementation than the "simple" sustained yield approach, which addresses only the stable provision of timber. But, is it feasible to include multiple human needs into silvicultural concepts considering increasing claims of land use, and facing global problems such as climate change and poverty? Which strategic pathways have to be established for tropical silviculture to embrace all dimensions of sustainability? This paper attempt to summarize the scientific discussion about possible strategic implications of modern tropical silviculture beyond production of timber.

Intensification of Management and Silvicultural Treatments

"It should be possible to grow most of the wood humans need in managed plantations, and hence eliminate the need to log wild forests." This statement of SEDJO (1999) pinpoints two major aspects of intensive management, first, the extraordinary potential of managed plantations for efficient production of timber, and second the importance of connecting plantation forestry with conservation issues in natural forests, and thus contribute to unburden natural forests for improved conservation of biodiversity or ecosystem services. The more intensive the production of forest products at one site, the more effectively can the protection functions be realized at other sites. In this sense, intensification of timber production in plantations can also be regarded as a conservation strategy when conservation efforts can be implemented complementary in spatially segregated areas, for example in protected areas. But in spite of great efforts in intensification of plantation forestry and, contrary to the statement of SEDJO quoted above, it may not be possible or desirable to exclude all natural forests from utilization. In practice even many protected areas are subject of illegal logging, hunting or other extractive activities. Forest management in natural forests outside of protected areas will likely become necessary to fulfill growing demands for forest products of local populations, and avoid their conversion into agricultural land. Given that there are limits to the area of forest that can be totally protected, conserving tropical forest biodiversity will depend a great deal on strategies for protecting biodiversity in areas where timber is harvested (FREDERICKSEN & PUTZ, 2003). This management intensification should not necessarily be directed toward increased timber exploiting strategies, but rather toward improved quality characteristics of the harvested timber by more sophisticated silvicultural techniques. In general, to be compatible with conservation issues intensification in plantation and natural forests should comply with the following requirements:

- Adequate spatial distribution of production and conservation areas: for example, maintenance of a complex landscape matrix, including a well-composed mixture of forest plantations of different type, size, and shape.
- Delineation of buffer zones and corridors: forest plantations should not disturb the connectivity among remaining natural forest patches; strict protection of conservation areas, or of areas that are prone to disturbance, degradation, erosion; halting road building or commercial logging in centres of diversity and endemism.
- Application of dynamic conservation strategies: for example: preference of indigenous species; maintenance or improvement of connectivity among forest fragments; and conservation of natural understory and genetic diversity.
- Effective land use planning: participation of stakeholders to mitigate conflicts; proper classification of soil types, zoning to determine intensity of interventions.
- Stable environmental policies: Clear property rights; establishment of land cadastres; effective institutions.
- Effective control: application of forest product certification, proof of origin and chain of custody certification to counter illegal logging.

Since most tropical landscapes are located in developing countries in which institutions and governance structures are commonly weak, one or more of the above-mentioned requirements may not be effectively fulfilled in practice. However, gradually higher intensity of management in planted and natural forests is an important means for meeting the increasing demand for timber.

Subsequently, we will highlight important aspects for management intensification in plantations and in natural forests. Our concept of "intensification" goes beyond that of "spatial segregation of uses or zoning" as discussed by DIACI *et al*. (2011) because the increasing demand of forest products and services most likely will depend on higher productivity and efficiency of forest management practices in addition to spatial segregation.

Intensification of plantation forestry

Domestication and tree improvement

Many indigenous plantation species are still in a very early stage of domestication (FINKELDEY, 2011) limiting the yield and/or quality of the timber and NWFPs produced. For example, for the establishment of plantations, very often noncertified or low quality reproductive material (seeds and seedlings) of unspecified regional origin is used (STIMM *et al.*, 2008). Consequently, tree improvement or domestication programs offer huge opportunities for plantation forestry. The example of *Eucalyptus* in Brazil shows that such efforts can increase the yield of plantations by a factor of five (CAMPINHOS JR., 1991; cited in SAWYER, 1993). EVANS & TURNBULL (2006) summarize several best management practices of plantation forestry across the tropics in their book. However, in the following we present several aspects in plantation forestry with particular potential for intensification.

Site improvement and forest protection

For sustainable production in high yielding tropical plantations, adequate site conditions are a crucial prerequisite. On sites with insufficient nutrient availability, high variability of soil conditions, or high risk for pests and diseases, the application of fertilizers and chemicals (herbicides, pesticides) may be necessary means to cope with these challenges. A number of silvicultural techniques are also available which can be applied to improve the site conditions for high production: homogenization of site conditions prior to planting (e.g., by ploughing, harrowing, trenching), use of nitrogen-fixing species, drainage, or irrigation. However, there is still an urgent need for research to ensure the long-term ecological integrity of these measures and their compatibility with conservation efforts and the continued provision of environmental services.

Better matching of species to sites

A major concern of plantation silviculture is to ensure the best match possible between the site requirements of a given species and the conditions at the planting site, a task that is not always easy given often highly variable site conditions and the numerous species used in plantation forestry in the tropics, whose requirements in this regard may be poorly known. Consequently, a major challenge for silvicul-

tural science and practice is to develop decision support tools that are based on proper site classification and good knowledge of the site requirements of the tree species used. Unfortunately, this latter information is only available for few tropical tree species with high timber value (e.g., GÜNTER *et al*., 2009; STIMM *et al*., 2008). Knowledge is also often lacking about the interactions between climate and site variables and their influence on plantation success, an aspect which will become of particular importance in the light of the need to adaptation of forests and forest plantations to climate change. In the context of climate change, intensively managed plantations with short rotation cycles offer good opportunities to gradually adapt to detected changes by switching to other species, varieties, or provenances, irrigation, fertilization or phytosanitary measures (herbicides, pesticides).

Intensification of Natural Forest Management

Shelter systems vs. selection systems

In natural tropical forests, the most commonly used logging practice is creaming of the most desirable trees or high-grading, which usually does not ensure sustainability in the long run. There is a notable absence of silviculture and management. Intensification of management of natural forests does not mean the intensification of silvicultural interventions in the sense of creaming, but the maximization of output per time and area within the limits of sustainable forest management. Silvicultural systems are normally based on analysis of the shade tolerance of key tree species. For example, ASHTON & HALL (2011) state that shelterwoods with a short period of shelter can be considered appropriate for less shade-tolerant canopy trees or forest types that are driven by stronger episodic disturbance regimes. Many valuable timber-producing tree species can benefit from larger disturbance than is typically created when minimal impact logging techniques are used and logging intensities are low, for example *Swietenia macrophylla* and *Cedrela* spp. in the Americas, *Entandrophragma* spp. in Africa, and *Shorea leprosula* in Asia (SNOOK, 2005; FREDERICKSEN & PUTZ, 2003). SIST & BROWN (2004) summarize a number of studies which show that several of the species mentioned above can have poorer germination and establishment in very open conditions than in partial shade. Therefore they hardly can establish naturally in large felling gaps, making them more suitable for selection systems. Additionally, shelterwood systems are usually better for maximization of timber yields, causing less damage to the remaining stand and are more cost efficient than selection systems. In addition, they can be run over longer cutting cycles. Selection systems, in which disturbance regimes are small and frequent, are more appropriate for shade-tolerant, slower growing tree species. These, in turn, are characterized by shorter cutting cycles, lower harvest volumes per unit area, slower tree growth in early phases, and more complex forest structures. While selective logging usually causes high damages to the remaining stand, reduced impact logging (RIL) offers new opportunities to intensify management in such forests without increasing damage (SIST *et al*., 2003). In forests where conservation aims have to be considered, carefully applied, well-designed, and controlled selection systems may provide good options, but there is little knowledge of or application of such systems throughout much of the tropics. Nevertheless, in terms of intensification of production, shelterwoods are much more appropriate. It is noteworthy, that both the selection and shelterwood systems can help ensure that a large proportion of the pre-harvest biodiversity is retained, much more than would be retained if the forests were to be converted to cattle pastures, agricultural fields, or plantations (FREDERICKSEN & PUTZ, 2003).

Silvilcultural treatments

There is quite a spectrum of silvicultural activities for intensification of management in natural forests, such as pre- and post-harvesting activities, assisted regeneration, improvement thinning, sanitary cuts, and enrichment plantings. However, most of these activities are presently not applied in the tropics. For example, consideration of plant–site matching (ASHTON & HALL, 2011; GROGAN *et al*., 2011), liana cutting or early liberation of potential crop trees (VILLEGAS *et al*., 2009; GÜNTER *et al*., 2008), or other pre- and post-harvest measures, all have an enormous potential for ensuring higher yields and less damage from natural forest management interventions. There are many good examples across the tropics where silvicultural techniques are applied, e.g. Dipterocarp forestry in Asia (ASHTON & HALL, 2011), management of mahogany in Mexico (SNOOK, 2005) or South America (GROGAN *et al*., 2011), CELOS system in Surinam (WERGER, 2011) among many others. Forest certification was established in the 1990s to link marketing of forest products to good social and ecological development. This instrument created many expectations, especially about obtaining addi-

Experimental trials to silvicultural treatments in a tropical montane rain forest of South Ecuador. Photograph S. Günter.

Exploitation of high-value timber from forestry concessions at the Ucayali River, Peru.
Photograph S. Günter.

tional financial benefits for good forest management (GÜNTER *et al*., 2012; OZINGA, 2004). However, only approximately 10% of the world´s forest surface has been certified so far, most of them located in the temperate zones (FCRC, 2011). Data from FAO (2010) indicate that most countries in Latin-America exhibit less than 25% of the forested area count with management plans. Thus, there is still an enormous potential for introducing silvicultural techniques for most tropical forests. This is, mainly due to a lack of investment in basic forest management practices, but also because of insufficient knowledge about species-specific requirements and responses to treatments (UHL *et al*., 1997). PUTZ *et al*. (2000) state, for example, that reduced impact logging practices are largely disregarded in the tropics due to their investment costs and the lack of incentives for best management practices. Thus, intensification in natural forest management is a very promising strategy, but it depends largely on progress in research and financial considerations, beyond the limits of the respective management unit, and of course on political conditions such as enforcement of laws and support of sustainability strategies. Additionally, the maximization of one product (e.g., timber) can be in conflict with the maximization of the yield of other products or services (e.g., NWFPs, ecotourism, water quality, carbon sequestration), especially when these aspects are managed by different stakeholders (GUARIGUATA *et al*., 2010). Optimization of the total economic return from a given forest area hence requires appropriate balancing between different aims, for example, by means of diversification of forest structures products and services.

Diversification of forest structure, products and services

For many years, the demand for services and products from forests has been steadily increasing and expanding. GALE (2000) argues that current ecosystem decline is a consequence of the over-extension of the principle of specialization, particularly "intensification" of management: "When the specialization principle is applied wholeheartedly to natural systems to speed up their delivery of desired commercial products it leads to ecosystem simplification, loss of integrity and stress". Thus, besides intensification, diversification should also be considered an essential objective in order to meet all stated demands in terms of quantity, quality, and type of products and services. This approach is also known as multiple-use forestry (ASHTON *et al*., 2001), diversified forest management (CAMPOS *et al*., 2001) or the integrative management approach (DIACI *et al*., 2011). Uneven-aged silviculture in its broadest sense may be the oldest existing example of the integrative use of forest resources (DIACI *et al*., 2011). Intensification and diversification have to be regarded as complementary elements of sustainable forest management on larger spatial scales (GÜNTER *et al*., 2011). The more intensive and specific the management is on some sites, the more important is diversification on other sites in order to mitigate possible environmental damage and shortages in the provision of other goods and services. Diversification can be applied for different ways, for example diversification of forest structures and diversification of products and services.

Diversification of forest structures

There is increasing evidence that the combination of species in mixtures not necessarily implies lower production rates, in several cases this can even result in higher growth and production compared to monocultures (RICHARDS & SCHMIDT, 2010; PIOTTO, 2008), which can be attributed to better utilization of the full site potential. Thus, mixtures can also at times improve economic returns (MONTAGNINI & PIOTTO, 2011). Additional benefits of tree mixtures can be provided by positive plant–plant interactions, for example by nutrient input via litter fall and optimum shading conditions for lower forest strata. A key benefit of mixtures is the ability to apply risk management. Single products (or services) are prone to uncontrollable market price fluctuations. Just like stock markets, a diverse portfolio of land uses or plantations offering different products (with non-correlated prices) or different species, provides lower risks than highly specialized management with only one single species or product (KNOKE *et al*., 2009, 2005). To identify, establish, and maintain the optimal combination of species mixtures, products and the corresponding silvicultural treatment will be one of the key challenges for the future.

Besides mixing tree species in plantations, there are several other possibilities of achieving diversification of forest structure. For instance, all-aged forests are receiving considerable attention in the scientific community; the method is also termed multi-aged forestry (O'HARA, 1996), close-to-nature forestry (MLINSEK, 1996) or continuous-cover forestry (MIZUNAGA *et al*., 2010). The major advantages of such forests are higher resilience against environmental stress, and permanent forest cover. Therefore, these forests may be more compatible with the provision of many environmental services. In a recent paper, PUTZ *et al*. (2012) reviewed more than 100 publications about selective logging. They revealed that timber yields decline by about 46% after the first cutting cycle but then sustained on this level in later cycles, 76% of carbon is retained and 85-100% number of species from different taxa remain after logging. However, selective logging in all-aged forests usually provides lower yields than in mono-structured stands imply higher requirements for management, and more elevated costs for harvesting and tending operations. Additionally these systems are usually accompanied by suppression of light demanding species. VINCENT & BINKLEY (1993) showed for example that two stands with dominant use of one of two products are economically more effective than multiple use forests providing both products from the same stand. From a silvicultural point of view, it is important to reflect on the spatial patterns of species mixtures, ages, and strata. The choice is whether to establish small areas of monocultures of different species of a specific age, that is, "coarse grained" mixture or "landscape mosaics"; or whether a plantation should be established as a "fine grained" or "intimate" stand mixture of different and intermingled tree species. While the principles of multipurpose forests are intensively discussed in the literature, the manifold interactions among tropical timber species and between timber and NWFP producing species and their concrete silvicultural consequences offer enormous opportunities for research.

Diversification of products and services

Several authors indicated that the demands of human society for forest goods and services are shifting from pure maximization of timber production to multipurpose management (ASHTON & HALL, 2011; GÜNTER *et al*., 2011; KOTRU & SHARMA 2011; WEBER, 2011). They note that in tropical forests there is an increasing awareness of the importance of NWFPs and environmental services such as ecotourism, provision of clean water and landscape scenery on the local scale, and mitigation of climate change effects and conservation of biodiversity on the global scale (PUTZ, 2011; VANTOMME, 2011). However, the provision of all products and services is not always compatible.

Conservation objectives and protective functions of forests have long been considered as conflicting with productive aims being predominant in natural forests and plantations. Consequently, for many forest users, conservation aspects have been considered restrictions for productive forest management. However, since PES (payments for environmental services) are slowly percolating into forest practice, the acknowledgement of the importance of the protective functions of forests is changing, and it is becoming an additional objective of silviculture in production forests as well. Thus, when PES can contribute to a significant improvement of the land users´ livelihood income the protective functions of forests have not necessarily been seen as management restrictions but rather as an additional income opportunity. The main problem may be opening the access to potential markets. WUNDER (2005) listed five essential principles for successful PES systems:

- Voluntary transaction;
- Well-defined environmental service, or a land use likely to secure that service;
- Being "bought" by at least one ES buyer;
- From at least one ES provider;
- If, the ES provider secures ES provision, i.e., conditionality.

Consequently, forest managers have to analyse prospective markets for protective functions, calculate costs and trade-offs related to other forest products or services and incorporate them into silvicultural concepts designed to combine the interests of specific land owners and specific ES buyers.

The success of diversified management therefore depends largely on proper spatial scaling and arrangement of the corresponding factors involved. For example, for combining management for timber with management for NWFPs, several factors have to be considered (GUARIGUATA *et al*., 2010). These range from ecological dimensions (seasonality, habitat overlap, growth range and product type) to social or legal dimensions (for example property rights, gender aspects, local knowledge etc.). Integrating the most important environmental services such as carbon sequestration, provision of water, conservation of biodiversity and landscape scenery into forest management and into appropriate silvicultural systems is very challenging. A comprehensive silvicultural approach must first integrate and optimize a products and services portfolio according to accessibility of potential markets, and then it is to decide how to arrange the corresponding silvicultural treatments in the field; either by spatial segregation of priority areas for specific products and

services, or by spatial integration. Segregation and integration strategies must be applied as complementary components of forest management to ensure best public welfare in the future. This requires that silviculture is accompanied by:
- Effective monitoring and control of environmental and economic conditions;
- Looking for possible synergetic effects between classical silviculture focused on timber production and the production of alternative or complementary forest products and services;
- Applying optimization techniques.

Where compatibility or synergies between environmental services, NWFPs and timber can be expected, an integrative approach may be the most appropriate one, while segregation is necessary where conflicts, unclear property rights, economics or management capacities may impede such more complex forest management systems. This is a rather demanding task, even for scientists. The subsequent practical implementation in the field is even more demanding.

Consideration of appropriate scales of management

Several authors (e.g., ASHTON & HALL, 2011; PUTZ, 2011; WEBER, 2011; GUARIGUATA *et al.*, 2010; SIST, 2000) stress the need for better consideration of different temporal (short to long term) and spatial scales (landscape, ecosystems, community, species, and genetic level) in forest planning and silvicultural management. Small-scale forestry can supply a wide array of goods and services. From the management point of view, spatial segregation of highly specialized forest functions bears great advantages: More homogeneous site conditions or a lower number of tree species involved facilitate planning, forest operations, control, and merchandizing of products. Less complex silvicultural concepts are easier to implement in the field, an important argument for many tropical countries with lower institutional control and formal educational level. Thus, for profit maximization it may be recommendable to specialize on one single product or service per unit area, which leads to the highest possible internal rates of return. While it may be possible for single land-owners to supply few products on a sustainable basis, the provision of multiple services for local, national, or global societies usually have to be planned, monitored and controlled on higher spatial levels. If not properly integrated in a comprehensive silvicultural concept on a broader scale, segregated and highly specialized production will hardly be able to satisfy the manifold demands of private and public stakeholders. Increasing claims on land use, for example, for biofuel or food production, will complicate finding a sustainable balance between the manifold interests of stakeholders involved, especially in developing countries. Under sustainable multifunctional forest management, it will be necessary to include explicit spatial structures and objectives into planning, monitoring and implementation. Silvicultural activities need to be embedded in sustainable landscape management plans that consider responses to different silvicultural treatments of forest ecosystems as well as markets.

Better matching of operational units and ecological scales

Silviculture in the tropics is usually strongly focused on operational units, which are closely related to the size of a land owner´s property: for a small-scale farmer the whole property will be his or her operational unit, while big concessionaires will divide their concession into different operational units according to forest structure, expected products, or infrastructural or logistic aspects. Furthermore, in practice the operational units are often just schematically adopted to the number of cutting cycles or rotations. Consequently, silvicultural treatment is more often determined by the scale of the operational unit than by ecological dimensions. A clear example for frequent mismatching of operational and ecological spatial scales is plant–site matching. A major concern of plantation silviculture is achieving the best match between species requirements and planting site conditions. The high variability of site conditions and numerous tree species used in plantations in the tropics result in an extraordinary high number of possible species-site combinations. The development of species and site specific management guidelines will consequently be a task for several decades of silvicultural research. Land users have to invest considerable resources in the assessment of their specific site conditions and then decide which species may be most suitable or which silvicultural interventions may result in highest yields or healthiest stands - efforts which are hardly affordable for small-scale forestry. Thus, in most cases, site-specific management has been largely disregarded in favour of large-scale and broadly applied management prescriptions (APPANAH & WEINLAND, 1993). Similar problems arise for the appropriate consideration of genetic aspects as related to population dynamics. A major challenge for science and practice is to develop and implement affordable inventory-based decision support systems, which consider temporal and spatial variability to achieve better matching of ecological scales and operational units (HEINIMANN, 2010).

Better matching of operational units and socio-economic scales

In addition to the above deficiencies there is also a discrepancy in the scales of operational units and societal structures. Forestry is a good example of potential conflicts between individual and collective decisions and benefits. Frequently, the measures for profit maximization of the forest owner differ from those needed to maximize the benefits for the society at large. Conflicting aims between optimization of benefits on the local scale and on the regional or global scale have to be identified, communicated, and negotiated between stakeholders (GUARIGUATA *et al.*, 2008; WALTERS *et al.*, 2005). Any restriction for landowners and local land users which may be necessary for optimization of forest products and environmental services for the larger society should be compensated to avoid understandable but undesired interventions by owners. Proper implementation requires active participation of all stakeholders involved and integration of silvicultural and forest management interventions into national and regional planning, involving especially those responsible for allocation of PES.

Participation of stakeholders

Since many countries in the tropics are developing countries or countries in transition, tropical forests often have to fulfill subsistence needs and suffer from higher human pressure. They are frequently converted into alternative land-use forms which provide either food or cash crops with higher economic returns, at least from a short-term and non-sustainable point of view. Further, many governments have poor or almost no control over the forests and cannot balance conflicting land-use interests properly. Users' needs, of course, are often much more dynamic and different and diverse than those of users in temperate ecosystems. According to the above-mentioned definitions, silviculture in the tropics therefore requires much more careful integration of the social and political dimensions. WESTOBY (1987) summarizes: "Forestry is not about trees, forestry is about people".

Sociocultural structures, demands and requirements have changed drastically with time. IFTHEKAR (2005) describes the evolution of forest ownership patterns as follows: "Common property resource (common ownership as typical for many indigenous groups until recently, now strongly decreasing) - state ownership (prominent today, but especially in the tropics not always efficient due to governance problems) - private ownership (increasing in the tropics, due to legalization of land titles and increasing recognition of traditional rights) - joint ownership (currently prominent approach in tropical countries in order to improve the condition of the forests and the community dependent on the forests simultaneously). "The continuing rise of community-managed forest area in the neotropics which often involves the extraction of multiple forest products, will require cost-effective integration in order to build sustainable small-scale forest enterprises and to facilitate product certification in the future" (GUARIGUATA *et al.*, 2008). The development of co-management structures could therefore be a promising approach to overcome the above-mentioned socioeconomic scaling-problems. However, successful decentralisation as a step prior to empowerment requires careful consideration of the following questions (ANDERSON, 2000):

- What should be decentralized and to what extent?
- Do local entities have the capacity to adequately fulfill their "new" roles and responsibilities?
- How can decentralization avoid becoming de-concentration and the status quo in new clothes?
- Does decentralization implicitly mean a broader and more diverse institutional landscape?

Frequently, decentralization is top-down initiated– resulting in non-organic structures and decision processes. Therefore, "sometimes decentralization helps to achieve sustainable forest management and sometimes it hinders the achievement of this goal" (ANDERSON, 2000). At the community level, positive examples of participatory approaches and the transfer of results into silvicultural implementation in the field do already exist (KOTRU, 2011; LESKINEN, 2004; KLOOSTER & MASERA, 2000). Public participation as a common practice at the local level results in extremely demanding mediator/facilitator efforts for the planner (LESKINEN, 2004). Therefore, sometimes, but not always, the establishment of co-management structures and/or good governance practices goes hand in hand with the success of sustainable forest management concepts and silvicultural implementation in the field. Impressive work has been done around the adaptive collaborative management approach, especially in Asia and Africa (GUIJT, 2007; COLFER, 2005; WOLLENBERG, 2005). This approach avoids the above-mentioned problem of top-down developed non-organic structures as well as the scaling problems by involving other people acting on different scales, usually at least one level down and one level up. Effective facilitation is thereby important in order to empower communities to improve their life conditions (CIFOR, 2008). It is worth noting that the provision of tangible benefits to local stakeholders is the most essential component for the success (KLOOSTER & MASERA, 2000). Besides the manifold good examples shown by CIFOR, there are good experiences in Latin America and other regions worldwide provided by the model-forest network (LANDRY *et al.*, 2011; SABOGAL & CASAZA, 2010). The most important principles for this international governance platform are voluntary partnership of the stakeholders on a landscape level, and commitment to sustainability.

In complementary fashion, ANDERSON (2000) emphasizes the importance of governmental structures: "Governments can help build social capital and capacity. What it appears to be needed are new forums for the various actors to come together and methods of participation that are indeed empowering and take into consideration dissension and dissonance". Foresters have to recognize that their "competence"-monopole to managing forests is history: today, multiple stakeholders such as governments, conservationists, indigenous groups, local communities, NGOs and private profit makers are having an impact on the management of forests. It must become a self-evident task for silviculturists to actively involve these stakeholders in their considerations and to communicate and discuss with them possible silvicultural alternatives; that is what kind of interventions may fit best with the specific aims; but also to explain the respective technological and ecological restrictions, limitations, and financial consequences.

Subsistence farmers in the peruvian highlands, Huaraz. Photograph S. Günter.

Integration of silviculture into sustainable forest management concepts: moving from timber mining to adaptive ecosystem management

While there is broad consensus that modern forest management and silviculture need to fulfil multiple demands such as the provision of NWFPs, timber and environmental services (BENSKIN & BEDFORD, 1995), the silvicultural concepts generally still today applied in the tropics, however, have been developed almost exclusively for timber production (DAWKINS & PHILIPS, 1998; LAMPRECHT, 1986). Therefore, control mechanisms, communication between stakeholders and the development and implementation of silvicultural concepts adapted to incorporate also ecological and societal dimensions require links between forest management and silviculture. Without appropriate silviculture, SFM cannot be achieved. Silviculture without close linkage to societal requirements in turn is unoriented and ineffective. Figure 1 indicates schematically the role of silviculture as a mediating discipline between natural and societal dimensions. Figure 2 presents examples of different stages of silviculture along a gradient of increasing complexity, from forest exploitation to SFM.

There is broad consensus that modern silviculture has evolved from simple exploitation practices to complex adaptive ecosystem management with sustainability as the leading management objective (HEINIMANN, 2010; PUETTMANN *et al*., 2009; KERR, 1995; MOSANDL & FELBERMEIER, 2001). However, "perfect sustainability" with perfect development of all components (ecological, social, economic) is an ideal without a chance of realization (WEBER-BLASCHKE *et al*., 2005). Therefore, silviculture aims at approaching sustainability in a process of monitoring, application, and adaptation. In theory, reaching "perfect sustainability" would end up in a never-ending cyclic approximation process implying infinite costs and infinite manpower. In practice the decision maker has to decide at which point to stop this process, which information provides acceptable accuracy for the prediction of consequences of silvicultural treatments and which level of added scientific accuracy is affordable. The level of sustainability achieved in a given society and ecosystem will consequently strongly depend on availability of resources, efficiency of government structures and information management. Large efforts are undertaken by the international development agencies in order to foster social, economic and ecological sustainability in tropical countries. However ecological dimensions are of immediate importance for these stakeholders when social or economic dimensions are directly affected by the availability of ecological resources and services. The underlying processes and ecosystem functions in turn are poorly understood and mostly subject of interest of the scientific community. Involving the importance of ecological processes for the societies into the agendas of decision makers is thus a major challenge for tropical silviculture (GÜNTER *et al*., 2012).

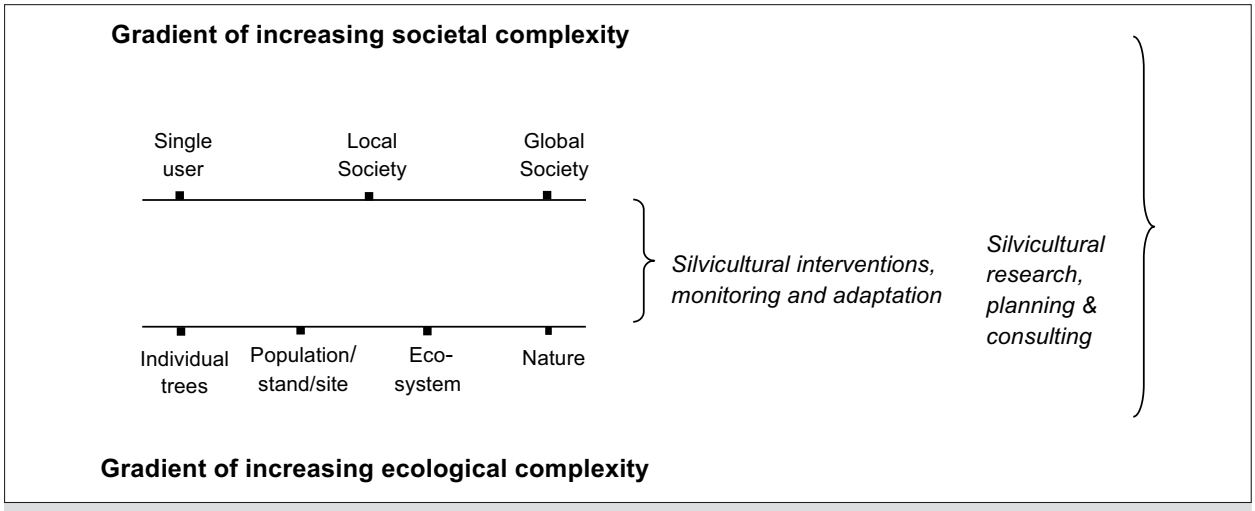

Figure 1.
Role of silviculture as a mediating discipline between natural and societal dimensions (Adapted from THOMASIUS & SCHMIDT, 1996; MOSANDL & FELBERMEIER, 2001; PUETTMANN *et al*., 2009). Silvicultural activities can be directed toward single users, communities, countries and finally also to the global society. Affected ecological dimensions have to be considered at several scales of complexity, from individual trees, to populations, plant–site interactions, site conditions, and ecosystem functions. While silvicultural interventions, monitoring and adaptation of treatments are concrete activities of practical silviculture with manifestations in the physical landscape, the scientific discipline of silviculture goes far beyond these limits. Tropical silvicultural in particular should deeply be rooted in basic ecological disciplines and closely linked to social disciplines and management.
Source: GÜNTER *et al*., 2011; Springer book "Silviculture in the tropics").

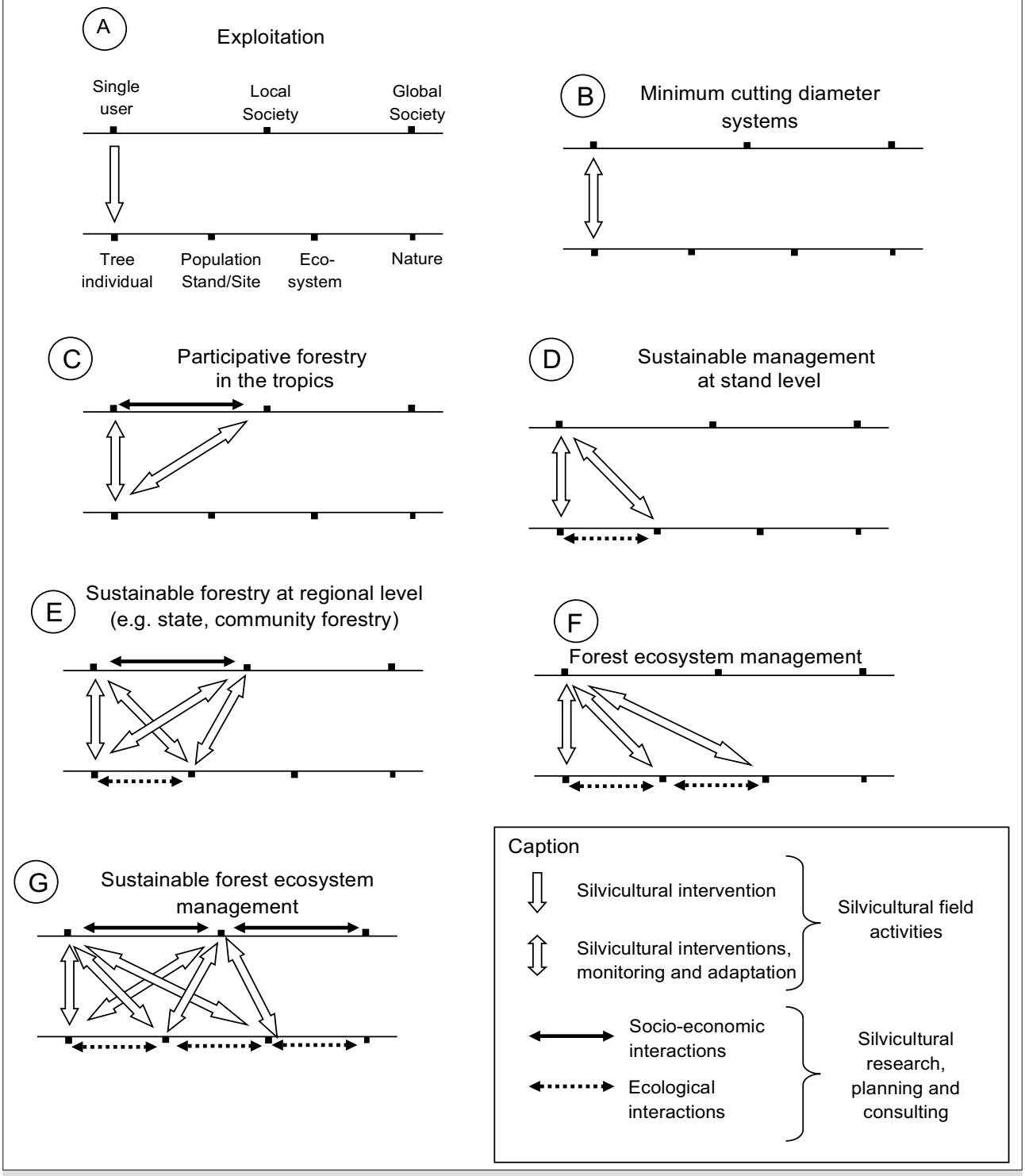

Figure 2.
Examples for silvicultural interventions along a gradient of increasing complexity, from mere extraction of timber over application of silvicultural treatments to sustainable forest ecosystem management. Simple white arrows indicate directions of human interventions. Two-headed arrows in white indicate silvicultural interventions including monitoring and adaptation in case of non-sustainable results. Black arrows represent ecological (dashed line) and socio-economic interactions (continuous line) which have to be considered in silvicultural research, planning, and consulting. Case (A) indicates a typical situation of exploitation without any consideration of sustainability aspects. Simple monitoring systems for timber volume are applied in case (B), interventions and treatments are adapted when mid- or long-term provision of goods or environmental services is endangered. (C) represents a case with higher social complexity with direct benefits to the land owner and additional requirements from the corresponding local community. Silvicultural concepts have to consider both of these societal dimensions, usually by applying participatory approaches. (D) and (E) already include more complex societal and ecological dimensions representing "good" silvicultural practice in the tropics today. However, they do not yet consider complex ecological interactions (biotic–biotic, abiotic–biotic), dynamic aspects and characteristics of all species, products and services involved, as indicated by (F). (G) represents the development of this approach by integrating all societal and ecological aspects, for example global change issues, and economic valuation and local compensation of providing ecosystem services (Source: GÜNTER *et al.*, 2011; Springer book "Silviculture in the tropics").

Providing Ecological Roots to Tropical Silviculture and Forest Management

Even for the supposedly best known tropical tree species such as mahogany or teak (*Tectona grandis*), our knowledge is still limited (ASHTON & HALL, 2011; GROGAN *et al*., 2011). The differences in growth performance on different sites are almost unknown for most species, including the most valuable ones. Also the light–plant and plant–soil interfaces and interactions as well as the differences between ecotypes are not sufficiently understood up to now (GÜNTER *et al*., 2009; KUPTZ *et al*., 2009). Most empirical studies are based on a per plot basis, which implies a relatively low number of individuals on the species level. Especially for silvicultural target species, additional data about growth and mortality covering larger areas, bigger populations and longer time scales under variable environmental conditions, and combination of experimental and modeling approaches are urgently needed. A promising contribution to the solution can be provided by an increasing number of permanent sample plots. By combining data from these with modeling approaches (e.g. KNOKE & HUTH, 2011), we can expect great advances in our understanding of long-term and large-scale ecological processes. Models can help silviculturists to better understand complex effects of intervention and interactions and to find a balance among ecological functions of forests and the different needs of local people and regional stakeholders. However, decision makers will still require the silviculturists´ imaginative skills for interpreting scientific knowledge for sustainable management of natural resources within societal expectations (SHEPHERD, 1986; NYLAND, 1996). Highly sophisticated and innovative approaches for gaining better understanding of ecosystem functions are probably of the same importance as calibration of results with simple parameters in the field for easier implementation, monitoring and evaluation. The greatest challenge for forest managers and silviculturists is to put together the puzzle of countless ecological publications as a foundation for developing sound concepts which link sustainable forest management and silviculture.

Conclusions

Tropical silviculture requires a balance between approaches of intensification in order to fulfill the growing demand for forest products and services and diversification in order to mitigate potential environmental damages. This requires a combination of spatial segregation of silvicultural interventions, accompanied by high specialization, as well as multi-purpose forestry which integrates spatially the provision of products and services. Silvicultural planning and monitoring beyond the classical stand-based approach are important measures in order to achieve a reasonable balance between both complementary components.

Therefore, tropical silviculture must be closely linked to landscape management. It must be clear on which spatial scale environmental services have to be considered and how they can be integrated into management plans at the level of land owners. Linkages to market mechanisms are required in order to create and allocate financial benefits for the forest owners from compensation payments. Valuation of possible environmental services is of essential importance as well as an effective communication of scientific results to respective institutions in charge for distribution of payments.

Better linkages between tropical silviculture and forest management underlie strong constraints from the political context in the respective countries and regions. Conflicting aims as well as synergies at different spatial scales have to be identified, communicated and negotiated with various stakeholders. In cases where good-governance practices are lacking, appropriate co-management structures need to be developed within the political framework.

Adaptive management and silviculture must be rooted in ecological and social disciplines and require a subsequently implementation in the field. Technology and knowledge transfer may be of the same importance as basic research, especially regarding quantification and modeling of ecological processes and the impacts of human interventions.

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