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SPECIAL FEATURE

Environmental change, pathogens and human linkages

David J. Rapport · Luisa Maffi

Eco-cultural health, global health, and sustainability

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Abstract Anthropogenic stress on the earth's ecosystems has resulted in widespread prevalence of ecosystem distress syndrome, a quantifiable set of signs of ecosystem degradation. At the same time, the planet is witnessing rapid declines in global cultural diversity and in the vitality of the world's cultures, which closely mirror, and are interrelated with, ecological degradation. As a consequence of this converging crisis of loss of ecosystem and cultural health, global health and sustainability are increasingly under threat. An eco-cultural health perspective based on understanding the linkages between human activities, ecological and cultural disruption, and public health is essential for addressing these threats and achieving global sustainability.

Keywords Ecosystem health · Eco-cultural health · Ecosystem distress syndrome · Global health · Sustainability · Ecology and health

Introduction

It is no secret that the health of the earth's ecosystems is in a downward spiral. All the recent global environmental assessments provide ample documentation for the rapid decline in the viability of life systems. The Living Planet Index (LPI) tells the story of life being extinguished at unprecedented rates (WWF 2008). This index measures the state of the world's biodiversity based on trends from 1970 to 2003 in 1,313 vertebrate species, comprising 695 terrestrial species, 274 marine species, and 344 freshwater species. The LPI shows an overall decline of 30% over the 33-year period—reflecting declines in each of the major species groups. During the same period, global satellite imagery records rapidly eroding seascapes and landscapes, including the eutrophication of semi-enclosed seas and coastal areas, deforestation particularly in tropical regions, the desertification of arid lands, the near total desiccation of the Aral Sea, the draining of the Mesopotamian marshlands—and the list goes on (MEA 2005). Add to these cases the rapid erosion of tropical coral reefs, the loss of boreal and coastal coniferous forests, the degradation and destruction of the world's grasslands and wetlands, marked deterioration of the world's lakes and rivers, the disappearance of coastal mangrove forests, and so forth, and an unequivocal picture emerges of many of the earth's major ecosystems in a state of imminent or present collapse.

The catastrophic loss in the vitality of the world's ecosystems is a consequence of cumulative anthropogenic stress (Rapport and Friend 1979; Rapport et al. 1985; Rapport 2007a, 2007b). This has now been documented in a number of case studies of freshwater, marine, and terrestrial ecosystems around the world. These include the Laurentian Great Lakes (Regier and Hartman 1973; Rapport and Regier 1980), the Baltic Sea (Rapport 1989a; Hildén and Rapport 1993), the desert grasslands of southern New Mexico (Schlesinger et al. 1990; Rapport and Whitford 1999), and the Aral Sea (Macklin 2007), among many others (Vitousek et al. 1997, MEA 2005).

Less well known, but of great significance, is the parallel loss in the viability of the world's cultures and languages—which are vast repositories of knowledge and know-how in terms of sustaining human life within diverse ecosystems and landscapes (Maffi 2001, 2005, 2009; Harmon and Loh 2010; Maffi and Woodley 2010). The dramatic losses in biological diversity over the past half century have been accompanied by equally dramatic losses in cultural diversity and in the vitality of the world's cultures and languages, due to many of the same

D. J. Rapport (✉)
EcoHealth Consulting, Salt Spring Island, Canada
E-mail: eco_health@hotmail.com

D. J. Rapport
Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang, China

L. Maffi
Terralingua, Salt Spring Island, Canada

pressures. This configures a "converging extinction crisis" of the diversity of life in nature and culture (Harmon 2002).

These interrelated changes have profound implications for human futures in terms of public health and sustainability. Here, we explore these implications by first reviewing the ways in which human activities have led to the breakdown of ecosystems, and how we can identify dysfunction in ecosystems as a consequence of anthropogenic stress. We then turn to the flip side of this topic and define healthy ecosystems and their main characteristics, looking at how the loss of ecosystem health impacts human health and at the efforts underway to address global health issues from an ecosystem perspective. Building on this, we argue that attention to the cultural dimensions of ecosystem health and dysfunction calls for an even more integrative perspective, embodied in the concept of 'eco-cultural health'. By means of an illustrative example, we discuss how the breakdown of eco-cultural health impacts human health and well-being. Lastly, we discuss the implications of this perspective for public policy and action.

Signs and causes of ecosystem pathology

The path-breaking work of Rachel Carson in the early 1960s (Carson 1962) was a profound wake-up call that human activities can inadvertently compromise the vitality of whole ecosystems. Carson focused on the production and use of man-made chemicals, particularly those substances that were long-lived in the environment. Carson drew attention to the fact that organic pollutants such as DDT, PCBs, and others bio-accumulate through the food web, with lethal effects on bird populations and other biota, including humans.

Recognizing the growing relevance of environmental issues, statistical agencies began to seek ways and means of documenting changes in the environment in relation to human activities. Statistics Canada became one of the early leaders in this endeavor, through its development of the Stress-Response Environmental Statistical System (Rapport and Friend 1979), a framework that served as the model for Canada's first national State of the Environment Report (Bird and Rapport 1986). This framework, now known as the Pressure-State-Response system (PSR), was quickly adopted by the Organization for Economic Cooperation and Development (OECD) and many countries and international agencies, and has formed the conceptual basis for numerous regional and national state of environment reports and assessments (Rapport and Singh 2006).

The PSR system comprises a taxonomy of the major types of anthropogenic stress that impact the world's ecosystems. These include: land-use change (physical restructuring), over-harvesting (resulting in over-exploitation of species and/or serious damage to habitat), introduction of non-native species (whether purposefully or accidentally), release of waste residuals (both nutrients and toxic substances) to air, water, and land, and extreme natural events (e.g., volcanic eruptions, weather and climatic events).[1] The PSR system also incorporates a set of indicators of ecosystem dysfunction [e.g., loss of biodiversity, loss of soil fertility, increased presence of invasive (non-native) species, etc.], as well as indicators of societal actions (responses) that may be taken to prevent or mitigate damage to the environment.

Utilizing the PSR framework, various assessments, including the Millennium Ecosystem Assessment (MEA 2005), the Helsinki Commission assessment of eutrophication of the Baltic Sea (HELCOM 2009) and various country- and regional-level assessments have documented ecosystem degradation induced by anthropogenic stress. Among the many signs of ecosystem impairment are reduced biodiversity, altered primary and secondary productivity, leaching of soil nutrients, shifts in community composition to favor smaller life forms, reduced symbiotic relationships amongst biota, increased success of invasive species, loss of endemic species, increased presence of contaminants (particularly toxic substances that bio-accumulate in the food web), increased disease prevalence in various component species (including *Homo sapiens*), reduced efficiency in nutrient transport, and reduced ecosystem-level productivity/respiration ratios.

These signs, collectively, comprise what was identified early on as an 'ecosystem distress syndrome' (EDS) (Rapport et al. 1985). Initially, EDS was recognized on the basis of comparisons of ecosystem behavior under stress among a dozen or so documented case studies from the literature. Subsequently, new case studies (e.g., Rapport 1989a, Hildén and Rapport 1993, Rapport et al. 1998a, Rapport and Whitford 1999), as well as a plethora of government and international agency reports on the state of the environment, have confirmed that EDS is a widespread problem. Interestingly, the signs of EDS were already observed in the early 1940s by the great American naturalist, Aldo Leopold, and recorded in his landmark (although rather obscurely published) essay on what he called 'land sickness' (Leopold 1941). Even back then, Leopold observed that in his rural Wisconsin countryside there was abundant evidence of soil erosion, nutrient depletion, reduced crop yield, loss of native species, increase in invasive species, and increases in plant and animal pathogens.

Today, it is widely recognized that EDS[2] is caused by anthropogenic stress (Rapport et al. 1985; Rapport and

[1] "Extreme natural events" now would include those associated with global climate change—which in turn is triggered mainly by anthropogenic stress (i.e., the release of greenhouse gasses).

[2] EDS is sometimes referred to as 'environmental distress syndrome' (Frumkin 2005). This term, while identifying the same general signs of EDS, focuses on the consequences for human health, pointing for instance to the re-emergence of infectious diseases such as cholera, typhoid and pneumonia and the emergence of new diseases such as drug-resistant tuberculosis; the loss of biodiversity and thus of potential sources of both crops and drugs; the decline in specialist species, particularly pollinators, which are vital to maintain populations of flowering plants; the proliferation of harmful algal blooms causing diseases such as ciguatera poisoning and paralytic shellfish poisoning; and so forth.

Whitford 1999; Vitousek et al. 1997), and that it characterizes many of the world's ecosystems, providing evidence of widespread and growing ecosystem pathology. Regional examples of EDS are to be found in the cases of the Baltic Sea (Rapport 1989a, Hildén and Rapport 1993; HELCOM 2009), the Laurentian Great Lakes (Rapport and Regier 1980; Bails et al. 2005), the Aral Sea (Macklin 2007), the Mesopotamian Marshlands (Lawler 2005), the Caribbean Coral Reefs (Hughes 1994), the grasslands of New Mexico (Schlesinger et al. 1990), among many others (Rapport et al. 1995; Rapport et al. 1998a, b, c).

The main three drivers of ecosystem degradation resulting in EDS—habitat fragmentation and destruction (physical restructuring), over-exploitation of species (over-harvesting), and introduction of exotic species—have been called the ''evil trio'' accounting for the worldwide loss of biodiversity (Aguirre 2009). Along with global toxification (release of waste residuals), pathogen pollution, and global warming, all these drivers comprise what Aguirre (2009) refers to as the expanded ''savage sextet'' accounting for biodiversity loss.

Ecosystem health

Growing awareness of widespread ecosystem pathology begs the question: what are 'healthy' ecosystems, and what constitutes ecosystem health? These are questions that go well beyond the confines of a single discipline, and have over the past several decades encouraged contributions from many disciplines, including ecology, economics, anthropology, engineering, medicine, public health, veterinary medicine, and ethics among others. This convergence has led to a number of international meetings, the formation of international societies, and several peer-reviewed journals focused on ecosystem health. The history of the development of the transdisciplinary field of ecosystem health is summarized in the Appendix.

Early debate on the validity of the concept of ecosystem health raised two key questions: (1) does the use of the term 'health' to describe the state of an ecosystem require resurrecting the much-discredited analogy between 'ecosystem' and 'organism'? and (2) can 'ecosystem health' be objectively determined, or does it rest on the subjectivity of human goals and value judgments? These issues have been the topic of much debate (Wilkins 1999; Rapport et al. 1999; Lancaster 2000).

With regard to the first question, the short answer is a resounding 'no'. From early on, it has been clear that the organizing principles for ecosystems are very different from those for organisms. The behavior of organisms is a product of natural selection. The behavior of ecosystems arises from the emergent properties of self-organizing systems (Rapport et al. 1985), which can yield multiple dynamic states (Levin 1998). However, both systems can become dysfunctional under certain conditions. Thus, without the need to make an analogy between ecosystems and organisms, one can recognize that both systems can be described in terms of their state of health (proper functioning) or pathology (dysfunction).

With respect to the second question, as to whether ecosystem health depends on human goals, here too the short answer is 'no'. It is unnecessary to bring human goals and values into the equation, when it is evident that ecosystem organization and functions can be objectively measured and compared with earlier states. Just as conservation biologists can assess biodiversity loss against situations that have prevailed in previous times, ecosystem health practitioners can assess the health of ecosystems by comparing metrics describing ecosystem properties (including biodiversity) under conditions prior to the onset of anthropogenic stress with conditions that prevail under stress. This can be done objectively without the need to invoke human values or goals (Rapport and Whitford 1999).

Ecosystem health can be assessed in terms of three general properties, each of which gives rise to a number of specific indicators or metrics (Rapport 1989a; Mageau et al. 1995, Rapport et al. 1998a, b, c). These overriding properties of ecosystem health are:

- *Organization* (Structure): The capacity of ecosystems to maintain their biotic structure, their characteristic biological diversity, their interactions between species and with the abiotic environment;
- *Vitality* (Function): The capacity of ecosystems to maintain biological productivity; and
- *Resilience*: The capacity of ecosystems to rebound from perturbations such as those caused by fire, flood, drought, and so forth.

Ecosystems are dynamic and in constant flux owing to natural disturbances. Therefore, they are seldom in a steady-state condition. However, healthy ecosystems have the capacity to rebound from natural disturbances and recover their key characteristics (that is, they are resilient). Ecosystems compromised by anthropogenic stress, however, tend to lose the capacity to rebound, and, when subjected to natural disturbances (such as, for instance, drought episodes in desert grasslands), tend to become further compromised (Rapport and Regier 1995; Rapport and Whitford 1999). This situation may give rise to another objection to the notion of ecosystem health, insofar as ecosystems under anthropogenic stress do not ''die'' but transform to alternative states. However, this objection is somewhat of a 'red herring', in that it ignores the well-established phenomenon that anthropogenic stress severely compromises the structure and functions of ecosystems, rendering them less capable of sustaining the diversity of life, including human life. Further, ecosystem transformation under stress is often irreversible in ecological time.

In the case of the irreversibly degraded rangeland ecosystems in southwestern New Mexico (Eve et al.

1999; Kerley and Whitford 2000), livestock overgrazing has triggered the transformation of desert grasslands into mesquite and creosote shrublands and then further to coppice dune ecosystems. This has resulted in significant changes in both the grass and rodent communities, along with substantial losses of biodiversity and productivity, greater vulnerability to invasive species, and so forth. In this sense, it might be argued that this is merely a case of a healthy grassland turning into a healthy desert. Yet, this transformation represents a degraded condition compared with the initial state. A desert ecosystem—healthy or not—is less supportive of life than a grassland. Furthermore, in this case, the desert itself continues to degrade over time, becoming less and less supportive of life in all its forms. Similar examples could be given of transformations in many other ecosystems around the world.

While healthy ecosystems are defined independently of human goals, sustainable societies cannot be defined independently of the health of their ecosystems. This recognition has prompted Nielsen (1999) to propose a definition of health in terms of both ecological and social dimensions. In this context, a healthy social-ecological system is one with a "capacity for maintaining biological and social organization on the one hand, and the ability to achieve reasonable and sustainable human goals on the other".

Ecological imbalance and threats to human health

Threats to human health have changed considerably over the course of human history. When modern humans first appeared, approximately 200,000 years ago, the most likely causes of mortality included encounters with predators, famine, and vector-borne diseases. With the gradual shift from hunting and gathering to agrarian societies, beginning 8,000–10,000 years ago, new kinds of health threats appeared, particularly the rise in infectious diseases, as larger numbers of people began to live in closer proximity to one another in settlements and villages. With the further development of agriculture, towns and eventually city states emerged—with correspondingly larger density of population. This situation gave rise to contamination of water from human and animal waste, and thus to an increase in water-borne diseases (e.g., diarrhea), and multiplied the potential for more deadly contagious diseases. In the Middle Ages, great plagues swept through Europe. The "Black Death", a bubonic plague, ravaged Europe between 1347 and 1353, reducing its population by at least one-third.[3]

With the Industrial Revolution, beginning in the late 18th century, new threats to human health arose from exposure to air pollution, carrying with it various toxic substances. Even today, it is estimated that some 4 billion people (2/3 of the global population) are at risk from exposure to various sources of pollution, including industrial air pollution as well as tobacco smoke, indoor cooking smoke, and the like (Pimentel et al. 2007). While the health burden from air pollution is felt mainly in developing countries (e.g., China, India), some 2.8 billion kilograms of toxic chemicals are released annually into the US environment alone, exposing its population to mercury, benzene, and pesticides (Pimentel et al. 2007).

While this situation is potentially reversible through development and implementation of less-polluting technologies, the same cannot be said for health risks arising from ecological imbalances (McMichael et al. 2008). The decline in ecosystem health that results from ecological imbalances is ongoing and largely irreversible.[4] As ecosystem pathology becomes ever more widespread, there are two main impacts on human health futures: (1) the loss in capacity of ecosystems to support human needs for shelter, food, and water, and (2) the spread of human and animal pathogens that thrive in degraded ecosystems (Rapport et al. 2009). Table 1 illustrates some of the implications of ecological imbalance for global health. What is striking is the multiplicity of routes by which ecological imbalance results in increased disease prevalence—in terms of both the resurgence of infectious and water-borne diseases and the emergence of novel diseases. The table also shows that the rise in disease prevalence as a sign of EDS significantly impacts our own species.

Construction of dams as well as irrigation and flooding of new areas have favored the spread of vector-borne diseases such as schistosomiasis in a variety of geographic settings from Egypt to China. Nutrient enrichment from human activities (especially agriculture) resulting in eutrophication of freshwater and marine aquatic ecosystems has favored human (and animal) pathogens, including *Vibrio cholerae* (Huq and Colwell 1996; Colwell 1996), cryptosporidiosis, cyanobacteria, and highly pathogenic *E. coli*. Other ecological imbalances are associated with emerging diseases (both viral and bacterial), including human immunodeficiency virus (HIV), Lyme disease (Gratz 1999), SARS, hanta virus, highly pathogenic avian influenza (H5N1) (Rapport 2006) and swine flu (H1N1).

Ecosystem approaches to global public health

Recognition of the linkages between ecosystem health and human disease risks has spurred transdisciplinary programs in faculties of medicine, public health, veterinary

[3] Bubonic plague, a vector-borne disease, is caused by *Yersinia pestis*, a Gram-negative rod-shaped bacterium belonging to the family Enterobacteriaceae. This disease is transmitted to humans by fleas infected with *Y. pestis* from feeding on the blood of infected rodents (e.g., rats, squirrels).

[4] A recent series of articles in *Science* on Ecosystem Restoration (Roberts et al. 2009) indicates far less success than was hoped. Once ecosystems reach a tipping point, there is little possibility to restore functions in ecological time.

Table 1 Various human health consequences of ecological imbalance

Anthropogenic stress	Ecological imbalances creating health risks	Examples of disease consequences
Land-use change (e.g., large dams, irrigation projects, deforestation)	Creates favorable habitat for vector-borne diseases	Malaria[a], leishmaniasis, dengue, schistosomiasis, Lyme disease, Ross River virus, plague, hanta virus
Nutrient loading	Favors algal blooms and associated human pathogens	Water-borne diseases: cholera, cryptosporidiosis, paralytic shellfish poisoning
Human encroachment on wild areas	Increases human contact with potentially lethal pathogens that have jumped species, such as human immunodeficiency virus (HIV)	Auto immune deficiency syndrome (AIDS)
Over-harvesting and soil depletion	Leads to reduced crop yields, lesser availability of marine and freshwater fisheries, resulting in poorer nutrition and lower immunity to infectious diseases	Dietary shifts to carbohydrate-rich foods, increasing risks for obesity, late-onset diabetes and cardiovascular disease
Global warming	Favors the spread of vector-borne disease previously kept in check by lower temperatures	Expanding range for malaria, dengue fever and other vector-borne diseases

[a] According to recent WHO data (January 2009), there were 247 million cases of malaria in 2006 resulting in nearly 1 million deaths, mostly amongst African children. Source: http://www.who.int/mediacentre/factsheets/fs094/en/

medicine, and environmental management and environmental studies (Rapport and Lee 2004). Among these, in 1998, the University of Western Ontario (UWO) established the first program in Ecosystem Health within an undergraduate medical curriculum (Rapport et al. 2002; Howard and Rapport 2004; Howard 2004).[5] Courses and seminars in ecosystem health at UWO are interdisciplinary and are taught by faculty from many departments, including oceanography, environmental chemistry, anthropology, microbiology, physiology, law, and business. Other universities in Canada, the USA, Europe, and Australia now offer ecosystem-health-based research and teaching programs within their professional schools.

While medical students are generally well aware that man-made chemicals released into the environment are a potential cause of cancer in humans, and that smog and small dust particles are associated with acute (and sometimes lethal) asthma attacks, few are aware of the many routes by which ecological imbalances may increase the burden of diseases in humans (as seen in Table 1 above). The UWO program was designed to bridge this gap and encourage students (future physicians) to think well beyond the traditional medical model of diagnosing a disease and prescribing treatment (Rapport et al. 2002).

The ecosystem health approach to medicine broadens the scope of diagnosis well beyond the questions that the physician asks in the classical approach: (a) ‘‘What is the disease?’’ and (b) ‘‘How do I fix it?’’, and even beyond the more recent questions that arose from the adoption of a ‘patient-centered’ approach to medicine in the 1990s: (c) ‘‘What are my patient’s unique needs?’’ and (d) ‘‘How do I help my patient meet those needs?’’. From an ecosystem health perspective, each individual is part of an environment that includes family, community, society, ecosystems, and the biosphere. It is this larger interactive matrix that, as we have seen, is often decisive in the spread of pathogens, or even in the origin of emerging diseases. Adopting an ecosystem health approach presents the physician with two additional critical questions: (e) ‘‘Why does this patient have this disease?’’ and (f) ‘‘What can I do to prevent others from having this disease?’’

Adding these questions to those of a traditional medical practitioner does not of course guarantee that physicians will choose to be directly involved in advancing knowledge in this area, or in directly advocating enlightened policy, although some physicians have done so (Rapport and Lee 2003, Arya et al. 2009, Chivian and Bernstein 2008). Rather, through programs of this nature, a new generation of medical practitioners is made increasingly aware of the importance of healthy ecosystems to human health. This awareness will strengthen support for the maintenance of ecosystem health in the interest of improving human well-being. It should also encourage a transition from the nearly exclusive focus on ‘cures’ to a much needed focus on ‘prevention’. Physicians have long known of the admonition: ‘‘An ounce of prevention is worth a pound of cure’’. As they become more aware that reducing risks to human health requires fostering ecosystem health, they can become far more effective in encouraging the transition to global environmental, social, and health sustainability by promoting, through public education programs, the kind of care required to maintain ecological balance in the interests of public health and human well-being (McMichael et al. 2008).

A broader synthesis: eco-cultural health

As we have shown, the concept and applications of ecosystem health have central relevance to assessing and evaluating ecological transformation and to connecting ecological imbalance to human activities and to the

[5] One of the authors (Rapport) is the co-founder, with John Howard, of the Program in Ecosystem Health at the University of Western Ontario, and held an honorary appointment as Professor in the Faculty of Medicine from 1998 to 2004. This program was initiated with support from the Richard Ivey Foundation.

consequences for human health and well-being. At the same time, recent advances in our understanding of the interconnections and interdependence between nature and culture (Maffi 2001, 2005, 2009; Harmon 2002; Harmon and Loh 2010; Maffi and Woodley 2010) call for an even broader synthesis. It is increasingly recognized that, wherever there is a long history of human presence within and interaction with ecosystems (and this in fact applies to most of the world's ecosystems), one cannot make a clear-cut separation between 'nature' and 'culture'. Rather, it is more appropriate to speak of the integration of nature and culture within an 'eco-cultural' system (Rapport and Maffi 2010).[6] In this context, eco-cultural health has been defined as a dynamic interaction of nature and culture that allows for the co-evolution of both without compromising either critical ecosystem processes or the vitality of cultures (Rapport and Maffi 2010). Parallel to the cardinal features of healthy ecosystems described above, the key characteristics of eco-cultural health have been described in terms of:

- *Organization* The alignment of cultural institutions and practices with the maintenance of biotic composition, interactions and integration;
- *Vitality* The capacity of the system to sustain itself (transmit/reproduce) so that its potential for life in both nature and culture is undiminished; and
- *Resilience* The maintenance of coping mechanisms in nature and culture to enable rebound from ecological and social disturbance, such as drought, floods, epidemics, conflict, etc. (Rapport and Maffi 2010).

The concept of eco-cultural health thus integrates a wide range of considerations for the purpose of assessing the viability and sustainability of nature and culture at local, regional, and global levels. It combines a concern for maintaining the organization, vitality, and resilience of ecosystems with a concern for ensuring the continued organization, vitality and resilience of the local human communities living in and interacting with the ecosystems. An eco-cultural health approach looks at the health or pathology of ecosystems—and the respective implications for human livelihoods, health and well-being—from the point of view of beneficial or detrimental interactions between people and the environment, both historically and at present. Such an approach seeks to sustain and foster cultural values, beliefs, institutions, knowledge systems, and practices that are favorable to maintaining the health of ecosystems while enabling humans to meet their basic needs for food, water, shelter, health, security, cultural cohesion, and societal well-being.

All these dimensions are vital to the sustainability of life systems for the benefit of all life. For example, economic sustainability is ultimately dependent on sustaining the health of agro-ecosystems, forest and grassland ecosystems, and freshwater and marine ecosystems, which supply many of the basic requirements for life for human and other species; the vitality of cultural traditions is important for the maintenance and transmission of values that promote harmonization of human activities with the environment, and thus contribute to sustaining life; and in turn this harmonization requires maintaining and developing institutions and decision-making processes that foster eco-cultural health. As we will show by way of example in the next section, it is the breakdown of the complex interdependencies built, over centuries or even millennia, between people and ecosystems that accounts for many if not most of the cases of ecosystem and societal collapse we have witnessed in the past and are increasingly witnessing today, along with increased disease vulnerability for humans and other species.

The Inner Mongolian grasslands: an example of loss of eco-cultural health and its implications for human health

For a telling example, we can look to the recent history of the grasslands of Inner Mongolia (Rapport and Maffi 2010). Inner Mongolia contains five major grasslands, each with its unique ecology and history of human activity. The Horquin Sandy Lands in northeastern Inner Mongolia have been periodically occupied by Mongolian nomadic herders for many thousands of years. Over this period, the herders developed their nomadic lifestyle, adapting to the ecology of the grasslands by moving their herds (sheep, goats, horses, and camels) as seasonal grasses became available. In this way they maintained low grazing pressure, which sustained the health of the grasslands and their culture. However, at least three times over the past 8,000 years (including at present), the symbiotic relationship between nature and culture was interrupted by large-scale influx of farmers and sedentary pastoralists, which transformed the grassland into vast agricultural lands. Each time, once the limited soil nutrients were depleted, the grasslands became desertified, and were abandoned for millennia. When the soil and vegetation rebounded, the regenerated system was weaker than that of the previous cycle.

The Horqin Sandy Lands are now well into their third cycle of desertification. This cycle is the outcome of twin pressures on the land both from the influx of farmers and pastoralists, converting large areas of the grasslands to agriculture, and from government-imposed restrictions on the movements of Mongolian nomadic herders, resulting in the intensification of grazing pressures. Since the 1950s, more than 2.5 million hectares of grasslands in

[6] In this context, the term 'culture' is understood in a broad anthropological sense, to refer to worldviews, values, beliefs, institutions, knowledge systems, languages, and practices held by human communities—including ones that have developed from long-standing relationships between people and nature. In this sense, culture encompasses the social dimension. The latter is taken to refer to the culturally bound institutions that form the basis of social organization and provide the ground rules for societal interactions, such as political, legal, economic, and administrative systems, regulations, and customs.

the Horqin Sandy Lands have been converted to farmland, and farming activities have expanded to the northern frontier areas. In recent times, farms have been abandoned owing to nutrient decline, and seasonal wind storms blow off remaining soils and expose underlying sand, leading to dune mobilization. By the late 1950s, 28% of the land in the Horqin steppe had become desert; by the mid-1970s, this area had increased to 53%, and by the end of the 1980s it stood at 78% (Liu et al. 2003). As of 2006, for Inner Mongolia as a whole, an estimated 90% of grasslands have been degraded to some degree—more than twice the amount of a decade earlier—while productivity of disturbed grasslands stood at only 50% of the productivity of the undisturbed steppe (Jiang et al. 2006).

Today, blowing and drifting sands threaten remaining farmlands, and roads are often buried by the wind-borne sand particles. Desertification has resulted in reduced populations of megafauna, including Mongolian gazelle, roe deer, foxes, and wolves. It has also threatened the livelihoods of both the farmers/pastoralists and the Mongolian nomadic peoples. As croplands are abandoned and dunes mobilized, people are being forced to exploit marginal lands for growing crops (such as along the margins of river beds), and towns have been overtaken and abandoned. As the sands advance, grazing lands are progressively reduced, adding to the adverse political conditions that threaten the continuation of ecosystem-friendly nomadic ways of life. The health of millions of people in Inner Mongolia is under severe threat, owing to increasingly harsh environments, declining availability of food and water, severe respiratory problems and eye infections from dust and sand storms, exposure to contaminants (including toxic substances and heavy metals) and pathogens (such as TB, flu virus, and hantavirus) carried by dust, and other ills (Griffin et al. 2001; Ellis 2007; Pimentel et al. 2007). The grasslands of many regions of Inner Mongolia are likely to be well beyond the point of self-repair, leaving little hope for the improvement in the health and well-being of people. These conditions will increase the likelihood of abandonment of the region by both the Mongolian herders and immigrant Han farmers. Restoration efforts have thus far proved of very limited success. What is needed are much more concerted efforts and political will to restore eco-cultural health to the region.

Implications for policy and action

The field of ecosystem health has been built upon a transdisciplinary perspective from the very beginning (Rapport et al. 1979; Rapport 1995). As it has evolved, the relationships between ecological health, cultural health, and public health have come into focus (Appendix). While public policy continues to place emphasis on short-term solutions to looming environmental and health crises—for example, in the case of water-borne diseases, opting for water-treatment plants rather than for restoring the health of watersheds (Arya et al. 2009)—such strategies offer only stop-gap measures and fail to address the fundamental causes: namely, deterioration in eco-cultural health.

An eco-cultural health perspective must become the cornerstone of an enlightened governance of the commons—both in terms of community-driven initiatives and in terms of policies at regional, national, and international levels. Good governance is essential to achieve communal goals relevant to the use, management and conservation of the environment for human well-being and the benefit of all life. Often, as Eleanor Ostrom and colleagues have shown (Ostrom 1990; Ostrom et al. 1999; Dietz et al. 2003), governance decisions made through consensus-building within local communities are more effective in preventing the 'tragedy of the commons' (i.e., the degradation of open-access resources; Hardin 1968) than decisions made by a remote regional or national authority that lacks the intimacy of local knowledge. At national and regional levels, good governance must rely upon appropriate tools for assessing and forecasting trends in eco-cultural health, in order to identify the main threats to the health of both ecosystems and people and their implications for sustaining life. There are some promising examples. In recent years, recognition of the importance of this broader perspective gave rise to an agreement among the leaders of the Mesoamerican countries (Mexico, Guatemala, Belize, and Honduras) to take collective action to mitigate the deterioration in the off-shore Mesoamerican coral reef, based not only on ecological considerations, but as well on cultural, socio-economic, governance, and public health dimensions (World Bank 2006).

Such examples of good governance must be multiplied and strengthened if there is to be hope to stem further degradation of the earth's eco-cultural systems. Addressing this challenge requires an integrative approach that takes into account all the components of eco-cultural systems. Strategies that focus on single issues—be they economic, public health, or ecological—in isolation of others are bound to fail. To be sure, eco-cultural systems are of immense complexity, and their dynamics invariably include thresholds that can trigger sudden and unpredictable non-linear transformations (Rapport and Regier 1995; Levin 1998; Lyytimäki and Hildén 2007). However, as the framework for analysis must match the complexity of the problem, ecologists must develop the capacity to work closely with those in the social and health sciences to approach these issues from an integrative, transdisciplinary perspective. In this paper, we have suggested that the concept of 'health' is a fundamental property of life systems in nature and culture, and that sustaining life will require a perspective that identifies key indicators of healthy eco-cultural systems, delineates the pathways and mechanisms by which eco-cultural health can be compromised, and sets polices that will be effective in restoring health to the world's eco-cultural systems. The further evolution and articulation of the nature and parameters of eco-cultural health will contribute to this vital societal objective.

Appendix

Table 2 Brief history of ecosystem health and eco-cultural health: 1941–2010

Year	Event/Key publications	Details/References
1941	Essay by Aldo Leopold on "Land Sickness"	Leopold (1941)
1974–79	Statistics Canada develops a comprehensive framework for environmental statistics, integrating human activities and the environment; adopted by the OECD as "Pressure/State/Response" (PSR) framework	Rapport and Friend (1979)
1979–81	Linking medical diagnostics to ecosystem assessment	Rapport et al. (1979); Rapport and Regier (1980); Rapport et al. (1981)
1984–89	Early publications on ecosystem health and medicine	Rapport (1984), Schaeffer et al. (1988), Rapport (1989b)
1985	Identification of an "Ecosystem Distress Syndrome"	Identification of common signs of ecosystem breakdown under anthropogenic stress (Rapport et al. 1985)
1986	1st Canadian State of Environment Report; application of PSR framework	Bird and Rapport (1986)
1991	1st International Workshop on Ecosystem Health	University of Illinois, Allerton Park. Co-Chairs: David Rapport and David Schaeffer
1991	Formation of the International Society for Ecosystem Health (ISEH)	David Rapport, President (1992–2000); Robert Costanza, President (2000–2002)
1992	First book on ecosystem health	Costanza et al. (1992)
1992–Present	Governments and international organizations incorporate ecosystem health principles and goals in mandates and monitoring programs	Beginning with the adoption of Principle 7 of the Rio Declaration[a], ecosystem health appears in statement of goals of a number of leading international organizations including WWF, UNEP, IUCN, WHO
1993	NATO Advanced Research Workshop on the Health of Large-Scale Ecosystems	Chateau Montebello, Quebec. Co-convenors: D. Rapport and P. Calow
1994	1st International Symposium on Ecosystem Health and Medicine	Ottawa, Ontario. Co-chairs: D. Rapport and R. Costanza; 800 participants from more than 30 countries
1995	Establishment of Ecosystem Health Program by the International Development Research Centre (IDRC), Ottawa, Ontario	IDRC initiates a program in ecosystem health with a focus on ecosystem approaches to human health
1994–97	Agro-ecosystem Health program at the University of Guelph (Canada)	Sponsored jointly by the three national science councils (Tri-Council) of Canada and D. Rapport
1994–97	1st University Chair in Ecosystem Health	Sponsored by the three national science councils (Tri-Council) of Canada—awarded to the University of Guelph and D. Rapport
1995	Publication of NATO Advanced Research Workshop papers: Evaluating and Monitoring the Health of Large-Scale Ecosystems	Rapport et al. 1995 (eds) Springer-Verlag, Heidelberg. 454 pp.
1995	Launch of the first international peer-reviewed journals in ecosystem health	Ecosystem Health (Blackwell Science), Journal of Aquatic Ecosystem Health and Management (Kluwer)
1996	1st Eco-Summit	Copenhagen, Denmark. Co-convenors: D. Rapport and S. E. Jorgensen
1997	Ecosystem health introduced in Canadian veterinary schools	Ribble et al. (1997)
1998	1st Ecosystem Health Program in a medical school, at the University of Western Ontario (London)	Co-founders: D. Rapport and J. Howard
1998	1st graduate textbook on ecosystem health	Rapport et al. (1998c)
1999	International Congress on Ecosystem Health	Sacramento, California. Co-chairs: D. Rapport and W. Lasley
2000	International Symposium on Ecosystem Health	Brisbane, Queensland. Co-Sponsored by ISEH
2002	International Symposium: Healthy Ecosystems, Healthy People: Linkages Between Biodiversity, Ecosystem Health and Human Health	Washington DC. Co-sponsored by ISEH, Conservation International, World Health Organization, and the United Nations Environment Programme. R. Costanza, Chair
2002	Indo-Pacific Conference on Ecosystem Health	Perth, Australia. Sponsored by Edith Cowan University
2002	White Oaks Symposium on "Conservation Medicine: ecological health in practice"	Aguirre et al. (2002)
2003	Publication of *Managing for Healthy Ecosystems*	Proceedings of the International Congress on Ecosystem Health. Rapport et al. (eds) (2003)

Table 2 continued

Year	Event/Key publications	Details/References
2003	International Symposium on Ecosystem Health "Airs, Waters, Places": Transdisciplinary Conference on Ecosystem Health	Newcastle, Australia. Albrecht (2003)
2003	"International Forum on Ecosystem Approaches to Human Health"	Montréal, Quebec. Sponsored by International Development Research Centre, Ottawa. Co-chairs: D. Rapport and D. Mergler. See Rapport and Mergler (2004)
2004	*EcoHealth* launched (successor journal to *Ecosystem Health*)	An international peer-reviewed journal published by Springer. B. Wilcox, editor
2000–04	Ecosystem Health Programs in professional schools	Rapport et al. (2004)
2006, 2008	EcoHealth Conferences (Wisconsin and Mexico) under the newly formed International Association for Health and Ecology	Following the dissolution of ISEH (2002), some members proceeded to form a new association more exclusively focused on the intersection of health and ecology
2007–10	Principles of eco-cultural health	Presented at University of Tokyo, campus-wide seminar, April 2007 (D. Rapport & L. Maffi); also at Symposium "Sustaining cultural and biological diversity in a rapidly changing world", American Museum of Natural History, New York, April 2008 and at World Conservation Congress, October 2008. Rapport and Maffi 2010; Rapport 2010

[a] Principle 7 of the Rio Declaration on Environment and Development (1992) reads: "States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystems. In view of the different contributions to global environmental degradation, states have common but differentiated responsibilities." (Johnson 1993)

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