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Sustainable Allocation of Biodiversity to Improve Human Health and Well-Being

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The concept of sustainable development attempts to reconcile the real conflicts between the economy and the environment, and between present needs and those of the future. Many explanations of sustainable development exist, but generally the term refers to sustaining intact ecosystems with their associated species while developing or improving ways to meet human needs for health, nutrition, and security (Kates, Parris, and Leiserowitz 2005). The Brundtland Commission defined sustainable development as the ability of humanity to ensure that it meets the needs of the present, without compromising the ability of future generations to meet their own needs (WCED 1987). Sustainable development attempts to raise awareness and to create links between human values, responsibilities, and environmental decisions that in many cases have been decoupled. Sustainability strives to create new solutions that are beneficial for all interests—both humans and the environment.

Strategies for sustainable development that conserve biological diversity while also meeting human needs must satisfy multiple, often conflicting demands. Ecosystems fulfill basic requirements associated with maintaining and improving human health, often in the form of ecosystem services harnessed by society. In some instances, there are win-win management opportunities that maximize several ecosystem services. In other cases there are trade-offs among services, some potentially difficult to evaluate because of the different nature of the services being compared or because the services occur at different temporal or spatial scales.

The conceptual framework that guided the March 2005 workshop in Paris on which this book is based maintains that biodiversity affects human well-being through four parallel paths: quality of life, provisioning of medicinal and genetic resources, spread of infectious disease, and provisioning of ecosystem services (see this volume, chapter 1). In this chapter, we explore trade-offs and synergisms in allocating biodiversity and resources to these four different determinants of human health and well-being. We first examine the issue of scale—both the interactions among human health determinants that can occur at different scales and the distinctions between local and global biodiversity. Explicit identification of scalar differences is critical because it may help to clarify potential allocation conflicts. We end the chapter with a discussion of trade-offs and synergisms in the allocation and use of land, water, and fertilizers.

Local and Global Scales at Which Biodiversity Affects Human Health

Human activity alters biodiversity as a result of habitat destruction, climate change, invasive species, and nitrogen deposition (Sala et al. 2000). Habitat destruction is currently the most important driver of biodiversity change, first operating by reducing habitat availability and extirpating local populations (Sala et al. 2000, 2005). When local extirpations and extinctions occur in several locations, they reduce the overall area of distribution of the species of interest. When the total species habitat becomes smaller than the minimum required for a viable population to survive, the species enters into a trajectory that eventually leads to global extinction (Tilman et al. 1994). However, global extinctions do not occur immediately after habitat availability falls below the specific threshold. Lags in the extinction response vary among functional groups and species. For example, a study of fragmentation in Kenya found that 50% of the bird species predicted to go extinct went extinct in the range between 23 and 80 years after habitat degradation (Brooks, Pimm, and Oyugi 1999). A similar study with plant species in the North American tallgrass prairie reported a range of 32 to 52 years and a loss of 8% to 60% of the original species (Leach and Givnish 1996). Both studies demonstrate the delay in the effects of land use change in terms of causing extinctions, as well as the variability in the time frames in which extinctions occur.

The four biodiversity drivers of human health that we have identified—quality of life, medicinal and genetic resources, constraint on infectious disease, and ecosystem services—respond differently to local and global extinctions. For example, the ability to discover new drugs or molecules that can be used to cure current or future human diseases is directly related to global biodiversity. However, the abundance of individuals of a desired species does not affect to a large extent the availability of drugs and genetic resources. A small viable population (even one under cultivation) may be sufficient to

Table 5.1. The scales at which the biodiversity determinants of human health operate

Biodiversity Determinants of Human Health	*Local Scale*	*Global Scale*
Quality of Life	✓	
Medicinal Resources:		
Modern	✓	✓
Traditional	✓	
Constraint of Infectious Disease	✓	
Ecosystem Services:		
Provisioning	✓	✓
Regulating	✓	

maintain the genetic library and keep the possibility open to discover new drugs and molecules with interest for human health. Nonetheless, the extirpation of local resources of medicinal species may preclude their use by people and cultures, and local benefits may be lost. Similarly, provisioning (e.g., food) and regulating (e.g., climate) services may be dependent on biodiversity at different scales. For example, globalization has made food production an ecosystem service that now operates on local, regional, and global scales. Global carbon and water dynamics may be dependent on large-scale biodiversity, whereas control of pests and disease may operate over local scales. Table 5.1 summarizes the spatial scales on which these biodiversity drivers operate.

Quality of Life

Standards for "quality of life" vary by country, culture, and economic expectation. However, there are common threads that run through all criteria for quality of life, including meeting human needs and improving human health and well-being, such as proximity to nature, maintenance of sociocultural links with biodiversity, and provision of sufficient food. Extinctions of species at the local scale impair quality of life in multiple ways. For example, chapters 6 and 7 of this volume describe the multiple positive effects of biodiversity on human health, healing, worker satisfaction, productivity, and intellectual performance. Humans require proximity to natural or seminatural environments to enhance their well-being. While global species extinctions can certainly diminish quality of life in a large sense, positive and negative effects on quality of life are determined for the most part by local extinctions and reductions in native biodiversity. Therefore, in many cases, self-interest and necessity may drive people to protect local biodiversity, which in turn may lead to global protection.

Political orientation may well affect whether a person views the environment from a perspective of self-interest or one of altruism. Most people express a combination of these views, but their particular environmental circumstance and access to information on local and global issues can predispose them to articulate one over the other. For some people, local environmental conditions affecting quality of life heighten awareness of biodiversity issues. This raising of awareness may then later extend to an interest in global biodiversity issues beyond their own society. In this way, self-interest may be converted into more altruistic beliefs and actions over a period of time—one psychological process that underpins progress on the sustainability front. When people care, and if they have sufficient resources to meet their basic needs, they are willing to allocate resources to preserve global biodiversity even though it may not affect their daily lives. Hence, reasons range from pragmatism to aesthetics and ethics but commonly drive the desire to preserve biodiversity and slow global extinctions.

Medicinal and Genetic Resources

A recent estimate approximates that more than 50,000 plant species are used medicinally worldwide (Schippman, Leaman, and Cunningham 2002). In China and India alone, more than 7,500 species are used in traditional therapies. Herbal remedies have become popular in developed nations, a market sector that has recently grown at 10%–20% annually in Europe and North America (ten Kate and Laird 1999). Modern medicine benefits from biodiversity by providing ingredients for pharmaceuticals. For example, plant species are estimated to be the resource for 121 drugs in current commercial use, such as Taxol (antitumor), podophyllotoxin (antimitotic and antitumor), chiratin (anti-inflammatory), allicin (antidiabetic), artemisinin (antimalarial), and ephedrine (central nervous system stimulant) (Conforto 2004). However, biodiversity operates at different scales for traditional and modern medicines.

Global-scale biodiversity primarily affects modern medical resources, whereas local-scale diversity affects traditional medical resources (table 5.1). Modern medicine uses biodiversity to find unique molecules that can cure current and future diseases of humans and domesticated plants and animals. At this scale, abundance and proximity do not matter because once the source organisms are identified, they can be artificially multiplied and the compounds synthesized. However, users of traditional medicine must harvest their medicinal resources from the region where they live, and the existence of this resource in a distant location may not satisfy local needs.

Native plants and animals often form the basis of traditional therapeutics that are effective in treating nonchronic and noninfectious diseases. They are also an important part of many cultures. Concern is growing about the effect of biodiversity loss on traditional medicinal resources because the raw materials are collected from the wild rather than cultivated. Out of the more than 50,000 medicinal plants currently in use, more than 4,000 (ca. 8%) are already threatened, many of which are used either in modern or in traditional medicines (Canter, Thomas, and Ernst 2005). Extraction from the wild

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specifically for pharmaceuticals or other therapies is unsustainable for many species, particularly those that come under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendices I and II, such as rhino, tiger claw, and bear bladders among animals and *Phodophyllum, Sausoria castus,* and *Taxus baccata* among plants. Where it is possible, sustainable cultivation of these species is desirable to provide societal health and economic benefits. Where cultivation is not possible, therapies that use imperiled or endangered species should be strongly discouraged and alternatives made available.

Modern medicinal and genetic resources depend on natural plants and some animals, but these still represent a minor portion of all medicinal resources, in part because of the high cost of developing and producing medicines. Screening every plant or animal for compounds to treat every disease is unrealistic since a plant may contain hundreds of compounds, and there are tens of thousands of plants to screen versus only hundreds of ailments. Using current technological capacities, a thorough cross-testing of all such compounds would undoubtedly prove economically and temporally impractical. However, it is likely that compounds exist in nature that hold the cure to some of the diseases that plague humans. Therefore, a sustainable approach to these resources requires that provisions for modern medicinal and genetic resources be made where they are needed *and* that native biodiversity is protected to ensure continued and sustainable access to potential medicinal resources.

Constraint of the Spread of Disease

Noninfectious diseases such as hypertension, cancer, and heart disease are strongly influenced by social and environmental factors but are likely to have limited (and only indirect) links to biodiversity. On the other hand, infectious diseases have a direct link to biodiversity since they are caused by living organisms and may additionally involve disease vectors and species that serve as reservoirs for pathogens. Consequently, changes in biodiversity at genetic, population, or ecosystem levels can have marked effects on the epidemiology of infectious diseases, although the effects and mechanisms can be complex.

Local biodiversity affects the spread of infectious diseases because disease dynamics are a local phenomenon (table 5.1). Disappearance of vertebrate predators, for example, may alter the abundance of rodent reservoirs and induce an increase of zoonoses. However, if the diversity of rodent reservoirs rises and there is an increase in the proportion of incompetent hosts, then disease impact may fall via dilution (see this volume, chapter 12, for further discussion). Such apparent conflict identifies the need for greater understanding of the role of biodiversity, ecosystem complexity, and local ecological context in the ecology and evolution of infectious diseases.

Conventional approaches to disease control aim principally to reduce diversity by targeting disease agents (e.g., with antibiotics) and, where appropriate, disease vectors (e.g., with pesticides). However, such approaches can overlook potential beneficial effects of biodiversity. For example, elimination of one vector species might lead to the emergence of a previously suppressed competitor with higher vector competence and could therefore lead to indirect nontarget effects elsewhere in the food web. Biodiversity is also a source of biological control agents that may play a role in the control of vector-borne disease in the future (Blanford et al. 2005).

Infectious diseases, like any other living organisms, have their own life history. There is evidence that some diseases that were historically severely pathogenic (e.g., the English sweating disease in Tudorian Britain) have completely disappeared, whereas other, entirely new diseases emerge regularly. Ecosystems rich in biodiversity, such as equatorial rainforests, can harbor hidden biohazards, especially among wild game. For example, consumption of bushmeat presents large risks, as illustrated by the infections with human T *lymphocyte* viruses (HTLVs), human immunodeficiency viruses (HIVs), foamy viruses, and Ebola virus (Walsh et al. 2003). Even though humans have inhabited forest ecosystems for millennia, many forests continue to generate seemingly new emergent diseases. These diseases may at first be confined within remote areas, but with the development of trade, travel, and transport, they can spread to larger scales.

Biodiversity and Ecosystem Services

The availability of provisioning ecosystem services, such as food production, depends on both local and global diversity (table 5.1). Human gatherers depend directly on local plant and animal diversity for food quality and quantity, and therefore local extinctions affect the nutrition and well-being of local human populations. Under these circumstances, there is little benefit from the maintenance of the plant and animal populations in distant locations, and the provisioning ecosystem service (human health and food availability) depends directly on local diversity.

Food production relates to global biodiversity because the ability to sustain and even increase food production depends in many cases on crop breeding programs that utilize wild genetic resources. Past experience has made it clear that reliance on agricultural monotypes is unwise and can, in fact, lead to disasters like the Irish potato famine of the mid-1800s. Crop breeding programs rely heavily on the availability of biotypes carrying traits and genes to be incorporated into improved varieties using traditional approaches or genetically modified organisms (GMOs). New molecular techniques allow for fast incorporation of traits into "improved" varieties, even inserting genes from unrelated species. However, our limited ability to prevent genetically engineered biotypes from escaping cultivation is a potent reminder that while technology can provide new solutions that boost production, it should be used judiciously to avoid creating long-term problems for the sake of short-term gains (Marvier and Van Acker 2005). Both traditional breeding and the development of GMOs rely on the existence of genetic combinations that may enable crops to adapt to a changing environment or acquire resistance to new pests and diseases. Improving and sustaining crops and food production in the future, particularly in the face of global change, will depend in large part on the maintenance of a rich global genetic library, both wild and engineered.

While agricultural production is central to human health and well-being, conversion of land for agriculture generally has a large negative impact on biodiversity. The extent of land conversion may be dramatic, such as the felling of forests or the drainage of wetlands, and the agroecosystem created may bear little resemblance to the ecosystem that it replaced (Hannah et al. 1994). Clearly, land conversion results in large losses of biodiversity and can conflict with biodiversity conservation, the maintenance of the genetic library, the determinants of quality of life, and constraint of the spread of diseases. However, the changes wrought by land conversion are not always dramatic—some conversions maintain the general characteristics of the ecosystem. Irrigated and rain-fed rice, for example, is commonly grown in floodplains so that the herbaceous wetland vegetation is replaced by similar vegetation (at least structurally), albeit at reduced levels of biodiversity. Paddy rice maintains an extremely high arthropod diversity (Way and Heong 1994). Therefore, sustainable agricultural production should be concentrated in areas and systems where impacts are minimized, or in regions where land conversion has already taken place.

Many crops are dependent on specific natural pollinators for fertilization and require specific insect morphologies for flower pollination, so a wide diversity of insects is a necessity to ensure food production. Organic matter, such as crop residues, is decomposed by soil biota such as mites, earthworms, and a large diversity of microorganisms. Complete decomposition thus requires a suite of detritovores and microbial species because it is a multiphase process. Pesticides are mainly biodegraded by specialized microorganisms—an ecosystem service that assists in reducing accumulation of potentially harmful compounds in plants, soils, and surface waters, and that reduces leaching to groundwater. These and many other examples of biodiversity-dependent ecosystem services have been thoroughly reviewed by the Millennium Ecosystem Assessment program (MEA 2003).

Freshwater is essential for maintenance of life, and thus its allocation is a serious concern, particularly in association with climatic variations (e.g., drought). Freshwater is a provisioning ecosystem service affected by local biodiversity (table 5.1), as demonstrated by two examples from South Africa and New York City. The Working for Water program began in 1995 in South Africa to increase water security by removing high water-consuming invasive plants and replacing them with less thirsty native vegetation. In South Africa, many invasives directly threaten biological diversity via competition and also significantly decrease available freshwater supplies that support people, natural ecosystem functions, and agricultural production (WfW n.d.). New York City's drinking water supply has greatly benefited from local biological diversity in the Catskill Mountains watershed. Recognizing that water quality was declining due to development and that the cost of an artificial filtration plant for New York City would reach into the several-billion-dollar range, New York City instead chose to protect a natural ecosystem service. A suite of conservation acts, property purchases, and implementation of land use restrictions and septic system improvements on private property is protecting natural ecosystems and biodiversity and guaranteeing New Yorkers a continued supply of chemically untreated clean drinking water (NRC 2004).

Both estuarine and marine (especially nearshore) waters are important resources for recreation, maintenance of aquatic biodiversity, aquaculture, and fisheries. Sustainable development on a local and regional level therefore becomes challenging under the conflicting exploitation of limited water resources. In the United States, water terrestrial agriculture and drinking water compete for the same resources (Pimentel et al. 2004a). World agriculture is estimated to use around 70% of all extracted freshwater annually, reducing availability of water for other uses by humans and other species. Aside from water utilization for food production and drinking water, the production of energy from hydroelectric dams is essential for the dispersal of waters for crop irrigation and drinking water, in addition to other energy production (e.g., electricity).

Water shortages have been linked with reductions in biodiversity in both terrestrial and aquatic ecosystems (MEA 2003; Pimentel et al. 2004b). A notable example is the construction of dams on large rivers, where the benefits of generating hydropower and increasing capacity for irrigation and drinking have been compromising the biodiversity and integrity of both downstream and upstream ecosystems. For example, the construction of the James Bay Dam in northern Quebec has produced economic benefits through the generation of hydropower but has resulted in mercury contamination of traditional fisheries of native communities and associated reductions in quality of life. In addition to biodiversity changes associated with alterations in water availability, the erosion and salinization of soils caused by crop and livestock (e.g., inland shrimp farming) irrigation are growing concerns (Bouwer 2002; FAO 1998).

One of the most important regulating ecosystem services is the control of pests and diseases that directly affect food production. However, these apparently negative elements of biodiversity have the potential to play a positive role as antagonists of pests and diseases themselves. This is most apparent in applied biocontrol approaches such as classical biocontrol, in which one or a few enemy species (i.e., predators, parasitoids, or pathogens) are introduced for the control of an exotic pest or weed. Thus potentially damaging species in one system could be beneficial in another, creating a possible conflict between the desire to reduce diversity of, for example, plant pathogens (or at least to accept genetic and species diversity loss) and a need to conserve diversity of such enemy species for future weed biocontrol programs.

A more subtle but possibly more important variation on this theme is the role that native natural enemies, particularly diseases, appear to play in the dynamics and impact of invasive species. Nearly all species are subject to attack from natural enemies, and one of the mechanisms identified in determining the postinvasion success of exotic species is the escape from indigenous natural enemies in the novel environment. Often parasites do not invade with their hosts, leading to a decrease in the number of parasite species and the proportion of hosts infected in the introduced range (Cornell and Hawkins 1993; Mitchell and Power 2003; Torchin 2004).

Reestablishing the link between invasive species and their key natural enemies is at the heart of classical biocontrol, as outlined above. However, it appears that some new associations between exotic animal and plant species and native parasites present in the exotic range may also reduce the spread and impact of invasive species. In the United States, for example, a negative relationship has been demonstrated between the noxiousness of an exotic weed and the number of native pathogens accumulated by an exotic weed in the introduced range (Mitchell and Power 2003). As such, parasites and pathogens, which on the one hand could represent damaging elements of biodiversity in their own right, could provide a valuable service by contributing to the biotic resistance of an ecosystem to invasion.

The role that diversity plays in biocontrol in general creates both possible synergies and conflicts between diversity conservation and pest control functioning. Natural biological control can benefit enormously from habitat diversification options (e.g., Landis, Wratten, and Gurr 2000 and references therein). Such options include the establishment of flower-rich field margins that provide essential nectar and pollen sources for many insect parasitoids and predators, such as hoverflies, and the installation of grass margins and "beetle banks" across large fields to act as reservoirs of carabid beetles and other ground-dwelling predators, and to aid their timely dispersal into crops in the spring.

Our understanding of the relationship between biodiversity (as affected by habitat manipulations) and pest control functioning remains poor, and the mechanisms through which natural enemies interact to determine the extent and stability of pest control are unclear. For example, in a recent study of the effect of landscape, habitat diversity, and management on species diversity in cereal systems, Weibull, Östman, and Granqvist (2003) revealed that there was no straightforward relationship between species richness of natural enemies at either the farm level or in individual cereal fields, and biological control.

Moreover, while there are examples of synergistic interactions between predators (e.g., foliar predators eliciting dropping responses in aphid prey, which increases their vulnerability to ground-foraging predators; Losey and Denno 1998) and examples of increased predator diversity increasing prey control because of functional complementarity (e.g., Riechert 1999; Wilby and Thomas 2002), processes such as intraguild predation can severely disrupt biological control (Rosenheim et al. 1995; Snyder and Ives 2001). These potential negative effects of increased diversity on pest control highlight a possible conflict between the goals of conservation and the goals of biological control (Finke and Denno 2004). Whether positive or negative effects of predator diversity on pest control predominate is a subject for further research.

Table 5.2. Trade-offs and synergisms in the allocation and use of land, water, and fertilizer

Allocation of Resources	*Trade-offs*	*Synergisms*
Land	Food vs. genetic resources and quality of life	Genetic resources and quality of life
	Food vs. water quantity and quality	Spread of disease, genetic resources, and quality of life
Water	Water for food production vs. genetic resources, quality of life, spread of disease	Genetic resources, quality of life, and spread of disease
Nitrogen / Phosphorous	Nitrogen for food production vs. genetic resources, quality of life, human health, spread of disease	Reduced genetic resources, quality of life, spread of disease

Trade-offs and Synergisms

Land conversion to agriculture and food production has both benefits and costs for human well-being (table 5.2). In addition to altering cover type, agriculture often requires a diversion of water resources and applications of fertilizers to boost productivity. While quality of life is enhanced through increased availability of food and improved nutrition, land conversion, water diversion, the application of fertilizers, and intensified agriculture can reduce local biodiversity (or lead to extinction in the case of endemic species), result in the loss of genetic and medicinal resources, and have serious health consequences if nitrogen is leached to drinking water. On the other hand, some genetic diversity that might otherwise be lost may be preserved through agriculture and animal husbandry if pressures on native wild species (e.g., bushmeat) are reduced and if contact with vectors of zoonotic diseases are minimized.

Although conflicts between agriculture and other land uses, such as biological reserves or recreation areas, depend jointly on the extent of conversion and historical patterns of land use, it is clear that the recent intensification of agriculture to meet production goals usually has a serious impact on both the aesthetic quality of landscapes and the biodiversity they house. This is partly because intensified management commonly follows a broad-brush approach having impacts far reaching beyond those intended. Thus biocides targeted at pestiferous species commonly affect nontarget species, and resource inputs (e.g., fertilizer) leach out of agricultural systems away from the species they were intended to support. A future imperative to reduce agricultural impact will be to better focus interventions so that nontarget effects and conflicts with biodiversity conservation are minimized.

Opportunities to more sustainably improve quality of life and human health and well-being exist. For example, technology transfers between nations can accomplish major improvements in energy efficiency while potentially reducing costs, resource use, and pollutant emissions. Other win-win strategies can be applied within and around protected areas. For example, an unanticipated result of the end of the decades-long civil war in Guatemala has been the increased colonization of the Maya Biosphere Reserve in the Petén. The region's occupation by guerrilla fighters during the war, ironically, served to protect the forests and biodiversity by forestalling development and internal migration.

Many migrant families who have subsequently illegally colonized the reserve subsist on slash-and-burn agriculture and hunting. They often have had little access to family planning, and therefore women have more children than they would otherwise choose and face increased maternal mortality and other reproductive health risks. The resultant rapid population growth also increases pressure on the reserve resources—including the taking of protected species. Greater availability of family planning and health resources would have the benefits of improving quality of life (e.g., reducing health risks to mothers, achieving desired family size, needing fewer resources to support a family) and of reducing pressures on protected areas. Cost-benefit analysis also suggests that family planning programs compare very favorably to other modes of reserve protection, particularly in the long run (F. Meyerson 2003).

While there is a trade-off with maintaining biodiversity, water that is used for irrigation results in increased food production and food security via a reduction in interannual variability in production. However, it has been clearly demonstrated that diversion of river water for irrigation reduces the river flow and can drastically reduce fish diversity (Xenopoulos and Lodge 2006). The reduction in fish species diversity in turn affects food availability for those dependent on fish resources and who may or may not benefit from the irrigation-related increased food production.

Fertilization with nitrogen has allowed one of the largest increases in food production in the history of humankind and has helped to fuel global human population growth. Loading of nitrogen and phosphorus to groundwater and aquatic ecosystems is a global concern because unregulated loading of these chemicals can cause excessive algal and bacterial growth, promote algal toxins, impair taste and odor, and require disinfection of affected waters (see this volume, chapter 8). As the concentrations of nutrients increase, algal communities increase biomass, especially cyanobacterial species that produce toxins detrimental to human health. These algae produce foul taste and odor, and, following decomposition, cause anoxia and associated fish kills. Nitrogen loading is also linked to "blue baby" syndrome and some cancers caused by high levels of nitrate in drinking water. On the other hand, increased agricultural productivity has reduced famine and therefore improved human health, particularly in developed nations. Developing countries are short of nitrogen and have serious human health problems related to malnutrition. Developed countries have the opposite problems with excess nitrogen fertilization and the human health negative impacts described above. Therefore, in many cases, the economic and societal benefits of nitrogen fertilization are countered by a trade-off of excess nutrients in soil and runoff that impairs water quality, productivity, and associated native biodiversity of aquatic ecosystems.

The Path to Sustainable Development

All human activity modifies biological diversity to one degree or another, and there are substantial and varied positive links between biodiversity and human health and well-being. Conservation of biological diversity will deliver benefits to quality of life, medicines, genetic resources, biological control, and constraints on infectious diseases. Inevitably, however, conflicts between maintaining biodiversity and benefits to human health and well-being will also arise since all biological resources are limited. Agriculture, human construction, and even recreation result in land conversion or the introduction of invasive species that are detrimental to native biodiversity.

Therefore, real and significant trade-offs exist between development—even when it is considered to be *sustainable development*—and conservation of biological diversity. Developing and developed nations alike have experienced increased trade, travel, and transport—thus increasing introductions of invasive species, which, while beneficial in some cases can threaten natural ecosystems, agriculture, and human health, and pose threats to a nation's biosecurity (L. Meyerson and Reaser 2002).

Further modifications to biodiversity are inevitable as countries develop and strive to improve health, well-being, and the quality of life for their people. The path to undertaking this development in a sustainable way will be to minimize development impacts on biodiversity—both in the short term and the long term, and over multiple spatial scales. The impacts that will occur need to be carefully planned and considered, and gene banks and biotic specimen banks will need to be further expanded or established. To achieve conservation, protected areas and natural parks will have to be considered more holistically—in the matrix of the local, regional, and global area.

Conservation of biological diversity will require that people reevaluate what is truly necessary to fulfill human needs. The answers will be different across different societies and cultures and, to some extent, individuals. However, at the present time, the global human population continues to increase by more than 70 million people annually even though growth rates are declining. The United States and China have populations that are increasing by 3 million and 10 million people per year, respectively. Consumption of natural resources globally is sure to increase as populations grow and standards of living improve. Sustainable development offers a pathway for improving human health and well-being while minimizing impacts on biological diversity, but ultimately there are limits to growth, and difficult choices between conservation and development remain.

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