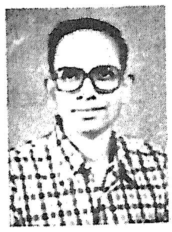
Life: Complexity and Diversity

3. Growing Larger

Madhav Gadgil

Living organisms continually evolve to occupy newer environmental regimes. In the process they develop more complex structures and grow to larger sizes. They also evolve more intricate ways of relating to each other. The larger, more complex organisms do not replace the simpler, smaller ones, rather they come to coexist with them in increasingly complex ecosystems. This promotes a continual increase in the diversity of life over evolutionary time.



Madhav Gadgil is with the Centre for Ecological Sciences, Indian Institute of Science and Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore. His fascination for the diversity of life has prompted him to study a whole range of life forms from paper wasps to anchovies, mynas to elephants, goldenrods to bamboos.

Ways of Life

Decomposing, photosynthesizing and feeding on other organisms are three broad ways of organizing fluxes of energy necessary for the maintenance and propagation of all life *(Figure 1)*. But

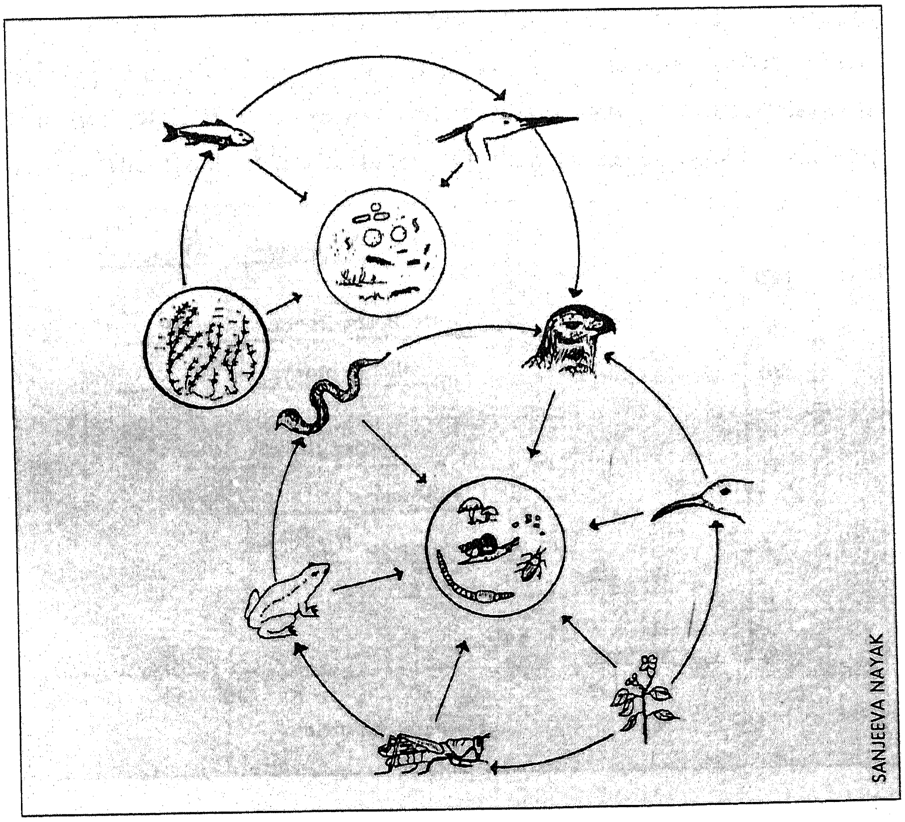


Figure 1 Decomposition, or living off preformed organic molecules is the oldest way of life and is still at the centre of both terrestrial and aquatic food webs. Autotrophy, or manufacture of organic molecules through photosynthesis came next; followed later by heterotrophy or feeding on other living organisms giving rise to the elaborate food webs of present day ecosystems.

As living organisms have adopted these newer ways of life and invaded an ever greater range of habitats, they have assumed larger sizes and more complex structures.

living organisms have created an infinity of variations around these themes. Among the green plants, for instance, are some that do well in bright, open light, while others thrive in the dim light of the forest floor. There are plants that grow well in swampy places and others that prefer the desert sand. Animals graze on grass or browse on leaves, burrow inside stems or gnaw on roots. There are predators that sit and wait for the prey to be caught in their traps or webs, and predators that pursue and run their prey down. There are parasites that live inside cells of other organisms, even becoming a part and parcel of their nucleic acids, and others that live in their gut or on their skin. Honeybees and other insects are rewarded by flowering plants with nectar and superabundant pollen for the services of pollination rendered by them.

As living organisms have adopted these newer ways of life and invaded an ever greater range of habitats, they have assumed larger sizes and more complex structures *(Figure 2)*. Bacteria subsisting as decomposers on dead organic matter are among the simplest, smallest organisms. It has been but a small step for them to live inside bodies of other living organisms, and feed on living organic matter, without any great elaboration of structure. But when creatures took to tapping light energy, they had to produce special pigments, like chlorophyll. They also had to elaborate protective structures as well as special chemicals or enzymes to

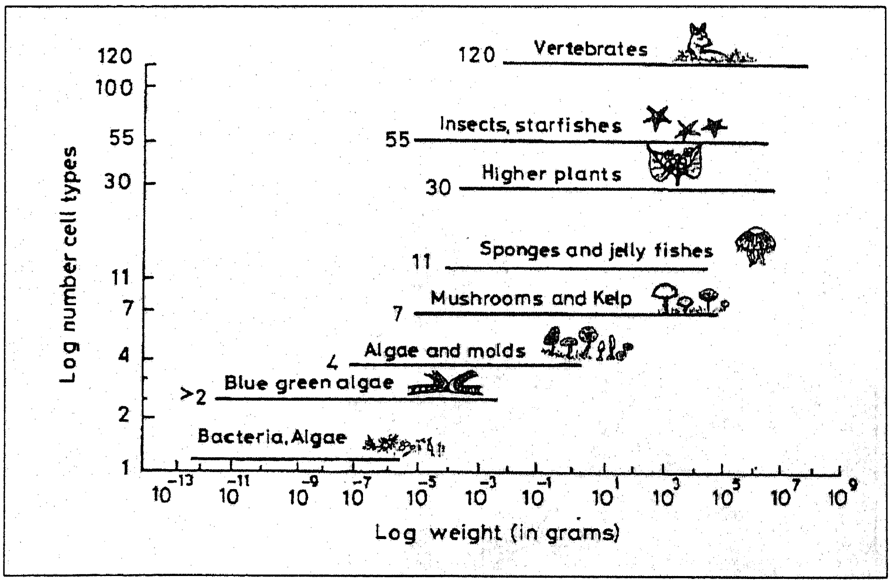
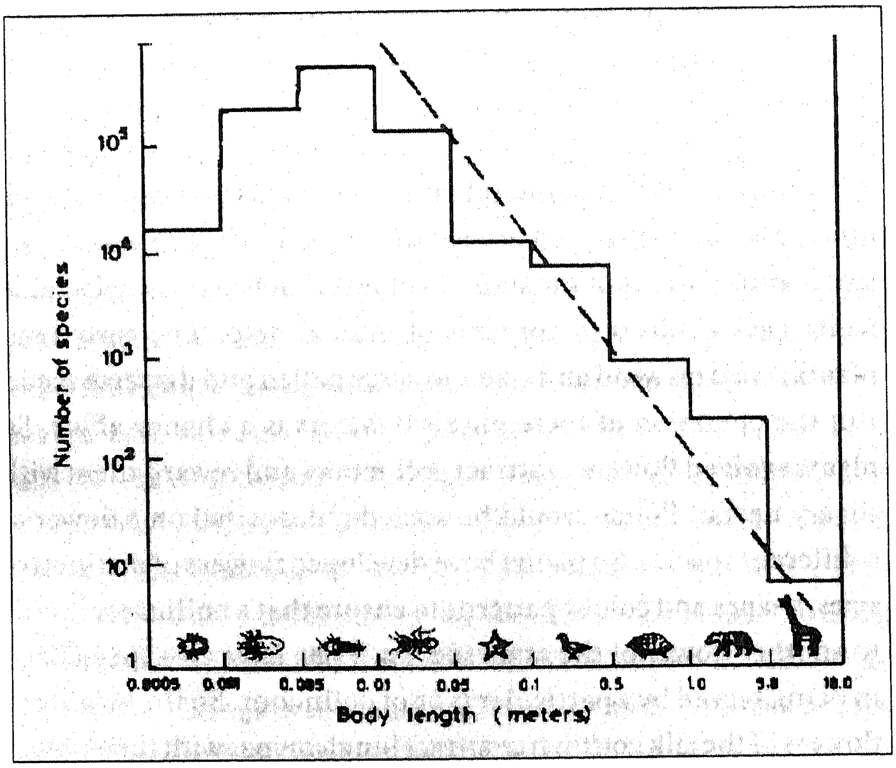


***Figure 2** The simplest and smallest organisms are composed of single cells; the more complex, larger organisms like us are made up of billions of cells. But just as the whole complex machinery of life is constructed from a small variety of building blocks, the most complex organisms are made up of a small number of basic cell types. This graph based on the work of J T Bonner, plots the number of cell types against size of the organisms on a logarithmic scale.*

make sure that the oxygen released did no damage. The efficiency of the process of photosynthesis was further enhanced by concentrating the chlorophyll in specially structured bodies. This was accomplished by the establishment of cellular co-operatives, with the elaboration of much larger cells of higher organisms which contained within them descendants of smaller cells that now served as oxygen processing mitochondria and light trapping chloroplasts. Cells of plants and animals with their mitochondria and plastids are much larger than those of bacteria. But there are distinct limitations to how large a single cell can become, the largest being an egg of the ostrich, largely loaded with stored food. So, to achieve larger sizes favoured for instance by the advantage that larger organisms have in getting at resources like light or in escaping predation, plants and animals have developed yet another form of cellular co-operation. They have become multicellular. Indeed, today the vast majority of living organisms are multicellular. As plants invaded land, a whole range of new structures had to be formed to resist rapid loss of water and to fight gravity. So plants began to produce large quantities of tough yet flexible molecules of cellulose. Cellulose is today one of the most

To achieve larger sizes plants and animals have developed yet another form of cellular co-operation. They have become multicellular.



SANJEEVA NAYAK

***Figure 3** The possibilities of diversity of designs obviously increase with the size and complexity of an organism. It is therefore to be expected that there is a smaller variety of species of the smallest, simplest organisms such as bacteria. But the variety of species increases with size only up to a size of 5 mm to 1 cm. Beyond this, presumably physiological limitations come into play so that the diversity of species declines with increasing size (this figure is based on the work of Robert May).*

Feeding on other plants and animals locks many animals into a contest with their victims. While the victims continually evolve new ways to foil the predators, the predators evolve to overcome these defences.

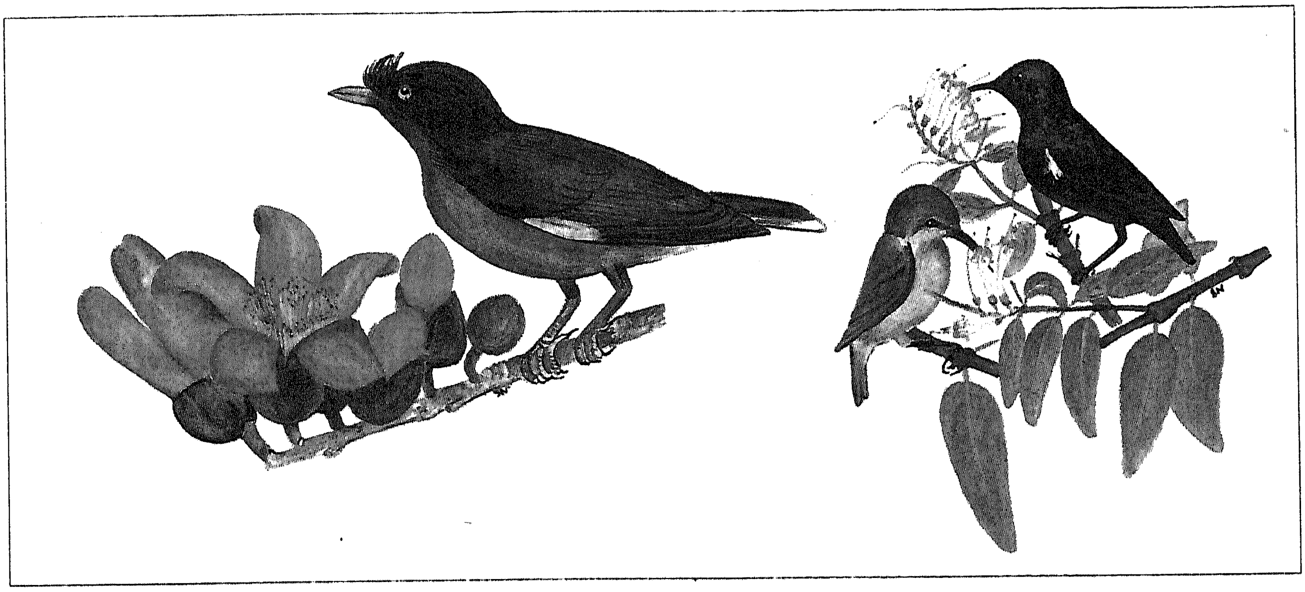
abundant of molecules on earth. Once established on land began to compete with each other for light and water.In the humid environments, light becomes the key resourc plants get locked into a race to outgrow each other. S produce more structural matter and grow taller until f they reach the gigantic proportions of a redwood or a b tree *(Figure 3)*.

Feeding on other plants and animals locks many animals contest with their victims. While the victims continually new ways to foil the predators, the predators evolve to ove these defences. Thus while antelopes become ever fleeter o cheetahs evolve to run faster and faster. While rhinos an phants evolve to a large size and thick hides, lions and tig to be big enough to tackle their young prey, if not the full adults. In the rain forest the lush green leafy matter is cons by myriads of insects. Rain forest plants produce a whole ra toxic chemicals to counter this threat. In turn, the insects means of neutralizing these poisons. It is this chemical w that is responsible for the evolution of many valuable dru humans extract from plants of the humid tropics.

Mutual Aid

Some of the most attractive manifestations of life such as colourful flowers and delectable fruits have evolved in contexts of mutual help.

But animals, plants and microbial species not only subsist o other, they also help each other. Indeed, some of the most tive manifestations of life such as colourful flowers and dele fruits have evolved in contexts of mutual help. The earl plants relied on wind and water to carry pollen and disperse But the operation of these physical factors is a chancy aff plants evolved flowers to attract pollinators and reward ther sugary nectar. Pollen would be wasted if deposited on a flo a different species. So plants have developed flowers of disti sizes, shapes and colour patterns to ensure that a pollinator to another flower of the same species. They have also speci in being served by a particular type of pollinator. So the bri flowers of the silk cotton tree attract junglemynas with their



SANJEEVA NAYAK

Figure 4 (top left) The pollen of the red silk cotton tree attaches itself to the pollen brush at the base of the jungle myna's beak.

Figure 5 (top right) The slender curved beak of the purple sunbird enables it to get at the nectar in the long tubular flowers of mistletoes..

brush of modified feathers over their beaks, and sunbirds insert their slender, curved beaks inside the tubular flowers of mistletoes (*Figures 4, 5*). Honeybees visit the blossoms of jamun, and night flying moths those of the night queen.

Plants have also developed fruits whose flesh rewards animals for dispersing their seeds. Again there are myriads of specializations directed at many different animals. Mangoes hang on long stalks to help bats pluck them, while sandal berries attract bulbuls. There are other intricate mutualisms as well. Very few living organisms can produce chemicals capable of breaking down the tough molecules of cellulose. Certain microorganisms can do this and animals like cattle and deer have special chambers in their gut to lodge these helpers. Wax is yet another kind of molecule that few organisms can break down or extract useful energy and material from. Plants produce wax to prevent water loss from their leaves and to resist animal grazing. Animals like honeybees secrete wax to construct their hives. Such a honeybee hive with its stored food in the form of honey, eggs, larvae and pupae is a rich and attractive source of food for many animals. But it is a food source most ably defended by worker bees that launch suicidal attacks on potential predators braving certain death as they firmly embed their stings in the bodies of their enemies. Animals in turn have developed elaborate structures and behaviour patterns to

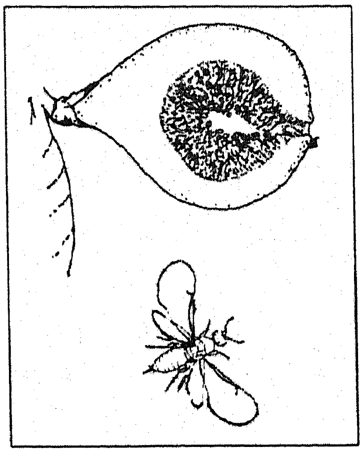
Pollen would be wasted if deposited on a flower of a different species. So plants have developed flowers of distinctive sizes, shapes and colour patterns to ensure that a pollinator moves to another flower of the same species.

overcome these defences. One such predator is the honeybadger equipped with a thick coat of fur and a very loose skin which keep the bee stings out of reach of most of its organs. But honeybee hives are at a height and honeybees operating in the forest canopy are not easily visible to the badger. They are however much more easily tracked by a bird called the honeyguide. The honeyguide on its own is too frail to attack a honeybee hive. It has therefore evolved a mutualistic relationship with the honeybadger(*see cover picture*). When a honeyguide locates a hive it looks for its ally, the honeybadger and freezes in a characteristic posture. The honeybadger then begins to follow it on the ground. The honeyguide flies in stages towards the hive with the badger following it all the way. The honeybadger then successfully attacks the hive and feasts on the honey, the eggs, the larvae and the pupae. But it cannot digest the wax which is left behind. The honeyguide feeds on the wax, for it has yet another ally, a protozoan lodged in its gut that helps it digest the wax. Thus have organisms continually evolved more and more complex structures and behaviour patterns as they have devised ever more diverse ways of getting at energy and material resources to keep them going.

Growing Diversity

Life has expanded during its three and a half billion year history on the earth, evolving larger and more complex organisms. The bigger and the more complex have added on to, and not replaced, the smaller and the simpler.

In this manner life has expanded during its three and a half billion year history on the earth, evolving larger and more complex organisms. The bigger and the more complex have added on to, and not replaced, the smaller and the simpler. So, when a branch of a giant banyan tree snaps in a storm and begins to rot, this, one of the largest and most complex of all creatures nourishes decomposing bacteria which are among the simplest and smallest of creatures. The history of life has therefore been a process of continual increase in the variety of life. It is a process that feeds on itself. The banyan tree is one of a group of strangler figs — trees that are adapted to begin their life on top of other trees. Only after other trees have formed a forest canopy could such stranglers have evolved. Growing in litter accumulated in crevices and hollows on host trees, the strangler figs are freed from the compulsion to produce seeds for germination in a restricted season, such as at the beginning of the monsoon. So unlike most other tree species, figs have taken to fruiting at all times of the year. This requires pollinators the year round. Since there would be few other trees to pollinate in the general off season, figs need specialized pollinators. A special group of insects, the fig wasps, have evolved to fill in this role *(Figure 6)*. There is a whole diversity of such fig wasps, often a separate species specialized to a given species of figs.



SANJEEVA NAYAK

***Figure 6** The entire development of a fig wasp takes place inside a fig fruit, with the fertilized female emerging to seek fresh figs in which to lay eggs.*

The availability of fig fruits throughout the year greatly improves the availability of fleshy fruits in their tropical forest habitat. This is especially significant in months when almost no other fleshy fruit is being produced. Figs help monkeys and fruit eating birds like barbets and fruit pigeons tide over such a pinch period. This has made possible the evolution of many animals specialized on a fruit diet. In turn the fruit eating animals support many species of parasites, which have evolved to live on or inside the bodies of individuals of one particular host species. Some of these parasites, such as hair lice, have their own specialist parasites: bacteria, viruses and fungi.

Packing Species

The diversity of living organisms has exploded, hand in hand with the evolving complexity of their interactions in communities. In the dance drama of life the plot becomes ever more intricate, calling for newer roles and recruiting more players. And there are many such dances in all corners of the earth, sharing some actors, but not many others. That adds another dimension to the diversity of life. Thus red-whiskered bulbuls replace red-vented bulbuls as one goes from drier to moister woodlands. And different species of snails walk up a beach in the zone where tides wash back and forth. Along all gradients where the environment changes, for instance, from moister to drier conditions, as one goes away from a river bed, or as one goes from a region of higher to one of lower rainfall, the set of species changes. This also

The diversity of living organisms has exploded, hand in hand with the evolving complexity of their interactions in communities. In the dance drama of life the plot becomes ever more intricate, calling for newer roles and recruiting more players.