

The Roles of Biodiversity in Creating and Maintaining the Ecosphere

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This is a revised and updated text of: "*A Conceptual Framework for the Ecological Functions of Biodiversity*," Global Biodiversity, 1994, vol. 4(3): 2-16. This updated version has also been published as Chapter 6 of a book entitled: **Biodiversity in Canada: Ecology, Ideas, and Action**, Broadview Press, Peterborough, Ontario, 1999, [ISBN 1551112388] \$29.95. Stephen Bocking (Ed.). Stephen is a professor at Trent University, Peterborough, Ontario. The book contains 18 chapters by 16 authors; it explores the nature of biodiversity, addresses political, legal, economic, social, biological and ecological issues and challenges associated with the conservation and use of Canada's biodiversity. More information about the book can be found at <http://www.trentu.ca/biodiversity/>. Inquiries about the book should be sent to Stephen Bocking: sbocking@trentu.ca. This article considers biodiversity in the Earth's Ecosphere as a whole and not only that part contained within the political borders of Canada.

This article considers several intriguing questions: First, what specific functions of ecosystems and their organisms have enabled the unfolding and evolution of such a complex, astounding, and harmonious variety of life in the many marine, freshwater and terrestrial regions of the Earth? Second, which of these functions of biodiversity have been most instrumental in creating the Ecosphere that humans encountered when they first arrived on the scene?

By Ecosphere I mean the whole living Earth - a deep magma/solid rock/soil/ sediment layer, an atmospheric layer, a water layer, the biotic communities at the surface, together with their contained assemblages of organisms - the biotic communities that have evolved and within which organisms are intricately linked. When left to operate in its timeless old-fashioned way, the Ecosphere has proved itself to be an intensely stable and generative system, but necessarily supported by an external source of energy, the Sun.

This article identifies and describes 18 functions of biodiversity. Together, they illuminate the seemingly mysterious and miraculous workings not only of ecosystems and their individual species but of the Ecosphere as a whole.

Imagine yourself walking in a natural forest, native grassland or perhaps snorkelling through a rich marine kelp bed or coral reef, and reflecting on the following sorts of questions: What ecological processes are going on here? Which organisms are carrying them out? Which organisms are relatively independent and which are symbiotically linked to others? How does energy flow among these species? Who is doing the re-cycling? What systems of communication mediate processes such as reproduction and dispersal? Who is producing the oxygen? How did it come to be that such harmonious and cooperative communities have come to exist and be so pervasive in all ecosystems? Then imagine yourself in a corn or potato field or in a salmon holding tank at the edge of the sea. Again ask yourself the same questions, but also ask which functions are completely absent or are only present due to human management.

By describing functions of ecosystems and organisms, readers will be better able to assess and reflect upon the deeper values of different parts of biodiversity and of the Ecosphere. This article should also help to develop an ecocentric valuation perspective on nature, one that emphasizes nature's value as something other than simply a source of economic commodities for humans. It will help to expose the narrow, selfish and Earth-destroying argument that "capricious nature" offers no guidelines for our conduct, and that therefore ecosystem management must respond only and exclusively to what people want.(1)

For 3.5 billion years organisms and ecosystems have been integral elements of the evolution and gradual emergence of the Ecosphere. Organisms and ecosystems together created the Ecosphere (with essential energy from the sun) as humans found it. We are ourselves one consequence of the workings of the highly stable and complex functioning of the emerging Ecosphere. But what exactly are these functions? What are the linkages between them and to what extent are they mutually exclusive?

Ecospheric functions are those processes that organisms and ecosystems perform or participate in, and that provide products and/or consequences for themselves, for other species and ecosystems in the community or region, and often in more distant lands. They are natural processes that have evolved in organisms and ecosystems, and that have enabled major new kinds of life forms to thrive, new functions to evolve and more complex ecosystems to exist.

This article considers the value of ecospheric functions to the Ecosphere as a whole, not merely their utility to humans. This is in sharp contrast to the purely anthropocentric approach to valuing "nature's services," described by other authors (see Table 1).(2) The values of nature identified by these authors are an anthropocentric subset of the 18 "intrinsic" functions described here. Defining ecospheric functions as "ecoservices" assumes that only humans have a high value and that wild species and ecosystems are valuable only if they have commodity or instrumental value (i.e. are "of service") to humans.

Reproduced in Table 1 are two lists of "ecosystem services" that are examined (and/or priced) in two of the above referenced publications for readers to contemplate.

These two lists should be compared with the functions listed in Table 2. Since humans evolved within the planetary Ecosphere, it is not surprising the some anthropocentric functions listed below are similar (several are identical) with the all-inclusive ecospheric level functions described in this article.

Table 1: Two Anthropocentric Approaches to Valuing "Nature's Services"	
Source: Costanza et al. "Value"	Source: Daily, <u>Nature's Services</u> .
1. Gas regulation (regulation of atmospheric chemical composition)	1. Purification of air and water
2. Climate regulation (global and local levels)	2. Mitigation of floods and droughts
3. Disturbance regulation (storm protection, flood control, etc.)	3. Detoxification and decomposition of wastes

4. Water regulation (provisioning of water for agriculture, industry, transport.	4. Generation and renewal of soil fertility
5. Water supply (provisioning of water by watersheds, reservoirs, aquifers.	5. Pollination of crops and natural vegetation
6. Erosion control & sediment retention.	6. Control of the vast majority of agricultural pests
7. Soil formation (weathering of rock and accumulation of organic material)	7. Dispersal of seeds and transportation of nutrients
8. Nutrient cycling	8. Maintenance of biodiversity, from which humanity has derived key elements of its agricultural, medicinal and industrial enterprise
9. Waste treatment (recovery & breakdown of toxics, nutrients, etc.)	9. Protection from the sun's harmful ultraviolet rays
10. Pollination (provisioning of pollinators for reproduction of plants)	10. Partial stabilization of climate
11. Biological control	11. Moderation of temperature extremes and the force of winds and waves
12. Refugia (habitat for harvested species)	12. Support of diverse human cultures
13. Food production (production of fish, game, crops, nuts incl. subsistence farming and fishing)	13. Providing of aesthetic beauty and intellectual stimulation that lift the human spirit
14. Raw Materials (production of timber, fuel or fodder)	
15. Genetic resources (sources of unique biological materials for agriculture, medicine, and the like)	
16. Recreation (providing opportunities for recreational activities)	
17. Cultural (providing opportunities for non-commercial uses)	

The notion of intrinsic value recognizes that objects, whether species, individuals or things have an innate worth, regardless of human benefits.(3) When human wants are overvalued, the Earth is devalued, taken for granted, and abused as a mere commodity - to the long range detriment of other forms of life. Thus, this article does not ask the question: What do organisms do for people? Rather, what have wild organisms and ecosystems done (and what are their modern-day descendants continuing to do) to create the world as humans found it? Viewed in this logical and truthful way the anthropocentric perspective is revealed as a narrow and selfish ideology.

Palaeontology has revealed that wilderness ecosystems and wild species have lasted for eons. Such systems represent the normal environments, or norms of the Ecosphere. All organisms within wilderness systems represent the end-products of evolution within these norms. The survival of natural or wild ecosystems with their "normal" species therefore provide the only known standards

against which the success or failure of biological resource management (in forestry, agriculture, fisheries) and economic development can be judged. Agriculture, for example, is a major and drastic deviation from planetary norms, and economic development is laying waste to all parts of the Earth. Thus, "hunting and gathering" cultures are entirely within the norms of the Ecosphere while modern industrial agriculture is destroying these norms. These norms can provide guidance for human conduct, by indicating what is stable, time-tested and normal, rather than what is merely what people want. The only alternative norm is that created by our own technologies, and, these have not been tested for their long-term stability. However, enormous damage is being done by the blind belief that technology is intrinsically good, while natural systems and species are mere commodities, to be cared for and nurtured if and only if they are of instrumental value to humans. The postmodern/hypermodern ideology which says "Adapt to humanity, serve humanity--or die" is drastically altering all of the normal ecospheric functions of our planet.

Many of the functions of organisms and ecosystems described in this article have been widely explored.(4) This article deals with those functions that can be described as ecocentric: they describe what ecosystems and their species do and have done to cause the world to come to be the way it is.

The Meaning of Biodiversity

In this article the broadest possible, most inclusive meaning of biodiversity is adopted. Biodiversity has been described as "the variety of life and its processes in an area".(5) To this we can add "the popular way of recognizing the ecological concept that everything is connected to everything else". (6) The four key words in these definitions are variety, processes, connections and area. The inclusion of 'area' is essential because it is only in a physical context that variety, processes and connections have meaning. "Area" is also essential when we are talking about conservation, preservation or restoration of biodiversity. It is, after all, the only real proof of loss or gain of biodiversity is what is actually happening to ecosystems and their organisms on the ground and in fresh and marine waters.

But while this description provides a general insight into why biodiversity should demand our concern, it is not adequate for scientific analysis of the basic parts of biodiversity. We need a more rigorous definition.

TABLE 2. THE FIVE PARTS OF BIODIVERSITY

1. Genetic variation. Genetic material in all individuals of all living things.

2. Taxonomic variation. Taken together, all taxonomic groups in nature-- subspecies, species, genera, families, orders, classes, phyla, and the five Kingdoms.

3 Ecosystem variation. Ecosystems, i.e. three-dimensional (volumetric) spaces on the surface of our planet where organisms dwell, including all "abiotic" matter therein, from the deepest rocks and oceans to high up in the atmosphere with inputs and outputs of energy from and to adjoining ecosystems.

4. Functions, or "ecoservices." The specific processes that organisms and ecosystems carry out that affect themselves, their immediate neighbours and surrounds, communities in which they live, and the Ecosphere as a whole. Functions describe what organisms and ecosystems *actually*

do (and their ancestors have done) to have enabled the emergence and evolution of the Ecosphere.

5. The "abiotic" matrix. The enveloping rock, soil, sediment, water and air that organisms and ecosystems have participated in creating and within which all are embedded.

Table 2 outlines the scientifically definable and inseparable parts of biodiversity: genes, taxonomic groups, ecosystems, functions and abiotic. Three of these parts (genes, taxonomic groups and ecosystems) are widely recognized and reviewed in the literature.(7) As the meaning of these three components is widely understood they will not be further reviewed here. But failing to consider functions and the abiotic component produces a simplistic and highly misleading notion of the meaning and importance of biodiversity. In particular, the abiotic (inorganic, inanimate, physical, etc.) part is essential, as the life-giving water/air/soil/ sediment/mineral environment within which organisms and ecosystems evolved, in which they are inextricably embedded and without which they cannot live.(8) Fish could not have evolved without water, birds without air, or trees without soil.

Framework for the Functions

Table 3 identifies 18 ecospheric functions of organisms and ecosystems. The functions are organized into four groups of increasing complexity: starting with those carried out mainly by individual organisms; those performed by small numbers of very different species; and those which are the result of hundreds or thousands of different species working together at the community, region or landscape scale.

The least complex function is primary production (Function 1). It mainly involves organisms operating independently - although, of course, within the abiotic part of the Ecosphere and with the energy of the sun. The most complex functions are those of stability and harmony (Functions 17 and 18). These depend on most if not all of the other functions. The functions contributing to "ecosystem level" biodiversity may include very different combinations of functions depending on the particular ecosystem. Generally, the table illustrates that the more complex a function, the more it relates to, even depends upon, other functions.

Functions are best appreciated in terms of long-term evolutionary processes. When an unique process (here called a function) originated, it made possible the evolution of other novel things or functions. Thus, as the framework illustrates, the complexity of nature has increased, as new functions have been made possible by the evolution of other functions. One could think of this increasing complexity through time as a kind of 'law of ecospheric functions.' If one were to suggest a general rule it might be that: "All ecospheric functions except primary production are derived from and dependent upon pre-existing functions." It appears highly probable that these functions enabled the Ecosphere to evolve, persist and become ever more complex (and stable) over several billion years.

Obviously, for areas heavily altered by human activities, the number of functions are greatly reduced or impaired while one or two may be vastly expanded. For example, primary production in a corn field is achieved at the expense of the many functions that were carried out in the natural prairie or forest which the cornfield replaced. As well, the variety and total number of functions would vary greatly in different areas and climatic zones. Additional reconsideration of numbers of species involved in these functions as well as a further review of the biological and ecological literature

could result in an improved classification, particularly as the activities of taxonomically little known groups of organisms are studied in soils and in freshwater and marine ecosystems.

Ecospheric functions are sometimes referred to as "ecoservices". This term should not be misunderstood. All organisms "service" themselves in addition to carrying out functions which incidentally benefit other species or the community. Herbivores did not evolve only to provide a service to carnivores. Yet herbivory is a necessary service to carnivory, since only after herbivory originated (independently in a great many different animal taxonomic groups), were carnivores able to evolve.

TABLE 3. A FRAMEWORK FOR THE ECOLOGICAL FUNCTIONS OF BIODIVERSITY (adapted from Mosquin 1994; Mosquin et al. 1995)

A. FUNCTIONS PERFORMED PRIMARILY BY INDIVIDUAL ORGANISMS

1	Primary production - creation of many kinds and forms of biomass though photosynthesis and (around deep sea vents) chemosynthesis
2	Oxygen production - by oxygen-producing bacteria, algae and plants
3	Sequestering of carbon dioxide
4	Herbivory - the eating of primary producers by bacteria, protozoa, fungi and animals.
5	Carnivory - the eating of protozoa, fungi and animals by protozoa and animals
6	Control of soil erosion

B. FUNCTIONS INVOLVING INTERACTIONS AMONG LOW NUMBERS OF DIFFERENT KINDS OF ORGANISMS (These functions are carried out by usually very unrelated species in an area, often in immediate proximity, or from time to time).

7	Population moderation - a powerful and essential aspect of herbivory & carnivory - includes diseases, parasitism upon over-abundant species.
8	Seed & spore dispersal (plants); migration & larval dispersal (animals).
9	Symbiosis (mutually beneficial, intimate, co-evolved associations - extremely widespread and variable in nature). Examples: a. nitrogen fixation (esp. bacteria and algae in higher organisms; lichen partnerships) b. pollination involving insects, birds, etc. c. mycorrhiza (fungi & plant roots) d. enable food digestion (bacteria & fungi in animals) e. "fish cleaners" on coral reefs f. dozens/hundreds of others

C. COMPLEX FUNCTIONS INVOLVING INTERACTIONS AMONG LARGE NUMBERS OF DIFFERENT ORGANISMS (these functions represent an increased level of complexity and some might better be included in 'D' below)

10	Soil and sediment creation/bioturbation
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11	Moderation of macro & microclimate
12	Decomposition (primary & secondary detritivory; including digestion, mineralization of organic compounds, fermentation, etc.)
13	Maintenance of 3-dimensional, structures - (consequences of multicellularity - trees, shrubs, herbs, kelp, larger animals, forests, soils; creation of "habitat")
14	Communication (both intra- and inter-specific) - i.e. sight, sound, taste, smell, touch via colour, shapes, pheromones, mimicry, camouflage, bioluminescence, radar, etc.
D. ECOSYSTEM FUNCTIONS AND PROCESSES (dependent upon most or all of the above contributory functions of organisms)	
15	Food webs and chains (trophic structure)
16	Biogeochemical nutrient cycling and transport - via individuals, local and sectoral ecosystems and the Ecosphere as a whole)
17	Stability (consequences of complexity, connectedness, keystone species, deceptive "redundancy," generalist behaviour, trophic structure, succession and some others)
18	Harmony (combinations of form, movement, structure, and functions resulting in a proportionate, orderly, cooperative condition - pervasive in individuals, natural ecosystems, and ultimately in the ordered and harmonious functioning of the Ecosphere as a whole.

Ecospheric functions are "polyphyletic," meaning that similar functions (e.g. nitrogen fixation, decomposition, carnivory, symbiosis, similar food webs, communication) arose repeatedly in different phylogenetic groups. Thus, in all ecosystems there was a consistent increase in complexity and harmony. We do not understand why evolution causes the emergence of similar functions in dozens of entirely different groups (12). One must conclude that within entirely different taxa, innate processes are at work which make possible the emergence of parallel functions in different groups.

ECOLOGICAL/ECOSPHERIC FUNCTIONS DESCRIBED

Primary Production - Function 1

Primary production is the capture of energy from sunlight through photosynthesis and associated production of carbohydrates, fats, proteins and other organic compounds needed by all herbivores. A second group of primary producers that live near deep sea vents relies on chemosynthesis to capture energy from sulphur compounds. But it is not primary production as such that is responsible for the megadiversity of herbivores, carnivores and detritivores. Rather, it is the sheer variety of organisms engaged in primary production, the stupendous variety of carbohydrates, proteins and fats produced, and the great diversity of forms in which biomass is produced. Some primary producers are photosynthetic bacteria which feed protozoans, which feed microinvertebrates which feed larger invertebrates and vertebrates as in aquatic ecosystems. Other primary producers are so large and diverse (trees, shrubs, herbs) as to create habitat (both within themselves and as 3-D ecosystems [Function 16]) for all manner of terrestrial life.

Taxonomic groups which perform this function include cyanobacteria, chloroxobacteria, archaeobacteria, all algal phyla, lichens, mosses, and all (except saprophytic) vascular plants. Primary production can sometimes be greatly increased through symbiotic associations among organisms (11)

Oxygen Production - Function 2

All free oxygen in the air, water and soils has been slowly generated over billions of years, first by photosynthetic bacteria, then by algae and eventually also by higher plants. This has had two entirely different beneficial results. First, all the free oxygen found today is necessary for the life of aerobic biota and for decomposition (Function 13). Second, this oxygen is the source of Earth's protective ozone shield. Free oxygen is produced by the same taxonomic groups engaged in photosynthetic primary production.

Sequestering of Carbon Dioxide - Function 3

Many different life forms contribute to the removal of carbon dioxide from the atmosphere, soils and waters through mechanisms such as the precipitation of calcium salts, the amassing of organic deposits or of living biomass. While stress here is placed on CO₂, the role of living things in removing other compounds, particularly toxic substances from ecosystems, and adding them to accumulating muds or sediments is not insignificant. Taxonomic groups that sequester large amounts of CO₂ include marine cyanobacteria, algal prototists such as charophytes, chrysophytes (make limestone plates & ooze), protozoan prototists such as *Globigerina* (which deposit massive layers of CO₂ in the form of marine chalk and limestone), hydroids (which create coral reefs), mosses, forbs and woody plants (that deposit peat in fens, bogs and marshes), and trees, shrubs and herbs (that tie up biomass in plant tissue).

Herbivory - Function 4

Herbivory is the function of animals eating primary producers. The repeated emergence of this function early in the history of life on Earth and among different groups of animals has made possible the diverse world of herbivores. Taxonomic groups where herbivory is the sole or dominant function are the filter feeders: protozoans, rotifers, many molluscs and many crustaceans. Among non-filter feeding herbivores are nematodes, millepedes, most insects, symphylids, springtails, waterbears, kinorhynchs, many echinoderms, many fishes, amphibians (tadpoles), some reptiles, many birds and mammals.

Carnivory - Function 5

Carnivory is the eating of herbivores and other carnivores. Without it, trophic structures (Function 15) would be far simpler. Harmony in nature (Function 18) would also be much diminished. Taxonomic groups where carnivory is dominant are filter feeders: protozoans, sponges, hydroids, combjellies, various worm groups, molluscs and many crustaceans. Among non-filter feeders, carnivores include spiders, many insects, all centipedes, all lampreys, sharks, most bony fishes, amphibians (adults with one exception), most reptiles, many birds and many mammals.

Both herbivory and carnivory constitute a kind of "superfunction" in which organisms eat other organisms. Predation is not considered to be a function but only part of the mechanism through which the carnivory function is performed. Herbivory and carnivory (including filter feeding) are

inextricably linked to the detritivory (decomposition) function, since food needs to be digested to provide energy for living.

Control of Erosion - Function 6

The control of soil erosion, especially in terrestrial ecosystems, is a particularly powerful enabling function of vascular plants, since it can transform associated plant, animal and microorganism biodiversity. Aquatic vascular plants and some algal phyla also play an important role in estuaries and in riverine and lacustrine sites in reducing erosion. In shoreline marine areas, kelp beds and seagrass beds reduce loss of enriched sediment. In terrestrial regions, we may see extensive root growth, accumulation of an organic soil layer, litter accumulation and recycling and retention of nutrients. In such circumstances, soil builds up faster than wind and/or water can carry it away. The consequence for biodiversity is the evolution of more complex and diverse ecosystems.

Population Moderation - Function 7

Population moderation refers to the limiting of runaway population increases or "blooms" of individual species. This function has commonly been described as maintaining the "balance of nature." The cyclical dynamics of predator/prey relationships and plant/herbivore relations, and diseases of humans provide examples of this function. Parasites often are major factors in controlling population. Humans are unique in that we have controlled numerous diseases, parasites, and predators on our own species to the extent that feed-back mechanisms limiting our populations have largely ceased to operate. At least in the short term, humans have escaped from the norms of the Ecosphere. This has grave consequences for the health of the Ecosphere. Taxonomic groups important in this population moderation function include viruses, many phyla of bacteria, fungi, protozoa, many invertebrates, many herbivores and many carnivores.

Seed, Spore and Larval Dispersal; Migration - Function 8

This function is the spreading of propagules or reproductive animals to new areas where they might complete their life cycles or otherwise reproduce. This function enables individuals to reach the optimum range within which a species can survive and adapt. Dispersal is a characteristic function of all organisms and facilitates the emergence of new adaptive variants. This function is also critical to re-colonization and restoration of natural ecosystems where they have been destroyed or highly modified. Successful long distance dispersal or migration of organisms has also been essential to the evolution of the world's unique endemics on remote oceanic islands or in similar terrestrial ecosystems in different parts of the world.

Symbiosis - Function 9

Symbiosis is the mutually beneficial, co-evolved association of a species with other (usually very unrelated) species. The degree of interdependency varies greatly. It may involve cooperation among three or more species. Symbiosis is one of the most powerful functions of the Ecosphere because as unrelated organisms began to depend on each other, wholly new kinds of life forms originated. There are tens of thousands of co-evolved symbiotic systems in all ecosystems in virtually all phyla (14). In the dawn of life symbiosis brought many submicroscopic organisms together permanently and, over eons, shaped the world of life as we know it today. In fact, all individual cells of "eucaryotes" (algae, protozoans, fungi, animals and plants) are permanent symbiotic systems, indicating that ecological

functions operate even at the cellular level. The loss of any species, however small, may decrease the possibilities of new forms of symbiosis, and new life forms, tomorrow.

Mycorrhizal associations are widespread between fungal hyphae and vascular plant roots, in which fungi enable more efficient mineral absorption by the root hairs. In temperate forests some 80 to 90% of higher plants have roots associated with fungi.(15)

Lichens combine a green algae and/or a nitrogen fixing cyanobacteria with a fungal partner. The algae or cyanobacteria provide nutrients to the fungal host, and in return receive living space.(16) Some lichens contain both algal and cyanobacterial partners. Symbiotic associations are found between coelentrates and algae growing in their cells; between bacteria and echinoderms; between bacteria, protozoans and/or fungi living in the gut of animals (essential for food digestion); between ants and aphids, and ants and fungi.

Bioluminescence is the emission of cool chemical light by some groups of organisms such as plankton, many deep water fishes, some shallow water fishes, squids and fireflies. It is a unique kind of symbiosis. While in some cases the organism produces the light itself, in many species the light is emitted by phosphorescing bacteria which the host shelters and nourishes. In oceanic waters bioluminescence caused by bacteria occurs in fish species that live in the darkness up to 500 metres deep. For fish the light enables them to recognize species and mates (a form of communication), attract prey, camouflage their silhouettes from prey species through "countershading", and startle and distract predators.(18)

Symbiosis is also evident in pollination, in which an enormous variety of insects, birds and bats are adapted to pollinate tens of thousands of different species of flowering plants, and where plants have responded by evolving floral fragrances, reflectance spectra, flower forms, markings, and flowering-time sequences.

The biological complexity of pollination is underlined by the many forms that are mediated by the abiotic matrix of biodiversity, namely wind and water, both of which are the active agents of pollen transport between many plant species. In Canada, most trees, many shrubs, grasses, sedges, cattails and many forbs are wind pollinated. Water carries pollen in marsh plants such as the water shield, *Brassenia schreberi*, American eel grass, *Vallisneria americana*, the many species of *Potamogeton*, and others.

Impairment of many elements of symbiosis, through habitat fragmentation, pollution, pesticides, and other human activities has already caused extinction of thousands of races and species worldwide.

Soil and Sediment Creation/Bioturbation - Function 10

The growth of roots and fungal hyphae, and tunnelling by worms and other soil invertebrates builds, aerates and maintains soils. Soils are ecosystems created and maintained by a great variety of living organisms, present by the tens of thousands in each cubic centimetre of soil and sediment. Countless biochemical processes take place here, including decomposition, and recycling of carbon and nutrients. Many animals live in freshwater and marine sediments and help bring about a constant mixing of sediment and nutrients from deeper layers. Taxonomic groups that have major roles in carrying out this function include bacteria, cyanobacteria, algae, fungi, numerous invertebrate phyla including arachnids and insects, as well as plants (roots, leaves, dead trunks).

Moderation of Macro and Microclimate - Function 11

Macroclimate - the prevailing weather in a region, as well as meteorological conditions over a period of years - is an 'abiotic' factor that powerfully determines biodiversity in a region. The distribution of major ecosystems such as tundra, boreal forest, prairie or west coast rain forest is determined by macroclimate. However, once vegetation is firmly established, it can itself then affect the macroclimate, both locally and in distant area. Ground cover (vegetation, snow, water, soil) greatly influences albedo (the percentage of sunlight reflected from an area) and this influences air temperature. In addition, transpiration from forest canopies and ground vegetation can significantly increase atmospheric humidity, affecting rainfall and determining the kind of biodiversity present. Air temperature and rainfall in more distant regions can also be affected.

In terrestrial ecosystems, plants have a profound effect upon ground level climate, as do macroalgae and eel grass in intertidal ecosystems. Trees, shrubs, forbs, grasses and mosses, through effects on shade and humidity, moderate the microflora and fauna of an area. In areas devoid of plant cover (such as deserts or cultivated fields), extremes of light intensity, humidity, temperature and wind can greatly affect the local flora and fauna. In deserts, uniquely adapted floras and faunas evolve in response to both macroclimate and microclimate.

Decomposition (Primary & Secondary Detritivory) - Function 12

Decomposition (detritivory) is the natural recycling of residues of life. Most decomposers require oxygen (function 2). Next to primary production, decomposition is the most important ecological function of organisms. A very wide range of life forms participate in decomposition: from bacteria to protozoa, filter feeders, humans and scavenging biota in all ecosystems, and also within many larger organisms (i.e. digestion). Fermentation is a specialized method of decomposition.

Primary detritivory is the absorption of free organic molecules as food. Bacteria obtain all their food this way, as do two phyla of marine worms. They metabolize these molecules to create nutritive blocks (called plaques) that are eaten by multitudes of protozoa and other plankton (functions 2 and 3). These, together with photosynthesizing algae and cyanobacteria (function 1) are the primary "pastures" for all freshwater and marine food chains.

Secondary detritivory is the "digesting" of animal and plant tissue and its degradation into simpler organic compounds. All filter feeders are secondary detritivores because they cannot discriminate between living planktonic organisms and floating dead tissue biomass. Life on Earth could not survive without primary and secondary detritivores because there would be no way of cleansing the Ecosphere of the "products" of life. Indeed, oil and coal may have been deposited only because the detritivory function had not yet by that time been perfected by the evolving Ecosphere.

Many bacteria have developed a very powerful ecological function: that of ingesting organic molecules (toxics, oils, etc) and reducing a portion of them to less harmful substances and minerals. Mineralizing bacteria, since they metabolize toxic organic compounds (and return part of the molecule to harmless mineral matter) can be amazingly abundant in many ecosystems, and play an influential role in detoxifying soils and waters in local and regional ecosystems and the Ecosphere as a whole.

Creation and Maintenance of 3-D Ecosystem Structures - Function 13

The capability of different phyla to evolve multicellular structures is the basis for this function. During the history of life on Earth, the emergence of multicellular organisms has profoundly affected associated organisms and made possible the 3-D structure of ecosystems such as forests, tundra, prairie, kelp beds, submergent freshwater plant beds, coral reefs, and others. As well, most larger

organisms provide homes for various biota, such as wood boring insects, cavity nesting birds and animals, and fish seeking the protection of coral reef structures. As a consequence of multicellularity, entire assemblages of life forms, in all major groups have been able to evolve in, and depend on these structures.

Marine taxonomic groups that dominate in this function include tall sponges, macro algae (green, red and brown), and large sea animals; in terrestrial areas they include herbs, shrubs, trees, and large land animals; in freshwater areas all submergent vegetation and larger animals play roles. The 3-D structures can be submicroscopic: even single celled organisms often have parasites, or have parasitic symbionts living within them.

Communication - Function 14

Communication is an ecological function because it has a profound effect upon the substance, nature and quality of species and ecosystems. This is a widespread and essential function of all complex life forms. A diverse array of methods of contact between individuals of the same species and between different species have evolved and are now intrinsic to ecosystem processes.

Simple chemical sensory abilities enable more primitive organisms to communicate for purposes of reproduction or finding food. Among higher forms of life, communication includes the use of taste, sight, touch, sound, radar (bats), sonar, the sending and detection of electric currents and other specialized methods. Sight (between organisms and between organisms and their surroundings) influences all manner of activity: courtship, parenting, food gathering, migration, herding, flocking and escape from carnivores. The capacity of some to perceive colour has had stupendous impact upon the evolution of colour in birds, fish, mammals, and colour-perceiving insects like pollinating bees. Flower colours have evolved in response to the capacity of pollinating insects to see colour. Intricacies of mimicry, widespread among insects, is the result of the ability of insect-eating birds to perceive differences not only in the shape of their food but in its colour, taste and behaviour. Pheromones released by female insects ready to mate attract males from more than a kilometre away. Substances released from injured skins of minnows alert other minnows to the possible presence of a predator.

The evolution of the ability to use sound in communication has also produced what can only be described as a wondrous diversity of bird, animal and insect sound and song, enriching the harmonies and beauty of natural ecosystems beyond the bounds of human imagination. Much of the communication taking place in nature cannot even be sensed by humans, except through scientific instruments. For example, ultraviolet light reflected by many specialized flowers can be seen by some pollinating insects. In the sense that communication is the product of the evolution of biodiversity, there can be little doubt that much that is beautiful and meaningful vanishes as biodiversity is reduced.

Food Webs and Chains (Trophic Structure) - Function 15

The movement of energy through organisms in a community defines its trophic structure. It is considered as a separate ecological function because it enables species to utilize many trophic pathways, and to shift from one to another depending on what has been closed off by factors such as extirpations or habitat destruction. All food webs begin with primary production (function 1). Most bacteria and all fungi, protozoans and animals cannot manufacture their own food and hence are always at higher (dependent) trophic levels.

Food webs are usually not discrete. Among plants and mammals, for example, a variety of primary producers are usually eaten by herbivores which are then eaten by a number of omnivores and vertebrate carnivores. Humans regularly shift from eating algae to wheat to fungi to meat, consuming snails here and grasshoppers there, corn in one area and bowhead whales in another. Some species, however, are more limited when it comes to finding alternate sources of energy.

Trophic structure among micro-organisms and invertebrates can be incredibly interlinked and complex: many invertebrates are filter feeders, and most will ingest any bit of organic material whether it be phytoplankton, bacteria, other zooplankton, or detritus. In these circumstances there are many interlocking levels and 'feedback' webs, because consumers are neither 100% herbivorous grazers nor 100% carnivorous predators. Movement through complex food webs is analogous to the way information can travel through the Internet.

Biogeochemical Nutrient Transport and Cycling - Function 16

This function describes the physical transport of nutrients (phosphorus, potassium, nitrogen and trace elements) via living tissue and the "abiotic" part of the Ecosphere. This is an ecological function because of its effects upon the distribution and occurrence of ecosystems and the abundance of many species. Organisms that carry out this function include fungi (through hyphae in soils), plants (through root systems and leaf dispersal), and mobile animals (through animal droppings and upon death).

Nutrient pathways are pervasive and the processes complex. All major elements required by plants and animals move in cycles within the organic part of communities (the biosphere) and in the abiotic matrix of the Ecosphere. All essential nutrients including trace elements are involved, and are recycled and reused again and again. The term 'biogeochemical' cycles has been coined to emphasize that both organisms and the 'abiotic' part of biodiversity play essential parts in this process. An indication of the scale and evolutionary consequences of these cycles can be provided by the example of calcium: all calcium carbonate of the great limestone deposits of the earth was precipitated from dissolved carbon dioxide by living organisms in marine systems. The importance of carbon fixing organisms becomes more obvious when one considers that it is the near exclusive source of the calcium in the bones of vertebrates and the exoskeletons and shells of invertebrates.

Human activities (through agriculture, industry, and in our homes) add millions of tons of nutrients into waters, soils and the atmosphere causing major changes to ecosystems and species composition.

Stability - Function 17

Evidence of stability as an important ecospheric function has been provided by paleontological and evolutionary research, that has revealed the remarkable staying power of natural communities and many of their component species. Over billions of years a stupendous variety of communities and species have evolved in marine, freshwater and terrestrial ecosystems. While most organisms live their entire lives within only one of these three ecosystem types, numerous species have survived and evolved in two, such as amphibians, some reptiles (turtles), anadromous fish, sea birds which nest on land, and so on. Because of the great stability of ecosystems, so many phylogenetically distinct taxonomic groups and communities originated, became ever more diverse, acquired new and parallel functions and extended themselves into all habitable parts of the Earth. At the same time these organisms helped fashion an increasingly healthy and productive Ecosphere, making it ever more possible for a great variety of organisms to thrive harmoniously.

Understanding why the Ecosphere has been so unerringly and increasingly stable has been the subject of scientific inquiry. In recent years the Gaia Thesis has been proposed: that the Earth's Ecosphere is a system with certain self-regulating features, controlled by the combined activities of the biota and the "abiotic" environment.

That even today's natural systems change only very slowly (major human impacts excepted) is encapsulated by the phrase 'balance of nature' which is widely held to be self-evident, based on lifelong experiences and observations of people living relatively close to nature. To analyse and describe the elements of this emerged stability is a formidable task. Here are some elements of the stability function that can stimulate discussion and thought:

Complexity: This article accepts that increased complexity in naturally evolved ecosystems leads to greater stability. Thus, ecosystems in a climax condition are considered to be optimally stable. Climax communities (left on their own with no human management and no introductions of aggressive alien species) have been extremely stable over eons. Without humans introducing alien species such ecosystems strongly resist invasion, although some naturally evolved ecosystems are vulnerable to randomly introduced alien species. However, the linkage between complexity and stability is rejected by some ecological models which assume that an ecosystem's complexity should be measured only by the number of its parts. The models do not consider, though, the time it took to evolve the climax ecosystem; nor do they consider how the climax is organized. Two recent authors noted that "stability may decrease or increase with reductions in species number in a given system, and the effect may be different in temperate, tropical, and Arctic habitats". These authors did not make the vital distinction between those species naturally co-evolved within a system, and aggressive, destructive aliens (such as loosestrife, zebra mussels, carp, chestnut blight, Dutch elm disease and others). In other words, these modelling exercises are hardly relevant to what actually goes on in nature.

Connectedness: The notion that "everything is connected to everything else" is an essential element of stability since species need to meet their requirements in consort with others and through cycles, trophic levels, dispersal and other functions that involve most or all of them either permanently or from time to time.

Redundancy: It has been argued that many genes, individuals or even species in an ecosystem may be surplus to the requirements of the system. A surplus species, for example, would be one whose functions are seemingly identical to those of a certain companion species. Thus, its elimination would not significantly change the characteristics of the ecosystem. Examples would be: the loss of two species among 20 of single celled, free floating green algae in a pond; extinction of one of five species of bumblebees in a meadow (all opportunistic pollinators); or the death by disease of one of ten species of deciduous trees in a forest (all of which provide the principal canopy), as happened with the American chestnut. However, it is highly unlikely that such species are actually surplus to the ecosystem (in terms of functions and potential functions) since genetic and chemical differences may well indicate opportunities to interact uniquely with other species and to secure a more diverse evolutionary future. It has been suggested that redundancy provides long term resilience to ecosystems. If so, this could mean that it is a positive mechanism for increasing diversity and buffering ecosystems against abrupt change, thereby enhancing both short and long term stability.

Generalist Behaviour: Ecosystem stability would be enhanced when an important species such as a pollinating bee would care little as to which flowers were available for nectar and pollen, and so would pollinate numerous plants. Alternatively, when a particular carnivore could exploit many different kinds of prey, its survival would not be jeopardized by extirpation of one of its food species.

These are examples of how fluctuations in species numbers are dampened by spreading risk more widely.

Keystone species: A keystone species is one that has a disproportionate effect upon the persistence of other species. Obviously the strength of the effect depends on how many other species are affected. Keystone species include: carnivores (mountain lions, killer whales, sea otters), herbivores (snowshoe hares, caribou), competitors (aggressive exotics, dominant forest trees), symbionts (major pollinators, mycorrhizal fungi of dominant trees), earth-movers (earthworms, pocket gophers); plants which alter the fire regime (producing major fire loads), and system processors (nitrogen fixers like lichens). The presence or absence of these 'keystone' species will significantly affect the presence and abundance of certain species, and will help determine the stability or instability of the ecosystem.

Food webs/chains (trophic structure): The varying intricacies and lengths of food webs (from only a few, simple pathways, to extremely complex cycles at many levels -- such as occur when filter feeders are involved) may affect stability of a community. Humans have the most complex of all food chains, since they eat thousands of different species in most phyla either directly or by assimilating domesticated animals and plants. Complex webs enable dependent species to survive by shifting to alternate trophic pathways when one or several fail. However, according to some models, webs with more trophic levels undergo such severe fluctuations as to lead to the extirpation of top carnivores. Again, however, we are dealing with models rather than real nature. Obviously, the matter of species richness of herbivores and carnivores generated by complex trophic systems over large landscapes is insufficiently understood. However, since communities and organisms can move while ecosystems are geographically circumscribed, more complex trophic systems would appear to foster more stability rather than less.

Community Succession: Succession is defined as a continuous directional change in an ecosystem at a particular site lasting dozens or hundreds of years and involving both colonization and extirpation of species in response to innumerable factors. Succession occurs, for example, when old fields are recolonized by forest ecosystems. It is the unique genetic traits of each species that determine whether and at what rate it can participate in succession, and return to communities disturbed by human activities, fire, storms, insect herbivory and other events.

The positive effect of natural fires and other local disturbances upon ecosystem stability are also evident within large landscape regions. Repeated fires or wind-throw in ecosystems prone to fire (boreal forest, lodgepole pine forest, prairie) greatly increase their overall complexity by creating numerous successional stages which can support a wider variety of biota. This phenomenon has been described for Banff National Park, where Parks Canada has instituted a fire management policy to encourage biodiversity and maintain a permanent patchy disturbance regime.

Many ecological functions also affect community succession, and act to determine the species present. One example is the mutualistic symbiosis between plants and various soil microbes in forest communities. The presence or absence of mycorrhizal fungi can strongly determine the kind of succession that follows clearcutting and deep soil fire (where the fungal mat has been burned off), or that takes place in an area where one is attempting to restore a prairie after farming has been carried out for decades. Plant species that do not require linkages with mycorrhizal fungi are less constrained successional since they can invade without the presence of the soil microbes which may take decades or longer to enter a degraded or destroyed ecosystem. Following disturbance, when the community at a site is considered to have reached a near "steady state" (i.e. no apparent net gain or

loss of species over a period of time), succession would be so low as to not be perceivable by humans.

Harmony - Function 18

Harmony is the ultimate function of biodiversity: the consequence of the 17 functions already described. Harmony in nature is diverse, pervasive and persistent, existing at all levels necessary to the maintenance of the whole. Harmony emerged slowly in both aquatic and terrestrial ecosystems. We can observe harmony in many aspects of the Ecosphere: animal and plant form (trees, flowers, birds, fish, insects), the obvious grace of animal movement (swimming, flight, running); colours of birds, fish, insects, trees, leaves, flowers; radial or bilateral symmetries of individual animals and flowers. Even the world of microorganisms is full of harmonies of many types. Another aspect of harmony is the innate capacity for hundreds and indeed thousands of life forms to live together "in relative harmony" within a community or larger ecosystem, and to form linkages, co-adaptations, and symbioses. The developmental and physiological harmonies that have evolved within individual organisms is another level of harmony. Wholeness, completeness, health, and integrity are the broader aspects of the innate harmony function in the Ecosphere.

Harmony cannot be separated from the abiotic part of biodiversity: the matrix of rivers, lakes, waterfalls, wind, pounding of oceanic surf, landforms, clouds, and all other "abiotic" conditions (within which organisms and ecosystems evolved and apart from which they cannot survive). Indeed, since the beginning of life, organisms have dramatically changed and shaped the characteristics of the Ecosphere. Harmonies appear to be the ultimate consequence of the workings of the laws of nature. The deeper origins of the pervasive persistence of harmonies in nature may be due to an innate drive of organisms to achieve maximum "self-realization" during the course of their lifetime, a concept described by a number of authors, including Arne Naess, Stuart Kaufmann, Edward Goldsmith and Holmes Rolston, III. (36)

Harmony is distinct from beauty. Beauty has a philosophical and ethical dimension and is a subject of discussion among philosophers and some scientists. Some feel that to include beauty as another function of biodiversity is crossing a fine and dangerous line: unlike other functions, it is too subjective to measure by the methods of science.

Harmony has an obverse side, and this can help to visualize its nature. Thus, "disharmony" or ugliness is created when organisms or ecosystems are reduced to fragments or parts. For example, as the poet Robinson Jeffers wrote, "a severed hand is an ugly thing." Likewise, a cut-off tree or headless body would certainly not be harmonious entities.

At the level of ecosystems, harmony is reduced and violated when a road is cut through a previously natural forest, when a fully developed old forest is clearcut, when a river is toxified by a sewer or pulp mill, when an oil spill baths a rich intertidal shoreline, or when a coral reef disintegrates due to global warming or runoff of fertilizers from nearby human activities.

Conclusion

The ecospheric functions of biodiversity are far more pervasive, diverse and complex than generally realized. When ecosystems are left undisturbed by humans, they exhibit an inherent self-organizing capability. Over billions of years life forms and ecosystems became ever more complex, leading to the emergence of a stable and harmonious Ecosphere.

By identifying and classifying these ecological/ecospheric functions, one can better comprehend the creative, secure and resilient path that the Ecosphere has sustained and amplified since the beginnings of life. Certainly, the Ecosphere has been super-stable and resilient, gaining in diversity, complexity and internal harmonies over several billion years, interrupted by abrupt extinctions caused by several big comets - events from which the Ecosphere was able to recover. That, given time, complexity begets increased complexity and increased stability is a remarkable phenomenon of our Ecosphere.

By identifying ecocentric/ecospheric functions we can also provide a tool for ecologists, naturalists, environmentalists, ecophilosophers, wildlifers, foresters and others who, like myself, have been troubled for years by the imprecise definitions of some widely used ecological terms such as ecological processes, ecological functions, land health, ecological integrity, environmental quality, and ecological complexes. Perhaps these functions could be of value to economists as well, although it is hardly conceivable that price tags can be placed on any of them. However, price tags have been put upon some of the "goods" produced through the workings of these functions.

Today, some writers view the value of the functions of the Ecosphere through anthropocentric eyes, asking only, "what good is nature for humans?" Instead, they should ask: "What do natural systems do and what have they done to create and secure the permanence, health, balanced productivity, and beauty of the world into the indefinite future?" We live in times when the time-tested functions of the Ecosphere are being thoughtlessly and brutally modified by those who consider nature to be nothing but a source of commodities to be valued only if they serve humanity's selfish wants and needs.

An extensive literature now exists on the toxification and destruction of ecosystems, and the continuing overexploitation of species and ecosystems which carry out irreplaceable ecospheric functions. The commodification of nature remains official government policy, while an extensive greenwash literature provides cover for reams of destructive federal and provincial legislation and policies in agriculture, fisheries, forestry and industry--particularly the chemical industry which manufactures millions of tons of toxics every year, for deliberate dispersal into the Ecosphere.

Securing better insights into the long term consequences of impairment of each of the 18 functions could take an army of researchers. I am not aware of any examples in Canada where policy makers or managers of forests, fisheries, agriculture or of the pesticide industry have carried out such analyses, or even care to. It would be a challenge to determine the scope of and changes to ecospheric functions in almost any area of land or sea. Where to start? How to measure? An insightful comment by Thomas Berry can serve as a general guide to thinking and action; he noted that "the integral functioning of the natural world is taken as the supreme model of managerial success."

[Other Ecocentric Texts](#)

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