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Despite the bad press that generally follows an El Niño episode, on Nov.2, 1997 the Italian News Channel (RAI), and the U.S. Sunday Report, showed a marvel engendered by El Niño: the flowering of the Chilean desert. This example shows clearly why the insistence on largely unmanipulated (if not “intact”, “pristine”, or “virgin”) systems is so vital to the understanding of integrity and to life on Earth. A desert area in Chile that, to the casual observer in recent times, was seemingly barren changed dramatically after El Niño. Because the latent biological processes of deserts in general and the specific biota characteristic of the Chilean desert were present, the unusual rains brought in by El Niño produced a wonderland of flowers and grasses, with all the accompanying complement of insects, such as bees, ants, butterflies and other species.

This burst of life occurred because anthropogenic stress was largely absent from the history of the desert; that is, this Chilean landscape had not been subjected to the chemical and biophysical stresses that prevail in exploited ecosystems around the world. In essence, the desert retained its biological potential (Westra 1994) because its vital state had not been reduced by human disturbance. The main point of this example is to emphasize the difference between a landscape that has been heavily utilized and one that has been left (for the most part) in its natural condition, following its own evolutionary trajectory. At one end of the spectrum, the remote desert area retained most of its capacities for development; largely untouched, the desert flowered. At the other end, the petroleum-laced fields where Royal Dutch/Shell Oil carries on its ecologically destructive enterprise in Ogoniland, Nigeria (Westra 1998) will not burst into flower in any circumstances. While most people were completely ignorant of the immense potential for diverse life that was present in that “barren” desert in Chile (although desert ecologists may be familiar with such phenomena), its integrity guaranteed that - under changed conditions - one of its possible developmental trajectories might come to be.

In this chapter we consider, in general terms, the meaning, measurement and policy implications of the familiar, fundamental, but sometimes puzzling concept of ecological integrity. First we offer a qualitative characterization of six themes associated with the concept of integrity. Then we consider two approaches to the measurement of integrity devised by James Karr and Robert Ulanowicz. Next we address a number of theoretical issues, related concepts and policy implications associated with integrity. Finally we summarize the approach of Noss and Cooperrider (1994) to implementing the policy of conserving global ecological integrity by protecting, in as wild a condition as possible, with buffers and connections across the landscape, viable areas capable of representing the ecological diversity of the world.

Integrity Revisited and Clarified

The generic concept of integrity connotes a valuable whole, “the state of being whole, entire, or undiminished” or “a sound, unimpaired, or perfect condition” (The Random House Dictionary of the English Language 1967). We begin with the recognition that integrity, in common usage, is an umbrella concept that encompasses a variety of other concepts (Westra 1994). The example of the blooming desert illustrates a number of the themes associated with ecological integrity.

1. The example is drawn from ***wild nature***, i.e., nature that is virtually unchanged by human presence or activities. Although the concept of integrity may be applied in other contexts, wild nature provides the paradigmatic examples for our reflection and research. Because of the extent of human exploitation of the planet, such examples are most often found in those places that, until recently, have been least hospitable to dense human occupancy and industrial development: deserts, the high arctic, high altitude mountain ranges, the ocean deep, and the less accessible reaches of forests. Wild nature is also found in locations whose capacity to evoke human admiration won their protection in natural parks.

2. The rapid bloom of desert organisms illustrates in a dramatic fashion some of the ***autopoietic (self-creative) capacities*** of life to organize, regenerate, reproduce, sustain, adapt, develop and evolve.
3. These self-creative capacities are ***dynamically temporal***. The present display of living forms and processes in the desert gains significance through its past and its future. Nature's rhythms are displayed over time; no momentary snapshot captures all of nature's potential.
    a) Conjoined with its past, the Chilean desert is a part of ***nature's legacy***, the product of natural history. Because of the relative absence of anthropogenic impacts, the desert biota is the creation largely of "evolutionary and biogeographical processes at that place" (Angermeier and Karr 1994). It thus illustrates what nature is and does in the absence of the human design and influence that dominate the built, modified and impacted environments in which we live most of our lives.
    b) The events of its past and present demonstrate the capacity of desert life-forms to maintain themselves and their evolutionary lineages across generations, to respond to changing conditions, to evolve. If those capacities are not destroyed, the system retains its maximum potential to evolve alternative future realizations.
    c) Neither the dry dormancy nor the flowering vibrancy by itself captures the desert's potential to move between these states. Emergent properties result from macro-organic interactions among and between species and local physical conditions. In another example, an intermediate stage in forest succession does not lack integrity simply because it does not have all the features of a climax forest. Thus, in determining the state of a system, persistent trends, and capacities that are only occasionally displayed must be taken into account.
4. Desert conditions, relieved by rains at rare intervals, are themselves the products of larger regional and global weather patterns. Indeed both the biological and geoclimatic

processes that led to the blooming desert play themselves out on a stage with much larger ***spatial scope***.

A major issue for conservation biology is the question of what spatial requirements are needed to maintain native ecosystems. What area and configurations are needed for land and marine ecosystems dedicated to the preservation of the native biodiversity and natural processes, whose joint presence constitutes integrity? How do conditions external to the protected area affect it, and what are effective means to buffer an area against adverse external factors? Global and regional atmospheric and climatic conditions - long-range material, chemical and biological transport; disease vectors; exotics; refugia; migratory patterns; home ranges; natural disturbance regimes; and the like - are spatial phenomena that impinge upon or are constitutive of local ecological integrity. Integrity at a local site requires favorable regional and global conditions.

5. Implicit in the above is the fact that biophysical phenomena constitute a system of interacting and interdependent components that can be analyzed as an ***open hierarchy of systems***. Every organism in the desert comprises a system of organic subsystems and interacts with other organisms and abiotic elements to constitute larger ecological systems of progressively wider scope up to the ecosphere.
6. Note, finally, that ecological integrity is ***valuable and valued***. In the case of the Chilean desert, the dramatic transformation of “barren” desert into a vital and diverse biotic community provoked wonder and appreciation. Other ecological communities, such as reefs and rainforests, display their prolific life in a more continuous, less seasonal or episodic fashion. More generally, the biological and physical processes at work in these instances gave rise to the totality of life on earth, including ourselves, and maintain the conditions for the continuation of life as we know it. Thus natural ecosystems are valuable to themselves for their continuing support of life on earth, as well as for the aesthetic value and the goods and services they provide to humankind. Indeed,

> ecological integrity is essential to the maintenance of ecological sustainability as a foundation for a sustainable society. For these reasons, there is a growing body of policy and law that mandates the protection and restoration of ecological integrity.

As a valuable and valued condition of biological systems, ecological integrity bridges the concerns of science and public policy. For both, we must be able to go beyond general qualitative descriptions to specify empirical and operational standards. Are integrity and its loss empirically measurable biological conditions? We believe so and present two basic approaches derived, on the one hand, from comparisons with a baseline condition in “wild” nature (i.e. places virtually free from human impacts) and, on the other, from complex systems theory. James Karr pioneered the creation of multimetric indices of biological condition (initially in streams and rivers) that measure the severity of biological degradation by deviations from a baseline condition of ecological integrity found in wild nature (Karr 1991, 1998, chapter 12, this volume; Karr and Chu 1999). Others have adapted this approach to forest (Loucks chapter 10, this volume; Miller and Ehnes chapter 9, this volume), shrub-steppe (Kimberling et al., in review), and wetland (Burton et al. 1999) ecosystems. Robert Ulanowicz has devised a different approach to defining and measuring ecological integrity in terms of several general characteristics of ecosystems related to their vigor, organization and resilience, which can be measured to produce another composite index of integrity (see also chapter 6, this volume). As in medical diagnosis, multiple convergent indicators of biological condition are an asset.

Assessing Biological Condition (Divergence from Integrity): Index of Biotic Integrity (IBI)

Water is both a symbol and a major constituent of life. Humans depend on living waters for many essential goods and services, from drink and food to cleansing of wastes to aesthetic and recreational renewal. But, in the settlement of North America, we have not treated this resource well. What a biologist sees in our rivers is a history of damaged landscapes and undervalued, polluted waters. In response to the deteriorating condition of our freshwaters, the U.S. Clean Water Act has as its objective: “to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters” [Clean Water Act (CWA) s. 101(a)]. Against this backdrop, the multimetric index of biological integrity (IBI) was developed to give empirical meaning to the goal of the Act (Karr 1981; Karr et al 1986; Karr and Chu 1999; Karr chapter 12, this volume).

Karr defines ecological integrity as “the sum of physical, chemical, and biological integrity” (Karr and Dudley 1981; Karr 1996). Biological integrity, in turn, is “the capacity to support and maintain a balanced, integrated, adaptive biological system having the full range of elements (genes, species, and assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of a region” (Karr and Chu 1995). We can measure the extent to which a biota deviates from integrity by employing an IBI that is calibrated from a baseline condition found “at a site with a biota that is the product of evolutionary and biogeographic processes in the relative absence of the effects of modern human activity" (Karr 1996), in other words, wild nature. Degradation or loss of integrity is thus any human-induced positive or negative divergence from this baseline for a variety of biological attributes.

Just as the index of leading economic indicators combines many financial measures to assess the state of the national economy, the IBI is holistic as it integrates measurements of many biological attributes (metrics) to assess the condition of places. Metrics are chosen on the basis of whether they reflect specific and predictable responses of organisms to human activities. Ideal metrics should be relatively easy to measure and interpret. They should increase or decrease as identifiable human influences increase or decrease. They should be sensitive to a range of biological stresses, not narrowly indicative of commodity production or threatened or endangered status. Most important, biological attributes chosen as metrics must be able to discriminate human-caused changes from the background “noise” of natural variability. Human impact is the focus of biological monitoring and assessment (Karr and Chu 1999).

Despite major variations in the structure and function of ecosystems throughout the world, a narrow range of IBI metrics has proven useful in evaluating the condition of places. IBI metrics evaluate species richness; indicator taxa (stress intolerant and tolerant); relative abundance of trophic guilds and other ecological groups; presence of alien species; or the incidence of hybridization, disease, and anomalies such as lesions, tumors, or fin erosion (fish) and head capsule abnormality (in stream insects) (Karr 1996). Note that, unlike the procedures for standard water quality testing, physical and chemical parameters are not measured for the IBI. If such physical attributes are biologically relevant, their impacts will be detected in the biological measures.

Regional calibration of IBI is appropriate because of natural differences between landscapes, just as different body temperatures are normal or healthy for different species of birds or mammals. As human actions touch almost all the different places on earth, we have no choice but to attempt to understand the specific effects of these actions in each region. This requirement is no more stringent than the requirements of medicine, for instance. Knowing what constitutes the appropriate diagnosis and treatment for a disease may refer to different conditions in the case of an infant, an adult or a senior citizen, or among species for veterinary medicine.

Although rivers and streams only represent a small portion of a landscape, their state is indicative of the condition of the whole watershed. “Rivers, like blood samples from a human, are indicative of the health of the landscape” (Karr 1998). Moreover, although the IBI was developed initially to measure the conditions of streams and rivers, the same principles for the construction of a multimetric index can be applied to terrestrial ecosystems. Karr and colleagues have developed a terrestrial IBI for the shrub-steppe ecosystem at the Hanford Nuclear Reservation in eastern Washington State (Kimberling et al., in review). Loucks (chapter 10) and Miller and Ehnes (chapter 9) in this volume discuss extensions of the methodology to temperate and boreal forests. Loucks introduces the concept of Mean Functional Integrity (MFI) based on several metrics for functions such as net primary production, hydrologic pumping/evapotranspiration, biomass decomposition, and nutrient/mineral cycling. Miller and Ehnes discuss a framework for linking the IBI concept to current Canadian initiatives to develop criteria and indicators for sustainable forest management. The latter approach includes a benchmark condition that encompasses a range of natural variability derived from sampling multiple sites within a landscape.

For nearly two decades now, university scientists, water resource managers, and citizen volunteers have used the multimetric IBI to evaluate the biological condition of streams and rivers throughout the world. Site specific assessments of biological condition are used to document the mean condition across a sampling of sites (even statistically representative of a population of places if the site selection is done properly) or the variability in condition of sites within a region. With GIS and other technologies one can couple knowledge of biological condition to spatial context, even associating the causes of degradation with specific human activities.

Once a relevant standard and index of integrity have been established, various sites or areas can then be ranked by the extent of their deviation from the integrity standard or benchmark. IBI is a measure designed to document biological condition, the position of a site or landscape on a continuum (see Fig. 12.1) from undisturbed (having biological integrity) to severely degraded. (See Chapter 12, this volume for use of concepts such as benchmark, guide, and goal in biological monitoring and assessment.) A heavily polluted or paved-over area at which there is nothing alive has a biological condition marking an extreme of disintegrity, whereas the conditions of agricultural lands and commercial forest plantations lie near the middle of the spectrum. Only pristine or minimally influenced wild lands meet the integrity standard or benchmark. In effect, there are no significant degrees of integrity; it is a standard existing only at the top of the scale of the IBI. Although there is considerable pressure to invoke lower standards of evaluation, that integrity benchmark defined by wild nature should be retained so that citizens, politicians, and policymakers know the level of degradation at sites subjected to the influence of human actions. Having a standard of biological integrity confers the ability to measure the full extent of our impacts on nature in exploited areas, as well as our success in protecting nature's legacy in wild areas. This is essential if we are to make informed social choices about land use.

Human survival depends upon many of nature's "goods and services" that are invisible to markets and the economy; some are no doubt invisible to scientists. To know ourselves, we need to understand not only the processes and products of human history, culture and technology, but also the processes and products of planetary evolution. We cannot hope to understand the effects of human actions on those products and processes without a systematic effort to evaluate trends in the condition of Earth's living systems. Neither can we restore structure and function, the parts and processes of living systems, to previously modified areas if we do not fully understand their role in wild nature. Because IBI is an accurate, empirically derived, and widely tested quantitative method, it is a valuable addition to the toolbox of twenty-first century science. IBI is also valuable because it provides ordinary citizens with locally meaningful indicators that can stimulate a local constituency to understand the condition of its bioregion. It is a practical index that can help make an explicit connection between ecological health and human population health. In short, IBI provides the kind of information that will ground decisions in broad understanding of the consequences of human actions, especially the loss of living systems, the basis for our own existence.

Assessing Biological Condition (Ecological Performance): Ascendancy and Resilience

The global success and widespread use of IBI has encouraged others with concern about trends in ecological, especially living systems, to use widely accepted phenomenological conventions to yield alternate quantitative descriptors of ecosystem integrity or health. Some have sought to formulate a generic approach to the measurement of ecological performance that does not require, as the IBI does, a benchmark condition derived from particular wild ecosystems. Such an approach, if successful, could generate a measure of ecological performance for those portions of the earth that have been so widely modified by humans that wild benchmarks no longer exist. A systems-theoretical approach recognizes that the elements and processes of particular ecosystems also exemplify more general physical, chemical and ecological functions and processes that can be quantified.

In this context, thermodynamic law and, in particular, the concept of “entropy” deserve some attention, in that they might be used to measure how “disordered” a system has become. Svirezhev and Svirejeva-Hopkins (1998), for example, suggested that “excess entropy production” to serve human needs (e.g., the excessive dissipation of biomass and fossil energy as indicated by the disruption of ecosystem structure and function) measures the degree to which an ecosystem has been disturbed from its natural state.

Ulanowicz and Hannon (1988), suggest another measure of integrity based on thermodynamic law. They argue that the rate of entropy production from the dissipation of solar energy by ecosystems can be accurately measured by comparing the spectra of incoming radiation with that leaving the surface. Because the incoming radiation is relatively constant over wide areas, comparison of entropy production rates should be possible by comparing the outgoing radiation profiles. Ecosystems that are performing close to their natural optima are healthier and should be able to extract more useful work from incoming radiation, and re-radiate energy at higher entropy (lower effective temperature), than systems that have been disturbed in some way. Integrity, by this measure, should correlate positively with entropy production. Indeed, preliminary results with remote sensors seem to indicate that more mature, less impacted biomes reflect less radiation and appear to have “cooler” spectra than early successional stages or disturbed sites (J.J. Kay, E.D. Schneider and J. Luval, personal communication). It may, therefore, prove feasible to make a preliminary assessment of the health of ecosystems using series of measurements from airplanes or satellites.

Unfortunately, knowledge about entropy production tells us nothing about the configuration of ecosystem processes. Ecology is, after all, the study of the relationships among the members of a biotic community and between the community and its physical environment. We therefore need to track the essential processes that link the ecosystem elements. One way to quantify ecological performance more fully, therefore, would be to measure the amounts of material or energy that are actually exchanged among the various parts of the ecosystem. The assumption here is that the magnitude and configuration of trophic interactions in an ecosystem can be quantified and used in assessing the system's relative integrity/health if we know the topology of the system interactions.

All these indicators suggest that a "healthy" system is one that is capable of performing well in multiple ways. In Costanza's (1992) terminology, adequate performance entails both vigor and organization (neither of which should be used in isolation from the other as a criterion of ecological performance). Having decided to emphasize trophic exchanges, the component of vigor inherent in these flows can most readily be quantified as the simple sum of the magnitudes of all the trophic exchanges involved. The corresponding aggregate in the human economy has been called (in ecological economic theory) "total system throughput" (Finn 1976.) It is important to recognize, however, that total system throughput, by itself, does not measure ecosystems integrity. For example, a eutrophic lake, polluted by domestic sewage or agricultural run-off, would be much more productive than the pristine oligotrophic system it displaced, but would lack the latter's biological integrity.

Remaining with trophic exchanges, we can identify the structure or organization of the energy or material flows as a second measurable component of ecological performance. The organization of these trophic exchanges requires somewhat more effort to quantify than their summation (vigor). Suffice it to note that an organized system is one that is constrained to operate in a certain way. Trophic flows do not occur willy-nilly throughout the ecosystem. One need not require microscopic descriptions of the exact signposts that cause material to flow along specific ecosystem pathways. Rather it is sufficient to measure the degree to which the observed configuration has been constrained by such mechanisms relative to the disorder or indeterminacy these activities might otherwise exhibit.

The measurement of the 'overall indeterminacy' is the crux of information theory, and may be quantified using the familiar, though not universally accepted, Shannon (1948) index of diversity applied to the types of flows (Ulanowicz and Norden 1990.) The formula reveals that when the different types of individual transfers are both many (richness), and more or less of the same magnitude (evenness), then the opportunities (overall indeterminacy) to develop either complex, well-defined, structured flows or confused, arbitrary transfers are high. Thus, overall indeterminacy is a measure of an ecosystem's ultimate developmental capacity. At any point in its developmental history, a system's overall indeterminacy will be partitioned between existing ordered structured flows and a 'residual indeterminacy' that represents remaining options for additional order.

To assess the degree to which the ecosystem flows are organized (i.e., well-defined and structured), requires that one calculate an index known as the "average mutual information" of the flow structure. When flows are linked up in rather arbitrary fashion, the mutual information about where a particle will next be transferred is low. The system is not well organized, trophically speaking, and there is high residual indeterminacy. One would expect to find such ecosystems where the natural and anthropogenic disturbances are irregular and intense, such as in polar ecosystems or highly impacted ones. On the other hand, if a system has been allowed sufficient time to develop within its environment without major external disturbance, cybernetic feedback will emphasize those pathways consisting of the more efficient transfers over and above arbitrary connections that are not cybernetically reinforced. Such a system acquires a complex, highly ordered structure: we say its flow structure has high 'average mutual information' and the system has low 'residual indeterminacy'.

The factor of vigor (system-specific total system throughput) can now be multiplied by the index of organization (the average mutual information just discussed) to yield a single index of system performance, called the system ascendancy (Ulanowicz 1980, 1986, 1995, 1997; and chapter 6, this volume). Ascendancy assesses the ecosystem's performance at processing material and energy and can serve as a surrogate for ecosystem health.

In addition to ascendancy, a further attribute often associated with integrity is the ability to withstand stress. Presumably, the responses to naturally occurring stresses that are encountered on a continuing basis (e.g., seasonal cycles, fire-climax forests, etc.) are incorporated into the organization of the system and contribute to the ascendancy. The ability to withstand novel stresses is, however, another matter. The system responds to new perturbations by accessing its repertoire of residual indeterminacies. That is, when the overall indeterminacy is diminished by the average mutual information, the residual indeterminacy is a direct measure of the freedom the system has to reconfigure itself in response to any new perturbation. It serves as a measure of potential resilience and suggests why a tropical rainforest has low resilience, because of its high average mutual information that leaves little residual indeterminacy.

The astute reader will have noticed that system performance (ascendancy) and resilience are antagonistic, i.e., mutually exclusive to a degree. Expressed in the language of information theory, each of the two attributes is quantified by one of two complementary terms (mutual information and residual indeterminacy) that sum to yield the overall indeterminacy of the system. The 'overall indeterminacy', then, represents the system's developmental capacity, "the greatest possible [number of] on-going developmental options within its time/location" (Westra 1994). It is the closest one can come (under the thermodynamic and information-theoretic assumptions made here) to quantifying the integrity of an ecosystem. Because the overall indeterminacy explicitly gauges the diversity of trophic processes that are occurring in the system, the need to conserve biodiversity becomes an immediate corollary of the need to maintain systems integrity.

In conclusion, integrity is not a unitary attribute of an ecosystem. Its various aspects require more than a single index for their quantitative description. This section has shown that the triad: natural capacity (overall indeterminacy); ascendancy (based on mutual information), and residual indeterminacy provides a 3-tuple with which to gauge the multifaceted integrity of a functioning ecosystem. In particular, systems exhibiting the ‘full integrity’ described by Karr above are likely to be characterized by full natural capacity, high ascendancy and, low residual indeterminacy.

IBI and Ascendancy Compared

The development and advance of integrative approaches to ecological assessment such as IBI and ascendancy demonstrate the growing concern among scientists about diverse environmental trends, especially the threat to our planet's living systems. Both approaches recognize that no single measure can adequately reflect the health of those systems, so they have adopted multiple measures of system condition. Both have foundations in ecological theory. Both provide analytical approaches that cut across ecosystem types. Both provide an approach to observation that is systematic and holistic. Both provide important insights about the condition or status of living systems, and thus the supply of goods and services those systems provide to human society.

The two are also fundamentally different in several respects. The triad of measures advanced by Ulanowicz - capacity, ascendency, and residual indeterminacy - emphasizes theoretical foundations in thermodynamic laws and function or process. Ulanowicz develops a logical framework for the development, empirical testing, and application of these measures. To date, empirical tests have been limited; their application in public policy contexts would be premature until more extensive empirical validation is accomplished.

The theoretical foundations of IBI derive from diverse wings of ecological science (demography, trophic dynamics, competition theory) as well as from the principles of toxicology and the health sciences (dose-response curves). The 10 to 12 metrics (e.g., taxa richness, relative abundance of trophic or other groups, incidence of disease) commonly incorporated into an IBI reflect this broad range of biological contexts. Incorporation of both structural (parts) and functional (processes) measures, either directly or indirectly, is an explicit goal of multimetric indexes. Although not called an IBI, Theo Colborn (Colborn et al. 1996) uses the condition of birds' eggshells, of fish's health and reproductive capacities, and even of certain human psychological and anatomical considerations to draw inescapable conclusions about the state of the Great Lakes basin ecosystem. Orie Loucks' (Chapter 10) MFI is a multimetric index that emphasizes functional measures to assess both specific functional disorders and the *extent* of the problem. That is, he examines which particular ecological functions are curtailed, and how seriously, and thus where the sub-optimal or dysfunctional system should be placed on a continuum from full integrity to the opposite extreme of dissipative disorder. Karr, Colborn, and Loucks examine the integrity of the biota of a landscape, while fully recognizing the relevance and the role of abiotic elements within the system under consideration.

Furthermore, the general principles for development and use of IBI apply to a wide range of ecosystems and human influences on those systems. Since the original application of multimetric indexes (IBI, Karr 1981) in biological monitoring and assessment, empirical tests have been extensive. They have repeatedly validated the core IBI principles while they improved understanding of how to use multimetric indexes to communicate with diverse constituencies. Perhaps most important, their influence in the public policy arena is widespread and growing. From their incorporation as components of water quality standards in a number of states in the United States (Davis et al. 1996) to the focus given to biological monitoring and assessment in regions throughout the world (e.g., European Union Water Framework Directive; Moog and Chovanec 2000), multimetric biological indexes influence diverse public policy issues. They have escaped from the halls of science, a critical step if human society is to protect its future by altering current environmental trends.

The Work of the Global Ecological Integrity Project: Issues and Prescriptions

The Global Ecological Integrity project has been guided by two complementary policy imperatives: conserve integrity and live sustainably. Living sustainably in turn requires that we halt the spiral of ecological degradation. Other chapters in this volume document the degradation in different sectors and make recommendations for response. But in whatever sphere we act, in order to conserve integrity and live sustainably, we must be guided by an understanding of our dependence on the ecological condition of the planet and knowledge of the consequences of our actions. To know those consequences, we must learn how to measure and evaluate the condition of places and learn how to use that information to make it possible to protect the long term interest of human society and of living systems indefinitely into the future. Learning how to conserve integrity means we must learn how to define and measure it. Learning how to live sustainably means we have to understand the consequences of human actions and avoid those actions that degrade life.

The preceding sections summarize our current effort to define and operationalize (give empirical significance to) the concept of ecological integrity. They revisit and extend earlier work of Westra (1994) and colleagues, which focused on the ***capacities*** of a system to retain its specific functions as well as its components (the parts and processes) as central to the integrity of the system.

It is very important to emphasize that “specific function” here refers to critical natural life-support processes and not to any function dedicated to specific human interests beyond survival needs (Westra 1998, see ch. 8 Df. of “sustainability”). Westra has defended and defined the maintenance of primary life-support functions as sustainability 1, or S-1, in contrast to sustainability 2, or S-2. The latter refers to the conditions necessary for the sustainability of human enterprises such as forestry or the fishing industry. This volume, with its emphasis on linking sustainability with integrity rather than with development, means that we focus principally and primarily on “the elements and processes of living systems to protect ***biological*** integrity” (Karr Chapter 12, this volume). In contrast, the “functions” defined narrowly “in a utilitarian context for humans” (Karr 1996; Karr Chapter 12, this volume) may be used to define a system’s “health,” but not its integrity. Thus, an exclusive policy emphasis on systems’ “health” in relation to human-related functions beyond survival, is inadequate for the preservation of biological integrity.

Nevertheless, ecological health (linked with Westra’s Sustainability 2) is a very important complementary concept to integrity, because it articulates a norm for ecosystems that are exploited or impacted to meet human needs – the places where we live, grow our food, harvest natural and plantation products, extract resources, create and use infrastructure, engage in intensive recreation, and dump our wastes and sewage. Although these areas may have lost the biological integrity of wild areas, our use of them is sustainable if their exploited condition is adequately productive and stable. Thus, we adopt Karr's definition of ecological health as a norm that applies to sites modified by human activity. It incorporates two criteria: "no degradation of the site that would impair its productive future use," e.g. no loss of soil or groundwater, and "no degradation of areas beyond that site," e.g. no production of acid rain that adversely affects vegetation and lakes elsewhere (Karr 1996, Karr and Chu 1995). When these two conditions are met at a site, human activity is sustainable at that site. For a society to be ecologically sustainable, every site upon which it depends must be healthy in this sense.

The work of Loucks (1998 and chapter 10, this volume), which focuses on the impacts of atmospheric pollution transport in "protected" forest areas in the eastern United States and Canada, is particularly significant in demonstrating how ecological integrity and health are compromised by off-site pollution sources. Some of the forests he studied show a shocking 80% loss of function. His research also raises questions about the links between loss of functionality and loss of species, whether there is a time lag between functional losses and certain species losses, and, if so, which precedes the other.

Ecological footprint analysis, developed by William Rees and his students, is another important tool for diagnosing unsustainability in relation to off-site impacts (Wackernagel and Rees 1996; Rees 1995, 1996, 1999; and Rees chapter 8, this volume). It is not enough that one's immediate habitat or environment is stabilized, or even flourishing, in its biological condition; we need to ensure that the distant terrestrial and aquatic ecosystems we 'appropriate' through trade and by exploitation of the global commons to support ourselves also remain in a productively healthy state. Ecological footprint analysis shows that our species, using prevailing technologies, has already exceeded global carrying capacity by one third. This means that we currently maintain our consumer lifestyles and economies, in part, by degrading and liquidating natural capital. The empirical evidence is clear in the form of ozone depletion, greenhouse gas accumulation, soils degradation, biodiversity loss, and the depletion of various natural capital stocks, from old-growth forests and wild fish populations to minerals, ground-water and petroleum, as documented in the other chapters in this volume.

In short, whether or not we experience such degradation directly, consumer societies inevitably degrade large areas ecologically and appropriate the biophysical output of a vast hinterland scattered all over the planet. Indeed, the present human population at current average consumption levels is dismantling and dissipating the ecosphere – we are currently losing biomass, species, ecosystem structure (the very essence of integrity loss) on all scales, from local to global. In this light, without significant reductions in total energy and material demand, any bioreserves (as proposed in the next section and Noss chapter11, this volume) will be temporary. Potential human demand is so great that, given present values, consumer behavior and technology, we will eventually need – and take for ourselves – everything the world has to offer. The United Nations World Commission on Environment and Development anticipates the need for a five-to-ten-fold expansion of industrial activity (WCED 1987). The addition of a quarter million people to the Earth each day renders these problems even more acute (Pimentel et al. 1992).

It is precisely this sort of scenario that the ethics and policy directives of integrity are intended to prevent. Humans can be part of natural systems, but with our present beliefs and values, technologically “enhanced” humans, the consumers in so-called advanced affluent societies, are aliens in nature, whose expanding ecological footprints threaten the basic life-support needs of all for the sake of satisfying an escalating plethora of wants. We have derailed the natural evolutionary processes in the landscapes we have come to dominate – and we dominate almost everywhere.

How, then, can we conserve integrity and live sustainably? Westra (1998) proposes eight second order principles (SOPs, listed in Appendix A) to define an ethics of integrity. For example, SOP 6 stipulates that humans must not only: a) “respect and protect ‘core’ wild areas” (Noss 1992), but that we must also b) “view all our activities as taking place within a ‘buffer’ zone. THIS IS THE ESSENTIAL MEANING OF THE ETHICS OF INTEGRITY" (Westra 1998, ch. 9, p. 234).

The contrast between the Chilean desert and Ogoniland with which we began reminds us of the importance of maintaining wild core areas of ecological integrity. But Loucks' research on stagnating and dying forests in "protected areas" indicates that even intense human use outside core areas must be modified immediately and drastically if we are to succeed in protecting integrity. The basic effect of the ethics of integrity is that modern humans must live their lives as if "living in a buffer" (Westra 1998).

This requirement demands the elimination of many accepted and institutionalized practices that ultimately rob us and non-human life of a normal future (Colborn et al. 1996). A further requirement is a more ecologically sensitive process for designing and implementing public policy, while reducing corporate autonomy that can ignore the public good and the requirements of global integrity and health (Korten 1995).

Note that the effect of the "live as in a *buffer*" maxim is to stretch the common meaning of "buffer" in natural resource management as a protective barrier lying between incompatible forms of land use. Under Westra's treatment, there is no "other side" of the buffer where we are free to engage in human activities that would be incompatible adjacent to protected wild areas. Noss's tripartite zonation of the landscape into areas of core wild lands, buffers and a matrix of intensely utilized lands is reduced to a dichotomous core and buffer (Noss 1992). The counsel is that *wherever* we live out our lives and produce the goods we need, we should do so as though our activities were taking place adjacent to wild lands, i.e., as in a buffer. Westra's dictum reminds us that, for many of nature's processes, particularly those involving pollution transport in water or air, climate change, and migratory species, we are as good as next door to the most remote of locations. Nursing Inuit mothers in the Canadian arctic feed heavy metals and other compounds originating in the industries of Asia to the infants sucking at their breasts.

Are We “Saving Nature’s Legacy” (Noss and Cooperrider 1994)?

Given the present world situation and the environmental problems that afflict us, we must acknowledge that the clean-up and restoration job that faces us is daunting. Moreover, since large areas in a condition of ecological and biological integrity are essential to the task, we must acknowledge this as our starting point. We know that the percentage figures referring to “wild” areas provided by the Brundtland Commission and others are arbitrary and grossly insufficient, especially as they stand with little or no effort to curb harmful activities beyond their immediate borders (Westra 1994). Twelve or fifteen percent of all global landscapes including land and water is not enough. Hence, a major question posed by the Global Integrity Project is, how much is necessary? How much is enough?

The protection of integrity, in both its structural and functional dimensions, recognizes the connection between the presence of biological integrity and the production of "services" by ecosystems or nature (Daily 1997). To this end the protection and restoration of health to exploited areas is also vital. Again, protecting small organisms in all habitats is critically important to the functioning of natural systems (Pimentel et al. 1997).

In previous sections of this chapter, we have focused on the conceptual, theoretical and methodological difficulties connected with the notion of integrity and the ecosystem approach that upholds it. The purpose of the Global Integrity Project is to identify appropriate scientific concepts and methods, but also to prescribe moral directives to guide and correct public policy. In this respect, it is an eminently practical project.

Our research was originally inspired by the work of Reed Noss, a conservation biologist, intent on preserving biodiversity and one of the co-founders of the “Wildlands Project” (Noss 1992; Westra 1995). The science and policy underpinning the Wildlands Project are given both scope and precision in ***Saving Nature’s Legacy*** (Noss and Cooperrider 1994). The task they set is to break the chain of causation leading to extinction (Figure 2.1).

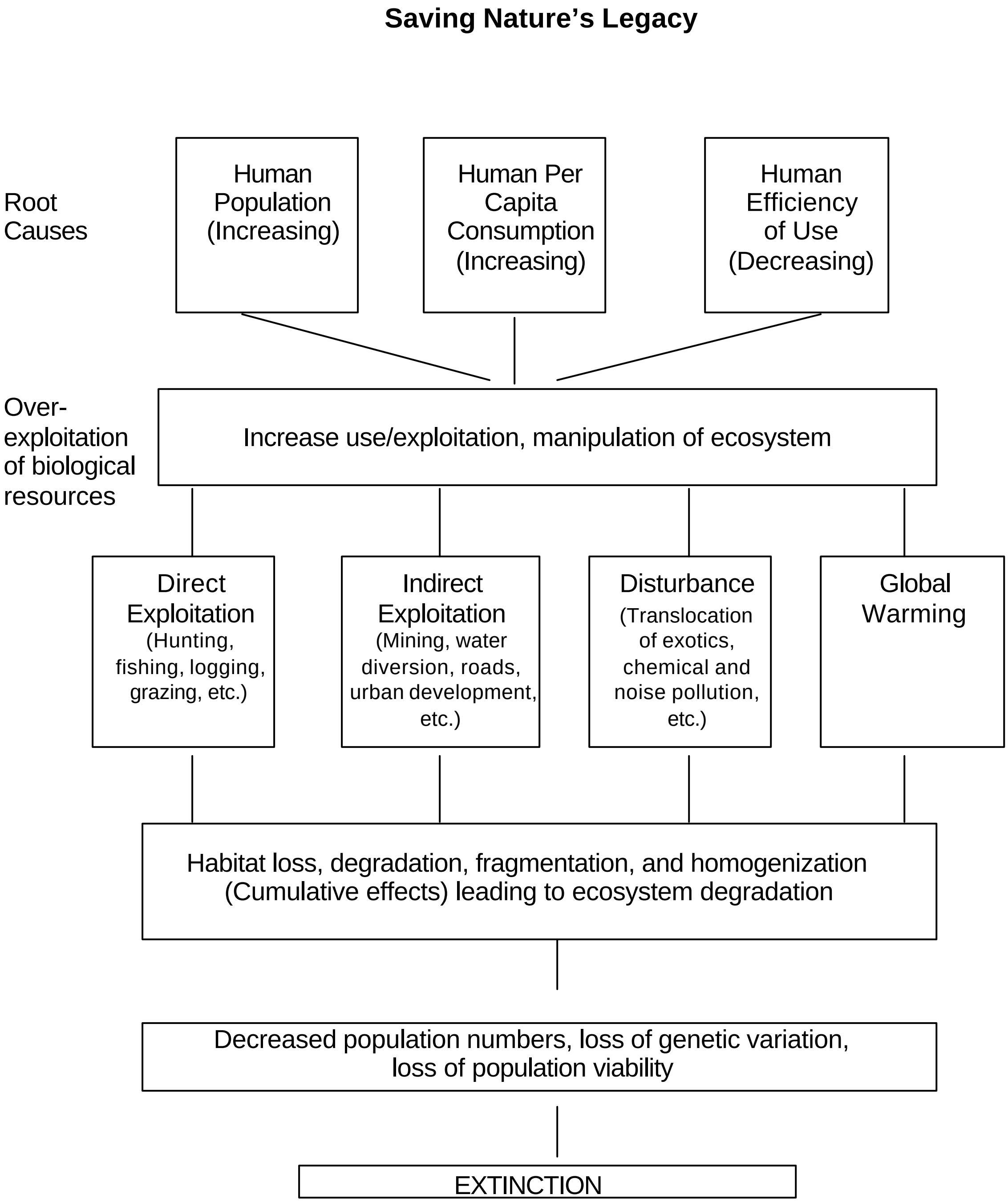

Figure 2.1 Relationship between root causes, overexploitation of resources, and loss of biodiversity. The final result is extinction. (Noss and Cooperrider 1994:51)

Several points raised by Noss and Cooperrider are worthy of emphasis: first, although people too seldom think of themselves as biological entities (Rees chapter 8), humans are part of the biota that loses health under these threats and may eventually fatally harm themselves. The problem is that accelerating habitat fragmentation everywhere as a result of population and economic growth and export-led development strategies imposes a heavy burden on the natural systems that provide necessary "services" for all biota, including humans. Although some species may be able to survive in highly fragmented landscapes, and smaller protected areas, even small gaps like roads can pose "a severe threat to sensitive wildlife and natural ecosystems" (Noss and Cooperrider 1994).

Second, wilderness areas represent an ethical restraint on the human manipulation of nature. There must be untrammeled spaces for other living things and ecological processes to flourish, interact and evolve in their own way. Ecologically representative protected areas provide the best prospect for ensuring the survival of the full diversity of the planet's co-inhabitant species, populations and ecological processes. These, and the coincident benefits to humans of life support, ecological knowledge, and spiritual value, are compromised or lost if we view the whole of nature as a domain for our unfettered manipulation and appropriation. There is an absolute imperative to protect wild areas if we hope to be able to preserve and restore enough of the planet's ecological integrity to ensure the continuation of critical life-support systems. As previously noted, protecting wild areas requires that we live elsewhere "as if in a buffer."

Noss and Cooperrider (1994) maintain that society's ability to restore large carnivores provides "a critical test of society's commitment to conservation." The sheer amount of land that must be set aside for large animals is daunting. "The required area of 32 million acres for a long-term viable population (of grizzlies) is roughly 60 percent of the U.S. northern Rockies region" (Noss and Cooperrider 1994, p. 163).

Equally worthy of note, Noss speaks of integrity and of biodiversity as desirable states, without offering detailed definitions of either concept. Nevertheless, he is prepared to suggest strategies to "begin turning degenerative trends around" (Noss and Cooperrider 1994).

Noss and Cooperrider suggest four fundamental objectives:

1. Represent, in a system of protected areas all native ecosystem types and seral stages across their natural range of variation.
2. Maintain viable populations of all native species in natural patterns of abundance and distribution.
3. Maintain ecological and evolutionary processes, such as disturbance regimes, hydrological processes, nutrient cycles, and biotic interactions.
4. Manage landscapes and communities to be responsive to short-term and long-term environmental change and to maintain the evolutionary potential of the biota.

Although these goals support “conservation planning” and are conveniently pursued at a “regional scale”, the ultimate scope of Noss’s strategy is global. “Land-use planning and zoning for biodiversity must be applied to all lands at local, regional, national and international scales” (Noss and Cooperrider 1994, pp. 89-90).

Thus the task at hand is twofold: we must select appropriate areas for reserves, “designing for reserve networks,” and provide for standard buffers and corridors. We must also decide on the ideal size and shape for each, based on the primary biota targeted for protection and restoration. In addition, qualitative and quantitative changes are necessary to our material-intensive activities to restore health to all utilized areas globally.

What about humans? People need both wildland and a healthy modified habitat, but the question of exactly how much, particularly wildlands, remains unanswered. For many people, particularly in less-developed countries, conditions in their over-crowded, under-serviced cities are already less tolerable than those we would impose on animals living in zoos. Things would be a good deal worse, even terminal, without the life-support services provided by naturally evolving large areas of biological and ecological integrity. Westra (1998) argues that although human made environments, in principle, should be as ecologically benign as beaver lodges or beehives, in practice, our “hives” are built and function in conflict with “natural biogeographical evolutionary processes” (Karr 1996).

But when Westra’s (1998) ethics of integrity propose principles that lead to the selection of wild areas of similar size to those required for human habitation and use, we have a revolutionary constraint on the expansion of the human enterprise. Grizzlies need large areas of wildlands to survive. This will certainly compromise some human plans and activities (but keep in mind that the large wild areas also provide natural services that support human life). “Protection should not imply a ’lock-up,’ as many core reserves and buffer zones can accommodate a variety of human uses, so long as they are compatible with conservation objectives” (Noss and Cooperrider 1994, p. 88).

How much wildland might suffice? While twelve or fifteen percent is not enough, and would be hard enough to achieve in most densely populated countries, various authors press for much larger reserves. Deep ecologist Arne Naess, for example, proposes a 30/30/30 percent guideline: 30 percent human activities, 30 percent carefully orchestrated activities compatible with the wild (“buffers,” in the language of the ethics of integrity), and 30 percent wild areas of biological integrity). This appears to be an ecologically appropriate goal but would clearly face insurmountable implementation difficulties in most of the human-occupied world.

Clearly, the imperatives to conserve integrity and live sustainably, the prerequisites for the continuation of life as we know it, make radical demands. And while meeting these demands may be essential, it is a paradox that even in matters of life and death, we perversely continue in our ways. Part of the reason, of course, is that many economists, technological optimists, and even world leaders do not acknowledge the existence of a serious crisis. As economist Richard Gordon recently declared: “The tendency to technical progress is viewed as the most critical economic law….” “Human ingenuity has been remarkable at advancing the real standard of living and warding off the pressures of resource depletion…. The immediate need, then, for avoiding depletion is nil…” (Gordon 1994). It is also clear that policy choices and preferences, even in democratic nations, are manipulated by economic interests that promote their own goals against the wider public interest. Major corporations may reject independent studies that find against their products and even suppress internal data that threaten corporate interests, particularly the bottom line (Korten 1995; Westra 1998). The harmful deceptions and secret strategies of the tobacco industry, over many years, to deny the harmful effects of smoking and actually increase levels of nicotine addiction are a case in point.

We assert that the reasons most often offered in support of the status quo (especially in affluent Northwest countries) do not stand up to scrutiny: First, the damage we wreak is potentially destabilizing of critical biophysical systems in the short term and interferes with slower natural evolutionary processes of change over the longer term; Second, even democratic choices, if manipulated and uninformed, do not validate decisions that attack our life-support systems and our lives (Westra 1998).

If humans need the wild for aesthetic and psychological reasons, and the wild is essential to conserve biodiversity and vital life support functions, then targets - percentages and specified areas – for preservation must be established and implemented globally. As difficult as it will be to implement specific reserve plans as public policy, strict controls on the rest of our activities within the human dominated “buffer” will be even harder to bring into force.

Nevertheless, if we fail in this vision, ultimately no area will be safe for non-human life and we will put our own security at risk. Is it not sufficient warning that in 1988, a record number of natural disasters caused massive property damage and drove more people from the land and their homes than war and civil conflict combined? Singular events such as Hurricane Mitch and the El Niño weather phenomenon, plus declining soil fertility and deforestation, drove a record 25 million people from the countryside into crowded under-serviced shanty-towns around the developing world’s fast growing cities. This is 58% of the world’s total refugees (International Red Cross 1999). Experts predict that developing countries in particular will continue to be hit by super-disasters driven by human-induced atmospheric and climatic change, ecological degradation, and rising population pressures. The miners’ canary has toppled from its perch. It is time to act, if only to save ourselves.

APPENDIX A - SECOND ORDER PRINCIPLES (SOPs)

SOP 1 In order to protect and defend ecological integrity, we must start by designing policies that embrace complexity.

SOP 2 We should not engage in activities that are potentially harmful to natural systems and to life in general. Judgments about potential harms should be based on the approach of "post-normal" science.

SOP 3 Human activities ought to be limited by the requirements of the precautionary principle.

SOP 4 We must accept an "ecological worldview", and thus reject our present "expansionist worldview" and reduce our ecological footprint.

SOP 5 It is imperative to eliminate many of our present practices and choices as well as the current emphasis on "technical maximality" and on environmentally hazardous or wasteful individual rights.

SOP 6 It is necessary for humanity to learn to live as in a "buffer". Zoning restraints are necessary to impose limits both on the quality of our activities, but also on their quantity. Two corollary principles follow: a) we must respect and protect "core"/wild areas; b) we must view all our activities as taking place within a "buffer" zone. *This is the essential meaning of the ethics of integrity.*

SOP 7 We must respect the individual integrity of single organisms (or micro-integrity), in order to be consistent in our respect for integrity and also to respect and protect individual functions and their contribution to the systemic whole.

SOP 8 Given the uncertainties embedded in SOPs 1, 2, and 3, the "Risk Thesis" must be accepted, for uncertainties referring to the near future. We must also accept the "Potency Thesis" for the protection of individuals and wholes in the long-term (Westra 1998).

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