Forest Biodiversity and the Delivery of Ecosystem Goods and Services: Translating Science into Policy

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Biodiversity is integral to almost all ecosystem processes, with some species playing key functional roles that are essential for maintaining the value of ecosystems to humans. However, many ecosystem services remain nonvalued, and decisionmakers rarely consider biodiversity in policy development, in part because the relationships between biodiversity and the provision of ecosystem services are not generally appreciated. To date, the majority of work in which the functional importance of biodiversity has been examined has been conducted in relatively species-poor systems. Focusing on forest and agroforest systems, we synthesize recent research on the role of biodiversity in the provision of ecosystem services and provide examples of biodiversity science that informs ecosystem management and policy. Finally, we highlight barriers to the transfer of knowledge from scientists to decisionmakers and suggest that scientists can be much more effective at informing policy and improving resource management by asking policy-relevant questions and providing timely and consistent information to decisionmakers and the public on the linkages among biodiversity, ecosystem services, and their value to people.

Keywords: ecosystem services, valuation, biodiversity, forest management, natural resources policy

***Biodiversity*—diversity within and among species—is** related to the production of most ecosystem services (e.g., Hooper et al. 2005, Balvanera et al. 2006). For example, biodiversity underpins a wide variety of goods and services provided by forest and agroforest ecosystems, including the prevention of soil erosion, pest control, pollination, clean water, food, climate change mitigation, control of disease vectors, and local ecosystem resilience and stability (table 1). When ecosystems are managed for only a limited set of goods and services, such as timber from forests (e.g., Nasi and Frost 2009), many other ecosystem services may be overlooked and therefore undervalued. Although the ecology research agenda for understanding biodiversity effects on ecosystem services is relatively clear (Kremen 2005), translating the growing body of research results into policy advice is a major challenge (e.g., Perrings et al. 2011).

If ecosystems are to be effectively managed and conserved, the value of all ecosystem services, including the externalized costs of their loss, needs to be understood by decisionmakers. A key role for science is to refine our understanding of how ecosystems function, to establish the links between functions and the provision of ecosystem services, and then to communicate that knowledge effectively to decisionmakers and the public. Illustrating the importance of biodiversity for ecosystem goods and services valued by people is an increasingly important contemporary approach to influencing conservation policy and complements other arguments for biodiversity conservation.

The multiple interconnections among species in complex ecosystems can result in redundancy within functional groups with key roles for some species (e.g., Díaz and Cabido 2001). The precise effects of this complexity on many ecosystem functions, especially during periods of environmental change, need to be understood if we are to maintain the provision of all of the goods and services that people require. These issues are particularly relevant to intensively managed forest and agroforest ecosystems, which are usually characterized by low levels of biodiversity relative to natural forests (Brockerhoff et al. 2008). For example, the extent to which plantation forests can provide a wide range of ecosystem goods and services is becoming increasingly relevant, as the global area of plantations expands, while that of natural forests continues to decline at a rate of about 13 million hectares (ha) per year (FAO 2010).

In the present article, we examine some of the known complexities in quantifying functions in forest and agroforest ecosystems, discuss examples of how some of this

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Table 1. Forest biodiversity and cross-sectoral ecosystem services.

Beneficiary	Ecosystem service	Important taxa	Related diversity	Management focus	References
Climate change	Carbon storage	Trees, decomposers	Species diversity	Forest area, forest degradation	Bunker et al. 2005
Agriculture	Pollination	Insects (e.g., bees and flies), bats, birds	Species diversity, ecosystem diversity	Heterogeneous landscape, plant diversity	Tylianakis et al. 2008
Agriculture	Biological control	Parasitic microorganisms, invertebrates (e.g., insects), birds, small mammals	Species diversity, ecosystem diversity, structural (habitat) diversity	Heterogeneous landscape, corridor, plant diversity	Tylianakis et al. 2008
Forestry	Seed dispersal	Birds, rodents	Species diversity, structural (habitat) diversity	Heterogeneous landscape, corridors	Wunderle 1997
Forestry	Soil formation and nutrients	Invertebrates (e.g., arthropods), microorganisms	Species diversity	Erosion prevention	Harris 2009
Forestry	Productivity	Mostly trees, but also fully functioning ecosystems	Species diversity	Plant diversity, resilience	Thompson et al. 2009
Forestry	Reduction or prevention of invasive species	All species in the ecosystem	Species diversity	Resilience	Dukes 2001
Life quality	Water retention	Plants, soil microorganisms	Ecosystem diversity	Heterogeneous landscape	Kumar 2010

science has been successfully translated into policy and management practices, and offer some ideas for scientists who wish to improve the impact of their work on policy formulation. In particular, we emphasize the need to ask policy-relevant questions by testing policies as hypotheses and to design experiments in such a way that they can provide clear messages to decisionmakers.

Science has advanced the understanding of the biodiversity effects on ecosystem services in forest and agroforest systems

Over the past two decades, ecological sciences have deepened our understanding of the complex relationships among biodiversity, ecological processes, and ecosystem services. Key testable hypotheses regarding the effects of species richness, functional traits, and community structure have elucidated these complexities within ecosystems (e.g., Yachi and Loreau 1999, Tilman and Lehman 2001, Hooper et al. 2005). Several reviews of the scientific literature on the biodiversity effects on ecosystem goods and services (e.g., production, water retention) broadly support the hypothesis that some services are reduced if biodiversity is lost (e.g., Balvanera et al. 2006, Cardinale et al. 2007, Thompson et al. 2009). Most experimental studies have been conducted in relatively simple grassland communities, rather than in more complex ecosystems such as forests. Nevertheless, some work has begun to reveal the interactions and support systems provided by biodiversity that generate goods and services from forests and agroforest landscapes and provide stability in the provision of these services under conditions of environmental change. The results from these studies suggest that, in most cases, biodiversity enhances the delivery of ecosystem services (e.g., Hooper et al. 2005, Balvanera et al. 2006), even in more complex systems (Tylianakis et al. 2008).

Biodiversity effects on the provision of forest ecosystem services. The potential for a positive relationship between functional diversity and productivity in forests has previously been suggested (e.g., Díaz and Cabido 2001). More recently, Thompson and colleagues (2009) reported that 76% of 21 studies reviewed showed a direct relationship between increased biodiversity (measured as tree and understory species richness) and increased primary productivity. The mechanisms varied and were related to improved soil fertility, partitioning of resources, and nutrient retention. Although not all species contribute functionally within ecosystems, many species play significant functional or keystone roles (e.g., 13% of forest tree species can contribute to 90% of the carbon storage; Balvanera et al. 2006). In their reviews on the relationship between productivity and plant community diversity, Balvanera and colleagues (2006) and Thompson and colleagues (2009) concluded that plant diversity enhanced belowground plant and microbial biomass and decomposer activity and diversity, resulting in greater diversity of primary consumers and a lower number of invasive species relative to systems with low levels of productivity.

In forests, cascading effects have been found involving predators, herbivores, and primary production, which suggests key top-down functional roles for biodiversity in forests. In a meta-analysis in which insect herbivory in mixed forests was compared with that in single-species forests, Jactel and Brockerhoff (2007) found that the more diverse stands were significantly less affected by herbivory. Several studies have documented the underlying mechanisms by which biodiversity can affect herbivory, including plant-released volatile compounds from diverse plant communities that interfere with host finding and colonization by insects (Jactel et al. 2001) and enhanced attack rates by diverse natural enemies in forests (Tylianakis et al. 2008), which potentially reduce prey numbers (i.e., providing biological control services; Bridgeland et al. 2010). Many authors have argued that pest-control services are provided by birds in forests (e.g., Whelan et al. 2008), and the predation of insects by birds has been directly related to tree productivity (Bridgeland et al. 2010). These services are highly relevant for plantation forests that are established as monocultures, where pest outbreaks may be prevalent and severe. However, it is not always biodiversity per se that explains these relationships, because the identity and biology of the species involved can influence the outcome of the interactions. For example, polyphagous insect herbivores may have a greater impact in mixtures of suitable host plants in which they can increase their population size on one species and then spill over to another (Jactel and Brockerhoff 2007). Knowledge of such relationships improves our ability to manipulate the species mix (e.g., of planted trees) to maximize ecosystem services, such as "natural" pest control (cf. Newton et al. 1993) and pollination in forests and agroforests landscapes.

Agroenvironmental practices that maintain natural forest ecosystems surrounding agricultural fields positively affect biodiversity, particularly of functionally important species, such as bees and spiders, which provide crop pollination and pest-control services (Kleijn et al. 2006), as was observed for Meliaceae species by Newton and colleagues (1993). Many species of arthropods move among habitats in landscapes composed of a mixture of agricultural lands and forests. Several studies have highlighted the strong effect of forest remnants on agricultural crops in terms of pollination (Taki et al. 2010) and pest control (Kagawa and Maeto 2009, Schellhorn and Bianchi 2010). Taki and colleagues (2010), Kagawa and Maeto (2009), and Schellhorn and Bianchi (2010) all found that more species of native pollinators and of natural enemies of agricultural pests moved from forests into agricultural fields than vice versa. Several species of natural enemies were also shown to occupy a variety of forest habitat types and forest–crop edges in mixed agricultural landscapes or were associated with particular forest types around agricultural fields, which suggests that the habitat diversity offered by forests supports diverse natural enemies of agricultural pests (Kagawa and Maeto 2009, Schellhorn and Bianchi 2010).

Biodiversity and ecosystem resilience. Biodiversity can also theoretically buffer against environmental change (Yachi and Loreau 1999), maintaining ecosystem services in the face of perturbation (e.g., Elmqvist et al. 2003). The strength of this buffering depends on the degree of asynchrony and plasticity in the responses of individual species to environmental fluctuation and on the specific nature of their responses (i.e., response diversity; Yachi and Loreau 1999, Elmqvist et al. 2003; and resilience; Winfree and Kremen 2009).

Forest resilience (recovery after a major disturbance) is of particular interest because of the current climate change effects on forest processes and on carbon storage in particular. Several authors have concluded that, for similar site types, diverse forests are both more resistant (remain unaltered in the face of chronic changes) and more resilient than those with less diversity (Stone et al. 1996, Thompson et al. 2009). Furthermore, interactions within communities of organisms play a key role in determining the stability of the ecosystem as a whole (e.g., Balvanera et al. 2006). Therefore, resilience is an emergent property of ecosystems that is conferred at multiple scales, through genetic, species, and landscape heterogeneity (Thompson et al. 2009) and redundancy in the food-web interactions among species (Laliberté and Tylianakis 2010). These findings suggest that the mosaic structure of entire landscapes should be a key consideration for ecosystem management to maximize spatial and temporal insurance in ecosystem services (Loreau et al. 2003) and to minimize agroenvironmental problems (Schellhorn et al. 2008). This suggestion contrasts with the majority of biodiversity policies that target smaller spatial scales (Tscharntke et al. 2005).

Science has played an important role in improving operational sustainable forest management

Sustainable forest management (SFM) is ecosystem management (e.g., Szaro et al. 1998) of forests and is a broad and evolving process in which the goal is to provide balance among social, economic, and environmental concerns including maintaining biodiversity, productivity, and resilience (e.g., Holvoet and Muys 2004). Scientific support for SFM includes a large body of published work on—among other topics—the emulation of natural disturbances, ecosystem function and processes, thresholds, successional dynamics, and biodiversity. Among the important advances made in forest ecosystem ecology over the past 25 years has been the gradual recognition that forest management at the stand level also has effects at landscape scales (e.g., Attiwell 1994). Considerable research has assessed the effects of past forest management practices on current forest structure and function, and consistent with adaptive management, this work has strengthened the scientific basis of forest management. Techniques such as reduced-impact logging, protecting advanced regeneration, and assisted regeneration are well-studied methods for improving forest resilience, including soil conditions and regeneration, following timber harvesting. On the basis of this knowledge and experience, comprehensive guidelines for the restoration, management, and rehabilitation of degraded and secondary tropical forests and for the conservation and sustainable use of biodiversity in tropical timber production forests have been published (ITTO and IUCN 2009). In boreal and temperate forests, managers now understand the need to consider stand and landscape scales and to maintain all forest age classes, types, and structures across a landscape to conserve biodiversity in a manner consistent with natural processes (e.g., Lindenmayer and Franklin 2002).

Biodiversity is generally greatest in natural old forests, intermediate in secondary forests, and least in plantation forests (e.g., Brockerhoff et al. 2008). Hooper and colleagues (2005) argued that maintaining high levels of productivity over time in planted monocultures almost invariably requires unsustainable subsidies of chemicals or energy. However, there are numerous opportunities for management activities that can increase biodiversity at the forest stand and landscape scales (Lindenmayer and Franklin 2002, Brockerhoff et al. 2008). Reducing the total area of monotypic stands (relative to diverse stands) across a landscape would be expected to increase the goods and services provided by that landscape (e.g., Brockerhoff et al. 2008).

Tropical forests present a complicated contemporary challenge to the application of SFM. Although they are necessary for conserving some tropical forests and their biodiversity, viable networks of protected areas alone are insufficient. These areas can never be extensive enough to encompass all of the biodiversity that needs protecting because of the costs (direct and opportunity), practicality, and the pressures of competing interests and land uses. However, the proper management of forests used to produce timber, nontimber forest products, and other services can further biodiversity conservation objectives (e.g., Lindenmayer and Franklin 2002). For example, selectively logged forests, if they are managed appropriately, can provide habitat for otherwise threatened species and complement protected areas (e.g., Clark et al. 2009). In the tropics, conserving biodiversity requires management of the landscape as a continuum of patches at a range of spatial scales rather than as a strongly differentiated patchwork at one scale. This includes (a) intact forest patches, from which people obtain various goods and services, including sustenance in times of hardship; (b) sacred groves, which remain untouched; (c) ancient agroforests; (d) land that may yet be cleared for settlement and cultivation; and (e) patches regenerating after being abandoned (Frost et al. 2006). The formal scientific basis for managing such complex tropical landscapes for both livelihoods and biodiversity conservation, however, is still poorly developed (Frost et al. 2006, Pfund et al. 2008).

More generally, management designed to maintain high conservation values should exhibit some key attributes, including authenticity, continuity, heterogeneity, proximity, redundancy, resilience, and uniqueness (Nasi 2010). This goal can best be achieved by designing and implementing forest management to maintain landscape heterogeneity; to maintain large, structurally complex patches of natural vegetation; to create buffers around sensitive areas; to maintain or create corridors to support landscape connectivity; to use appropriate disturbance regimes in management; to maintain functional diversity; to manage for keystone species; and to maintain endemic, rare, and threatened species (e.g., Nasi 2010).

Can degraded tropical forests be restored, and will these forests recover their resilience? Most tropical forests are highly resilient and rapidly recover their structural features, functional characteristics, and biodiversity following natural or anthropogenic disturbances, such as the creation of forest gaps by logging, forest conversion for short-term agriculture (as in traditional shifting-cultivation systems), or fire (e.g., Parrotta et al. 1997). There are, however, limits to this resilience. Forests that were converted to agriculture decades ago, subjected to repeated fires (i.e., more frequent or intense than natural fire events), overgrazed, or otherwise degraded by human mismanagement and overuse can lose their capacity to recover quickly (e.g., in a matter of years or decades). This loss results from soil erosion, from the loss of belowground biota essential for forest regeneration, and from habitat-simplification-induced losses of plant and animal biodiversity (e.g., Aide et al. 2000).

In such cases, including the most dramatic, such as mined sites and areas with severe erosion following unsustainable agriculture, the establishment of planted forests can be effective in restoring forest cover and biodiversity in a relatively short time (Lamb et al. 2005). Numerous studies have shown that planted forests on moderately to highly degraded sites can catalyze natural forest succession processes and biodiversity recovery through (a) the effects of planted trees on microclimates (light, temperature, and humidity regimes) and their resultant suppression of the grasses or ferns that typically dominate such sites; (b) the creation of more diversified habitat, particularly for seed-dispersing birds and mammals; and (c) the modification of the physical, chemical, and biological characteristics of soil that favor the germination and survival of trees and other plant species whose seeds are dispersed into the site by wind or animal dispersal agents (e.g., Parrotta et al. 1997).

The efficacy of approaches to forest ecosystem restoration depends on a number of factors, including the proximity of natural forests on the landscape (i.e., potential sources of biodiversity to recolonize the site); the selection of planted species or species mixtures (i.e., their effects on soils, microclimate, and attractiveness to seed-dispersing wildlife); the degree to which the recovering forest is protected from the stressors that earlier created and maintained the degraded ecosystem (e.g., fire, overgrazing); and stakeholder priorities that will determine planted species composition, management intensity for forest products, and services (Sayer et al. 2004, Brockerhoff et al. 2008). Together, the potential for the restoration of forest ecosystems informed by science and the growing evidence that biodiversity can benefit ecosystem functioning and services suggest that forests may be able to provide substantial benefits beyond timber and nonwood forest products. Yet the justification for specific management strategies, including the maintenance of natural habitats within mosaic landscapes, requires a common currency with which to compare costs and benefits, especially for policymakers.

Linking science and policy through the economic valuation of ecosystem services for the conservation of biodiversity

The economic valuation of ecosystem services is useful for identifying and resolving the trade-offs among different stakeholders and for ensuring that the management decision-making process incorporates considerations of equity and sustainability. Ecosystem-management plans often result in net gains for some sections of society and net losses for others. For example, forest conservation strategies designed to maximize carbon sequestration (a global benefit) might deprive local people of access to forest goods and services, such as timber and other forest products.

The economic valuation of ecosystem services can also help link conservation strategies to mainstream policies at national and regional levels. It can contribute to the efficacy of decisionmaking criteria (as in cost–benefit analysis or multicriteria analysis) and can thereby modify humans' choice of activities that subsequently impact the condition and trend of the ecosystems under consideration (Kumar M and Kumar 2008). The formulation of values in a decision-making framework is typically influenced by the robustness and accuracy of the various market-based and non-market-based valuation methodologies for capturing the production services that result from ecosystem functions. The application of a production-function approach provides the necessary credibility to economic estimates (Barbier 2008, Bateman et al. 2011) but requires data, especially on these initial ecosystem-function conditions and the magnitude of their perturbation. Such estimates are demanding in nature, but they have the ability to influence policymakers. The understanding of the effects of biodiversity on ecosystem services is still incomplete, and one can only be confident about cases in which strong data enable the valuation of ecosystem services. Otherwise, valuation requires collaboration between economists and ecologists in order to provide the necessary information on critical issues, such as the drivers of biodiversity change and their impacts on the ecosystem and flow of services.

Estimating the economic value of ecosystem goods like timber and fish (also known as *provisioning services*) is relatively easy, because they enter a market. However, this is not generally the case for *regulating services*—that is, the benefits that people obtain from the regulation of ecosystem processes, such as the regulation of climate, water flow, and some human diseases. Valuation should be focused on ecosystems and services that are socially important, the ecological responses should be evaluated in economic value-relevant terms, and the possible use of a broad range of valuation methodologies should be considered to estimate values (USEPA 2009). In addition to these economic hurdles, meaningful valuation of the change in ecosystem-service provision following biodiversity loss requires an ecological understanding of the functional importance of biodiversity. Once a robust valuation is achieved, however, the impact on policymakers can be consequential perhaps because of the surprisingly high values for many ecosystem services, such as clean water (e.g., Kumar P 2010).

There is wide-ranging evidence that the economic valuation of forest ecosystems has greatly enriched the design of public policy. While capturing the benefit of ecosystem services, the cost component must also be identified to help the policymakers who are confronted with limited and competing funds and conflicting policy goals. An example is provided by recent estimates that suggest that halving the current deforestation rates by 2030 would reduce global greenhouse gas emissions by 1.5–2.7 gigatons of carbon dioxide per year, thereby avoiding damage from climate change estimated at more than US$3.7 trillion in terms of net present value (NPV) (TEEB 2010). In Indonesia, Van Beukering and colleagues (2003) estimated the NPV of water supply from the Leuser Ecosystem (which comprises approximately 25,000 square kilometers of tropical forest) at US$2.42 billion. In many cases, valuations of ecosystem services do not account for the costs associated with a loss of the services, which does not help the decisionmakers. The valuation of forests and their ecosystem goods and services (timber, nontimber forest products, fuelwood, ecotourism, bioprospecting, groundwater augmentation, the prevention of soil erosion, and flood damage reduction) can provide the basis for a compensatory mechanism in cases in which losses occur as a result of developments. In one particular case, the Supreme Court of India, in 2009, directed that the estimate of ecosystem services from forests should become the basis of compensation of US$209 million toward reforestation (ten Brink 2011). Other examples of cost estimates for the loss of services include the following: Climate regulation by natural tropical forests in Cameroon were valued at US$842–US$2265 per ha per year (Lescuyer 2007); also in Cameroon, flood protection by tropical forests has been valued at US$24 per ha per year (Yaron 2001); and pollination services provided by forests for adjacent agricultural and agroforest lands in Sulawesi, Indonesia, have been valued at €46 per ha (Priess et al. 2007). Furthermore, the ongoing forest conversion in these same areas is expected to reduce pollination services and thus coffee yields by up to 18% and net revenues by up to 14% over the next two decades (Kumar P 2010). Factual values such as these provide solid arguments to decisionmakers for the conservation of habitats and the associated biodiversity in policy and planning.

A need to improve the influence of biodiversity considerations in policy formation

Biodiversity is often neglected in policy formulation outside of environmental portfolios and may be harmed as a result of unintended consequences in various development sectors. This is especially true of government agencies whose mandates have cross-sectoral implications for biodiversity, such as in energy, mining, agriculture, tourism, and transportation (e.g., Thompson and Christophersen 2008). Furthermore, not everyone has the same expectations of outcomes with respect to biodiversity. For example, some land managers might suggest that a limited emphasis on biodiversity conservation is acceptable because of their focus on the production of only one or very few other highly valued resources. Nevertheless, the continuing worldwide decline of biodiversity indicates that a more balanced approach to managing resources is universally required. The loss of biodiversity is somewhat analogous to the climate change problem, in that we need to apply the precautionary principle and act now because there is a delayed response to any action. The concept of the *extinction debt* (Tilman et al. 1994) suggests that we will see an ongoing loss of species and, potentially, ecosystem goods and services as a result of many factors.

That biodiversity is still declining nearly 20 years after the Rio United Nations Conference on Environment and Development conference, and the adoption of the Convention on Biological Diversity (CBD 2010) is in some measure an indication of the failure by scientists to convince the public and governments that biodiversity has value. Almost all indicators from CBD (2010) clearly support this contention: Thirteen million ha per year of deforestation has continued unabated for 20 years, the number of threatened species is growing, mangrove forests are disappearing, coral reefs are being lost, and the living planet index is declining.

Scientists often lack influence at the policy level, and many factors extrinsic to science affect the capacity for science integration into policy. For example, a European survey (European Commission 2007) showed that few people, including some scientists, believe that environmental and conservation issues are currently urgent. In this survey, depending on their ages, 61%–71% of the respondents had not heard of or did not understand the term *biodiversity*. Similar results were found by Hildén and colleagues (2006), who noted that "policy makers do not understand biodiversity [or] its value," whereas "researchers do not understand [that] management needs to mitigate further biodiversity loss" (p. 16).

Forest managers often consider biodiversity merely as a forest product, rather than as being integral to and responsible for ecosystem functioning and the delivery of goods and services. This problem has resulted partly from various forest criteria and indicator processes (e.g., Montréal Process 2009), because biodiversity is one of the criteria by which sustainable forest management is measured. Furthermore, forest management is criticized by some environmental nongovernmental organizations as an excuse to conduct business as usual. These groups suggest that forest management follows a reductionist approach (e.g., Bosselmann 2010) in which the complex processes in ecosystems and the associated supporting resources of soil and water are ignored, whereas the focus is only on increasing the production of wood fiber (see the Rainforest Foundation UK and Greenpeace's Comments on FIP Design Document, available online at *www.redd-monitor.org/wordpress/wp-content/uploads/2009/04/gp-rfuk-proposed-text-revision-to-fip-design-doc-_april-6.pdf*). Nasi (2010) noted that, at least in most tropical forests, the emphasis unfortunately continues to be on a nondeclining, even flow of limited goods (managed sustained yield); therefore, the principles of sustainable forestry are poorly applied.

Monoculture of the mind is a term that describes an inability for lateral thinking and formative groupthinking, which causes people to accept prevailing paradigms as the answer to a problem when they should be questioning if, perhaps, those paradigms are not part of the problem. For example, biodiversity is often considered a preservation issue by politicians, whereas, in reality, biodiversity conservation is about sustainable use. The CBD is only partly concerned with preservation, and it fully recognizes that the sustainable use of biodiversity is important to humans. The notion of preserving biodiversity for solely ethical or moral reasons is unlikely to convince politicians to consider biodiversity in policy development. However, illustrating the role and value of biodiversity in the production of ecosystem services is a clear role for scientists.

Raising the profile and understanding of biodiversity with the public and with politicians is possibly one of the most important contributions that scientists can make to global conservation efforts. Research aimed at understanding species biology, habitat selection, and various aspects of species demographics will only improve management practices if it ultimately influences the relevant policies. Educating policymakers about the importance of biodiversity is one way to improve policies and to avoid negative consequences for the conservation of biodiversity. Unfortunately, scientists have been frequently unsuccessful in communicating the linkages between species' functional roles in ecosystems and human well-being. Their efforts are further hindered when disagreement among scientists with different viewpoints (e.g., regarding the importance of different mechanisms or the relevance of controlled experiments) obfuscates the commonalities in their viewpoints (e.g., that biodiversity is beneficial to society; Benton et al. 2007, Solan et al. 2009).

Scientists usually lack the communications skills needed for dealing with senior managers, politicians, the media, or the public, and strong cultural differences in the way different disciplines communicate with their peers (Raffaelli et al. 2005) create barriers. Therefore, even some motivated scientists encounter problems in expressing their perspective in public forums or during interviews with various media. One key aspect of this problem comes from the discipline-dependent lexicon and jargon often used by ecologists without consideration that the general public may not understand terms such as *ecosystem*, *function*, *biodiversity*, or *landscape*.

Some examples of how biodiversity science has had positive effects on forest-related policies

Although there are a number of difficulties in translating the knowledge about the benefits of biodiversity on ecosystem services and human well-being, there are also some indications that decisionmakers are becoming increasingly aware of the importance of this relationship. First of all, increases in the funding of research relating biodiversity to ecosystem processes, at least in some countries (Solan et al. 2009), suggest that some funding agencies understand the value of such work. There is also some evidence that research on the importance of biodiversity is being increasingly disseminated outside of the scientific community. Solan and colleagues (2009) related a fivefold reduction in the time taken for research findings to be implemented in conservation management to three factors: (1) Credibility of this field has been established with the public over time, (2) more realistic experiments have made the research more directly applicable to conservation practice, and (3) more widespread adoption of sustainable ecological concepts in general has created a push toward the standardization of practical, ecosystem-based management approaches. The extent to which any such gains can be attributed to direct attempts by scientists to communicate with policymakers, however, may be questionable (Solan et al. 2009). We provide two examples (invasive species management and forest certification) in which biodiversity science has affected changes in policies regarding ecosystem management.

Invasive species management. Alien invasive species have become a major cause of biodiversity loss and can result in high costs for ecosystem recovery (e.g., Mack et al. 2000). In Japan, research on damage to ecosystem services by invasive species led to the enactment of the Invasive Alien Species Act (2004, Law no. 78). Most other countries now have plant and animal quarantine systems and invasive species prevention plans intended to prevent invasion by agricultural and forest pests and to intercept organisms that might harm endemic ecosystems. For invasive species control, networks of scientists, quarantine officers, and policymakers are recognized as important. Such networks now exist in many regions—for example, the North European and Baltic Network on Invasive Alien Species, the Forest Invasive Species Network for Africa, and the Asia–Pacific Forest Invasive Species Network.

Forest certification. *Forest certification* is a mechanism whereby an independent audit is conducted on a forestry operation to determine whether the forest is managed sustainably. Forest certification has had a significant influence on forest management practices in some forests, and most developed-country governments are in favor of and encourage it. In some markets, only certified wood can be used for products, and some consumers will pay a premium for biodiversity-friendly wood. Forest certification processes have been developed on the basis of forest and silviculture science, with guidelines and indicators that are periodically updated and supported by new research. Certification promotes science-based forest management, ensures that management planning occurs, requires management for biodiversity objectives, and ensures the monitoring of results. The certification of forests has undoubtedly been a major driver in the adoption of sustainable forest management principles in operational practices, despite the fact that these schemes are voluntary. One analysis points to considerable promise for these as processes to move forestry toward global-scale sustainability (Pedersen et al. 2002). Consequently, certification may lead to an enhancement of biodiversity (see, e.g., Gullison 2003), which is likely to contribute to increased forest ecosystem goods and services. To date, about 8% of the world's forests have been certified (FAO 2010), but the underrepresentation of the 47% of the world's biodiversity-rich tropical forests is of particular concern.

Some considerations for scientists to help improve their research impact

For society to benefit from scientific research, scientists should ask questions designed to improve our understanding of ecosystem processes but then also clarify the linkages to ecosystem services and convey the results in clear messages to resource managers and decisionmakers. Furthermore, to improve the impact of their efforts on policy, scientists need to understand that the policies already in place may have generated the conditions they are studying and to treat those policies as hypotheses and illustrate to decisionmakers the costs and trade-offs (to people) of policy options within ecosystems (e.g., Perrings et al. 2011). For example, the long-term effects of minimum-diameter timber-harvesting regulations on ecosystem processes are unknown. If a research question were framed in terms of the harvest diameter distribution and the changes in ecosystem services that resulted from this policy, the answers would be immediately applicable to policy formulation. Schmolke and colleagues (2010) made some similar suggestions for modelers, arguing that basing models on policy would increase the impact of the models. Finally, scientists could work directly with policymakers in the development of research programs to delineate critical needs (e.g., Bormann et al. 2007). This would have the dual effects of increasing the relevance of the project and ensuring the interest of decisionmakers before the results are achieved. Adaptive management is a reasonable approach, but if decisionmakers can avoid making mistakes in the first place and then having to correct them, conservation would be better served.

Scientists could be much more effective in influencing policy formulation by focusing on several key areas, including (a) the clarification of the mechanisms by which biodiversity supports and maintains ecosystem goods and services and the clear illustration of these mechanistic effects, (b) improvement of the valuation methods of these ecosystem services to human society, and (c) the derivation of meaningful values (target ranges) and known thresholds to improve the usefulness of biodiversity indicators.

Scientists should not view publication of research results in professional journals as the end of a project. Although such publications are clearly important, better communication of scientific findings to decisionmakers is paramount in order to affect change. This may require a broader set of skills than is typical of the academic training and professional development of most scientists. Training in media relations and communications can help scientists express complex ideas in clearer and simpler ways that will enhance the effectiveness of their communication with nonscientific audiences. Research grant proposals often require a budgetary line item for communications and technology transfer, which could be viewed creatively as an opportunity to do more than fund attendance at scientific conferences.

One way to improve the policy and management relevance of research design and the subsequent transfer of research findings is through workshops with resource users and in local communities before and after research projects. There are often local councils that provide input to forest and land managers who can both offer insights into local needs prior to a project's beginning and then benefit from the knowledge gained after completion. For example, in Tanzania and elsewhere, forest planning is sometimes advised by community groups (Topp-Jørgensen et al. 2005). Furthermore, there may be opportunities to actively involve local communities in research projects through participatory research. Once the projects have been completed, discussing the results with local communities can build trust for scientists while improving the understanding of biodiversity science among the public.

Scientists can deliver seminars to policymakers where they work. Visiting the head office of a management agency and talking about recent research results can be highly influential and can result in a broader appreciation for ecosystem complexity. Furthermore, scientists can address senior policymakers and their staffs by publishing policy-relevant articles in resource-management policy journals, whose audiences are different from those of science journals. Similarly, there are many national or regional resource-management journals that can be effective for communicating results more directly to resource managers. Writing in a prescriptive style is acceptable in such journals and can be an effective means of assuring that managers understand the importance of biodiversity in the context of their local ecosystems.

Conclusions

We have highlighted several examples of the effects of biodiversity in various forest and agroforest ecosystems (e.g., Balvanera et al. 2006) and how these ideas translate directly into benefits to people. Increased biodiversity can lead to increased rates of pollination, increased rates of pest control and reduced pest populations, increased productivity, and greater resilience in forest and agroforest ecosystems. In other words, not degrading the ecosystem will improve or maintain the flow of goods and services that the system is capable of producing. Recent and ongoing research has and is leading to an improved understanding of some of the underlying mechanisms, a greater appreciation of which could contribute to improved management methods with consequent human benefits.

Biological diversity underpins the ecosystem goods and services that people require, but biodiversity is not an ecosystem good or a service to be traded off. It is apparent that this concept and its importance have been largely misunderstood by managers and decisionmakers. Furthermore, given the apparent public apathy toward urgent issues in ecology, scientists need to make a greater effort to more effectively communicate the important role that biodiversity plays for human well-being. This might mean increased research on the direct benefits of maintaining biodiversity in managed systems. Improving the link between biodiversity science and policy can only come with continued and persistent efforts by scientists to work with decisionmakers in formulating their investigations and to share their findings directly to the public.

For ecosystems that are strongly influenced by human use, management objectives should be defined by societal demands in relation to the ecology of the ecosystem. The key role for science in such human-dominated systems is to better understand the social, economic, and environmental benefits of various levels of biodiversity that might be achieved under different ecosystem-management options and to more effectively communicate the results of research on these issues to decisionmakers and other stakeholders. Finally, the economic valuation of forest ecosystem services and biodiversity has the potential to help clarify trade-offs among conflicting environmental, social, and economic goals in the development and implementation of policies and to improve ecosystem management in order to conserve biodiversity.

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