FORM AND FUNCTION IN THE BIOSPHERE

Eville Gorham

Department of Ecology & Behavioral Biology, University of Minnesota
Minneapolis, Minnesota 55455

The biosphere comprises those parts of the earth inhabited by living organisms. It forms a thin envelope about 10 miles deep, around the outer part of the earth's crust where solid, liquid and gaseous phases (the lithosphere, hydrosphere, and atmosphere) are freely intermingled. It is a very tenuous and fragile envelope, amounting to only one four-hundredth of earth's radius, but it is the site of all the varied reactions and interactions that undergird the process of biological evolution and make earth unique among the planets.

The units of the biosphere are called ecosystems, short for ecological systems. By and large these are units of convenience, areas we have marked out for study; although they may often be areas easily recognizable as forests or prairies, woodlots or fields, lakes or bogs - to mention my own favorites last!

Ecology nowadays has as a major focus, though by no means the only one, the study of ecosystems - their structure, function, regulation, development, and history. These ecosystems are open systems, even the world ecosystem as a whole is open, depending upon an influx of energy from the sun, and losing not only re-radiated heat, but also some of the lighter elements such as hydrogen from the outer fringes of the atmosphere. Such a de-gassing is believed to have been very important in the formation of our atmosphere - allowing it to accumulate over time the large amounts of free oxygen which make our evolved form of aerobic metabolism much more efficient than the anaerobic metabolism of the earliest living things.

Not all of the material flux involves losses, however. At the present time we can observe a tiny, but measurable, influx of cosmic spherules, iron-nickel micrometeorites which constantly bombard our earth and can readily be isolated from ever so slowly accumulating oceanic sediments. Curiosities, but interesting curiosities because they are presently our most frequent visitors from outer space.

Nowadays we find it helpful, in fact vital, to recognize the openness of ecosystems. But back in the late nineteenth century the definition by the American Stephen Forbes of a lake as a microcosm, in effect a closed system, stimulated a good deal of work on lakes because of the idea that they could be treated as isolated units for scientific study. In recent years it has been equally stimulating to recognize the openness of the aquatic ecosystem, marked by the influx of nutrients from the drainage basin and from the falling rain, by the losses to outflow, and by the gaseous exchanges across the air-water interface. It is here that the inputs of pollution can be budgeted, so that they can be better understood and eventually countered.

Also necessary to the understanding of ecosystems is knowledge of ecosystem structure, which is easily seen in a walk through the woods, for instance in the Cedar Creek Natural History Area north of the Twin Cities of Minneapolis and St. Paul in Minnesota.

The woodlands are clearly seen to be layered, with a tree layer including perhaps several oaks, maples, birches and pines. Beneath the trees is a layer of shrubs, often dominated by hazel. Beneath the shrubs in turn is a layer of several herbaceous plants, for example asters, bracken fern, and woodland grasses. More northern coniferous woodlands often have an additional underlayer of feather-mosses, which have an intricate and unsuspected beauty when viewed close up. Lastly, there is a humus layer in the uppermost woodland soil, where leaf litter is broken down by a great variety of bacteria and of fungi, some of whose parasol fruiting bodies lend a pleasant contrast to the ever-present green of the higher plants. On these, and on the decomposing detritus, feeds a multitude of animals - among them earthworms, millipedes, mites and springtails. Beneath the humus layer again is a whole series of soil horizons, grading down to the little altered rock flour ground up and left behind by the retreating glaciers many thousand years ago.

A lake too has structure, horizontal as well as vertical. At the lake edge we often observe a zone of reeds and cattails, beyond which waterlilies and pondweeds provide a nursery for all sorts of aquatic life. Farther out in the open water is the quite different world of the "plankton", small, scarcely visible organisms that are rootless and drifting, lacking the security of stem, root, and lake bottom to which a firm anchor can be attached. Vertically, the lake in summer is divided into three zones. First comes an upper, warm, well-lighted zone where plants and animals grow and reproduce abundantly. After passing through a sharp transition zone - or thermocline - marked by a sudden change in temperature, we come to the deep, dark, cool waters where the dead and dying organisms sinking from above are broken down, some parts to be recycled, others to be deposited in the blanket of sediment which has been slowly filling up the lake ever since its formation at the end of the ice-age. This blanket of sediment provides for us a historical record of whatever has happened to the lake during its entire lifetime. In the words of Marshall McLuhan: "The medium is the message" -- if only we can read it! Sometimes pages have been removed by erosion, sometimes they are out of place owing to slumping of the sediment, or the record is blurred because some organisms leave no trace of their passing. Often the language is unfamiliar, made up as it is of pollen grains, seeds, carapaces of microscopic crustaceans, jaws of midge larvae, and the glassy, sculptured shells of microscopic algae known as diatoms. Small wonder that it takes a lifetime or more to become expert in unravelling from such a record the history - sometimes eventful, at other times dull - of the many different types of lakes we are fortunate to possess in Minnesota. Just lately Professor Jon Sanger and I have attempted a new and fascinating kind of historical analysis, looking not at <u>microscopical</u> but at <u>biochemical</u> fossils, the chlorophyll derivatives and carotenoids which are the relics of the photosynthetic mechanisms on which all life depends, inside the lake and out of it. From this study of "molecular ecology" we have gathered valuable evidence of past changes in aquatic productivity, and useful insights into the history of lake enrichment or eutrophication.

Just like natural ecosystems, our urban ecosystem exhibits structure, a knowledge of which is important to understanding its function. Downtown Minneapolis with its tall buildings shows a variety of vertical structures - offices above, shops at ground level, heating plants in basements (balanced by air-conditioning systems on roofs), and underground a whole network of sewers, water-pipes, and electric cables which we seldom consider until something goes wrong - when our urban dependence upon technology becomes suddenly and painfully obvious. Horizontal structure is present too, with the central downtown area of offices and shops separate from industrial parks, residential areas, and the ring of dormitory suburbs, - to say nothing of scattered parks, golf courses, and lakes which relieve the monotony of megalopolis for those able to enjoy them.

Of course all these varied layers and areas of the modern city are interdependent, and damage to any one of them compromises the survival of the others. Likewise in nature all parts of the ecosystem are vital, and unthinking damage to one part by indiscriminate exploitation, or by the dumping of wastes or the misuse of toxic biocides, may hazard the survival of organisms far removed, including

Another element of form in the ecosystem is expressed in the concept of the "ecological niche". Each different kind of organism has its own place in the ecosystem. Among the insect-eating warblers, for instance, the oven-bird is a ground-dweller, the chestnut-sided warbler hunts in shrubs and the lower branches of trees, and we look for the flame-throated Blackburnian warbler in the tree tops. But the concept of niche includes not only space but occupation, other birds coexist with the insect-eaters at any tree level by eating seeds instead. Likewise, among humans, many people in the downtown area coexist there by occupying different niches, some making goods, others selling them, still others repairing them. And the kinds of goods further distinguish the niches, just as the kinds of food do for the birds.

The differentiation of the world's diverse ecosystems rests ultimately upon the interaction of several partially independent environmental factors: climate, soil parent material, topography, biota and fire, acting over time. The major limiting factor on a regional or continental basis is climate. It is no accident that in Minnesota tall forests are found in the east and north, where rainfall exceeds evaporation. There the plants project much farther above than below ground. In the arid western prairies, on the other hand, the tops of the grasses may be inconspicuous and only a few inches tall, while the roots reach down several feet into the soil beneath to where water is available for them. Another limiting factor of great importance is soil nutrient supply. The dwarf trees on our northern peat bogs, some decades old but only a few feet tall, may send roots out thirty feet laterally because of the scarcity of available nitrogen and phosphorus in the acid bog peats. Fire is also a significant limiting factor in Minnesota. Without it, the prairie slowly turns to woodland as hazel and bur oak invade and conquer the prairie grasses. And the even-aged pine stands of the Boundary Waters Canoe Area are also largely a result of periodic fires - leading to the conclusion that prescribed burning will be a vital tool in the preservation of that northern wilderness. Parodoxical as it may seen, we must pursue a policy of wilderness management, it cannot be left alone without our continuing care.

When we consider how all the complex structure of an ecosystem is built up and maintained, we must start with the sun. There, a giant reactor ninety-three million miles away is operating by nuclear fusion, a process which may determine the fate of humanity as we develop it either to destroy the human race or to bring it almost limitless supplies of useful energy. The sun's energy flows along food chains or webs from green plants to a variety of herbivores and then to primary, secondary and occasionally tertiary carnivores. Opportunistic omnivores may of course exploit several levels of the food chain for their survival, and human beings are prime examples of this group. At each step most of the energy (often as much as ninety per cent) is dissipated in food-gathering, body-maintenance and excretion, which explains why food-chains seldom go beyond five links. It also explains why we shall be forced into vegetaranism if we do not control population growth, a ton of grain will support many more people if eaten directly than if first converted by cattle into beef. Nevertheless, a modicum of animal protein is highly desirable because of its higher quality (as human food, that is).

The food-chain already described, which is based on the capture and consumption of living organisms, is not always the major one. The detritus pathway, in which dead organisms or their parts (e.g., dead leaves) are consumed, may be more important. In a forest, less than ten per cent of the leaves may be eaten by insects, the rest dying and falling to the forest floor to be broken down by earthworms, mites, springtails, fungi and bacteria. Perhaps in the future we shall develop a "detritus agriculture" to make better use of plant parts we do not presently utilize. So far yeast, mushrooms, and oysters--all of which consume dead organic detritus--do not make much of a contribution to feeding the world.

Biological magnification is an important property of food-chains. Just as energy is largely dissipated at each step, so is material, the carbohydrates, fats, and proteins being broken down to carbon dioxide and water, and given off to the atmosphere where they provide basic resources for plant photosynthesis. But some things, elements of radioactive fallout, or complex, resistant organic molecules of DDT, are not broken down or excreted. Instead, they are conserved at each step and so increase in concentration, sometimes to levels which are harmful. This is why such toxic substances are most hazardous to organisms at the end of the food chain, whether they be caribou-eating Eskimos, or American bald eagles.

The forms of the biosphere are, like the forms of human institutions, not static but dynamic. Just as the forms of government remain while politicians, bureaucrats and voters come and go, so also do the forms of ecosystems persist while individual organisms are born and die. And on a smaller scale, the form of the individual persists despite a constant flux of the atoms and molecules of food and water through its body. This flux is part of a larger flux through biosphere as a whole, as rocks are weathered by the rain, and rivers carry the weathering products to the sea, from which new mountains eventually arise to repeat the weathering cycle. Similarly, organisms die and liberate elements and molecules which sooner or later will cycle through other organisms.

The numbers of organisms, and the factors controlling them, are of vital concern in our picture of how systems function. The main regulators of populations have always been the four horsemen of the apocalypse--famine and pestilence, and in the case of animals, strife and war. Human endeavor has ameliorated their influence, and so created at compound interest the population explosion, which we see as an upward sweeping curve when the human population of Spaceship Earth is plotted versus time. It might better be termed the population implosion, because it largely occurs by overcrowding further and further a limited number of major metropolitan centers. Biologists, more than most others, know that one cannot live forever on the slippery slope of a compound-interest curve, and that if we do not develop new and humane methods of population control the four horsemen will return with increased fury to carry out their age-old task of cutting back the over-abundance of shoots on the tree of life.

As some populations increase, while others decline, we see a gradual change in the nature of all ecosystems. Here in Minnesota, ecosystem development is seen most clearly at the edges of lakes, where we can often see the consequences of silting and in-filling in the form of a marginal plant zonation of the kind already mentioned. First come pondweeds and water lilies, then--as the lake shallows--reeds colonize and are followed in turn by sedges, alder and willow shrubs, and finally by forest trees. This zonation is a dynamic one, because the plants not only slow down water movement and allow silt to settle, but also deposit their own debris to increase the pace of shallowing. And if we core down through the final stage of damp woodland, we can find in the deposits of peat a complete record of the succession of plant communities--right back to the open lake formed at the end of the ice age

Coring can have its uses in the forest too. By coring tree trunks we can count their annual rings and so determine their ages. Knowing the ages of various forests, we can often reconstruct the sequence, or succession, of forest types. This in turn enables us to understand the historical development of, say, the Boundary Waters Canoe Area, which we must comprehend thoroughly if we are to preserve the northern forests for our descendants to enjoy.

Ecologists often owe their choice of profession to their early enjoyment of nature which, however, is seldom evident in their writings. And yet it is possible, as Aldo Leopold and Rachel Carson have shown us, to express scientific truths in language which appeals also to the aesthetic sense. It is equally possible for science to provide the inspiration for art. As an example of science expressed in poetry, let us read Josef Alber's poem on the hydrologic cycle and its control by negative feedback.

+ = -

Je mehr
die Sonne scheint
desto mehr
Wasser verdunstet
es entstehen
mehr Wolken
und
die Sonne
scheint weniger

Je weniger
die Sonne scheint
desto weniger
Wasser verdunstet
es entstehen
weniger Wolken
und
die Sonne
scheint mehr

da capo

(Freely translated by Eville Gorham)

The more the sun shines, the more
Water evaporates;
More clouds develop, and the sun
Shines less.

The less the sun shines, the less
Water evaporates;
Fewer clouds develop, and the sun
Shines more.

Da capo.

Or let us read Robert Frost on the role of trees in transpiring water from the soil to the atmosphere, a subject which has had its share of mystery for scientists in the past.

SPRING POOLS

These pools that, though in forests, still reflect
The total sky almost without defect,
And like the flowers beside them, chill and shiver,
Will like the flowers beside them soon be gone,
And yet not out by any brook or river,
But up by roots to bring dark foliage on.

The trees that have it in their pent-up buds
To darken nature and be summer woods-
Let them think twice before they use their powers
To blow out and drink up and sweep away
These flowery waters and these watery flowers
From snow that melted only yesterday.

Another aspect of the biosphere--the age-old cycle of matter--is at the root of two well-known stanzas from Fitzgerald's version of the Rubaiyat of Omar Khayyam.

I sometimes think that never blows so red
The Rose as where some buried Caesar bled;
That every Hyacinth the Garden wears
Dropt in her Lap from some once lovely Head.

And this reviving Herb whose tender Green
Hedges the River - Lip on which we lean--
Ah, lean upon it lightly! for who knows
From what once lively Lip it springs unseen!

The pattern of ecosystem development can also be described in verse, as in a delightful poem by a Minnesota writer, Betty Bridgman.

LOOK AT YOUR LAKE

A lake is for a long time,
  But not forever.
Let a chip break from the rim,
  It turns to river.
Or let aquatic plants take hold,
  They strew their feet
With year and year of mounting mould
  Till both ends meet.
A lake is for a period,
  For present tense,
Then flattens into marshy sod
  For pasture fence.
Look at your sunlit lake this morning,
  Aquamarine.
It's planning even now for turning
  Blue to green.

In "Message from Home" she shows us, in a mystical but wholly satisfying way, the ultimate roots of our humanity in the natural world.

MESSAGE FROM HOME

Do you remember, when you were first a child,
Nothing in the world seemed strange to you?
You perceived, for the first time, shapes already familiar,
And seeing, you knew that you have always known
The lichen on the rock, fern-leaves, the flowers of thyme,
As if the elements newly met in your body,
Caught up into the momentary vortex of your living
Still kept the knowledge of a former state,
In you retained recollection of cloud and ocean,
The branching tree, the dancing flame.

Now when nature's darkness seems strange to you,
And you walk, an alien, in the streets of cities,
Remember earth breathed you into her with the air, with
  the sun's rays,
Laid you in her waters asleep, to dream
With the brown trout among the milfoil roots,
From substance of star and ocean fashioned you,
At the same source conceived you
As sun and foliage, fish and stream.

Of all created things the source is one,
Simple, single as love; remember
The cell and seed of life, the sphere
That is, of child, white bird, and small blue dragon-fly
Green fern, and the gold four-petalled tormentilla
The ultimate memory.
Each latent cell puts out a future,
Unfolds its differing complexity.
As a tree puts forth leaves, and spins a fate
Fern-traced, bird-feathered, or fish-scaled.
Moss spreads its green film on the moist peat,
The germ of dragon-fly pulses into animation and takes wing
As the water-lily from the mud ascends on its ropy stem
To open a sweet white calyx to the sky.
Man, with farther to travel from his simplicity,
From the archaic moss, fish, and lily parts,
And into exile travels his long way.

As you leave Eden behind you, remember your home,
For as you remember back into your own being
You will not be alone; the first to greet you
Will be those children playing by the burn,
The otters will swim up to you in the bay,
The wild deer on the moor will run beside you.
Recollect more deeply, and the birds will come,
Fish rise to meet you in their silver shoals,
And darker, stranger, more mysterious lives
Will throng about you at the source
Where the tree's deepest roots drink from the abyss.

As moving testimony to the underlying harmony between the scientific and aesthetic views of nature we may read two poems by Kathleen Raine. In "The Moment" she deals perceptively with the evolving forms of nature.

THE MOMENT

Never, never again
This moment, never
These slow ripples
Across smooth water,
Never again these
Clouds white and grey
In sky sharp crystalline
Blue as the tern's cry
Shrill in light air
Salt from the ocean,
Sweet from flowers.

Here coincide
The long histories
Of forms recurrent
That meet at a point
And part in a moment,
The rapid waves
Of wind and water
And slower rhythm
Of rock weathering
And land sinking.

In teeming pools
The life cycle
Of brown weed
Is intersecting
The frequencies
Of diverse shells
Each with its variant
Arc or spiral
Spun from a point
In tone and semitone
Of formal octave.

Here come soaring
White gulls
Leisurely wheeling
In air over islands
Sea pinks and salt grass,
Gannet and eider,
Curlew and cormorant
Each a differing
Pattern of ecstasy
Recurring at nodes
In an on-flowing current,
The perpetual species,
Repeated, renewed
By the will of joy
In eggs lodged safe
On perilous ledges,

The sun that rises
Upon one earth
Sets on another.
Swiftly the flowers
Are waxing and waning,
The tall yellow iris
Unfolds its corolla
As primroses wither,
Scrolls of fern
Unroll and midges
Dance for an hour
In the evening air,
The brown moth
From its pupa emerges
And the lark's bones
Fall apart in the grass.

The sun that rose
From the sea this morning
Will never return,
For the broadcast light
That brightens the leaves
And glances on water
Will travel tonight
On its long journey
Out of the universe,
Never this sun,
This world, and never
Again this watcher.

Nothing in that abyss is alien to you.
Sleep at the tree's root, where the night is spun
Into the stuff of worlds, listen to the winds,
The tides, and the night's harmonies, and know
All that you knew before you began to forget,
Before you became estranged from your own being,
Before you had too long parted from those other
More simple children, who have stayed at home
In meadow and island and forest, in sea and river.
Earth sends a mother's love after her exiled son,
Entrusting her message to the light and the air,
The wind and waves that carry your ship, the rain that falls,
The birds that call to you, and all the shoals
That swim in the natal waters of her ocean.

In addition to developing a feeling for our biological roots, what can we learn from the biosphere, and from a consideration of natural ecosystems? In fact, a great deal, because the problems ecologists study in nature are simpler examples of the very same problems with which human society is now so deeply concerned. Studies of the dynamics of natural populations may provide us with insights concerning our own population problems, and those of our domestic plants and animals. Consideration of the energetics and nutrient limitations of natural populations and communities may provide models for the better understanding of the fields and forests which are vital to our well-being and indeed to our very survival. Nature provides the correct model for resource recycling, which we have for far too long ignored. Appreciating the significance of biological diversity in maintaining the more or less steady state of natural ecosystems may, perhaps, lead us to a better understanding of the value of racial and cultural diversity in our all too imperfect, but nonetheless perfectible, human society.

Lastly, if I may return briefly to the matter of our feeling for nature, we might consider its importance--especially in the form of wilderness--for our mental equilibrium and well being. This is something many of us will freely acknowledge, though others may attempt to deny it. In the words of Thoreau:

> We need the tonic of wildness, to wade sometimes in marshes where the bittern and the meadow-hen lurk, and hear the booming of the snipe; to smell the whispering sedge where only some wilder and more solitary fowl builds her nest, and the mink crawls with its belly close to the ground. At the same time that we are earnest to explore and learn all things, we require that all things be mysterious and unexplorable, that land and sea be infinitely wild, unsurveyed and unfathomed by us because unfathomable. We can never have enough of nature. We must be refreshed by the sight of inexhaustible vigor, vast and titanic features, the sea-coast with its wrecks, the wilderness with its living and its decaying trees, the thunder cloud, and the rain which lasts three weeks and produces freshets. We need to witness our own limits transgressed, and some life pasturing freely where we never wander. - Walden