REVIEW ARTICLE

Emerging Topics in the Study of Life on Earth:

Systems Approaches to Biological and Cultural Diversity

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There is broad consensus in the international scientific community that the world is facing a biodiversity crisis—the accelerated loss of life on Earth brought about by human activity. Threats to biodiversity have been variously classified by different authors (Diamond 1989, Laverty and Sterling 2004, Brook et al. 2008), but typically include ecosystem loss and fragmentation, unsustainable use, invasive species, pollution, and climate change. Across the globe, traditional and indigenous cultures are affected by many of the same threats affecting biological diversity, including the unsustainable use of natural resources, changes in traditional land use, and cultural assimilation. Academics and practitioners alike agree that to stem the erosion of biological and cultural diversity, we need to engage theoretical and applied perspectives from the natural sciences, social sciences, and humanities. In addition, we need to approach biological and cultural diversity from an integrated, systems-based perspective that emphasizes interconnections and interactions—and teach our students to do the same (Huggett 1993, Richmond 1993, Ford 1999, Sterman 2000, Richmond 2001, Kunsch et al. 2007, Nguyen et al. 2009). Fortunately, in our experience as scientists, social scientists, and teachers, sustaining diversity is a topic that interests students and can easily transcend and tie together diverse fields beyond biology, from statistics to law, from medicine to public policy. In this review, we highlight emerging topics related to sustaining biological and cultural diversity that are amenable to a systems-based approach. In the final section, we offer brief notes on active, student-engaged tools and approaches through which these topics can be taught to increase understanding of systems-based approaches by students.

Humans depend upon biodiversity in obvious as well as subtle ways: we need biodiversity to satisfy basic needs such as food and medicine, and to enrich our lives culturally or spiritually (Krupnick and Jolly 2002, Weladjii and Holand 2003, MEA 2005, West 2005, Losey and Vaughan 2006, Lambden et al. 2007, Ridder 2007). Yet in an increasingly technological world, people often forget how fundamental biodiversity is to daily life. When we hear about species going extinct or ecosystems being degraded, we assume that other species or ecosystems are around to take their place, or that in the end it does not really affect us. We rarely feel individually responsible for the loss of biodiversity, although human activities are the leading threat to the Earth's biodiversity. Immersed in our managed environments and virtual worlds, surrounded by houses and offices, streets and shopping malls, our direct contact with "nature" often consists of aquaria in our living rooms or manicured parks to which we drive in private automobiles. In many places it is hard to remember that food in the grocery store did not spring forth packaged, ready to cook and serve. Yet if we were to put a bubble over the managed environments of our cities and towns and tried to survive with no input from the natural world, we would quickly perish—humans are part of the natural system.

Simultaneously, at a time when the environmental and social consequences of human-induced changes such as deforestation, desertification, degradation and reduction of global water resources, and climate change are increasingly severe (MEA 2005), we are witnessing a homogenization of human cultures, livelihoods, and languages. In response, we need to broaden our traditional definition of what constitutes valid scientific data or "evidence," and appreciate and learn from the vast variety of approaches to human-environment relationships that have developed across the world's diverse cultures and languages, often through close interactions with the natural environment and based on a perception of humans as part of, rather than separate from, nature. The humanities, including history, philosophy, and the arts, play critical roles in exploring these issues. For example, cross-disciplinary scholarship has illuminated the critical intersections between art, science, and the environment in a broader cultural context (Blandy et al. 1998, Lambert and Khosla 2000, Thornes 2008). As global citizens, we need to re-examine and redefine the place of humans as part of life on earth, and to achieve a clearer understanding of the interconnections among biological, cultural, and linguistic diversity.

To achieve this vision, students need to be able to understand issues and challenges from an integrated, systems-based perspective; one way to achieve this goal is by teaching with active, systems-based techniques (Bosch et al. 2007, Westra et al. 2007, Mahon et al. 2008). In the classroom, teachers can use case-based examples that illustrate causal chains and attenuating or reinforcing feedback interactions. For example, students working through a case study of a fishery[1] as a complex system would discover that the system extends from the resource base and its supporting ecosystem through harvesting and distribution to the consumer, whether local or as a buyer in the global marketplace. In addition, students could identify disparate factors affecting the fishery, such as shifts in climate regime, rise or fall in energy costs, and government policies to protect or exploit a resource, and explore how their interactions can determine the collapse or the long-term sustainability of the fishery. Students may also consider the history of the fishery and the culture of the fishing community, a lesson that can reinforce the importance of understanding baselines and viewing cases from a historical perspective (Jackson et al 2001). Such an exercise reveals the system to be diverse, dynamic, and complex, and demonstrates that effective governance must recognize the interconnections and adaptive capacity of the fishery.

In this essay, we highlight several emerging topics in the study of cultural and biological diversity that could be used to develop systems-based skills in students, and then discuss specific implementation strategies for teaching these topics. Notwithstanding the contribution of the humanities disciplines to some of these topics, given our own disciplinary backgrounds, we focus on contributions from the natural and social sciences. We begin with two topics that illustrate the importance of biodiversity to humans (ecosystem services and ecosystem resilience), and then move on to consider climate change, human health, and cultural diversity. We continue with sections on community based conservation and engaging the public, and conclude with a discussion of how these topics can be taught in order to foster systems-based thinking in students.

Biodiversity and Ecosystem Services

An ecosystem is comprised of all the organisms that live in a particular place, and their abiotic (non-living) environment. The outcomes of interactions between organisms and the physical environment include complex processes, such as nutrient cycling, soil development, and water budgeting, which are all considered ecosystem functions. When these outcomes and processes are viewed in light of their benefit to humans, they are considered an *ecosystem service*. These services are far-ranging and include: the regulation of atmospheric gases that affect global and local climates including the air we breathe; maintenance of the hydrologic cycle; control of nutrient and

1 For an example, see the exercise Marine Reserves and Local Fisheries—an Interactive Simulation (NCEP 2009b).

energy flow, including waste decomposition, detoxification, soil renewal, nitrogen fixation, and photosynthesis; a genetic library; maintenance of reproduction, such as pollination and seed dispersal in plants we rely on for food, clothing or shelter; and control of agricultural pests. Humans can rarely completely replace these services and, if they can, it is often only at considerable cost (e.g., Costanza et al. 1997, Daily et al. 1997, Daily et al. 2000, Heal 2000, MEA 2005).

Plants and their pollinators (such as wasps, birds, bats, and bees) are increasingly threatened around the world (Buchmann and Nabhan 1995; Kremen and Ricketts 2000), yet pollination is critical to most major agricultural crops and virtually impossible to replace. In some places, a lack of pollinators has forced conversion to hand pollination (Partap and Partap 2000). There is a growing body of research that is attempting to estimate the replacement costs for natural and managed pollinators (e.g., Allsopp et al. 2004). In the Maoxian region of China, an important apple-growing region, it takes roughly 20–25 people to pollinate the apples in an orchard in one day, and costs the farmer roughly 70 US dollars. If pollination were done by rented honeybees, farmers would pay only 14 US dollars. Although the region has a long history of beekeeping, the pesticides used on the apple trees have made beekeepers unwilling to rent their bees to farmers (Partap and Partap 2000).

The relationship between biodiversity and ecosystem services is complex, and remains an active area of research (e.g., Naeem et al. 1995, Kremen 2005, Balvanera et al. 2006, Hector and Bagchi 2007, Schmitz 2009). Integral to any effort to sustain ecosystem services is an understanding of what traits and components of the system must be conserved in order for a particular service to persist. There is uncertainty regarding the ability of ecosystem services to persist in the face of reduced species diversity, and more research is needed to fully understand the importance of high levels of biodiversity on ecosystem function (Diaz et al. 2006). Despite these uncertainties, we do know the importance of individual species to ecosystem services is largely determined by the species' functional traits, or the ways in which a species interacts with its ecosystem, rather than just the number of species present (Chapin et al. 1997, Duffy 2002, Chalcraft and Resetarits 2003, Hooper et al. 2005, Wright et al. 2006, Violle et al. 2007, Diaz et al. 2006). We also know that functional diversity (the variety of different roles played by all species in an ecosystem) in the ecosystem is an important determinant of the magnitude of the impact the loss of a species will have on the ecosystem. In some cases there are multiple species that perform the same role in keeping an ecosystem functioning; for example there could be many types of invertebrates that assist in the decomposition of leaf litter. If a high number of species perform similar tasks, the loss of one functionally redundant species is likely to have a smaller effect than if only one species could perform the task, and it is lost from the system (Chapin et al. 1997, Tilman et al. 1997).

Recent research is considering ecosystems as multi-functional systems, rather than focusing on one ecosystem process, and is striving to measure the importance of species based on their roles in supporting multiple ecosystem functions (e.g., Hector and Bagchi 2007, Gamfeldt et al. 2008, Kirwan et al. 2009). These efforts indicate that measuring the impacts of species-loss on one ecosystem service at a time may undervalue the total contribution of species diversity to ecosystem function as a whole. As a consequence, overall ecosystem function may be more susceptible to species loss than single ecosystem services are, and thus, may be more vulnerable than earlier research may have suggested (Gamfeldt et al. 2008). Clearly, an integrated, systems-based approach is needed to understand the relationship between biodiversity and ecosystem services.

An emerging strategy for conservation involves incorporating ecosystem services into economic markets by making direct payments to local actors (payment for ecosystem services, PES). One such system in Nicaragua used payment to farmers as incentive for integrating additional trees into agricultural or grazing lands (Pagiola et al. 2007). PES practices can produce on-site benefits such as improved pasture production and fruit, fuel wood, timber, and fodder production. Adding trees to an agricultural system can also have off-site benefits for ecosystem services, such as carbon sequestration and maintenance of the hydrological system, and farmers were paid for both these on-site and off-site benefits. In this case, the additional payment for off-site benefits encouraged farmers to participate; on-site gains alone were not sufficient motivation to change behavior. Monetizing the positive contribution to ecosystem services created the incentive for local actors to shift practices.

PES can have beneficial social as well as ecological outcomes, as many underdeveloped and poor areas have the potential to provide large amounts of currently un-monetized ecosystem services (Bulte et al. 2008). For example, Wunder and Alban (2008) report on a program in Ecuador, where the residents of the Pimampiro municipality pay the largely indigenous and poor owners of the upstream forests to refrain from converting forest to agricultural land in order to protect the city's drinking water supply. PES programs must therefore evaluate the social setting in which they will be instituted, in addition to evaluating the ecological and economic costs and benefits, to determine the success of PES actions. PES supporters also have an obligation to consider the impacts of their actions on social structures and the rights of those involved (Bulte et al. 2008, Carr 2008).

Biodiversity and Ecosystem Resilience

Ecosystem resilience is the ability of a system to adapt and respond to changing environmental conditions. The relationship between biodiversity and resilience is complex and controversial (Lehman and Tilman 2000, Pfisterer and Schmid 2002), and an area of active research. Resilience theory is based on the idea that as certain thresholds are passed, long periods of gradual ecological change are punctuated by nonlinear, rapid, unpredictable, and extreme shifts in ecosystem composition and function (Folke et al. 2006), an ecosystem "regime shift." In the modern era, these sudden shifts have often been initiated by human activities, such as increased intensity of resource use, deforestation or ecosystem conversion, species introductions, or pollution. For example, Osterblom et al. (2007) suggest the Baltic Sea went through three key transitions in the last century. The first was a shift from a seal-dominated to a cod-dominated system; they conclude that this was due to a 95 percent reduction of the seal population, initially due to hunting (1900–40) and then due to pollution (1965–75). The second was a shift from an oligotrophic (low-level of primary productivity) to a eutrophic (high-level of primary productivity) state; this was mainly caused by anthropogenic nutrient loading around the 1950s. Finally, they suggest that by the 1970s the shift to a eutrophic state reduced cod numbers and, in combination with overfishing of cod, may lead to a regime shift from a cod-dominated to a clupeid-dominated system. Currently, Osterblom et al. (2007) only consider the shift from oligotrophic to eutrophic conditions as a true regime shift, meaning that it has reached a stable state and will remain eutrophic even with reduced nutrient loading. This shift will have lasting impacts on the cod fisheries of the Baltic and on the biodiversity of the region.

In general, the loss of rare species has a lower impact on ecosystem function than the loss of abundant species (Diaz et al. 2006). Some species, however, have important ecological roles despite their relatively low numbers and are called *keystone species*. Removal of one or several keystone species may have ecosystem-wide consequences immediately, or decades or centuries later (Jackson et al. 2001). The point at which major ecological changes, or regime shifts, will take place is highly unpredictable, but advances are being made in our ability to predict when species losses will result in these shifts. Current systems-based research continues to expand our knowledge of precursors of regime shifts, such as increased variability of state variables, or variables that determine the stable regime of an ecosystem (e.g. increasingly variable phosphorous levels before a shift to a eutrophic lake system; Carpenter and Brock 2006). This improved understanding should assist in improved ecosystem management. With advance warning, managers may be more likely to determine when efforts are needed to protect species, and when built-in redundancies are sufficient to sustain ecosystems in their current states. It is also possible that while some losses of biodiversity may not drive regime shifts directly, they can leave ecosystems more vulnerable to future changes that could have previously been absorbed (Folke et al. 2004). In the face of the biodiversity crisis, understanding resilience will be essential in directing limited conservation efforts to best protect ecosystem services.

Climate Change Effects on Biodiversity

As mentioned above, climate change as a threat to biodiversity has received increasing levels of attention in recent years. In February 2007 the Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report (IPCC 2007a). This report, with its observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, rising global mean sea level, regional changes in precipitation patterns, and variations in extreme weather, provides unequivocal evidence that the Earth's climate is changing. In this report, the IPCC (2007a) indicates that most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely*[2] due to the

2 Treatment of uncertainty as defined in the IPCC synthesis report (2007a, p. 27): "virtually certain >99%; extremely likely >95%; very likely >90%; likely >66%; more likely than not > 50%; about as likely as not 33% to 66%; unlikely <33%; very unlikely <10%; extremely unlikely <5%; exceptionally unlikely <1%."

increase in human-caused, or anthropogenic, greenhouse gas concentrations. Over the next two decades, a global average warming of about 0.2°C per decade is projected for a range of emissions scenarios, and continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21st century that will almost certainly be larger than those observed during the 20th century.

Evidence from the fossil record (Davis and Shaw 2001) demonstrates that changes in climate can have a profound influence on the myriad of species that comprise Earth's biodiversity. Scientists expect that climate change to date and predicted change over the coming century will have a significant influence on this diversity (Berry et al. 2002, Thomas et al. 2004, Malcolm et al. 2006). These effects have been investigated in hundreds of individual studies, and several important reviews and meta-analyses, including Walther et al. (2002), Parmesan and Yohe (2003), Root et al. (2003), Lovejoy and Hannah (2005), Parmesan (2006), and Parmesan (2007). Documented effects include upslope and poleward shifts in distribution to escape rising temperatures, changes in disease risk, phenological responses such as changes in the timing of flowering and fruiting, coral bleaching, and impacts on ecosystems as a whole. Scientists, social scientists, and members of local communities are also accumulating information on present and predicted future impacts of climate change on human populations, including changes to food security, health, climate, and the physical environment. (e.g., IPCC 2001, 2007b, Patz et al. 2005, ACIA 2005, Mustonen 2005, Macchi et al. 2007, Salick and Byg 2007, Frumkin and McMichael 2008, Patz et al. 2008).

Predictions of continued rapid climate change over the coming century have prompted many attempts to estimate future impacts on biodiversity. One study estimated that, on the basis of a mid-range climate warming scenario for 2050, 15–37 percent of species in their sample of 1,103 study species would be on a trajectory toward extinction. (Thomas et al. 2004). Such predictions of extremely high extinction risk due to climate change have generated debate among scientists, politicians, and the broader general public. Uncertainties inherent in the predictions, along with debate as to how (if at all) society should manage the threat, make this a controversial topic. This is complicated by the fact that a growing body of evidence supports the idea that individual threats to biodiversity rarely occur in isolation. Threats occurring together could be *additive*, in that the combined effect is the sum of each. However, in some cases, threats can be *synergistic*, where the simultaneous action of individual threats has a greater total effect than the sum of individual effects (Brook et al. 2008). To be synergistic, threats must not only interact, but they must do so in a mutually reinforcing manner that contributes to population decline, and possibly to local extirpation and/or global extinction for one or more species. The strongest evidence for synergy among threats to biodiversity would be data that allow examining the effects of each threat separately as compared with the effects of the threats considered together. However, the number of studies taking this approach is still small, and they have usually been performed under experimental or semi-experimental conditions (e.g., Davies et al. 2004, Mora et al. 2007). To date, most published examples of synergies with climate change are projections, simulations or models. For example, investigators have suggested that climate change may be facilitating the spread of chytrid fungus that is causing amphibian extinctions in Central America (Pounds et al. 2006; Rohr et al. 2008; but see also Lips et al. [2008]).

Species have survived major climatic changes throughout their evolutionary history (Davis and Shaw 2001). However, scientists concur (IPCC 2007a) that contemporary anthropogenic climate change presents a significant threat to biodiversity. A key factor that differentiates contemporary climate change from past changes is the potential synergies with multiple other threats, in particular ecosystem loss and fragmentation. Natural systems exist today on a planet that is dominated by humans, with 40–50 percent of the ice-free land surface now transformed for human use, primarily in the form of agricultural and urban systems (Chapin et al. 2000). Climate change thus presents an important challenge for conservation efforts and human populations. The variety of possible effects of climate change across various domains, and the potential for climate change to interact with other threats to biodiversity, illustrate the need to consider climate change from a systems-based perspective.

Health and Biodiversity

Particularly when considered broadly (i.e. not just as the absence of illness but including physical, mental, and social stability, and in inclusive spatial and temporal contexts), human health depends on biodiversity. This does not mean that all components of biodiversity have a positive effect on health at all times (consider for example that parasites are part of biodiversity), but rather that ultimately the health of all species on the planet depends on our shared ecological context. Human health and well-being requires *goods* (i.e. benefits derived from tangible commodities) and *services* (such as the ecosystem services discussed above) provided by biodiversity, and can therefore be negatively affected by its loss. The linkages between biodiversity and human health have been the focus of much recent attention and intense study and have been highlighted by international bodies such as the World Health Organization as well as conservation non governmental organizations (WHO 2006, WCS 2009).

Food, medicine, and medical models are among the goods derived from biodiversity that are critical for sustaining human health. Aside from purely synthetic food products, all of the nutrients we consume are derived from a plant, fungus, or animal species. People all over the world meet their daily caloric and nutritional needs through some combination of wild and domesticated sources, many of which are currently threatened. Studies have estimated that at least 80 percent of the world's population relies on compounds obtained mainly from plants as their primary source of health care (Fabricant and Farnsworth 2001, Kumar 2004). The importance of medicines derived from living things is not limited to the developing world: more than half of the most commonly prescribed drugs in the United States come from, are derived from, or are patterned after one or more compounds originally found in a live organism (Grifo and Chivian 1999). Finally, species belonging to many different taxa are invaluable in biomedical research and play a critical role in advancing our understanding of human anatomy, physiology, and disease.

Ecosystem services, as discussed earlier, support productive natural systems and large-scale ecological interactions such as pollination, pest control, soil creation and maintenance and nitrogen fixation, and are therefore critical for their persistence and the continued provision of the goods mentioned above. Other biodiversity mediated processes that benefit health and wellbeing include water filtration, flood regulation (Andreassian 2004), and waste removal (Nichols et al. 2008). In other cases, ecosystems can protect humans from natural disasters, such as cyclones (Das and Vincent 2009). Finally, empirical and theoretical evidence support the idea that species diversity can act as a buffer for the transmission of some infectious agents, including the Lyme spirochete, West Nile virus, and Hanta viruses (Ostfeld and Keesing 2000, Swaddle and Calos 2008, Suzán et al. 2009).

The differentiation between goods and services is a useful distinction with which to approach complex linkages among species and foster understanding and engagement in their conservation. In reality however, all goods are themselves the result of complex ecological interactions involving many species and their abiotic environments, and therefore broad, systems-level thinking is required to characterize, quantify, and conserve all these critically important benefits we obtain from biodiversity. As a consequence, the study of the relationship between health and biological diversity requires multidisciplinary collaboration, among biomedical professionals, ecologists and conservation biologists, and others. This kind of system-wide approach will augment our capacity to sustain the health of all species and conserve the biodiversity on which it ultimately depends.

Sustaining Cultural Diversity

The past two decades have witnessed an upsurge of interest in the links and synergies between linguistic, cultural, and biological diversity (Harmon 1996, 2002, Smith 2001, Toledo, 2002, Carlson and Maffi 2004, Stepp et al. 2004, Loh and Harmon 2005, Maffi 2001a, b, 2005, Cocks 2006). As previously mentioned, the world's biodiversity and the vast and diverse pool of cultural knowledge, arts, beliefs, values, practices, and languages developed by humanity over time are under threat by many of the same human-induced forces (Maffi 2001b, Harmon 2002). These circumstances call for integrated approaches in research and action since culture and nature interact at many levels that span values and beliefs to knowledge and livelihoods. Yet, both in scientific inquiry and in the realms of policy and management, the categories of "nature" and "culture" are still often treated as distinct and unrelated entities, mirroring a common perception of humans as separate from the natural environment. This conceptual dichotomy is also reflected in, and reinforced by, the mutual isolation that has historically characterized teaching in the humanities and natural and social sciences, leading to fragmentation and limited communication or collaboration among different fields concerned with diversity and sustainability in nature and in culture (Brosius 1999, Oviedo et al. 2000, Borrini-Feyerabend et al. 2004, Maffi 2004, Brosius and Redford 2006). The resulting approaches, in both theory and practice, have generally failed to recognize the interconnectedness of natural and cultural processes and of the threats they are facing, or at least to bring cross-cutting expertise to bear on these issues. Thus, they have not succeeded in stemming the erosion of the diversity of life in all its manifestations. The persistent loss of this biocultural diversity is resulting in an ever less resilient world (Wollock 2001, Maffi 2005).

Recent years have seen the emergence of integrative disciplines that seek to better comprehend the complex interactions between culture and nature, and that work to incorporate insights from both the biological and the social sciences, as well as from humanistic inquiry, non-Western perspectives, and traditional cultural knowledge systems. These include biocultural diversity, social-ecological systems, nature-society theory, anthropology of nature, ethnobiology, ethnobotany, ethnoecology, ecological and environmental anthropology, human ecology, human geography, environmental ethics and history, ecofeminist theory/ecofeminism, historical ecology, symbolic ecology, systems ecology and political ecology, among others (Berlin 1992, Cronon 1996, Kormondy and Brown 1998, Adger 2000, Moran and Gillett-Netting 2000, Townsend 2000, Egan and Howell 2001, Maffi 2001b, 2005, 2007, Harmon 2002, Toledo 2002, Berkes and Turner 2006, Rapport 2007a, b). Recent ethnographic and archaeological research has also shown that our conceptualization of the relationship between nature and culture must include a temporal dimension as humans have interacted with environments through co-evolutionary processes for many generations (Balée 2006). For example, pre-colonial Native Americans shaped landscapes once considered to be "pristine" through periodic burning (Cronon 1983) and some areas of Amazonia have been intensively managed by indigenous people for centuries (Heckenberger et al 2007). We need to examine and understand the formation of contemporary and past cultural landscapes and patterns of biodiversity and how interactions between societies and environments change through time. Agencies, institutions, and organizations broadly responsible for environmental conservation and management, development, and cultural issues (for instance UNESCO, UNEP, Convention on Biological Diversity, and IUCN—The World Conservation Union), are expressing interest in this kind of broad, integrative work and its policy implications (UNESCO 2006). This indicates that now is the time to both assess the scientific advances in all of these integrative fields and foster their contributions to addressing the vital issues of environmental, linguistic, and social sustainability, as well as to promote communication among different ways of knowing through both scientific and traditional knowledge systems. Effective, systems-based teaching should help establish more integrated approaches to research, policy, and management in years to come.

Adger (2000) has defined social resilience as "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change." A group's exposure to stress as a result of ecological change is known as social vulnerability. Social vulnerability is generally high for many indigenous and traditional peoples, who are often economically marginalized and rely directly on the natural environment for their food and livelihoods (Adger 2000, IPCC 2001, 2007b, Diffenbaugh et al. 2007, Macchi et al. 2007, Salick and Byg 2007). For these reasons, some threats to biological diversity, such as climate change and ecosystem loss and fragmentation, may be particularly acute threats to the lifeways of indigenous and traditional peoples. In particular, scientists and local communities in the northern latitudes have documented ongoing changes in their environment due to climate warming, such as reductions in sea and lake ice, loss of forest resources, changes in prey populations, and increased risk to coastal infrastructure (Lee et al. 2000, NAST 2001, CCME 2003, Weladji and Holand 2003, ACIA 2005, Ford 2007, Lambden et al. 2007). As climate change impacts arctic ecosystems, the predictive power of some traditional knowledge is reduced (Krupnick and Jolly 2002, Ford et al. 2007, Sakakibara 2008, Sakakibara 2009), which has the potential to leave societal structures weakened (Weladjii and Holand 2003, Lambden et al. 2007). It is therefore not surprising that some of the first initiatives bringing indigenous communities together to frame and address common problems related to climate change have occurred in the northern latitudes. Examples of these efforts include the compilation of the Stories of the Raven by the group Snowchange (Mustonen 2005) and the Arctic Climate Impact Assessment (2005), which was prepared by more than 300 participants from 15 countries and includes many examples of the local traditional knowledge of Inuit, Sami, Athabaskans, Gwich'in, Aleut and other Arctic Indigenous Peoples.

Community-based Conservation

From individual sacred trees to royal game preserves, strategies for conservation have historically relied on protected areas, or conserving biodiversity where it exists, *in situ*. Many early parks and reserves in the Western tradition of biodiversity conservation were modeled after Yellowstone National Park (established 1872) in the United States, and advocated strict preservation policies, seeking to safeguard natural resources through the exclusion of local populations (and in cases disregarding the role they had played in shaping those landscapes) (Adams and McShane 1996, Neumann 1998, 2002, Jacoby 2001, Adams 2004). By the 1970s, new ideas of sustainable development and a growing interest in human rights and different knowledge and value systems challenged this approach. Recognizing that conservation affects people's lives (West and Brockington 2006), and that restricted access to natural resources has costs that are often borne by those least equipped to pay them (Adams et al. 2004), international conservation efforts began shifting to a more people-centered approach (Adams and Hulme 2001, Naughton-Treves et al. 2005). At the same time, the effectiveness of the protected area approach itself was in question as people realized that parks were ecological islands covering only a fraction of larger ecosystems, and management authorities frequently lacked the funds or capacity to enforce their borders. Beginning with Integrated Conservation and Development Projects (ICDPs) in the early 1990s, conservation policy began to shift from state-centric, top-down approaches to attempts to incorporate society, sustainability, and markets (Wells and Brandon 1992, Adams and Hulme 2001, Barrow and Murphree 2001). While strict reserves remain important for certain vulnerable systems, the IUCN–WCU (2009)currently recognizes six categories of protected areas of varying degrees of protection and use. Today, the mission of some protected areas has expanded to include the protection of biological *and* cultural diversity, the provision of economic benefits, poverty alleviation, and even promoting peace (i.e. "peace parks", or transboundary conservation areas) (Naughton-Treves et al. 2005). Conservation efforts are increasingly recognizing the necessity of understanding the historical ecology of these protected sites and sustaining their cultural landscapes (UNESCO 2006).

"Community-based conservation" (CBC)[3] helps conserve threatened species and critical ecosystems beyond protected area boundaries by linking natural resource protection to communities and development—in other words, by thinking of the ecosystems and inhabitants as an integrated system. Emphasizing a participatory approach to biodiversity conservation, CBC strives for a "win-win" situation where local involvement leads to economic growth and a vested interest in conservation (Adams and Hulme 2001, Berkes 2004). The case of the African elephant illustrates this logic: locally, elephants can be dangerous pests that steal crops and destroy gardens; nationally, they are major tourist attractions and the source of significant revenue. CBC seeks to expand the benefits of elephant conservation to the local level through benefit-sharing schemes or prescribing wildlife conservation as a form of land use (an alternative to agriculture or pastoralism). In this model, natural resources are recognized as renewable, opening the possibility for controlled and sustainable use. Additionally, the separation of human-dominated landscapes and "natural" landscapes is less clear, as people are explicitly included, and community perspectives and knowledge are deliberately incorporated into conservation practice.

CBC initiatives range from programs as simple as protected area or private sector outreach (e.g., Tanzania's National Parks' Community Conservation Service program, "Ujirani Mwema"[4] [Bergin 2001]) to Community Conserved Areas (CCAs), terrestrial and marine spaces that have been conserved voluntarily by local communities (Kothari 2006). An important CBC model, CCAs vary widely in size and have been initiated for a number of reasons: to protect access to livelihood resources or community land tenure, for economic gain (e.g., ecotourism), or to safeguard vulnerable wildlife or ecosystem functions. They may include sacred spaces, indigenous peoples' territories, critical wildlife habitat, resource catchment areas, or mixed landscapes (natural and agricultural ecosystems).

CBC, through innovative partnerships among conservation biologists, social scientists, and communities living in and around biodiversity hotspots, is an important complement to traditional protected areas and a vital part of the conservation toolkit. But it is not a panacea for conservation problems: for instance, the goals of biodiversity conservation and development interventions are often conflicting; communities are not homogenous entities, but represent a wide array of viewpoints and motivations, and "success" is not easily defined (see for example Agrawal and Gibson 1999, Biesbrouck 2002, Berkes 2004, Chapin 2004, Tsing et al. 2005, Rao 2006, Igoe and

3 Also referred to as "Community Conservation," "Community-based Natural Resource Management," "Community-based Forest Management," or "Community-based Wildlife Management," depending on context.

4 Swahili for "Good Neighborliness."

Croucher 2007, Nelson et al. 2007). Ultimately, however, an effective approach to biodiversity conservation will involve diverse constituencies, including international organizations, nations and national governments, non-governmental organizations, academic institutions, local grassroots groups, and individuals.

Teaching Systems Approaches to Biological and Cultural Diversity

Too often, we do not think about the interconnections in the world around us. As illustrated in the topics discussed above, change in an ecosystem can cause a chain of reactions to reverberate throughout the system, affecting the well-being of humans and other species (Diaz et al. 2006). Studies of endangered species are now pointing to the importance of coevolution, with cascading extinctions leading to the disproportionate loss in groups such as parasites and mutualists (Koh et al. 2004, Dunn et al. 2009). Researchers are also learning that synergistic interactions between different direct and indirect threats to biological and cultural diversity may amplify or exacerbate individual threats. All these interconnections are crucial for us to consider when working to sustain diversity.

As our understanding of natural ecosystems and the role of humans within them has increased, we have realized that traditional "siloed," disassembled approaches for understanding and managing complex systems are severely limited. For instance, physical scientists study long-term trends in temperature; local communities observe changes through time in animal behavior, population abundance, and timing of reproduction; biologists study climate change and its effect on species distributions; and anthropologists study adaptation in human cultures to climate change. Rarely do these individuals come together to study the feedbacks among climate change, human adaptation, and biological responses, leading to further adaptation—yet clearly each discipline is only understanding one piece of the puzzle and cannot gain a complete picture in the absence of information from the other disciplines.

In our experience, an effective way to foster systems-based and interdisciplinary thinking in students is to combine the study of actual case studies of environmental issues (such as the fisheries case study referenced in the introduction) with active approaches to teaching. Such approaches engage students directly in the learning process, and can include a variety of activities, including interactive lectures, debates and role-playing, faculty or student-led discussions, student presentations, field exercises, and others (e.g., Bonwell and Eison 1991, Meyers and Jones 1993, Bean 1996, McNeal and D'Avanzo 1997, Silberman and Auerbach 1998, Handelsman et al. 2004, McKeachie and Svinicki 2006). There is ample evidence from the education literature that active-learning modes substantially increase student performance across many disciplines (e.g., Hake 1998, McKeachie et al. 1986, NRC 1996, Olson and Loucks-Horsley 2000), including those related to biodiversity and conservation biology (Ebert-May et al. 1997, Sundberg and Moncada 1994, Lord 1999, Ryan and Campa 2000, Burrowes and Nazario 2001, Udovic et al. 2002, Chopin 2002, Burrowes 2003). Many active teaching approaches involve students working together in small groups, and often involve an element of peer-to-peer teaching and/or collaborative learning (Slavin, 1990, Johnson et al. 2007, Barkley et al. 2004), which can foster development of the critical thinking, analysis, and synthesis skills that are important to a systems-based approach.

Each of the issues discussed in this review has its own "entry point" that can encourage students to adopt systems-based thinking:

- Because of our universal dependence on ecosystem services and their cultural, ecological, and economic value, ecosystem services provide students with concrete and relevant examples of the importance of biodiversity conservation from the perspectives of many different disciplines. Case studies of efforts to conserve ecosystem services can expose students to the complexity of real-life conservation issues.
- In the current politically charged public discourse around climate change and its effects, engaging students on this issue represents a significant opportunity for teachers. Indeed, this is such an important area that the Council of Environmental Deans and Directors of the National Council for Science and the Environment has established a special Climate Solutions Curriculum Committee (2009) to provide support and guidance to university teaching of climate change. Studying climate change can help students appreciate some of the difficulties and controversies that arise when scientists attempt to extend current observations to model future predictions, and understand that natural systems are composed of an interconnected network of interacting species and threats to those species.

- As an immediate concern and a topic of personal experience for all, health is a powerful motivator for changes in behavior, and can introduce the idea of multidisciplinarity in scientific endeavors and the interrelatedness of life on the planet. For example, topics in health and the environment can be presented as medical mysteries, in which students are encouraged to discover the drivers of changes in epidemiological patterns in human or animal populations, or as choices among various interventions, using a systems-based approach.
- The intersection between culture, biodiversity, nature, and the environment offers a rich lode for exploration with students, moving easily among philosophical and ethical realms. For example, students could discuss the issue of extinction and what it means for a species, language, or culture to disappear, given that our understanding of the world is that it is dynamic and continually evolving. Readings on resilience could explore the differences between social and ecological resilience and how those might lead to different frames within which to address the problems that we face in sustaining biological and cultural diversity.
- The study of community-based conservation can expose students to different ways of perceiving nature as well as the suite of possible conservation interventions. For example, students might debate the relative successes of current efforts to implement CBC, such as those of Wildlife Management Areas in Tanzania (see Goldman 2003, Igoe and Croucher 2007, Nelson et al. 2007). Offering a variety of real world case studies for examination, whether across the world or in their own backyard, CBC effectively demonstrates to students the complexity of conservation decision-making and the necessity of inter-disciplinary efforts.

A variety of freely available electronic resources are available that can be used to support systems-based, active teaching in topics related to biological and cultural diversity. These include resources of the Network of Conservation Educators and Practitioners (NCEP 2009a) of the American Museum of Natural History, materials from the Ecological Society of America such as the TIEE project (2009) and the EcoEdNet repository (2009), along with appropriate materials from the National Center for Case Study Teaching in Science (2009).

Final Thoughts

Even as natural and and social scientists work to make their work with students more meaningful, we also need to move beyond the classroom and into engaging the public more directly on issues surrounding biological and cultural diversity. With current levels of public understanding of science—particularly in the United States—recognized as being deficient (National Science Board 2002, Baron 2003, Brossard et al. 2005, Bonney 2008, Cohn 2008), active involvement in the scientific process can serve to increase interest and literacy. Participants can also improve their abilities to understand and interpret what is going on around them and how it relates to their lives, and in the process take part in translating science practice into public discourse and in turn, transform it into action. Wilderman et al. (2004) suggest that participants working together can develop a sense of community ownership of data and feel empowered to use them for advocacy and decision-making. Additionally, projects that involve volunteers in the study of a species or habitat make it possible to address questions of a scope and scale that would not otherwise be possible. By working with citizen volunteers, scientists may broaden support for their projects and form a more direct link with their constituency (Greenwood 2003). Decisions based on participatory research may also be more effective and less controversial when stakeholders who have an interest in the results are involved in the process (Pilz et al. 2005, Calhoun and Morgan 2009). Similarly, stewardship groups (who may be involved in research, maintenance, and/or tours or other educational activities) can develop a strong sense of responsibility and attachment to a place that they care for, and will strive to protect it for the health of the local environment as well as for community well-being. In general, environmental volunteering and stewardship can result in a wide range of benefits for the organizations involved, the volunteers, and for the community, including extending an organization's work and promoting its cause; giving people a chance to connect or reconnect with nature as well as gain new skills, make social connections, and improve their physical and mental well-being; and contributing to community goals for education, health, and social and environmental justice (O'Brien et al. 2008).

Programs that encourage broad public participation can also in some cases intersect with student programs. An example of this approach is ALLARM (Alliance for Aquatic Resource Monitoring), which forms partnerships between community groups and researchers and students at Dickinson College in Pennsylvania to conduct water quality monitoring and watershed management projects. ALLARM's goals include increasing community scientific knowledge while motivating students through engaging in research to solve real-world problems (Wilderman et al. 2004). These are the overarching goals, however, and each community group defines the goals for its own project. Volunteers engage in the scientific process, from defining problems, designing the studies, collecting and analyzing samples, to interpreting data. Scientists provide training and mentoring where necessary, particularly supporting the groups through the development of a feasible study design and in interpreting data so that the community members themselves are able to understand and share their findings rather than relying on researchers to speak for them. Volunteers also have the advantage of using their local knowledge for interpretation, making connections with nearby land uses that researchers might not be aware of (Wilderman et al. 2004, Wilderman 2007).

Students of today are challenged to try to make sense of a bewildering array of information and misinformation about environmental and cultural issues. This is certainly the case with biodiversity loss and sustaining cultures. Over the past decades, we have come to understand that sustaining cultural and biological diversity does not just mean placing boundaries around a static entity. Rather, it means moving beyond the patterns we see and understanding the processes that create diversity, allowing for change and evolution while maintaining integrity of a system. Human-induced threats to biodiversity are causing not only species loss, but also are negatively impacting ecosystem processes and function and might even alter the rate of evolutionary change, which in turn can influence ecological dynamics, creating "eco-evolutionary feedbacks" (Palumbi 2001, Stockwell et al. 2003, Post and Palkovacs 2009). Though we may not have a complete understanding of the theoretical underpinnings of the interactions between ecology and evolution, it is clear that planning for biodiversity conservation needs to happen in the context of dynamic populations and threats (Mace and Purvis 2008).

In order for the next generation of adults and voters to make intelligent choices about biological and cultural diversity, they will need to understand what the consequences of their individual and collective actions are—the evolutionary force that we have become. They need to know what diversity is, to understand the relationship between human beings and diversity and how our value systems affect sustainability of biodiversity and culture (Carolan 2006, Christie et al. 2006), the difference between sustaining just patterns/static definitions of diversity rather than processes, and they need to understand what threatens diversity. Finally, students need to have a sense of what they can do about the loss of biological and cultural diversity at the individual and collective levels. Overall, they will need to take a systemic look at people and their relationship to diversity, as complex systems such as these require systems thinking for solutions (Waltner-Toews et al. 2008). As teachers, we can support them in learning to do this.

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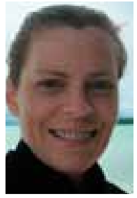

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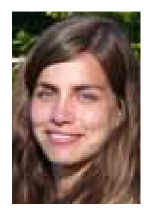

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