Complexity, ecosystem, and the art of the soluble.

Alan R. Walker, www.alanrwalker.com

Many books and research papers are published about ecosystems and how they work in complex ways. Seemingly, the closer biological complexity is examined the more difficult it is to understand. As comparisons between these books and papers are made it becomes apparent that two separate approaches are used in attempts to understand how the natural world works. One approach is the "art of the soluble", a phrase borrowed here from a book about how research into the natural world can be done.

Examples of distinct natural environments are needed here: lake and forest as parts of some remote national nature reserve with little human impact. A lake is easy to define with its distinct waterline and measurable depth holding a large volume of water. Within this domain there will be a small variety of plants, with distinctive adaptations to a wet habitat.

The waterline boundary of a lake is less than what is needed to sustain plant and animal life within. Leafy biomass is swept into the lake as decaying matter from grasses, herbs and trees on surrounding areas and contributes to the mineral nutrients that the plants need. This external source of nutrients, together with the lake's live plants and their remains, drives the food chain for animal life in the lake. This starts with herbivorous and carnivorous invertebrates such as insects, then herbivorous and carnivorous fish, also the birds and mammals that visit the lake as one of their many places to find food. Boundaries of the lake as a body of water do not define the lake as a fully self-contained thing or entity. Similarly boundaries of a natural forest are often diffuse and the number of species it contains will be much greater than in a lake because of greater opportunities of plants of a forest to gain energy from sunlight.

Both lake and forest are often described informally as an *ecosystem*, in the sense of a characteristic component of the landscape. In contrast, fields of wheat, or fenced pastures for cattle, will rarely be described as ecosystem, informal or formal , because they have been developed by people for production of food. However, there is a system here, called agriculture, and with its varied machinery and financial trading methods this human-made system is complex.

Ecologists have studied intensely lakes and forests to discover their dynamics. The flows of energy starting with sunlight; flows of nutrients that plants and animals need to grow; interactions between the component species and levels of the food chain of the lake. These flows and interactions are quantified using large sets of data measured by ecologists on site and over long times. Flows and interconnections are described through diagrams, charts and algebraic equations. In turn the equations are often developed as mathematical models of a system. The findings are by described by ecologists in research papers and textbooks as characteristics of an *ecosystem* in its formal sense, as abbreviation of *ecological system*.

System is a word with many definitions but first in a dictionary list will be examples such as financial system, or digestive system. The first here is designed and operated by people. The second has a design derived from evolution by natural selection, operating at the level of genes and individuals of a species. Neither of these evolutionary levels of operation includes anything like a lake or forest. So ecologists writing research papers and books often bypass the implications of the word system and use the terms *community* or *assemblage* of living things instead. Community, as a term of ecology, is a group of interconnected populations of many species in one place. Assemblage is simply various species populations in one place.

Ecosystem was formally defined more than one hundred years ago. Researchers have recently introduced the term *complex adaptive system* into the same context. A typical example is a financial system, another example is a software operating system for a computer. People invent and operate these systems. The systems are adaptive in the sense that they can be improved by their inventors, or a collapsing financial system will recover by intervention of bankers.

Ecosystem is also given as an example of complex adaptive system. But does this help in understanding what happens in a lake or forest as a combination of interactive elements forming a collective whole? What is to be included in a forest as components of such a system? All the trees certainly, and herbivores that eat trees, carnivores that eat herbivores, and so on. But what of all the other plants and fungi, let alone the birds in the air and microbes in the soil? A thousand species – ten thousand species counting those in the soil? What is there in the research literature that attempts to describe how all these species work together, species by species, as a functional whole?

There remains a problem about levels of connectivity between parts of such a system. Species of organisms as the operational parts of a system would have needed to co-evolve with other species to interact to some mutually useful degree. These interactions are like channels of communication between partners. Two partners: two channels; three partners: six channels; four partners: twelve channels . . . In nature two-partner symbiosis that is mutually beneficial, a mutualism, is common. But how many three partner mutualisms are there in nature, let alone four or more?

Another common example of complex adaptive system is the brain of mammals, also their immunity. Brains and immunity work within and for individuals of a species. In social species, such as those that hunt in coordinated packs, or live in cities where herd immunity protects the population against infectious diseases, immunity can also work collectively. Immunity has long been studied by researchers because of its vital importance to defend people and animals against invasion of pathogens and parasites, and to fight cancers. Brains are far more difficult to study because mostly inaccessible.

In contrast, immunity is now well understood despite its complexity. This understanding comes because its many separate parts and operations are accessible. These can be studied under the microscope, they can be manipulated using tissue-culture technique, and experiments yield quantitative data to test explanatory hypotheses. Essentially for this understanding, in comparison to things like lakes and forests, immunity works for individuals of a species. Immunity of one person, or one mouse, works against the threats of many varieties of pathogens.

Mammalian immunity has come into being by the process of evolution of each species by natural selection. This selection works ruthlessly. Ineffective immunity permits infection with pathogenic germs and parasites, causing disease or death and few or no offspring produced. A constant battle goes on between the ability of our immunity to produce new variants of defences against the new variants of pathogens that would evade our immunity and infect us. Humanity is locked in endless battle with the virus that causes influenza.

Immunity has overall coherence with direct effect on survival of each individual. Our immunity has agency and works autonomously. Immunity has *purpose*, in a defined sense of evolutionary biology. Immunity is adapted by evolution to assist our survival against lethal threat of pathogens; also against cancerous cells. This purposeful but unseen work of immunity is as vital to our survival as our conscious biological purposes in finding water, food and shelter, as in finding a mate and thereby producing offspring.

The science of immunology fills thick textbooks with complicated information, but accessible and useful to people who need to know. People fulfill cultural purpose through their technologies for therapies and vaccines based on that understanding, thereby influenza is now less threatening to us than it used to be. Our cultural purposes also include art, architecture, belief, law, science, sport . . .

I have deliberately referred to immunity here, not the immune system. Our immunity works in somewhat ramshackle way, using both simple components of the kind also found in invertebrate animals, to components so complex that they may over-react to presence of a parasite, producing symptoms of disease. Our multiple hypersensitivity responses to insects that would feed on our blood are important to protect against that feeding. But the itch and small suppurating wounds in our skin may prompt us to seek medical help, and even exposure to some modern chemicals can induce this hypersensitivity. Our immunity has evolved so effectively as to appear designed, as in a system like a computer program. But evolution does not design by conscious thought. Evolution makes mistakes like having our passages for food and air too closely connected, with risk of choking. The concept of system here is useful as metaphor, but taken literally leads to confusion rather than understanding.

An immunologist, Peter Medawar, was prominent in finding out how transplant surgery could be done without the graft being rejected by normal immune defences. He also wrote many books: one is about how scientific research can be understood and done. *The Art of the Soluble* is the title, a phrase similar to "politics is the art of the possible". Scientists need to solve a problem of understanding some part the natural world by devising means of providing data that can be tested against a tentative explanation of the problem – a hypothesis. Research is the practical business of finding out how things work in the sense of taking them apart, then mentally putting them back together and in so doing understanding them better.

This method is called *reductionism*, which can make it seem bleakly robotic. Reductionism is often associated with the idea expressed as: the whole is the sum of its parts. But the whole of something like immunity is the sum of how its parts *interact*. Discovering these interactions give insights into the intimacies of how the natural world works that can be entrancing, let alone new useful knowledge. Such knowledge gained about the workings of separate parts of a complex whole provide a powerful method toward useful understanding.

The familiar word purpose needs to be distinguished from the specialist word *teleology* as used by biologists: "Teleology, noun, the belief that natural phenomena have a predetermined purpose and are not determined by mechanical laws". Here predetermined requires some external source of agency and power to act upon the natural world, whilst the mechanical laws are those of physics, chemistry and the biochemical workings of genes and heredity. Thus purpose, as used in this argument, operates within the mechanisms of evolution by natural selection. If the way all the trees and other living things in a forest works as a whole can only be explained by something other than natural laws, then its workings are supernatural. The workings of an ordinary, natural, forest are simpler. Each tree has its own purpose: to survive and grow thereby to reproduce. Does an entire natural forest have a purpose that can be understood in terms of how its component species work? Probably not, here purpose works for each species separately.

Biologists use the theory of evolution when trying to understand how living things work. Theory in the sense of mechanisms of evolution at the most basic level: that of genes through to the level of a particular population of a species. New species of trees have come into existence through spontaneous changes, mutations, of some of the genes of an individual that makes it just slightly better able to develop, survive and reproduce itself. The rate of reproduction, as numbers of offspring that themselves will come to reproduce, is measurable as a precise ratio.

It is individual trees of a forest that survive and reproduce, or fail. Speciation operates at the levels of individual genes and the individual organisms that embody the genetic changes. In popular speech this is known as Darwinian survival of the fittest. This is not the fitness important to an athlete, but in the sense of individuals that are best fitted for their habitat produce the most descendants. A population of a species will increase in size and density until it runs out of space and resources or faces direct competition with other species sufficiently similar to be living in the same place. However, the concept of competition for mates within species and for resources between species does not conform readily to the concept of high levels of connectedness and inter-dependencies between most or all species in an ecosystem.

An approach to this question of coherence and unified power of a natural system is to propose that the forest has emergent properties that come into being because of complex interactions of numerous populations of plants, animals and fungi within the forest. It is proposed that complexity arising from different living things and their interactions produces order and coherence amongst the entire forest. The proposition of emergent properties has been formalized as the theory of *holism* and the related *systems biology*, as in taking the *holistic approach* to a problem. That a forest for example, can best be understood from a perspective that includes as many species as possible. How this can be done, and examples of holism applied to ecosystems are often found in the field of computational and mathematical modelling used to analyze systems. But the question then arises: can holism provide understanding of the natural world works without reductionist studies to provide data to test these models?

To these -isms are often added *empiricism* and similar, giving the impression that science research is done according to some fixed procedure. As Medawar and other authors have explained, for scientific findings to be accepted as a contribution to knowledge by other researchers and editors of journals, it matters little what procedure was used. What is required is that methods are effective and repeatable; that original data and analyses are clearly available; the question remains within the domain of natural laws already established by research; the question has been tested against ample data; that due recognition is given to alternative explanations. Field data from observation and experiment, in tandem with laboratory investigations, are the essence of research.

There are many detailed and long-term studies published about forests at the level of flows of energy through food chains, flows of the carbon cycle and the nutrient cycle, influences of mutualistic symbiosis between mycorrhizal fungi and trees, influence of large carnivores on deer populations and in turn on survival of tree seedlings. The flow of energy and carbon through the trees of a forest, typically of just one dominant species, has been thoroughly studied and quantified as data on primary productivity, as tonnes of carbon embodied in trees. This provides understanding of the ability of forests to take up carbon dioxide and sequester it as standing wood.

These examples of how a forest works are studied by examining separate parts of trees or populations of them. Each realm requires much field work, complex experiments, and often needs to match the slow growth of trees. At least trees just stand there, large and waiting to be counted. Well documented examples of such studies are from Harvard Forest (since 1907) Hubbard Brook Experimental Forest (since 1955) both in north eastern USA, and Lady Park Wood (since 1942) in south west England, yielding long runs of standardized quantitative information about how trees live. Many more similar quantitative studies of forests are now made in forests across the world.

These concepts and mechanisms of both evolution and competition between individuals of the same and different species are difficult to reconcile with concepts of complex adaptive systems with emergent properties. The differences of opinion and approach to understanding workings of a forest seem to derive from varied emotional responses that people have to the natural world. Forests for example: we can walk through them with a sense of peaceful contentment combined with awe at the beauty of it all. The idea that older trees of a species are helping younger trees of that species may seem more attractive than the idea that the older trees need to fall down and die before their own seedlings have some chance of growing in the light of the gap created by massive damage by storm, fire, or herbivorous insects.

It seems unproductive to ignore this discord between emotional response to nature and knowledge of the starkly harsh constraints and struggles of organisms to survive and produce offspring. Knowing and accepting both the beauty of nature, together with its intricate workings, could lead to a combination of emotional engagement with pragmatism in the use and care for our lakes and forests.

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