Ecosystems: how systematic are they?

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One hundred years ago several people enquiring about how the world of plants and animals works developed the idea of ecological system. The system was derived from analogy with the designs of mechanical and electrical engines, and business organisations. These had clearly defined flows of materials, energy, and information. They had their own developmental history from invention of simple forms to complex mature forms. In the language of modern technology these are cybernetic things, amenable to the techniques of systems analysis.

Soon a problem arose with this concept when it was promoted as ecosystems being literal organisms, entirely equivalent with an organism like a worm or a whale. Some researchers strongly disagreed, pointing out that unlike worms and whales ecosystems have no distinct boundaries, are not autonomously self-reproducing, and seem to have no mechanism to evolve coherently by Darwinian natural selection or genetic drift. Worse still, this idea of literal organisms, even super-organisms, had overtones of things designed by an external deity.

These objections went unheeded, and the ecosystem as organism idea penetrated popular knowledge of natural history. Many people viewed an ecosystem as a well defined and coherent thing where numerous plants and animals lived closely interconnected, all cooperating for their common good. The idea remains as generally popular now as it was then.

Definitions of ecosystem are ambiguous. "An ecosystem is a system involving the interactions between a community and its non-living environment. A community is a group of interdependent plants and animals inhabiting the same region and interacting with each other through food and other relationships." These inspire questions to which there are no easy answers. What size is this region and how are its boundaries defined? Is the timescale over which these interactions are measured that of a research project, or since the last ice-age, or since most of the species in the system first evolved? How many of these interdependencies are true mutualisms, or looser non-obligate symbioses, or non-existent? To avoid confusions in this essay, the neutral term assemblage will be used.

These difficulties lead to the proposition that ecosystems are neither organisms nor any kind of physical entity. They have no mass and no volume. A tree has these properties, a forest also has them. An ecosystem has neither because ecosystem is a concept, it is a paradigm, a method of thinking about the living natural world. A concept of ecosystem works by the firing of neurons in the brains of ecologists.

The difficulty of improving our understanding of these assemblages of plants and animals is their complexity. If the human brain (along with its human body of course) can be described as the most complex single entity in the universe, then how to describe the assemblage that is a forest? Thought of as an autonomous entity called an ecosystem it presumably includes all individuals of all the species populations of trees, small flowering and non-flowering plants, vertebrate animals and large invertebrates. Then in the essential soil are microscopic invertebrates, protozoans, fungi, and bacteria. In total a huge list of species populations even before the many species likely yet to be discovered in soil are named and included.

Understanding how animal brains work is one of science's greatest challenges, but a large body of interesting and useful knowledge has been gained. Students of behaviour have observed and experimented patiently to discover not only how animals behave but why they behave as they do. They know what advantages these animal behaviours provide for reproduction and survival. Theories of behaviour are testable in the field and laboratory; with difficulty but feasible because many of the behaviours of one or several species of organisms are easy to observe and manipulate. However, the brains within these organisms remain mysterious.

By comparison vast assemblages of many species of organisms are daunting to study and understand, but gaining pragmatic knowledge makes a start. Despite vague positions in space and time, and random variability of these assemblages, they have properties greater than the sum of their populations of species. Rooted plants depend on the living properties of soil, herbivores depend on plants and predators depend on herbivores, all channelling interconnected flows of energy and materials. The dynamics of birth and death of different populations are interlinked. Evolution of these species responded to competition, herbivory, predation and parasitism. Thus, an assemblage needs to be studied at the appropriate hierarchical level where its emergent properties can be measured. A prairie can be studied at structural levels of primary producers (grass leaves) or consumers (bison) or decomposers (soil organisms). It can be studied at process levels of energy capture, nutrient recycling, or regulation of rates of flow between these levels.

The ecosystem concept has vitally important work to perform for us. We are totally dependent for our reproduction and survival on what these assemblages of plants and animals out there beyond our glass windows do for us. We depend on them for the oxygen supply, regulation of carbon dioxide, food, fuel, shelter, and even beauty that sustain us. Within the natural world we are often the dominant keystone species. We wield much power to disturb the assemblages that we need as natural resources, often for the worse. Even as small bands of hunter gatherers we modified our habitats to suit our needs. Now, when most of us depend on farmers to feed us, there is little distinction between wild and farmed land within the ecosystem concept. If humans live in an assemblage it is no longer wild.

Will these assemblages collapse if we disturb them too much? Will they fail to deliver our services? If we hunt the wolves in a large forest so none are left, then the deer of the forest will increase in numbers. They in turn will eat so many seedling trees that the forest slowly disappears, replaced by scrubby grassland. This has been observed many times and the significance of both humans and wolves as primary and secondary keystone species is obvious. But what is also obvious to livestock farmers beyond the forest, where lone male wolves roam, is that hungry wolves eat sheep. How much compensation should be paid to the farmers? In a similar forest there might be a small population of a beautiful species of woodpecker bird. Rare because it is at the edge of the natural climatic range of the species of tree that it most needs for nesting and feeding. If the woodpecker disappears from that forest would an ecologist detect any change in the rest of the forest? How much would it cost for conservationists to plant enough of the trees that the woodpeckers need so that the service of aesthetic joy can be delivered to us?

These are simple examples of a more generic and widespread problem for ecologists. Is the continuing character of any specific assemblage of plants and animals more likely if the assemblage is highly diverse in terms of the number of species it contains? Or as an ecologist would phrase it: is ecosystem stability dependent on high diversity of species? This is not just of great concern to conservationists, who hope the answer is yes. Pragmatic managers of nature reserves and national parks, lakes and coral reefs, meadows and forests, need to know how much time and money to spend on maintaining or increasing diversity of species.

Many observational and experimental studies have been done in recent decades to answer this problem of diversity < > stability. Metanalyses have been made, some of them examining more than one hundred separate studies. These studies cover the constancy of species composition over time, or the productivity of biomass over time. The consensus now supports the proposition that the more diverse an assemblage is then the more stable, or the more productive, it is likely to be.

This stability or productivity is measured over the short term, less than a human lifespan. In the timescales of geology and Milankovitch cycles of the Earth's orbit every twenty-six thousand years, plus longer cycles, no assemblage can be stable. Living things evolve with their own dynamics: contrary, individualistic, opportunistic, striving only to survive. They defy our attempts to categorize them; their flair for innovative reproduction ignores the names we give them. So, there is a danger that attempting to conserve assemblages in the condition we first found them will be inefficient in the short term and futile in the long term.

The ecosystem concept, especially through its mathematical models, explains the positive relationship between diversity and stability as the result of varied levels of interdependencies between populations of species that act as buffers or dampers that absorb disturbances. But when it comes to identifying whether a species that is rare and getting rarer is a keystone species, then the complexity of the links overwhelms our ability to predict. So far: but now our understanding steadily increases as numerous ecosystem theories are put to the empirical test. In the meantime most ecologists recommend the precautionary principle. In the lack of sufficient empirical and experimentally tested knowledge we should manage a natural resource or nature reserve to maintain as much diversity of species as possible.

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