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Forest Systems: Living with Long-Term Change

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Introduction

Human societies depend heavily on forests for resources and habitat in many parts of the globe, yet the global extent of forests has declined by 40% through human actions since people first began clearing lands for agriculture. Forests still cover about 30% of the terrestrial surface and support 70% of Earth's plant and animal species (Shvidenko et al. 2005). Societies residing in tropical forests alone account for half of the world's indigenous languages. People have lived in and interacted with forests for thousands of years, both benefiting from their services and influencing the dynamics of the forests in which they live. Forests are therefore most logically viewed as social–ecological systems of which people are an integral component. Forests are globally important because of their broad geographic extent and the great wealth and diversity of ecological services they provide to global and local residents, including substantial biological and cultural diversity.

The character of forests and societal interactions with them vary greatly across the globe (Plate 5, Fig. 7.1). Belts of dense tropical rainforests encircle the earth in the equatorial zone, bordered at higher latitudes of Africa and South America by extensive savannas of scattered trees. Boreal forests stretch across high, northern latitudes. Conifer or broadleaf and mixed forests are common in intermediate latitudes, especially in the northern hemisphere. Individual forest patches may be managed by a household, local community, small or large corporation, or local or national government agency. The social settings of forests range from urban forests within cities and small sacred forests adjacent to villages to extensive tracts of forest in remote wilderness areas. The portfolio of forest uses and the relative extent of human–forest engagement vary greatly from country to country, reflecting the complex histories of forestlands and societies.

Rapid global changes in biophysical and social factors (see Chapter 1) are particularly challenging to forest stewardship because many trees live longer than the professional lifetimes of people who manage them, making it challenging to develop and sustain institutions with

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FIGURE 7.1. Patch clear-cutting that leads to plantation forests of native Douglas-fir in a matrix of 100- to 500-year native forest in the northwestern USA. Photograph by A. Levno, US Forest Service, photograph AEA-002 [online] URL: http://www.fsl.orst.edu/lter/data/cd˙pics/cd˙lists. cfm?topnav=116

time horizons that extend beyond the short-term motivations of individual decision makers. In this chapter we highlight four overlapping resource–stewardship challenges faced by forest managers throughout the world that are, in part, logical consequences of the long-lived nature of forest trees:

- **Sustaining forest productivity.** Institutions with a long-term view of the ecological conditions necessary to support forests and forest-dependent peoples are a foundation for sustainable harvest from forests. Given harvest intervals that are frequently 40–100 years or longer, large areas are required for forests containing the spectrum of age classes needed for a continuous flow of wood for human use. The large temporal and spatial scales required for sustainable forestry often clash with the short-term motivations and small-scale jurisdiction of forest managers. In order to meet these sustainability challenges it is critical to sustain social values and capacities for dealing with forest systems over long time periods.
- **Sustaining forest ecosystem services. Managing forests for multiple ecosystem services** involves strong tradeoffs among costs and benefits to different stakeholders, with choices having implications for multiple human generations. Forests provide a multitude of ecosystem services, including fuelwood, timber products, water supply, recreation, species conservation, and aesthetic and spiritual values. Together these services generate a diverse and challenging mix of management objectives to meet multiple societal needs.
- **Sustaining forests in the face of environmental change. Managing forests under conditions of rapid change is challenging** because a forest stand is likely to encounter novel environmental and socioeconomic conditions during the life of the individual trees in the stand. Forest ecosystems across the globe face myriad threats from both intentional and inadvertent human impacts, including air pollution, invasive species, and, perhaps above all, global climate change.
- **Sustaining the forestland base. Forest conversion to new land uses** is a state change that is difficult and time-consuming to reverse, given the long regeneration time of forest trees and ecosystems. Historic and ongoing land use has converted vast areas of complex, native forests to agriculture, built environments, and plantations of a single or narrowly constrained set of species, often exotics. Under other conditions, large-scale agricultural abandonment or increased economic value of forests, as for carbon sequestration, can foster **reforestation** or **afforestation** (the regeneration of forest on recently harvested sites or planting of new forests on previously nonforested sites, respectively).

We next address the importance of social–ecological dynamics in forest planning. We then consider each of the above resource–stewardship issues in greater detail, showing both the challenges and the opportunities for sustainable forest stewardship. We conclude with some recommendations for sustainable stewardship of forests in the future.

Forests as Social–Ecological Systems

Because of the longevity of forest trees and forest crops, decisions made today for forest use and management have inevitable consequences for future generations operating in different environmental and social contexts. Societies often face a broad spectrum of forest-management objectives and associated approaches, ranging from maximum wood production with relatively short (decadal) rotations to development of old forest attributes on the multicentury time scale to simple retention of native forest and the species contained therein for conservation, recreation, spiritual, or other objectives. Furthermore, shifting legal, regulatory, and economic contexts of forestry can cause gradual or disruptive, abrupt changes in management, so social disturbances can be as important as ecological disturbances in shaping the future of forest resources.

This complexity of the societal context for forest management is confounded by a web of forces operating at local-to-global scales. Human population growth and sprawl of rural residential development into forest areas increase local demand for forest products while constraining the range of potential forest management tools, such as prescribed fire, that may be critical to sustaining the properties of native forests. Social forces may shift the emphasis of management objectives within the portfolio of ecological services provided by public or private land, such as from wood production to protection of species, with various intended and unintended consequences for society. Thus, social factors can trigger abrupt and profound changes in forest policy and management that can ripple across scales (see Chapter 5). Globalization of commerce, for example, may connect a market place in Europe to forestry operations in a distant part of the globe through forest certification and international agreements against illegal logging. **Forest certification** is a procedure for assessing forest-management practices against standards for sustainability so purchasers can support sustainable management, even over vast distances.

Changing societal and environmental factors are colliding and interacting. Global changes in climate, climate variability, and species invasions, much of them human-driven, make it increasingly difficult to ensure a predictable flow of desired quantities and diversity of services from forests. These global changes have impacts at local to regional scales, sometimes causing landowners to modify forests in expectation of climate-change effects not yet realized on the land. In some cases these threshold changes in system condition and capacity may be influenced by legacies of past management that affect the organization (e.g., age class distribution of forest trees or agency culture of past management) and vulnerability of the ecosystem to disturbance. The resulting uncertainties place a premium on social capital and adaptive capacity.

Supply and Use of Ecosystem Services

Forests provide many important ecosystem services to society both globally and locally over a range of time scales (see Chapter 2). At the global scale, the human conversion of forests to other land-cover types in the last two centuries has had important effects on the climate system (Field et al. 2007). For example, glacial–interglacial changes in forest cover in response to small changes in solar radiation contributed to massive shifts in global climate (Foley et al. 1994, Friedlingstein et al. 1995). As home to 70% of Earth's biodiversity, forests are important sources of ecosystem services ranging from food and medicines to cultural appreciation of their spiritual and aesthetic values. In addition to these global services, forests are home to human communities, whose local use includes harvest of goods; regulation of water and natural hazards; and recreation and cultural ties to the land. Different segments of society often place different priorities on these services, raising challenging questions about tradeoffs and synergies.

Forests are obviously *the* major source of timber and its products, including lumber, veneer, and paper. Despite the importance of lumber and pulp products, more than half (55%) of global wood consumption is for fuelwood, which is used locally; is not well characterized in economic summaries of forest products; and is the primary energy source for heating and cooking for 40% of the global population, particularly in developing nations and rural areas (Sampson et al. 2005). Nontimber forest products also have considerable economic and cultural importance. In the northeastern USA and Canada, maple syrup, produced from the sap of local trees, provides income to rural residents and contributes to local identity. In Alaska the economic value of blueberries and moose harvested by local residents each exceeds the value of harvested timber. About 25% of currently prescribed medicines originate from plant compounds that evolved as defenses against herbivores and pathogens (Dirzo and Raven 2003). Consequently, property rights to the genetic diversity of tropical forests are an issue that is contested between tropical nations, local indigenous peoples, and commercial bioprospecting firms (Kursar et al. 2006). The harvest and sale of bush meat to city residents in Africa is also a controversial topic because it creates both a source of local income and an extinction threat to many of the species that are harvested.

In some cases the products provided by forests are part of an agricultural rotation (**slash-and-burn** or **swidden agriculture**), in which small forest patches are cut, the land is cultivated, and forests regenerate, as people move to clear adjacent forest patches (see Chapter 12). This rotation has been sustainable for millennia, but increasing human population density is reducing the length of the forest rotation; below a rotation length of about 10 years, slash-and-burn agriculture no longer appears sustainable, causing a transformation to continuous cultivation of cash crops (Ramakrishnan 1992).

Many forestlands are managed for the critical ecosystem services of water supply and watershed protection (Rockström et al. 1999, Vörösmarty et al. 2005). Forested watersheds account for more than 75% of the world's accessible freshwater (Shvidenko et al. 2005). Given the increasing scarcity of freshwater relative to human demands (see Chapters 2 and 9), forests are likely to become increasingly important for their capacity to provide and purify freshwater. Water quality and quantity also affect other resources, such as fish, so an ecosystem approach is required for sustainable management. An important aspect of forest watershed management is therefore to meet water quality objectives by minimizing soil erosion, which also sustains soils as a base for terrestrial productivity, limits sediment accumulation in reservoirs, and prevents damage to downstream freshwater and marine aquatic habitats (see Chapters 2, 9, and 11). Watershed-focused forest management can also reduce the potential for landslides and snow avalanches, thereby protecting life and property on the hillslopes and valley floor below. Appropriate actions include distributing forest harvest and roads to avoid unstable areas, creating buffer strips of forest along streams, and adjusting the frequency, spatial pattern, and intensity of management actions to minimize their impact.

Forests and forestry affect the global carbon budget in ways that can either increase or decrease CO_2 concentration in the atmosphere, hence global warming. Forests account for about two thirds of terrestrial net primary production and half of the terrestrial carbon stocks (Shvidenko et al. 2005). Any increases in forest extent or a positive growth response to increasing atmospheric CO_2 or nitrogen deposition removes CO_2 from the atmosphere and reduces the potential climatic impact of fossil-fuel emissions (see Chapter 2). This capacity of forests to sequester carbon appears to be saturating (Canadell et al. 2007), indicating that we cannot count on forests to "solve the problem" of climate warming without more concerted efforts to reduce fossil-fuel emissions. Although increased forest extent sequesters more carbon, it also reduces albedo (short wave reflectance), especially in northern forests during the snow-covered seasons. The reduced albedo leads to greater absorption of solar energy and more heating of the atmosphere. In the tropics, the effects of carbon storage and cooling of the surface by high transpiration rates predominate over energy-exchange effects, so any reduction in deforestation or increase in forest regeneration tends to reduce the rate of climate warming. At high latitudes, the tradeoff is less certain; the greater atmospheric heating by forests due to their low albedo reduces the benefits of carbon sequestration, with the net effect on climate currently uncertain (Field et al. 2007, Chapin et al. 2008). Therefore efforts to slow the rates of **deforestation**, the conversion of forest to a nonforested ecosystem type such as agriculture, are important to the global climate system, especially in the tropics.

Forests also provide important regulatory services at more local scales (see Chapter 2). Tropical forest pollinators, for example, are critical to coffee plantations, which show greatest fruit set and productivity adjacent to forests and forest fragments (Ricketts et al. 2004). Similarly, forests often harbor insect predators that reduce the likelihood of insect pest outbreaks (Naylor and Ehrlich 1997). As forests are cleared to support small-scale agriculture, people and their domestic cattle become exposed to diseases from forest animals. In this way, forest fragmentation reduces the capacity of forests to regulate diseases (Patz et al. 2005). In the northeastern USA forest disturbance and elimination of predators has led to dense deer populations that spread lyme disease, which in turn reduces human use of forests (see Chapter 6).

Cultural and spiritual values of forests have taken different forms in different parts of the world. The Druids, for example, held certain trees to be sacred deities in their Celtic religion. Patches of sacred forest, some only a fraction of a hectare, are an important part of life in many developing nations, including India (Ramakrishnan 1992), Madagascar (Elmqvist et al. 2007), and Benin and Togo (Kokou and Sokpon 2006; see Chapter 6). Forests also provide economically important cultural services such as recreation and tourism (see Chapter 2).

The existence of forests as reservoirs of biodiversity is important to many people and societies. Tropical forests alone house 50–90% of Earth's terrestrial species. Forested mountain landscapes are especially rich because the complex topography and steep environmental gradients create great habitat diversity. In some parts of the world large tracts of forestland have been reserved specifically for conservation of biological diversity, and rules for management of these reserves may, or may not, allow human use of other potential ecosystem services (see Chapter 6).

Sustainable Timber Harvest: A Single-Resource Approach to Forest Management

Evolving Views of People in Forests

Despite the huge ecological and cultural variations among forests as social–ecological systems, changes over time in social–ecological forest systems exhibit some striking parallels. Societal engagement with forests in Australia, Canada, and the USA, which share European cultural roots, for example, have exhibited a similar sequence of stages: "(1) use by hunter-gatherer societies, (2) exploitive colonization, settlement and commercialization, (3) wood resource protection, (4) multiple use management, (5) sustainable forest management or ecosystem management" (Lane and McDonald 2002), and finally (6) sustainable ecosystem stewardship (see Fig. 15.1). Transitions from one stage to the next have often occurred through a crisis triggered by biological forces (e.g., extensive insect outbreaks) or social events (e.g., law suits and court injunctions), or development programs sponsored by nonlocal agencies with interest in modernizing "primitive people" (Gunderson et al. 1995, Lane and McDonald 2002). These transformations can be important opportunities for innovation, because the crisis demonstrates that the current system is not working, making managers and the public willing to consider new alternatives (see Chapter 5). Although government controls on forestland and terminology for management systems may differ among countries, this general trajectory and the punctuated pattern of change have been quite similar among countries and biomes that range from drylands and freshwaters to cities and agriculture (see Chapters 8, 9, 12, 13, and 15).

However, not all societies engage with forests in this sequence. Developing countries, for example, sometimes find a path that draws on the ingenuity and knowledge of local people to meet pressing demands for both poverty alleviation and forest stewardship, providing a potential seedbed for new forest stewardship approaches that would benefit Western countries. However, indigenous and rural communities often face extremely difficult challenges in their efforts to use local forest resources because of governmental controls and corruption (Larson and Ribot 2007). In some very remote forests, however, population density may be limited by the capacity of forests to provide food, either through small-scale clearing and recovery of forests or through subsistence harvest of foods from the forests. These interactions limit both the human population that can be supported and the extent of forest harvest. Forests were harvested primarily to meet short-term, local human needs for resources provided by the forest rather than for commercial sale of wood products (see Chapters 6 and 12).

Expansion of agriculture and commercial trading of forest products led to more extensive forest clearing. This began in Europe in the Middle Ages and in eastern North America with European colonization and still characterizes many tropical and boreal regions. **Forest exploitation** is largely driven by demand for wood and depends on availability of labor, access, and markets in social contexts with limited local governance. Under conditions of illegal and even some corporate- and government-backed forest exploitation, little attention might be paid to whether forest practices are sustainable (Burton et al. 2003). For example, in the developing world forest exploitation is often fostered by unclear property rights, disempowerment of local institutions for managing common property, or government efforts to generate foreign exchange from wood exports (see Chapter 4). Under these circumstances, any unfavorable effects of forest harvest have relatively few consequences for those who make the decisions about the extent and nature of forest harvest.

As exploitation depletes forests, the importance of forest regeneration becomes more apparent, and there is a gradual transition to **maximum sustained yield** (MSY) of timber, rather than short-term profit as a guide for forest management. MSY sets a harvest level that does not exceed the expected annual growth increment (see Chapter 2). This leads to a harvest rotation system, in which forests are managed much like an agricultural crop. In this context, the value of the forests reflects both supply and demand. MSY is clearly motivated by efforts to manage sustainably, but with a narrow focus on wood supply and much less attention to other ecological services or to forest resilience to unexpected changes. Managing for MSY is challenging with long-lived species like trees and with uncertain variation in climate, pests, other disturbances, markets, and taxation systems. In many cases, estimates of future yield have been overly optimistic and probabilities of environmental consequences and disturbance have been underestimated, leading to harvest schedules that proved unsustainable over the long term. For example, climate warming may increase drought stress and the risks of fire and insect outbreaks to an extent that was not anticipated when plans for high levels of wood production were developed. Short-rotation production forestry on plantations is still guided by MSY, which provides a reasonable guide to sustainable timber production, if changes in slow variables such as soil fertility, disturbance, and pest populations are taken into account. Production forestry predominates where land is owned by forest companies or on public lands where wood production for short-term revenues is the primary objective for management. Even where wood production is the explicit management objective, silvicultural practices have been developed that enhance the delivery of other ecosystem services to society, as described below.

The shortcomings of MSY and public sentiment that public forests should serve more than industrial forestry interests pushed policy for public forestlands to embrace **multiple use management** that explicitly addresses a broad array of ecosystem services. In the 1990s growing global interest in species conservation, maintaining site productivity, and other ecological services, led to development of an **ecosystem-management** approach that emphasizes the well-being of the system as a whole, while capitalizing on natural ecological processes to do the work we wish to accomplish in the forest (Grumbine 1994). Even in the context of ecosystem management, crises may arise from influences such as extensive insect damage to forests or altered public opinion, resulting in environmental policy changes and new environmental regulations. Over the course of these changes in views and approaches to forest management, several trends are evident:

- Broader geographic and temporal scales are considered.
- More components of forests, hence more ecosystem services, are included as primary management objectives.
- Therefore, a greater variety of technical disciplines is engaged in planning and implementing forest management, and general professional oversight shifts from silviculturists and foresters to broadly interdisciplinary teams.
- In some cases adaptive management is implemented to monitor change, adapt plans based on new information, and, thereby, learn through doing.
- Research-management and science-policy ties are broadened and strengthened.

Current conditions of rapid environmental or social change have given rise to additional challenges that require an expanded vision of ecosystem management, which we term ecosystem stewardship (see Chapters 1 and 15). In this context, managers recognize that change is inevitable, although the nature and rate of change are generally uncertain. Under these circumstances, managers seek to respond to and shape changes and to be very judicious in identifying historical properties of the system to attempt to sustain into the future.

Despite these common trends, quite different forest landscape-management approaches are often evident even within a single forest region. In the Pacific Northwest (PNW) USA, for example, forestry practices range from an agricultural model (MSY) of 40-year cutting rotation on industrial lands to an 80- to 100-year rotation on government lands managed for timber production to wilderness, park, and other lands where no cutting occurs (Box 7.1). In some other countries, by contrast, laws designate narrowly prescriptive forestry management rules on most public and private lands. In yet other contexts ranging from communities in remote areas of developing countries to western government forestry, exploration of alternative future scenarios has been used to set a desirable future course of forest stewardship (Wollenberg et al. 2000). These contrasts suggest that there is no single "right" approach: different governmental jurisdictions, ownerships, and land allocations have different management objectives, hence management paradigms, approaches, and supporting science (see Chapter 4). Policy diversity and adaptive, learning social systems are sources of institutional and ecological resilience for an unknown future. Even if a "best policy" could be identified for today's conditions, other policies might prove more favorable as an uncertain future unfolds (Bormann and Kiester 2004) (Fig. 7.2).

Box 7.1. Blending Forest Production and Conservation in the Western USA

Development of forest issues and policies in the PNW of the USA (Fig. 7.2) over the past few decades presents dramatic examples of the challenge of conducting ecologically and socially sustainable forest management. The conflicting values people hold of PNW forests have been starkly framed—cut majestic, centuries-old forests or sustain local economies and families who for several generations have worked in the woods; save a cryptic owl species and iconic salmon or intensively manage highly productive forestlands for wood products that benefit a broad cross-section of society. Of course, the real issues are not such simple dichotomies, and societal complexities match or exceed ecological complexities. We consider this example of a region's quest for sustainable forestry in terms of the expanding breadth of multiple use objectives, the great diversity of livelihoods affected, and successes and failures in adaptive management.

Conflict over these forests grew out of three decades of intensive timber production on Federal forestlands commencing after World War II to supply wood for the postwar housing boom. Intensive timber harvest during this period focused on old growth (>200 years old) and cumulatively affected about 30% of the landscape by the late 1980s. Over the timber production era local communities grew dependent on livelihoods based on jobs in the woods and in the mills. Federal forestry agencies flourished by putting large volumes of wood into the marketplace, and the applied science community studied ways to enhance timber productivity and efficiency of logging systems. This pattern of natural resource system development follows the paradox framed by Holling (1995, p. 8): "The very success in managing a target variable for sustained production of food or fiber apparently leads inevitably to an ultimate pathology of less resilience and more vulnerable ecosystems, more rigid and unresponsive management agencies, and more dependent societies"—until some ecological or social disturbance triggers abrupt change.

That disturbance erupted as intense controversy in the late 1980s over the fate of old-growth forests, salmon, and northern spotted owl. Law suits hinged on protecting the northern spotted owl, "listed" under the Endangered Species Act, stopped all logging of forests in the 100,000 km^2 range of that species, extending from northern California to the Canadian border. To break the gridlock created by the resulting court injunctions that blocked timber cutting, President Clinton convened scientists to conduct a bioregional assessment (FEMAT 1993, Szaro et al. 1999) and craft a new plan with objectives of protecting species of critical interest and forming an interconnected network of old-growth forest reserves, while providing some flow of timber to local communities.

The resulting Federal lands policy, the Northwest Forest Plan (NWFP; USDA and USDI 1994), was a revolutionary departure from previous forest management in the region, and set an example of ecosystem management with broader impact. The NWFP greatly expanded the scope of ecological considerations under the multiple use rubric. For example, hundreds of species were designated for special attention under protocols called "survey and manage." The geography of planning under the NWFP was based more on ecosystem considerations than political jurisdictions, spanning many Federal agency lands and aligned with watershed boundaries. The plan placed 80% of the land in reserves for terrestrial and aquatic species and reduced the timber harvest level by more than 80% of the level of the 1980s. Harvest of old-growth forest outside reserves was to provide a significant share of timber volume in the early decades of NWFP implementation. Ecological considerations strongly influenced the harvesting systems. For example, 15% cover of live trees and substantial amounts of deadwood were to be retained to meet ecological objectives in harvest units that would have been clear-cut in earlier logging systems. The NWFP incorporated adaptive management at several scales, including designation of ten Adaptive Management Areas (AMAs) covering 7% of the plan area. The NWFP also commissioned a region-wide monitoring program for change in forest cover, northern spotted owls, socioeconomic conditions, and other attributes, to support adaptations of the plan at the regional scale.

How is the NWFP working? Results of a regional monitoring program document successes and failures over the first decade of plan implementation (Haynes et al. 2006). Dire predictions of collapse of rural communities did not occur, although more isolated communities highly dependent of Federal timber did suffer and livelihoods dependent on jobs in the woods and mills declined markedly. A long-standing system of payment of timber revenues to counties in lieu of property taxes on Federal lands has collapsed, leaving counties with extensive Federal timber land without funds which they had depended on for roads, libraries, and schools. Federal timber harvest has not reached even the greatly reduced level projected by the NWFP because of procedural challenges by environmental organizations, limited funding of forestry agencies, and other issues. The harvest of old growth was limited because of strong public opposition. The regional monitoring program revealed that the extent of old-growth habitat increased because forest growth exceeded losses to harvest and wildfire. Ironically, although suitable habitat increased, spotted owl populations continued to decline, perhaps in part due to competition from the more aggressive barred owl expanding its range from the north and east. Adaptive management proceeded in two ways: (1) a regional monitoring program (Haynes et al. 2006) that reported findings likely to influence future plan revision and (2) the AMA program in which scientists, land managers, and in some cases local public groups undertook studies to test assumptions in the NWFP and explore other management approaches. However, the regional monitoring program faces uncertain funding, and the AMA program faced substantial institutional barriers to success (Stankey et al. 2003). Before the AMAs were a decade old most funding had disappeared, and the commitment to this learning process largely evaporated.

What does the future hold? Federal forests in the PNW will doubtless present profound surprises, as they have in the recent past. Three factors are in play—the forests, their social context, and environmental change. Is the present NWFP harvest level so low that it is socially unsustainable? There has been no great public clamor to increase logging in the Federal forests of the region, but it may develop for social (e.g., more revenue to local communities) or ecological (e.g., reduction of vegetation that could fuel fires) reasons. However, changes in the global market place and other social factors may someday trigger increased forest harvest. Will the barred owl displace spotted owls, reducing the legal motivation to sustain old-growth habitat? This now seems possible, but the spotted owl is no longer critical to protection of native forests, especially old growth. The public seems thoroughly committed to protection of the remaining old-growth forests. Climate warming, invasive species, and changing fire regimes are creating a very uncertain future for forest management. In short, the forces of change, both environmental and social, have great potential to trigger new convulsions. The region remains caught in Holling's paradox—in part because of limited success in developing sustained learning institutions (Holling 1995).

Forest Exploitation and Illegal Logging

Illegal logging dominates the timber production of some developing nations and accounts for up to 15% of timber production globally (Contreras-Hermosilla 2002, Sampson et al. 2005). More than half (50–80%) of timber production in Indonesia, Brazil (in 1998), and Cameroon, for example, is estimated to occur through illegal logging (Sampson et al. 2005), although precise estimates are seldom available. Illegal logging includes logging in protected areas, without authorization, or more than authorized; timber theft and smuggling; and fraudulent pricing and accounting practices (Sampson et al. 2005). It can focus on high-value tropical woods, depleting local diversity, or extensive forest clearing, causing land degradation. Illegal logging deprives governments and local communities of forest revenues, often strengthens criminal enterprises, and induces corruption among enforcement and other officials (Contreras-Hermosilla 2002, Sampson et al. 2005). It is analogous (and is a similar proportion of total harvest) to illegal and unreported fishing (see Chapter 10). In the former Soviet Union (FSU), illegal logging was estimated to account for about 20% of timber production, but this practice largely disappeared, when the collapse of the FSU eliminated subsidies for transportation from forests to processing facilities (Sampson et al. 2005).

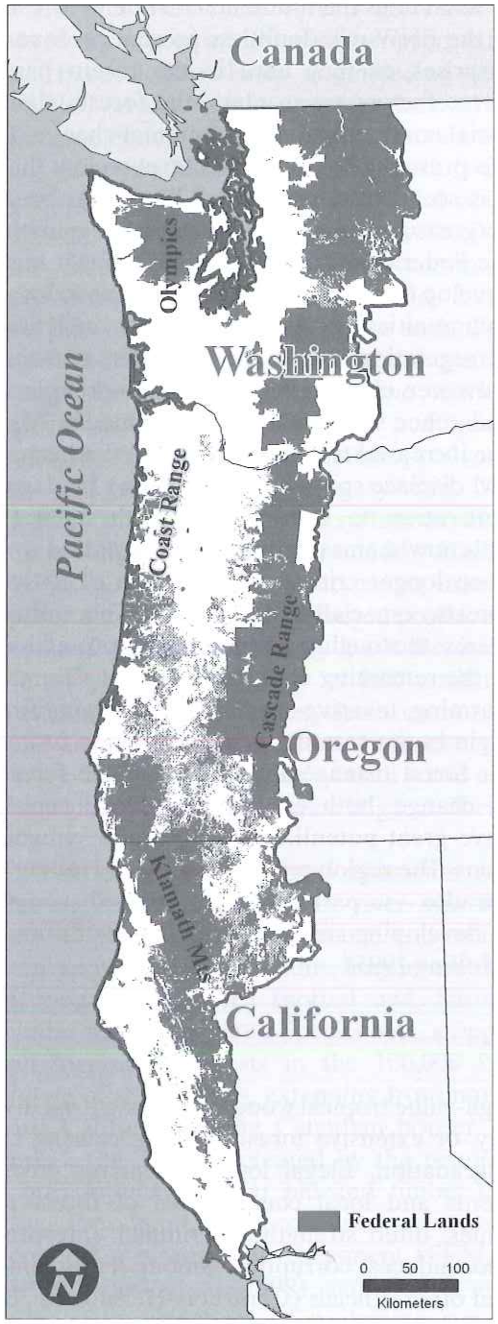

FIGURE 7.2. Shaded relief map of western Washington and Oregon and northwest California showing forested areas of coastal mountains and the Cascade Range and the outline of NWFP area covering the range of the northern spotted owl. Information from USDA and USDI (1994).

Just as in the forest exploitation phas of Europe and North America, illegal lo ging is driven largely by market value, acce and labor, with no regard for regener tion or sustainability. It often proliferat in response to multiple local, national, ar global circumstances, therefore requiring mu tipronged responses. Commonly contributi factors include:

- Disempowerment of local institutions th provide for sustainable forest manageme These could include a weakening of pro erty rights or weakening of some of the fa tors that facilitate effective stewardship common pool resources (Dietz et al. 200 Agrawal et al. 2008; see Chapter 4).
- Political corruption that prevents local in viduals or communities from benefiting fro the timber sales or that leads to national po cies with other social goals (e.g., forest clea ing for oil palm plantations in Indonesia meat production in Brazil) that subvert fo est sustainability.
- High market prices that increase the ben fits from illegal logging relative to the soci costs and political risks.

Actions that might reduce the likelihoo of illegal logging include the building of lo social capital and livelihood options; bridgi institutions at local-to-national scales; clarific tion of property rights; international aid that tied to changes in the incentive structure f illegal logging; or global forestry certificatio programs that encourage sustainable manag ment. The engagement of local forest users decisions about rules for management of pr tected areas generally results in greater co pliance and oversight of others than in cas where rules are imposed by higher autho ties (Nagendra 2007, Agrawal et al. 2008). the scale of international trade, on the oth hand, European purchasers of South Americ wood would like to know that it came fro forests managed sustainably. Forest certific tion currently covers a negligible proportion timber production, primarily in the tempera zone, with variable verification, but ultimate could substantially reduce forest exploitatio especially for high-value timber species wi specialized markets. International accords on forest conservation provide potential avenues to address both illegal logging and forest certification.

Timber Production from Natural Forests

Natural forests are forests that have regenerated naturally, in contrast to **production forests** in which trees are planted, often in regularly spaced patterns of a single species (Sampson et al. 2005). Logging of natural forests accounts for most (65%) of global timber production and is a significant source of local employment and livelihoods. In this chapter we use **timber** synonymously with **industrial roundwood**, which includes sawlogs and pulpwood (and the resulting chips, particles, and wood residues). Throughout the world, individuals, families, or local enterprises harvest most timber, providing both local income and cultural connections to forestlands. Although timber production continues to increase globally in response to global increases in consumption, the rate of this increase is slowing and is largely met by increases in production forestry. Until recently, the growth in timber production was approximately balanced by increased labor productivity (1.45% annually in the USA, for example), as labor-saving technologies and infrastructure expand, leaving a roughly constant employment in forest production (Sampson et al. 2005). This apparent stability hides huge national and regional shifts in timber harvest. For example, harvest declined radically in the FSU due to economic collapse and in the western USA due to shifts in forest policy (Box 7.1). Conversely, harvest from natural forests is increasing in many tropical countries, in part through illegal logging. Given the long-lived nature of forest trees, uncertain environmental change, and shifting markets, how can natural forests be managed more sustainably? The answer appears to be context-specific and differs substantially between developing and developed nations.

Rural communities in many developing nations depend strongly on the products of nearby forests, especially in the tropics and subtropics (Bawa et al. 2004). In some of these countries, such as Costa Rica, Mexico, and Nepal, large-scale reforestation is occurring either coincident with or following deforestation. In other countries, such as China, deforestation is the predominant trend (Nagendra 2007). Even within a country the balance between forest cutting and reforestation can be regionally variable. In Nepal, for example, all forests are nationally owned but are managed differently, depending on the land-tenure status of local residents. In national forests and parks that attempt to exclude local residents to meet conservation goals, deforestation is the predominant trend as a result of illegal logging, whereas areas that are managed by communities or by individual leaseholders show net reforestation (Fig. 7.3; Nagendra 2007). These trends toward reforestation are strongest where local residents participate in monitoring the patterns of forest use. These patterns of community forestry are more sustainable under conditions of clearly specified land-use rights and active monitoring, consistent with research on successful management of commons (see Chapter 4). Community engagement does not always lead to sustainable forestry, however, in part because several factors create significant misfits of institutional and ecological conditions (Brown 2003). Factors that can undermine sustainable forestry include inability of local residents to exclude nonresidents from forest harvest (e.g., illegal logging) or to participate meaningfully in defining the rules or resolving conflicts related to forest use (see Chapter 4). Globally there is a trend toward decentralization of forest-management authority (Agrawal et al. 2008), providing opportunities for concerted efforts to strengthen community-based management.

Sustained timber production from natural forests involves both the first cutting of native forest and the subsequent cuttings of forests that regenerate after the initial harvest. If reforestation is managed to sustain a near-natural mix of native species; biotic structures, such as standing and down deadwood; and ecological processes, such as a natural fire regime, successive forest rotations may provide many

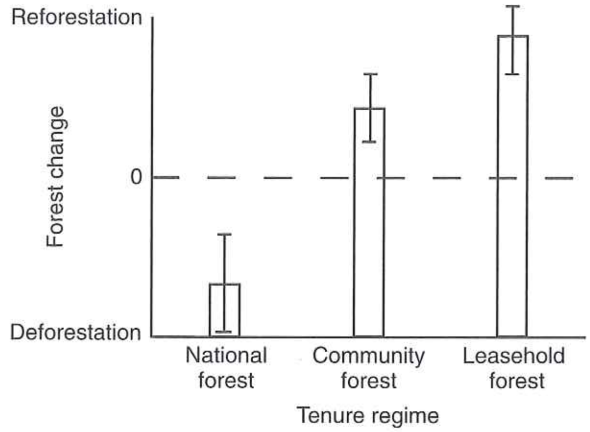

FIGURE 7.3. Relative extent of deforestation and reforestation of government-owned forests in Nepal. National forests are managed by the government, with little community engagement or protection, resulting in open-access use by people living nearby. Community forests are managed by local communities through community forestry user groups. Leasehold forests are small patches of forest that are generally highly degraded and available to households in regions of high poverty. Leaseholders often replant their own forests and harvest from nearby national forests. Adapted from Nagendra (2007).

of the same services as the initial forest. In ecological terms, this forestry system contrasts sharply with management of plantations of exotic species. In some parts of the world first cutting of natural forests remains the dominant practice—in Siberia, for example, where old-growth forests are extensive and forest regrowth is slow, and parts of the tropics, where ecological, social, and economic factors have constrained reforestation. Even in places where native forests were converted to agriculture and then monocultures of native or exotic tree species, such as forest plantations on public lands in the Southeastern USA, some forests are being managed for more natural biological conditions of species and processes combined with the intent of maintaining a flow of forest products from the land. In these cases forestry has both wood production and forest restoration objectives.

A common theme in forestry in natural systems is the need to understand the ecology of the system. This is the gist of ecosystem management (Grumbine 1994). What limits and capacities does the native ecosystem impose? How can native ecosystem processes help us efficiently work toward our management objectives? For example, many native ecosystems contain plant species with the capacity to fix nitrogen, which can contribute to soil fertility. Intensive plantation forestry may preclude these nitrogen-fixing species by eliminating the stages of forest development in which they prosper. More natural and diverse ecosystems may help retain the roles of nitrogen-fixing species in the forest system, resulting in greater, sustained site productivity.

The practice of sustained production from natural forests therefore requires development of tightly integrated ecological and social dimensions of forestry practices. Adaptive management (see Chapters 4 and 10; Walters 1986) provides a context for bridging the contrasting workplace cultures of science and management. Scientists like to ask questions and challenge ideas; land managers tend to work together and seek public license to operate by using "best management practices." But, if scientists, forest managers, and communities can work together in an adaptive management framework, it may be possible to develop management systems that are scientifically credible, socially acceptable, and adaptive to changing social and environmental circumstances (Box 7.2). Some government agencies, such as Forestry Tasmania and the US Forest Service have both management and research branches, which have the potential benefit of cultural proximity, but the disadvantage of too much familiarity and collegiality, which may limit objectivity and critical analysis. Another research-management partnership model is the alliance of state forestry with academia, such as extension programs in the USA for forestry and agriculture. However, these tend to be simple consultations rather than sustained programs of adaptive management. In very limited instances the forest industry has had in-house research programs that may set the stage for a sustained adaptive management program. A critical issue in all such cases is the institutional capacity to sustain adaptive management programs over the long time spans appropriate to trees, cropping rotations, and institutional change.

Box 7.2. The Many Roles of Scientists in Management and Policy

Scientists involved in forestry stewardship are among the many people whose livelihoods are deeply engaged with forest systems—such as loggers, heavy equipment operators, mill workers, forestry and regulatory agency staff, and environmentalists, to name but a few (see Chapter 3). Among these groups scientists have a unique and difficult challenge in their need to produce new knowledge, interpret monitoring and research findings, and in many cases comment on policy alternatives.

To display some of the complexity of types of livelihoods and other engagements with forests, we briefly examine scientists' roles in shaping, supporting, and even attacking forest management and policy (Swanson 2004). It is useful to view these roles in the context of stages of forestry management and policy paradigms in the panarchy framework of Gunderson and Holling (2002), who envision natural resource management as a series of cross-scale, interacting adaptive cycles punctuated by periodic crises (see Chapter 1). However, some roles of scientists are continuous, such as conduct of basic science, despite periodic crises and regardless of the management approach of the day. The role of scientists can be broadly grouped as operating inside the system in support of the prevailing management paradigm and those operating outside as shadow networks that attempt to influence decision making through the production of knowledge and critique of proposed management and policy options.

Recent forestry conflicts reveal the quite varied roles of scientists over the course of development of a resource exploitation management paradigm, through the crisis of its demise, and into establishment of the next set of policies (Box 7.1, Fig. 7.4). These roles may take the forms of:

1. Exploitation phase
   - "Applied scientists" working in support of the prevailing paradigm studying methods to enhance productivity and management efficiency. Information exchange is termed "technology transfer," implying one-way flow of information in the form of technology. Government and industry are likely to fund this science work.
   - "Canary in the mine" scientists identify species or other ecosystem components or processes that are perceived as imperiled by the management paradigm of the day. This is a risky, public, and generally unfunded role.
2. Conflict phase
   - Scientists may conduct bioregional assessments of the history and current conditions of the ecosystems and resources in question to set the stage for resolution of conflict (Szaro et al. 1999).
   - Scientists may participate in development of broad-scale management plans that set new policy intended to resolve past conflict. Bioregional assessments may be used as a foundation for the new plan.

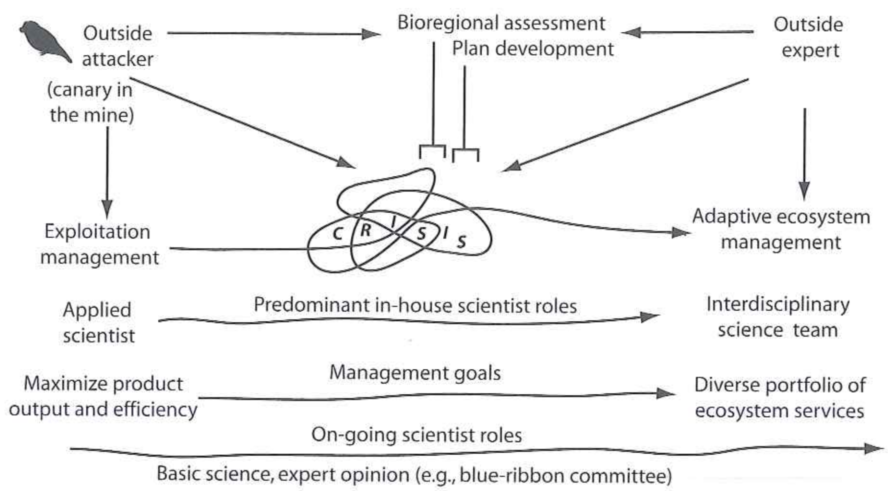

FIGURE 7.4. Schematic representation of the varied and changing roles of scientists during a transition from a predominantly exploitation phase of forest management through a conflict phase to a postconflict ecosystem-management phase. This paradigm shift involves important changes in the roles of in-house (agency or industry) scientists from leadership by applied scientists, whose goal is to improve productivity and economic efficiency, to interdisciplinary teams of basic and applied scientists who may have pivotal roles in bioregional assessments and development of new management plans. These scientists together with land managers may assume responsibility to design and implement adaptive management. Scientists outside of agencies also play key roles—most frequently as outside attackers in the exploitation phase or as outside experts in the postconflict phase. Ongoing roles for scientists at all times include conducting basic science and serving as sources of expert opinion (e.g., blue-ribbon committees). Adapted from Swanson (2004).

3. Postconflict phase

- "Adaptive management roles" have scientists working in support of the new management paradigm. In current terminology that may mean participation in adaptive management programs with scientists and land managers working in close partnership to develop new management approaches that have scientific and operational credibility. This is quite different than the old "technology transfer" model of scientist and manager relations. The adaptive management relationship between scientists and managers can feature two-way exchange of views and shared learning. A strong base of adaptive management can set a stage so that when the policy window opens, innovative, grounded approaches are ready to be spread via a shift in policy (see Chapter 5).

4. Science roles at any time

- "Long-term basic research" is a continuing role of scientists, whose findings may be useful in policy and management at some later point.
- "Outside attackers" criticize the prevailing management paradigm and may work for interest groups or with personal motivations. Attackers may operate at any stage of policy and management, but are especially significant in triggering crises and bringing down an existing paradigm. Attackers of a new management approach may come from the ranks of those who benefited from the earlier management paradigm.
- "Episodic venues" for science input to policy makers occur via participation in processes such as "blue ribbon" commissions on special topics intending to inform the public and the policies.

- "The isolated individual" is a single scientist or small group with limited support operating in areas with little science infrastructure, including developing countries. In this case an individual may play many of the above roles to try to improve stewardship of forests and other natural resources.

Scientists engaging in natural resource issues, especially leading up to, through, and shortly after a major policy convulsion, can find professional life very challenging. Education programs generally do not train students for the social and political turbulence that can come with these roles. Many dilemmas about professional conduct arise in the context of public policy disputes. Some scientists play multiple roles during their careers or even simultaneously, such as government scientists who may be a dispassionate provider of science-based information in that government role, but work clandestinely on behalf of an interest group in the off hours. Scientists confront many tough personal choices, such as advocate aggressively for a policy outcome in the immediate crisis or hold back to maintain a reputation of objectivity, hoping this to be an asset in future crises.

Thus, scientists have many decisions to make about their conduct. Even advocating use of science in natural resource decision making may be a contentious proposition in some circumstances. Young scientists in particular have a great deal at stake—credibility with the public and peer groups, continued and future employment prospects, even self-esteem. Attitudes about appropriate roles of scientists differ among scientists, land managers of science information, interest groups, and the informed public, although these groups do endorse the role of scientists to help integrate their knowledge with other information (Lach et al. 2003). Attitudes about appropriate roles of scientists vary from one societal context to another (Lach et al. 2003). Decision making and policy advocacy by scientists is more accepted in Europe than in the USA, for example; and in the USA these actions may be more accepted for academics than for government scientists, who are viewed as sources of objective scientific information to decision makers, who may be elected officials or their appointees possessing little or no scientific background. Therefore, decisions about professional conduct as a scientist are very dependent on institutional context, potential impacts on career, and the environment in both the near term and the long term. This issue has been debated at length (Fischer 2000, Weber and Word 2001), especially in the aftermath of highly disputed cases. University programs in natural resources and related fields should provide training in values, professional conduct, and environmental ethics, but ultimately the resolution rests with the scientist or natural resource professional.

Production Forestry

Intensive production forestry on plantations accounts for an increasing proportion of the world's timber supply, about 35% in 2000, with the proportion expected to increase to about 44% by 2020. As in the case of intensive agriculture (see Chapter 12), an important benefit of production forestry is that a substantial proportion of the global demand for timber can be met on a relatively small land base, reducing pressures for harvest of natural forests that have high conservation, watershed, and recreational values. Production forests currently account for only 5% of forestlands, but 35% of timber production. Production forests are intensively managed, regularly spaced stands, often monocultures of *Pinus* or *Eucalyptus* where they are exotics. They are managed with agricultural approaches that maximize the efficiency of wood production.

Although management practices vary geographically, production forests can provide many important ecosystem services in addition to the wood for which they are explicitly managed. Water and energy exchange, for example, may not differ substantially between production and natural forests. Production forests have high rates of carbon gain, but their role in carbon sequestration depends on the size of dead wood carbon pools left on the forest site and the lifetime of wood products from these forests. Wood used in construction, for example, may have as long a lifetime as a solid form of carbon as it would in the forest, whereas paper products might decompose and return their carbon to the atmosphere quite rapidly. Old-growth forests, in contrast, have rates of production that are only slightly higher than rates of decomposition and therefore sequester carbon relatively slowly (Schulze et al. 2000). These forests have high standing crops of carbon, including in the dead wood component, which gets released to the atmosphere upon cutting and conversion to intensively managed young forests (Harmon et al. 1990).

Sustainable management practices that maximize both forest production and other ecosystem services generally also sustain slow variables, including the retention of soils and their capacity to supply water and nutrients, provisioning of high-quality water in streams and groundwater, and many of the aesthetic and cultural benefits that foster public support for forests and forestry (see Chapter 2). Production forests can provide employment for local residents, enabling people to remain in rural areas and sustain their cultural connections to the land. However, not all production forests are managed in an environmentally sound way. As with intensive agriculture, some production forests receive large applications of fertilizers and pesticides, with similar detrimental consequences for the environment and local communities (see Chapters 9 and 12).

The most consistent losses of ecosystem services with production forestry are associated with reduced biodiversity. Production forests are typically single-aged, single-species stands that maximize the efficiency of planting, thinning, and harvesting of trees, but lack the structural and biotic diversity of natural forests. In regions dominated by production forestry or plantations of trees such as oil palms, much of the regional diversity has been lost, especially those species that require the structural complexity, long periods for dispersal, or decaying wood typical of old-growth forests.

Restoring biological diversity within highly managed landscapes is one of the greatest challenges faced by production forestry, but in some cases it can be accomplished to a significant extent without greatly sacrificing economic efficiency. The most simple and cost-effective way to restore diversity is to facilitate processes that naturally generate and maintain ecosystem and landscape diversity. These processes include periodic disturbance, such as fire—perhaps approximated by harvest patterns that create habitat heterogeneity within and among stands; maintenance of landscape patterns that provide corridors for spread of native species and barriers to spread of early successional exotic species; and protection of rare habitats to which some species are restricted (Hannah et al. 2002, Chapin et al. 2007, Millar et al. 2007). In general, if a diversity of habitats and environments is created and sustained, the appropriate organisms will find and exploit them, if they are locally available.

Within-stand heterogeneity and diversity can be increased by silvicultural practices such as retention of some live trees, dead standing trees, and decaying wood at the time of harvest, and protection of key habitats and buffer strips between managed stands (Larsson and Danell 2001, Raivio et al. 2001). A spectrum of tree ages also fosters diversity, because wood-decaying fungi, insects, and bird predators found in late-successional forests are quite different than species found in younger stands (Chapin and Danell 2001). A flexible rotation schedule can augment stand-age diversity. Allowing some trees to die and produce dead wood is critical to maintaining trophic diversity. As coarse woody debris becomes more available on the landscape, it will likely be colonized by wood-decaying taxa. In some forestry cultures, dead wood was removed to protect crop trees—to remove logging slash to reduce fire danger and ease planting, and to remove habitat for pest organisms that might attack live crop trees (e.g., removal of dead wood under forest hygiene laws in parts of Europe). In a manner similar to shifting attitudes about fire—from enemy to potential collaborator—forest managers have come to see dead wood as integral to ecosystem management rather than a threat to the forest. In summary, a spectrum of forest-management approaches exist from highly "agricultural" forest plantations to plantations that are managed with substantial structural and biological diversity to natural forests that are managed largely for timber production to natural forests that are never harvested. This blurs the distinction between natural and plantation forests.

Economic and cultural diversity can be just as important as ecological diversity to sustainable forestry, even in production forestry operations. Economic subsidies to initiate new types of businesses, such as the harvest of nontimber forest products (e.g., berries, guided hunts, medicinal herbs, edible fungi, greens for floral displays), the production of local crafts, and promotion of recreation can generate a wide variety of economic options, increasing the likelihood of long-term economic vitality, regardless of the social and economic events that may occur (Chapin et al. 2007). Alternatively, payment to local forest owners to provide ecosystem services such as berries and wild game could alter the incentive structure for forestry planning in rural areas. If local users strengthen their personal and cultural connections to the land, they will have a stronger long-term commitment to sustaining its important qualities.

Multiple Use Forestry: Managing Forests for Multiple Ecosystem Services

Given the breadth of ecosystem services provided by forests, there is a long history of efforts to balance exploitation of forests for wood production and their value in providing many other services. In some cases this balancing act has been fraught with conflict (Box 7.1); in other cases societies have been very accepting of tradeoffs to meet multiple objectives. Management of forests for multiple objectives was well established long before the term "**multiple use**" gained formal definition in contexts such as the US Multiple-Use Sustained-Yield Act of 1960. Many indigenous societies traditionally managed forests for multiple uses (see Chapter 6) and recognized that the gifts received from forests (i.e., ecosystem services) entailed a responsibility to manage the forests in ways that sustained the capacity of forests to continue providing these services. Community forestry, which has deep roots in indigenous cultures, has recently experienced a resurgence of interest in many societies, leading to establishment of NGOs and governmental programs to provide support (Gunter 2004). The case of moving from the management of forests for timber to multiple uses requires at least two steps: (1) recognition by forests managers (whether they are in a government agency, a company, a forest community, or a family) that forests provide multiple services with both synergies and tradeoffs among the provisioning and use of these services and (2) fostering a sense of community responsibility to sustain the capacity to provide multiple services over the long term.

During the 1990s public pressures and conflicts forced forestry from an emphasis on resource extraction to a focus on stewardship of the ecosystem as a whole. The resulting **ecosystem-management** paradigm emphasizes forest practices for multiple services by capitalizing on and sustaining native ecosystem processes (Grumbine 1994, Szaro et al. 1999; see Chapter 2). As a consequence, in many jurisdictions the extent of forest reserved from cutting has been increased; the intensity and frequency of cutting have declined; and historical disturbance regimes have been increasingly used to guide future management.

Given the inevitable tradeoffs among ecosystem services, multiple use management is challenging and benefits from regular engagement and open communication among multiple stakeholders. Sometimes acceptable solutions are possible by managing different portions of the landscape using different but complementary approaches.

Managing Forests Under Conditions of Rapid Change

Global Change

Rapid changes in environmental and social drivers of forest dynamics increase the uncertainties of how to provide long-term forest stewardship. Environmental changes occurring at local to global scales shape the forest environment in ways that alter options for sustainable forestry. For example, air pollution, such as that resulting in acid rain and nitrogen deposition, affects large regions, such as northeastern North America and Eastern Europe, with net effects across the gradient of pollution ranging from stimulation of tree growth by nitrogen addition to severe growth reduction due to leaching of essential cations from soils (Driscoll et al. 2001). Resulting changes in soil properties, such as organic matter content and pH, have effects that will likely last for centuries. Introductions of exotic species such as earthworms or forest pests have in some cases directly and radically altered entire ecosystems. For example, the spread of exotic insects (e.g., defoliators, bark beetles) and pathogens (e.g., root-rot fungi) can cause range-wide extirpation or profound suppression of key forest trees, with impacts that ripple through the affected ecosystems (Ellison et al. 2005). Notable examples in the USA include the chestnut blight in the early twentieth century and the hemlock wooly adelgid and Sudden Oak Death Syndrome that are current, acute management concerns. Perhaps the most daunting driver of forest change will come from global climate change, which may cause migrations of species across the landscape, reshaping forest communities and making them vulnerable to pests, pathogens, and other disturbance agents at unprecedented scales. Some system responses to climate change and/or land use history may be gradual and others abrupt. Threshold system changes can have critical effects on forest systems by mechanisms including pine beetle outbreaks, permafrost thaw, and altered disturbance regimes. Some threshold changes may shift forests to other ecosystem types (Folke et al. 2004), thus eliminating forest-specific ecological services. Not all forest changes are negative. Abandonment of agricultural lands has led to forest expansion in portions of Europe and eastern North America. Combinations of rising CO_2 and modest nitrogen deposition can stimulate forest production, which can have both positive (e.g., carbon sequestration) and negative effects (e.g., reduced species diversity; Chapin et al. 2002) .

The world is now hyperlinked via near-universal, instantaneous communications and intricate economic networks. Public attention to the well-being of forests has grown over recent decades as a result of controversies over deforestation in the tropics, global loss of biodiversity, and protection of old-growth forests in temperate regions. In this context growing attention to sustainable forest stewardship and combating illegal logging appear poised to make substantial advances.

Disturbance Management

The paradigm for managing forest disturbances has changed dramatically in recent decades. Through much of the twentieth century "disturbances" were viewed as bad, so fires and insect outbreaks were fought with military zeal. Training and practice of this dimension of forest management was termed "forest protection." When forests are viewed as a crop, disturbances are a simple loss of capital and investment, so this single-minded management response was logical. Mid-twentieth-century practices, such as extensive use of persistent chemicals like DDT, were gradually revealed to be very damaging to the environment, so they were replaced by pesticides more targeted to the "pest" species. But even these pesticides, as well as native biocontrol agents like *Bacillus thuringiensis*, a bacterium that attacks the blood of Lepidoptera, such as gypsy moth, raised challenges because it can kill desirable, nonpest relatives of the target species. Thus, as the appreciation of ecosystem complexity grew, so too did the difficulty of combating pests and other disturbances.

Furthermore, practical experience and ecological studies have shown that disturbances are integral to the well-being of many types of forest ecosystems and their provisioning of ecosystem services (Gunderson and Holling 2002). Attempts to suppress native disturbance processes have in some cases resulted in even more explosive disturbance events when they escape that suppression—extremely intense fires may feed on an unnatural buildup of fuels; floods that breach dikes may create unusual havoc when the dikes slow drainage of the inundated area; insects feeding on stressed, vulnerable forest stands and landscapes may spread rapidly (Holling and Meffe 1996). Consequently, there has been an accelerating shift from attempting to exclude fire and other disturbance agents from forests to adopting management systems that seek to retain roles of these processes within accepted limits. For example, frequent, low-intensity prescribed fire is now an important management tool in systems where ground fires occurred naturally (Schoennagel et al. 2004). In some cases a legacy of fire suppression has permitted forest fuels to build to unnatural levels that pose the threat of stand-replacing fires in systems where that was not characteristic. In these circumstances mechanical reductions of woody biomass may be necessary before reintroducing fire to the forest. In other cases managers attempt to control forest vigor by thinning overcrowded stands, with the goal of keeping insect outbreaks within limits. However, these forestry practices are generally expensive and require extensive implementation to be effective at the landscape scale, so they have been applied primarily in targeted situations, such as the "wildland–urban interface" where high-value homes are threatened by wildfire (Radeloff et al. 2005).

Historic disturbance regimes are increasingly used as a reference point to guide management of future landscapes (Perera et al. 2004). This approach is based on the premise that native species and ecological processes might best be maintained by retaining ecological structures (including whole landscapes) and disturbance processes in a seminatural range of conditions to which native organisms are well adapted. Several provinces in Canada (Perera et al. 2004) and forestry organizations in the USA (e.g., Cissel et al. 1999), for example, have explored this approach to forestland management by studying historic wildfire patterns over time and space and then developing management plans with frequency and severity of harvest treatments that emulate the wildfire regime. Although this concept has been extensively discussed in the literature (Burton et al. 2003, Perera et al. 2004), no examples have been implemented extensively, in part because of the long time periods required to produce an imprint on forest landscape structure where cutting rotations approach or exceed 100 years.

In addition, many challenging questions have been raised concerning the use of the **historic range of variability** to guide future management (see Chapter 2): What period of history do we use as a guide? What aspects of historic disturbance regime do we incorporate in the management plan (e.g., frequency, severity, spatial pattern of disturbances)? Climate change presents many challenges that are difficult to anticipate. Millar et al. (2007) present the options for employing adaptive strategies in these cases, but we know of no cases where actual practices are in place on the ground.

The challenge of using an historic approach brings into focus the question: What does "conservation" mean in a world with so much change? Given the dynamic state of the environment, an iterative approach seems prudent:

1. Identify the climatic and other forms of environmental change that are most likely to occur and the likely ecological responses, both gradual and abrupt/threshold;
2. examine and implement management approaches that may confer social and ecological resilience in the face of anticipated change;
3. design an assessment process that provides a basis for adaptive change, as learning occurs; and
4. be prepared to adjust objectives from cultivating resilience to transformation, if environmental or social change is so great that an alternative trajectory may provide greater

ecological and social benefits in the face of inevitable transformation.

This sequence of steps required for adaptive management (see Chapters 4 and 8) may take many decades. In many cases, desirable and undesirable outcomes are strongly shaped by social forces, as described in the next section.

Forest Conversion to New Land Uses

Conversion of forests to other land uses and potential for reversion to forest are critical determinants of future forest extent and the services they provide to humanity. The history of forest clearing is deep, but the process is accelerating in response to a wide range of social and economic drivers. Forest clearing for shifting agriculture has caused cyclic change in the past, although increasing population pressure may lead ultimately to deforestation. Other forms of forest clearing may be immediate and irrevocable.

Tropical deforestation, both legal and illegal, to make way for agriculture, such as production of beef and biofuels, has been an issue of critical concern because of the profound social and environmental consequences. All ecological services that are distinctively provided by forests are lost. Tropical deforestation involves cross-scale interactions in driving local change and the large-scale feedbacks to the climate system, as described earlier.

An important form of forest conversion may occur due to the intimate mixing of forest and other land uses, even where the landscape remains largely forested. For example, low-density residential development in forest landscapes is common in many parts of the USA, creating conflicts when forest processes, such as wind-toppling of trees, wildfires, and wild animals (e.g., cougars drinking from children's wading pools) impinge on a suburban life style. In these circumstances, some ecological services provided by forests may be partly maintained (e.g., carbon sequestration, water regulation, habitat for some groups of forest species), but others are lost (e.g., wood production, fire, and habitat for species considered threatening to people).

Not all forest conversion is irrevocable. For example, waves of land-use change began in New England when the "soft" deforestation for agricultural development took place in the late eighteenth and early nineteenth century (Foster and Aber 2004). Industrialization, access to superior farmlands in the Midwest, and other factors led to farm abandonment and reforestation largely by natural reseeding. Now, however, the sprawl of urban and rural residential development is a new wave of "hard" deforestation; the pavement and dwellings will be more difficult to return to forest. New conservation strategies are being put forth to identify the best of the remaining forestland tracts in a regional design intended to provide large habitat patches and dispersal corridors between them (e.g., the Wildlands and Woodlands program in Massachusetts and neighboring states—http://harvardforest.fas.harvard.edu/wandw/).

Changes in subsidies and taxation systems can precipitate shifts in property ownership and attendant shifts in commitment to sustainable management. In the USA, forest companies that have a long-term stake in forest productivity are being taken over by Timberland Investment Management Organizations (TIMOs) and Real Estate Investment Trusts (REITs) that seek very short-term (fraction of a cutting rotation) financial return in part by selling forestlands for residential development (Fernholz 2007). In the eastern US conservation NGOs are partnering with timber companies to purchase development rights that protect forestlands from development and allow small-scale logging to continue (Ginn 2005). Similarly, in some developing nations, debt-for-nature swaps have allowed foreign debts to be forgiven in return for conservation protection of lands that might otherwise be cleared. The long-term outcomes of these emerging transactional mechanisms controlling forests are far from clear—will they lead to more sustainable forest-management practices or to a serious departure from sustainable forestry? TIMOs and REITs appear to encourage unsustainable practices, whereas the debt-for-nature program may protect forests from clearing. The intermediate case of conservation easements on private lands may prove to be a compromise that provides both ecological and social benefits. Management of public lands seems to be on the pendulum swing between reserve and rather intensive management, as, for example, the New Zealand bifurcation of lands to native forest without management and plantations largely of exotic species (mainly *Pinus radiata*). Only time will tell the outcome of these alternative approaches to governance.

Change in national policies to shift energy production from fossil fuels to forest-generated biofuels will intensify forest management, as currently being considered in Sweden, or lead to clearing of native forests for oil palm plantations, as is occurring in Indonesia.

Synthesis and Conclusions

These many approaches and challenges to forestry lead us to seek an expanded view of forest stewardship for tomorrow's forests, drawing on the large bodies of practical and scientific knowledge of forests and associated communities and also calling for greatly enhanced adaptive capacities to face the changing societal and environmental conditions. Despite their social–ecological diversity, forests face similar challenges throughout the world, suggesting some general strategies for sustainable forest stewardship. The implementation of these strategies must be context-specific, taking into account local, national, and global drivers of change.

- Institutions governing forest stewardship must allow planning for the long term by promoting practices that maintain the social and ecological capital required for multiple generations of trees and forest users, whether they are in developed or developing countries (see Chapter 1). In the absence of such institutions, positive social outcomes are most likely to result from attention to capacity building and adaptive governance that would foster development of institutions and policies that might lead to favorable social–ecological transformations to an alternative state.
- Sustainable timber production requires sustaining the slow variables that maintain the productive potential of ecosystems, including soil fertility, a disturbance regime to which local organisms are adapted, and both the ecological and the socioeconomic diversities to maintain future options.
- Effective stewardship to sustain multiple ecosystem services provided by forests requires a clear understanding of the controls over these services and the synergies and tradeoffs among them. Although it is unlikely that all these services can be maximized simultaneously, careful planning that engages stakeholders can lead to well-informed choices that address multiple needs and concerns.
- Given that social and environmental conditions are quite likely to change and unknowable surprises will occur, forest stewardship should foster flexibility to respond to these changes through adaptable governance and the fostering of biological and socioeconomic diversity that provides the seeds for multiple future options (see Chapter 5).
- Given the frequent mismatch between the requirement for long-term vision for forest stewardship and the short-term motivations and path dependence of decision options, forests are quite prone to social–ecological transformations, suggesting the benefit of planning that considers multiple alternative states and their relative social and ecological benefits. Think outside the box.

Although none of these strategies is unique to forests, the longevity of forest trees makes the importance of the long view particularly apparent and could therefore inform ecosystem stewardship in a broad range of social–ecological systems.

Review Questions

1. What are some of the challenges to forest stewardship that result from the long-lived nature of trees? What other systems face similar stewardship challenges?

2. What are the major stages of development of management practices that have characterized forestry practices in many parts of the world? Based on this understanding, how might policy makers avoid detrimental phases and foster sustainable forest stewardship in regions that are just beginning to develop forest resources?
3. What common and distinctive challenges do communities in developed and developing countries face in exercising local influence on forest management and ecological services received from forests?
4. How can production forests be managed in ways that provide multiple ecosystem services within a management framework geared to maximizing wood production?
5. What institutions and social practices are most likely to foster long-term sustainability of forest values that reflect inevitable trade-offs among multiple ecosystem services?
6. What roles do scientists play in natural resource decision making? What challenges do they face in each of these roles?

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