# How to Build an Ecosystem

by Dana Visalli

This is Anak Krakatoa, "child of Krakatoa." Krakatoa itself was an island volcano in Indonesia that erupted in 1883, nearly destroying itself. Anak first arose out of the sea in 1927, a new volcanic island. While it remains mostly bare rock today, it will someday be covered with lush tropical vegetation.

Ecology is the study of the relationships between living organisms with one another and with their physical environment. The subject sounds a little dry at first blush, but it is full of interesting surprises. An ecosystem is a community of interacting organisms and their environment. It usually has some definable boundaries but can vary wildly in size. For example a glass aquarium is an ecosystem, and so is the large region of the Cascade Mountains.

The remarkable thing about natural ecosystems is that starting with little more than a pile of rocks, they somehow manage to build rich communities of life. The only energy they have available is sunlight, the only water that which falls from the sky. A highly prolific tropical rainforest produces 175 tons of biomass per acre year, and yet no more solar energy strikes that acre than it did when it was bare rock or dirt. How can an ecosystem create so much out of so little?

One answer to that question is that life makes ecosystems and the earth itself more habitable over time. This is illustrated by the fact that there was initially no life on earth, then one or a few species managed to survive in the sea, now there are an estimated 10 million species. Land was not only initially uninhabitated, it was uninhabitable--there was no food on land, no nutrients in the soil, and no ozone layer to shield terrestrial life from damaging cosmic radiation. It is life itself that changed all this.

Life in a terrestrial ecosystem needs solar energy, food, water, and essential nutrients (primarily carbon, nitrogen, oxygen, and phosphorus). After any of the many glacial advances that have scoured the Methow watershed, what remains is sunlight and regolith--sterile, rocky ground. There is no organic matter, no way retain water, and no way to capture nutrients from the enviornment.

Early colonizers of glaciated soils include mosses and lichens, both of which are photosynthetic and can therefore produce their own food from air and sunlight. At the same time they are very small organisms whose nutrient and water needs are minimal. Mosses and lichens can dry out completely and remain that way for years, then rejuvenate within minutes when moisture is available. Neither mosses nor lichens have true roots; they obtain most of their nutrient needs from wind, rain and air.

Carbon, oxygen and nitrogen are all present in the atmosphere. The air around us is 78% nitrogen, but it is bound up as the inert molecule $N_2$. Neither plants nor animals have ever developed the ability to split nitrogen apart and make it available to living tissue; only a few species of archaic bacteria, called nitrogen-fixing

A waterbear, also charmingly known as a 'moss piglet.' These are tough little creatures; they can go without eating for 10 years.

bacteria, ever evolved this capacity. Without these nitrogen fixers more complex forms of life could not exist. There would no eukaryotes (the type of cells in all plants and animals) and no multicellular organisms. Some mosses and lichens enter into symbiotic relationship with nitrogen-fixing bacteria and begin to make this nutrient available in the soil.

Solar energy hitting bare rock is simply reflected or re-radiated as heat. Solar energy hitting green leaves is captured and transformed into chemical energy--sugar. Thus once plants and lichen colonize bare land a food source for animals appears in the energy stored in their tissue. Predictably small herbivorous animals appear to graze. One such animal is known as a waterbear--so-called because it requires moisture to remain active, and in it's better moments can resemble a tiny bear, one-half millimeter long. Grazing herds or oribatid mites will also appear, also about 0.5 mm long, to feast on the miniature moss leaves. So the ecosystem starts small, but continues to build on itself.

Once there are plants and small herbivores, small carnivores will appear to capture the energy now contained in bodies of the plant-eaters. Insects and other arthropods do appear on land in the evolutionary record soon after plants appeared. This growing menagerie of plant life and invertebrates with then become a food source for vertebrates that can survive out of water for periods of time, which fact initiated the evolution of amphibians.

Because of the process of natural selection, in which many more offspring are created than can survive, competition for survival is initiated in our nascent terrestrial ecosystem between plants and animals, and between herbivorous animals and carnivores. Mosses cannot grow upwards because they have no water conducting tissue, no plumbing. Plants that by chance evolve some capacity to conduct water and can grow upright will have a survival advantage because they can avoid predation and can monopolize access to sunlight. Such plants will be more likely to survive and will pass on their genetic traits.

Thus club-mosses, horsetails and ferns can and do grow tall, up to 180 feet in the case of ancient club-mosses. Animals grew bigger as well; the largest animal ever to exist is thought to be the dinosaur *Supersaurus*, which attained heights of 100'. Conifer trees outgrew even the dinosaurs, with redwoods setting the record for all living things at nearly 400 feet tall.

In an ecosystem where previously sunlight was reflected off of bare rocks back into space, now there are forests of trees hundreds of feet tall capturing that solar energy and transforming into stored chemical energy. Meanwhile increasing amounts are water are retained within the ecosystem as organic matter builds up in the soil *and in the air*; the upright plants are now colonizing the atmosphere, and they are about 65% water. Gophers and moles burrow into the soil, creating entry points for water storage, while beavers dam side channels of the river and restrain water that would have run to the sea. Decomposers--fungi, bacteria and insect larvae--are hard at work breaking down the organic material of dead organisms and returning nutrients to the ecosystem that formerly were washed away. If salmon are present, they arrive in tremendous numbers every year bearing tons on rich marine nutrients which they distribute in the highlands when they die. The glacier-carved, and fomerly nutrient-starved upland ecosystems are reach a crescendo of biological activity as they modify their environment.

Nature is forever innovating and creating new forms of complexity. A new level of complexity appeared when mutualistic, symbiotic relationships arose

Pacific salmon die after spawning, and thus contribute the large quantity of ocean nutrients in their bodies to the upland habitats of their birth.

Spotted Coralroot, *Corallorhiza maculata.* Coralroot is a 'mycoparasite'- a parasite on the mycorrhizal relationship between a fungus and a plant.

between organisms from different life kingdoms (there are currently thought to be six kingdoms of life, Archea, Bacteria, Protists, Plants, Animals and Fungi). Symbiotic means 'life together,' and refers to an interrelationship between organisms, but one that is not necessarily beneficial to both. For example parasitism is symbiotic. A mutualism is a symbiotic relationship that benefits both members.

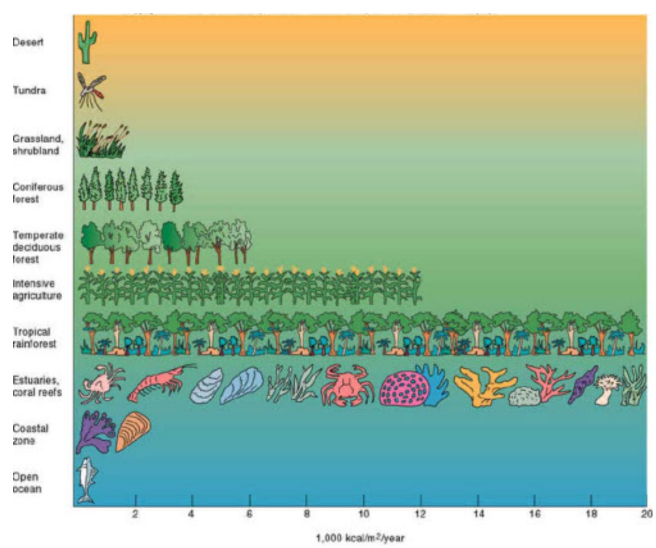
Relationship between plants and fungi can be found in the fossil record as far back as 400 million years ago. It is thought that today up to 90% of all flowering plants are in some form of mutualistic relationship with one or more fungal species. Most of these are mycorrhizal (which means 'fungus-root') relationships: the underground portion of a fungus, called mycelium, binds to the roots of a plant. The fungus makes nutrients from the soil available to the plant, while the plant feeds photosynthetic sugars to the fungus.

Seemingly anything goes in nature, and the appearance of mycorrhizal relationships opened up a new niche that could be exploited. With nutrients flowing from fungus to plant, and sugars flowing in the reverse direction, it wasn't long before a 'robber' species arose to intercept this underground transport system. In fact a number plant species in the Methow are parasites on mycorrhizal relationships, including our coralroots (orchids in the genus *Corallohriza*) and pinedrops and pinesap (Heather Family plants in the genera *Pterospora and Hypopitys*).

Another notable mutualistic relationship is between pollination partners---typically flowering plants and insects, although birds and bats also sometimes pollinate. What had been an antagonistic, predator-prey relationship between plants and insects evolved into one in which both plant and insect gained from their interaction. The plant supplies nectar (which is sugar) to the insect, who in turn provides high-quality transportation services, dutifully carrying pollen from one individual plant to another.

So much diversity from such simple beginnings! From the early days of the evolution life has been been based on ecological relationships, sometimes antagonistic, sometimes mutualistic. All animals survive by eating other organisms. At the same time most complex organisms could not exist without mutualistic relationships. Charles Darwin was well aware of the intricate and emergent nature of ecosystems, so much so that he concluded his world-changing book *On the Origin of Species* with this passage:

"There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."




This graphic illustrates the relative productivity of different ecosystems measured along the bottom in kilocalories per meter per year. Tropical ecosystems are more productive than northern ones because they are warmer and wetter.

**Ecological Eyes**

The Basics:
Energy enters an ecosystem from the outside—usually in the form of sunlight—flows through, and leaves. If there was no life present, the sun would simply warm the rocks and then be radiated back into space as heat. The almost magical aspect of ecosystems is that a complex community of thousands of species and billions of individuals can develop on a once barren spot—but no more energy arrives from the sun in either situation, barren rock or diverse life. Somehow life itself is able to retain the energy of the sun and distribute it across a broad array of life-forms.

On land, water also enters the ecosystem from the outside, flows through, and leaves. Water is necessary for life, and for a living community to grow it must slow the departure of water flowing though.

Many critical nutrients (e.g. phosphorus) cycle within the ecosystem; unlike energy and water, usually additional nutrients are not delivered from the outside. For life to exist and to flourish, phosphorus must be retained rather than washed away. Nothing is discarded and there is no waste) in an ecosystem.

All ecosystems have a carrying capacity for any one species—a limit to the population it can support with being degraded. This is so in part because there are many roles that need to be fulfilled for the ecosystem to function properly, from capturing sunlight and water to building or breaking down organic matter. For all of the 'ecosystem services' to be fulfill many species are necessary and no one species can dominate.

Somewhat surprisingly, there is a thousand times as much plant biomass in terrestrial systems as there is animal biomass. Plants are of course the base of the food chain, as they are the ones that can make food out of sunlight and carbon dioxide via photosynthesis.

Below are some ideas and observations for developing ecological eyes; eyes that can see the interrelationships within living communities.

1. It is said that 'everything is connected to everything else' in ecosystems. Identify some of the interconnections that may exist in a given ecosystem.

Comment: It is somewhat axiomatic in ecology that 'everything is connected to everything else.' One basic example is the oxygen/carbon dioxide balance in the atmosphere; plants breathe in CO2 and give off oxygen as a waste product; animals breathe in oxygen and give off CO2. Oxygen is such a reactive element that if it were not constantly pumped into the atmosphere by plants its current abundance of 21% of the atmosphere would diminish to 1% in less than a year. Critical nutrients (elements) such as phosphorus and nitrogen are made available to the larger biosphere by neither plants nor animals, but rather by bacteria and fungi.

2. Where does the energy for the ecosystem come from? What are the variables in energy supply (day-length, summer-winter, cloud cover, aspect, latitude)? How does the energy leave the system?

Comment: Most of the available energy on earth comes from sunlight. Plants have to compete for it—that is one reason they have grown taller over evolutionary history. In the Methow, different plants grow on different aspects because the amount of solar gain (and evaporation) varies greatly between north and south-facing slopes. Other variables include day length through the year, the angle of the sun, cloud cover and latitude. The energy balance for the system has to be fairly precise, or it would either heat up and cook or freeze solid.

3. Where does the water for the ecosystem come from? What are the variables in water supply, and how do plants respond to these variables? How is water retained in the system.

Comment: Obviously water comes from the sky, but plants are very responsive to how it moves across the land, with different species on north and south slopes and in the draws. The shapes of conifer and broadleaf trees and their leaves/needles, the strategies of evergreen verses deciduous leaves, and the strategies of annual, perennial and woody plants are all varied responses to how moisture is delivered and how long it is available.

4. Where do the nutrients critical to life (carbon, oxygen, nitrogen, phosphorus) come from in this ecosystem, and how are they retained (cycled) within the ecosystem?

Comment: The atmosphere is composed of 78% nitrogen, but it is bound up as a molecule ($N^2$) and is unavailable to plants and animals in this form. Only certain species of bacteria can split the molecule and make nitrogen available to the larger life community. Carbon is critical to the structure of living cells; most of it is supplied by the carbon dioxide in the atmosphere, which only resides there in parts per million (currently about 390 ppm; it is estimated that life captures about 100 billion tons of carbon per year from the atmosphere). Phosphorus and potassium are present in rock and soil, but they are water soluble and will be lost to ecosystems unless retained in living cells.

5. Who are the main primary producers in the ecosystem? Who are the primary, secondary, and tertiary consumers? Who are the decomposers? In other words, who lives here?

Comment: Primary consumers are those that eat plant material, secondary consumers are carnivores that eat primary consumers, tertiary consumers are the top predators and eat everybody else. The earth only receives one billionth of the energy the sun gives off, and plants only capture about 1% of the solar energy that does arrive. Primary consumers are only able to utilize 10% of the energy stored in the plant tissues they ingest, and secondary and tertiary consumers only capture 10% of the energy in the animal tissue that they consume. So energy is always at a premium.

6. Ecosystems tend to grow more diverse, complex and biodiverse over time, slowing and refining the passage of energy and nutrients through the system. Give some examples from a particular ecosystem of how this is or is not occurring.

Comment: Areas of the Amazon rainforest have as many as 200 tree species per acre, while the Siberian taiga averages 1 tree species per acre. The numerous tree species in the rainforest would each have unique insect and other species associated with them. Such high levels of diversity seem to be the result of ecosystem stability (constantly warm and wet) and interspecies competition—individual species become experts in a particular niche.

7. What is the relative net primary productivity (amount of biomass) of this ecosystem? Is it highly productive, moderately productive, or is primary production relatively low?

Comment: One way to measure net primary productivity is in calories of energy captured per square meter per year. Wetlands and rain forests are the most productive at about 9000 calories captured and stored per square meter. Temperate forests capture about 6000 calories, temperate grasslands 3000 calories, and deserts 500 calories.

8. What are factors limiting primary (i.e. photosynthetic) production?

Comment: Sunlight, water availability, temperature, nutrient availability, carbon dioxide level in the atmosphere, latitude, aspect, ecosystem disturbance and stability over time and herbivores all have an effect on photosynthesis.

9. What are some factors limiting the overall carrying capacity of the ecosystem, and factors limiting the carrying capacity of a specific species?

Comment: Factors controlling overall carrying capacity are similar to factors limiting primary production (see above). Individual species are limited by food supply (including seasonal bottlenecks, like winter at high latitudes), water availability, predators, reproductive success, and intra-species competition.

10. How stable or unstable is the ecosystem? Is it at an early, mid- or late-seral stage?

Comment: The scale is relative; some tropical ecosystems may change little for many thousands of years, whereas there was a mile of ice covering the Methow just 15,000 years ago. Our local ecosystems can be rapidly set back to an early seral stage by fire and ice, water, insects and humans.

11. What are the assembly rules for the community? Who depends upon whom? Who arrived first? What is the likely succession scenario?

Comment: Colonizing plant species of bare land typically are annuals with limited needs for ecosystem relationships and services. They may for example be wind-pollinated, thus escaping the need for animal pollinators. Some weedy plant species reproduce asexually or self pollinate, obviating the need for a mate. Plants capable of fixing nitrogen (such as members of the Pea Family) are likely early seral species. Some plants need bare soil and bright sunlight to germinate and grow, other species are adapted to grow in humus and minimal sunlight.

12. What are some of the factors controlling disturbance and succession? Is the system subject to alteration by fire, water, storms, insects, grazing/browsing? How would potential early and late-succession plants disperse to the site?

Comment: Fire is obviously related to climate; the fire return rate for our shrub-steppe and ponderosa pine is about every 10 years (although frequent fires mean they will burn cool). That rate increases in years as you go up in altitude (because precipitation increases) or westward (ditto). The Pearrygin Creek blowout in 2011 showed the power of water; rocks, trees and shrubs were carried 2000′ down the mountain and carried on the flood tide onto the dry shrub-steppe at bottom of the hills.

13. Identify some community interactions: competition within a species and between species, predation and defenses against becoming prey (i.e. plant defenses against herbivory, animal defenses against predation), mutualism, commensalism, parasitism.

14. How will (or have) some of the species present alter the bio-physical environment over time?

Comment:
The presence of life tends to slow the movement of energy, water and nutrients through the system. Energy that would have been lost will be stored in plant biomass. Plants will both shade and add humus to the soil, increasing its water-holding capacity. Temperatures will be cooler at ground level due to shading. Roots will crack apart rocks and bring nutrients to the surface.

15. How biologically diverse is the ecosystem (relative number of species) and what are the factors controlling the level of diversity?

Comment:
Biodiversity is relative; it is generally much higher in the moist tropics and much lower in the cold high latitudes. Estimates of biomass (a stand-in for species diversity) are 4-7 lbs/m2/year for tropical rainforests, 0.5-1.5 lbs/m2/year for boreal forests, and 0.2-0.5 lbs/m2/year for tundra.

16. Where does the garbage and waste in the ecosystem go?

Comment: There is no garbage and no waste in nature.