CHAPTER 3

Ecology: life's networks

Ecology is the study of natural systems, their interdependence and inter-relationships. An ecosystem is a community of organisms interacting with each other and with their physical environment and functioning together as a complex self-sustaining natural system.

The study of ecology and cosmology over the last 30 years or so has introduced the idea of 'nested ecosystems', where separate microclimates are nested within a bioregion, nested within Earth's biosphere, nested within our solar system, nested within our galaxy, etc. In other words, local systems are autonomous in some senses but also interdependent with other systems in ways that we are only now beginning to understand. And at every level complexity is inherent.

Ecologists believe in what's known as 'the ecological imperative', which says that humans are part of ecosystems and must acknowledge their inter-relationship with and interdependence upon them. Permaculture is often called 'the cultivated ecology' because of its goal to integrate and transform human societies so they live in sustainably designed and highly productive ecosystems where self-interest is aligned with the common good.

Our ethical task is to:

- design ecosystems that maximise the number of productive species
- use energy and matter effectively
- move towards ecosystem perpetuation.

Our ecological design aims are to:

- preserve genetic diversity
- respect the right to life of all species to contribute to ecosystem structure
- allow ecosystems to evolve under changing conditions—the land forgives us
- use species and habitats sustainably so the essential life-sustaining processes can continue intact
- design closed systems in which all needs are met.

If we don't have ecological design aims:

- closed systems are broken open
- artificial industrial systems are created which depend on non-renewable energy sources. For example, when industrial agriculture, called monoculture, removes biodiversity the ecosystems collapse. Forest removal is especially damaging and its destructive effects multiply because when the closed system affects other connected systems they also collapse—a bit like taking the bottom out of a

pyramid. There are serious flow-on effects in time and space. Some examples are:

- We break fundamental and often unknown laws of nature.
- Rivers loaded with farm chemicals choke and die.
- Clear-felled forests become eroded and disturb rainfall patterns.
- Drained wetlands lose habitat for migrating birds.
- The atmosphere, overloaded with gases, causes global warming.

Closed systems

Natural ecosystems are known as closed systems because they meet their own needs internally. They supply pest management, nutrients for all species, temperature control, soil building and maintenance, wind control, pollination, germination and pruning. They don't need any human management or inputs. A well-designed mature permaculture system approximates a closed system in meeting as many of its needs as possible.

Look how the Banana Circle in Figure.3.1 is an example of a designed cultivated ecosystem.

- The acacia provides windbreak protection for the bananas, seed for the chickens, mulch for the ground and puts excess nitrogen into the soil. It needs weed control and nutrients.
- The growing banana plant uses surplus nutrients and holds soil against erosion. The stem holds water. It requires windbreaks and pest control.
- Chickens eat any pests of the bananas (a protein source), obtain water from the base of the banana, supply nutrients in the form of manure and eat the seeds of the acacia. They need water, seed and protection.

The functions of healthy ecosystems are to:

- create and support life
- clean air, clean water, and sometimes toxins through various filters
- regulate the atmosphere through recycling carbon and nitrogen
- build soil together with soil micro-organisms.
- manage pests and diseases

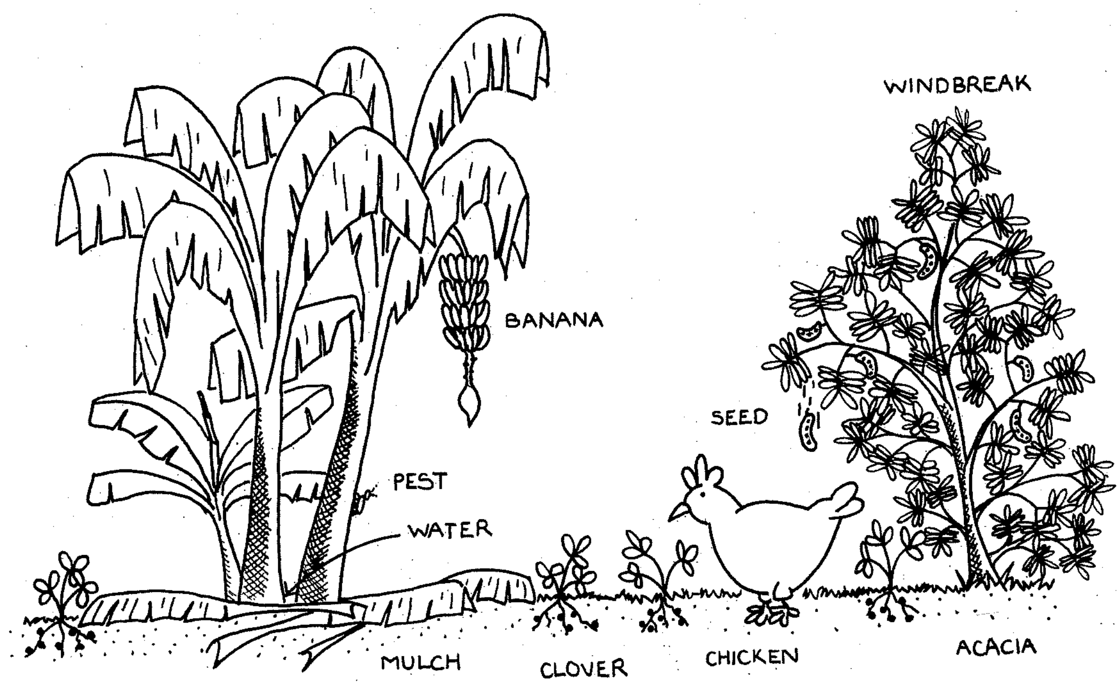


Figure 3.1 A cultivated ecosystem. Ecosystems can be consciously designed to be productive and sustainable.

- perpetuate themselves
- create highly integrated structures—often finely tuned
- become closed systems.

These concepts of natural functions translate into practices which you will learn. So, for example, biological water cleansing requires a design that approximates a wetland's because wetlands cleanse water.

Gaia

The Gaia theory was developed by the nuclear scientist James Lovelock in the 1980s. He hypothesised that the Earth could be imagined as one entire living super-organism evolving over the vast span of geological time. He believed that the Earth is a complete organism and, like all others, is essentially self-regulatory and keeps itself in good health. In his theory he suggested there are various organs which are critical to the survival and health of Earth. He made the analogy that forests are like the kidneys filtering and cleaning water; oceans are like the lungs; rivers are like the blood system; rocks are like the bones; and that when organs are destroyed, so the life of the organism is severely threatened. Each organ is intimately related to all others and disease in one affects the others. So, for example, destruction of forests causes imbalance in the Earth's atmosphere and hydrology.

Organs can only take so much destruction before a critical point is reached and they collapse. Lovelock suggests that when forest cover falls below 30 per cent of the Earth's surface then other systems will collapse. In permaculture we set goals to clean water, protect rivers, and maintain or create at least a 40 per cent permanent tree cover.

He also suggested that human impact on the earth should be seen in the same light as a virus's impact on an organism. The theory is now widely accepted. If it is proven correct we have a very unhappy future ahead of us. So now we must audit, monitor and regulate our consumption of non-renewable resources. We have two principles to guide us.

- *The precautionary principle*, which states that we should take seriously and act on any serious or destructive diagnosis unless it is proven erroneous. This applies to the Gaia theory. It is a basic principle of ethical design.
- *The intergenerational equity principle*, which states that all future generations have the same rights as us to food, clean water, air and resources.

Our ecological footprint

Since writing the first edition of this book, the exciting and useful concept of a measurable ecological footprint has emerged as a way for everyone to know, understand and compare their impact (footprint) on Earth and its resources.

The ecological footprint is a measure of a person, town, city, or nation's use of resources. It measures use of energy, water, food, clothing, housing materials and transport. Each of these is calculated and given in hectares. There is now no excuse for not knowing what we cost the Earth, and because our footprint is measurable we can also reduce it. To reduce our ecological footprint is one of the goals of permaculture design.

Anyone can measure their footprint. Schoolchildren now regularly calculate theirs. For a fair and equitable use of Earth's resources, each person requires a 2.5-hectare footprint to meet all their needs and sustain the processes of nature that make life possible. At the moment, Australians have a 7.6-hectare footprint. At this rate we require three Earths to continue to meet all our needs.

The larger your footprint, the more of the Earth's resources you use. For example, a child scavenging a dump in Mumbai has almost no footprint, whereas children in Amsterdam can have a footprint of 9 hectares. On average, the Dutch have a footprint of about 7 hectares. The world cannot afford this degree of consumption. It means that many nations send out and raid resources from all around the world, for oil, timber, heating, foodstuffs and clothing. A country like Afghanistan has a tiny footprint because it produces almost everything its population uses. The people build their own houses, grow most of their own food, use little transport and so do not contribute to reducing non-renewable resources. There is also little pollution or overloading of ecosystems. They are much nearer to being a closed system than most countries are.

Look at the website *www.myfootprint.com* and calculate your footprint. Then, after practising permaculture for a year, measure it again and you will find your footprint is reduced. You start by reducing your largest 'toe' or factor. If it is water then start there; if it is transport then reduce that.

The concept of 'food miles' is used for reducing your footprint for food. Food miles are a measure of how far your food travels and, consequently, of the resources used for it to get to you. We need to know the food miles of everything we eat.

A third important ecological measure is harder to find out but has been calculated for some products. This is the 'lifecycle cost', or the cradle-to-grave cost, of any product. Most often this is measured in terms of how much energy is required to:

- source the raw materials
- manufacture the product
- package, transport and market it
- dispose of it when discarded or useless.

This is usually referred to as the embedded energy cost. However, it can also be calculated in other ways. For example, every litre of bottled drinking water takes 200 litres of water to produce. This is its cradle-to-grave cost, or the real cost of finding water, piping it, cleaning it, making bottles, transporting them, packaging them and then tossing away the bottles and their effect on climate change. The cradle-to-grave cost of a pencil is 30 per cent of that of a ballpoint pen. A staple has a greater cost than a paperclip because the paperclip is reused many times. Every product has a cradle-to-grave cost. Any product with more packaging than an equivalent product has a greater cost. Always choose the product with the lower cost and boycott the other one.

The new science of networks

Network science is the newest science and was only defined in 2004. It explains the complexity and stability of ecosystems. Science until now has taught us about entropy—basically that things fall apart. According to this theory, the universe, left to its own devices, will degenerate and tend towards entropy, or ever-greater discord and randomness. And yet in permaculture we see things that do just the opposite, that seem to drive themselves to an ever-greater development of patterns and complexity, as happens with the evolution of ecosystems. In life we can go from a world in which everything is disconnected to a world in which everything is connected; for example, from putrid organic matter to composted humic acid.

According to the new science, integration and complexity rely on synchronicity and networks. Scientists have found that pairs and trio-links start first and these are called nodes. Then, as these make links, a giant component emerges in a very short time to form one huge 3D network called a cluster. So we go from a stage of disorder, of chaotic motion, to order where everything is linked. The point at which that happens is called a tipping point, or phase transition. When water turns to ice the tipping point is 0°C and all the molecules in water form ice. Nodes and clusters make this happen. Everything is a network: knowledge, epidemics, diseases, nutrient cycles, electricity grids, crickets chirping, nervous systems and roads.

Nodes and clusters dominate nature. The network structure is very efficient at passing information on and also enables us to understand why and how structures collapse. Take out a cluster with a high number of links and you get cascading failure—the systems collapses. This explains why, if you take out a keystone species such as bees, ants or some plants, a system will rapidly degrade.

So in a garden or on a farm, some species are nodes and others links. The daisy family, which many insects visit, is a node and bees are its links.

What will happen if nodes are destroyed or not included in a design plan? How do we make nodes and then link the nodes? We only know a little, but what we do know we use in our designs.

Permaculture has always known about nodes and links intuitively and has created links between species, especially keystone species. But now we have a name for it—network science—which gives us a clearer concept and the language to include it in our design thinking. We know that it is not the number of species as such that is important but the number of links between them.

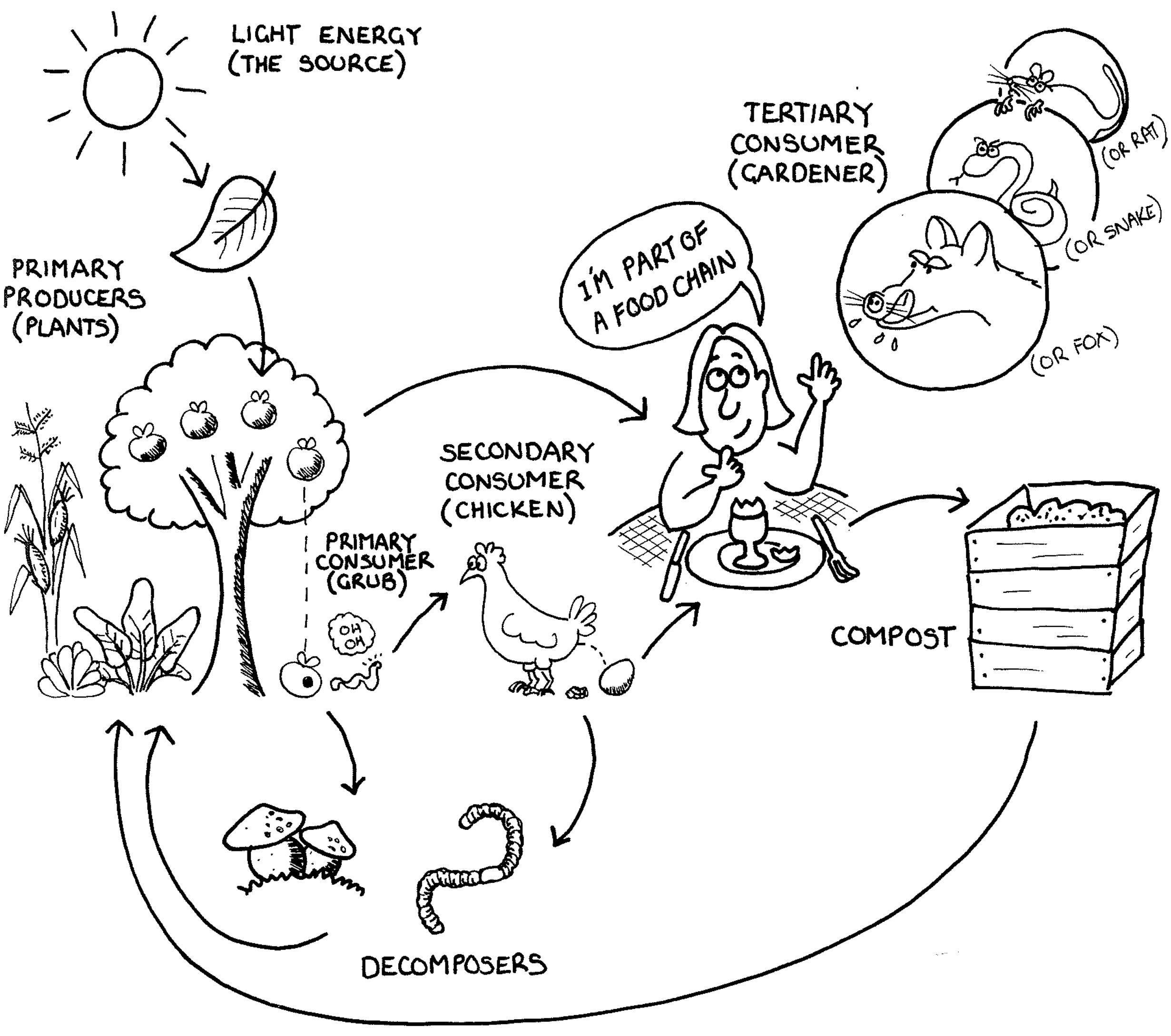
How ecosystems work

Ecology is a young science and we really know very little about it. However, here are some starting concepts that are helpful for designers.

Energy flows through ecosystems

All life forms must have energy to drive their activities. The primary source of energy for life is light energy from the sun. Plants capture light energy through photosynthesis and turn it into chemical energy, such as carbohydrates, sugars, waxes and oils which are eaten by organisms and, in turn, supply them with energy (see Figure 3.2).

Figure 3.2 Plant a garden and watch the energy flow.



Energy moves through all living systems from the sun (the great power station in the sky) to the plants (primary producers), then to the herbivores (consumers), which eat seeds, grass, leaves or fruit and a variety of other organisms. They, in turn, are eaten by carnivores. Eventually, everything decays and ends up in the gut of the earthworm (decomposer) where the remaining energy is finally released by a bacterium as carbon dioxide and water.

Figure 3.2 shows the flow of energy through a system called a food chain. By growing plants, whether a vegetable garden, or a forest, you are initiating the capture of energy from the sun. It then flows through all organisms by a variety of routes, which form a web or network.

Energy can be lost from your system (when you take leaves and grass cuttings to the tip, for example), or you can save it and reuse it (by turning those cuttings into compost). When you are conscious of the flow through of energy you use it many times. When chickens eat your diseased fruit to make manure, which is fertiliser for your garden, you are using energy well.

Matter cycles

Matter consists of all the elements and molecules which make up the gases, vitamins, proteins, minerals and other nutrients of life. The total amount of matter in the world is constant. Yet each element can change to other forms. For example, iron may take one form in blood and another in rocks. As it changes form, it cycles through various organisms.

All matter cycles through living and non-living materials (air, rock, trees, animals, etc.) on Earth. The cycling of matter is driven by the sun and facilitated by the flow of energy. Cycles can be fast, as in the simplified nitrogen cycle shown in Figure 3.3, or slow as for uranium.

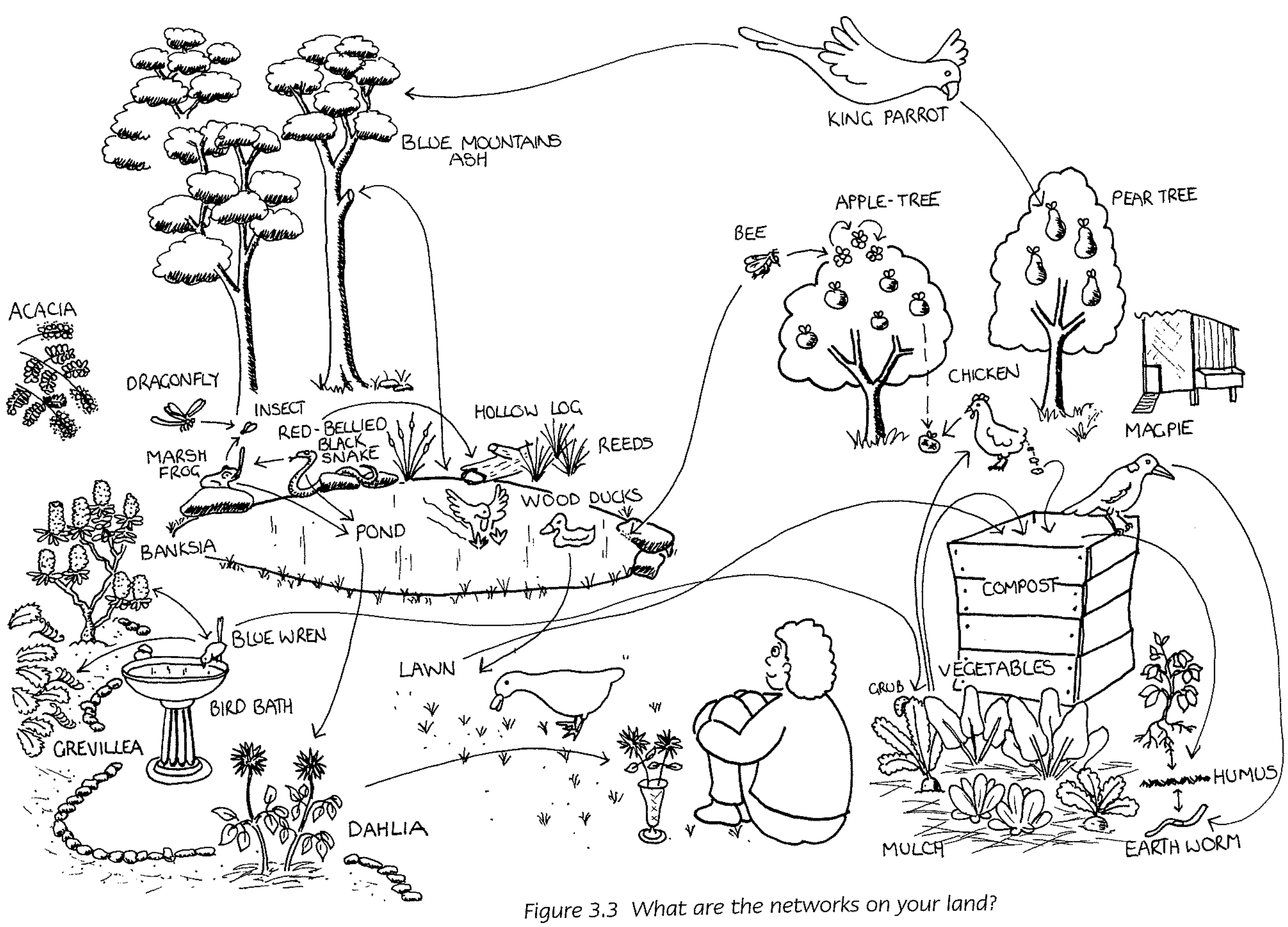


Figure 3.3 What are the networks on your land?

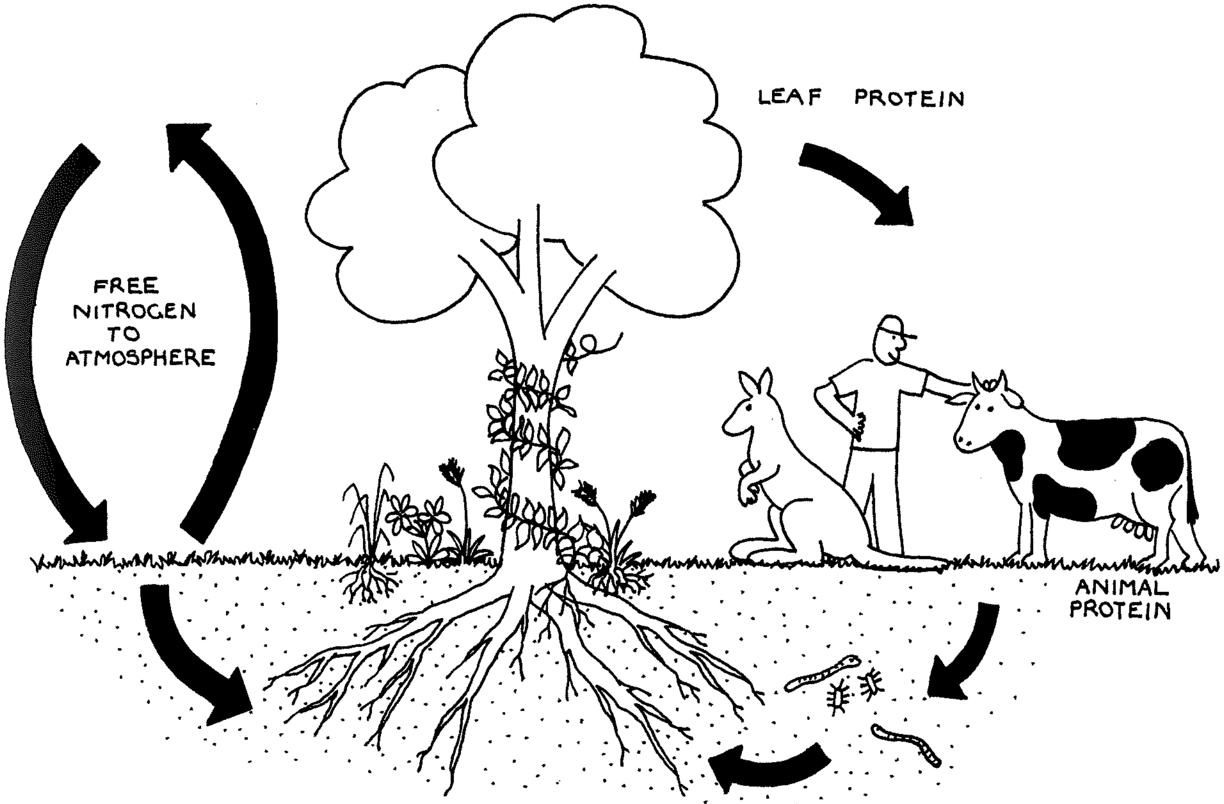


Figure 3.4 Cycling of nitrogen. The nitrogen cycle is one of the essential nutrient cycles which occur in ecosystems.

Surplus causes pollution

When there is surplus to any system's needs it causes pollution, whether it's unburnt gases, chemicals in water, exotic animal invasion or loud noises. Pollution is human design failure.

When inputs are not fully utilised in cycles of matter it is called bioaccumulation; this is one type of pollution. Surplus phosphate fertilisers not taken up by crops move into rivers and grow toxic algae. In this case, dense plantings of bands of trees alongside all waterways could usefully take up the polluting surplus and turn it into a valuable product.

Humans interfere in natural cycles when they release large quantities of materials that cannot move easily into webs or networks. DDT is one of these. It simply accumulates all the way through the food chain, ending up in human fat deposits, and is not broken down to simpler substances.

Biotoxicity occurs when materials, under certain circumstances, become toxic. So, for example, inorganic mercury found in rocks is reasonably benign until it moves into the food chain. There it is transformed into organic mercury, which accumulates in the brain and eventually destroys it. Inorganic mercury was thrown into Minamata Bay in Japan where it was absorbed into the food chain through fish. People ate the fish and 80,000 became sick or died. Today this is called Minamata disease.

Many products are marked biodegradable. Theoretically, biodegradable means a substance will be broken down into another that can move into food chains. However, very often it is broken down but then bioaccumulates because the quantity of, say, phosphates from household soap, although soluble, is simply too much for the cycle and can't be absorbed. In this way it becomes a pollutant of soils and waterways.

In permaculture we set up nutrient cycles. By using animals, compost, mulches and a selection of plants, we widen the range of materials being cycled and in some cases speed up the process.

Food chains and food webs are the structure of ecosystems

The flow of energy and the cycling of matter take place through food chains and food webs. These allow ecosystems to function. Figure 3.5 shows that from the king parrot to the earthworm is a line called a food chain. When food chains interlock they form a food web.

Together, food webs form the structure of an ecosystem. A small and weak web has very few species, few links and is vulnerable. The more complex the structure of an ecosystem, the greater its stability and strength. The more efficient the flow of energy and cycling of matter, the more likely it is to perpetuate itself. Think of a 10,000-hectare wheat field. It has a very few species and a weak structure. It can be blown down, attacked by pests, hail, drought, flood and so on. It functions inefficiently, requires huge energy inputs from the farmer, fuels and fertiliser, and can't perpetuate itself.

The key to resilience in permaculture systems is biodiversity of linked species, niches and habitats. A permaculture-designed wheat farm would have small fields protected by windbreaks of mixed species. All the necessary nutrients would be supplied by a variety of organic means, such as green manure crops and cover crops. If you don't know what these are you will find out in Chapter 6 on soils.

Succession and limiting factors

Earth has a huge range of ecosystems because of different factors acting on them. Limiting factors can be temperature, rainfall, soil, day length, altitude and distance from oceans. These tend to

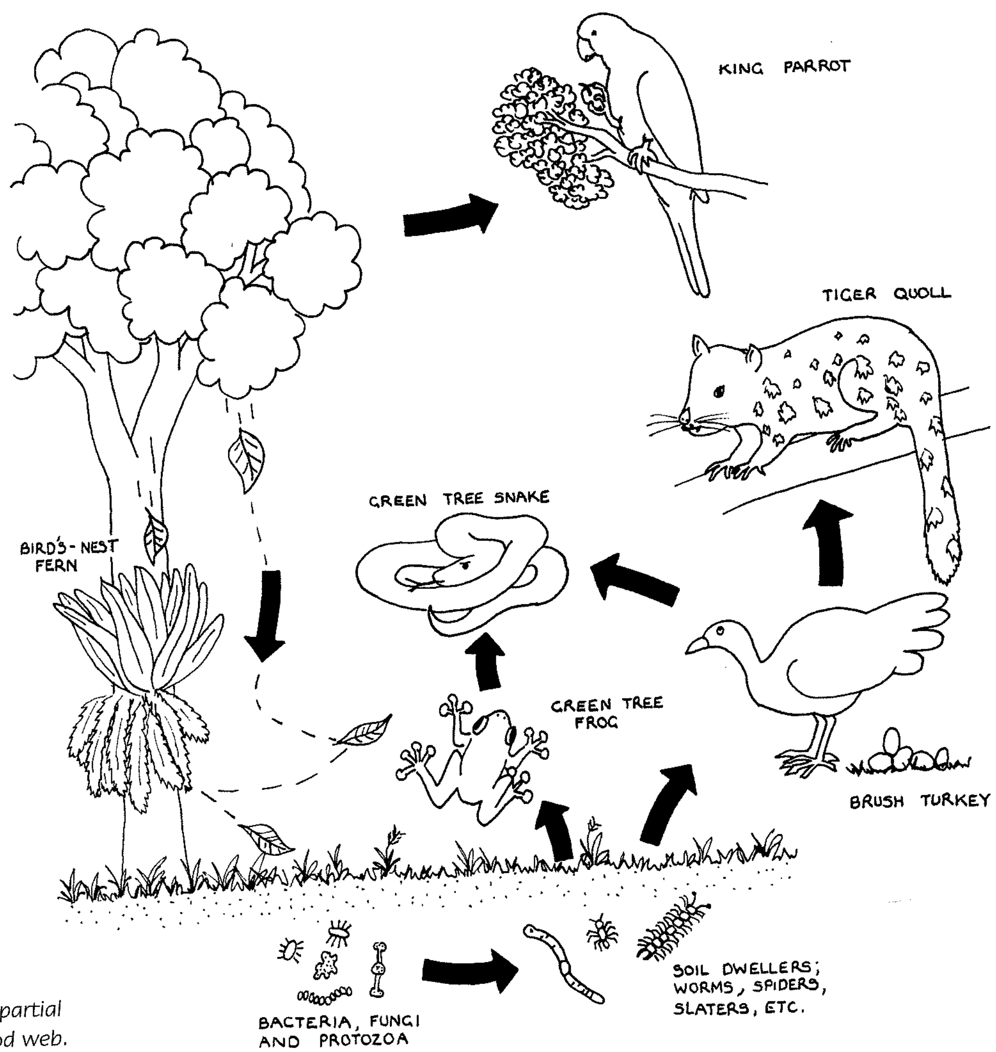


Figure 3.5 A partial rainforest food web.

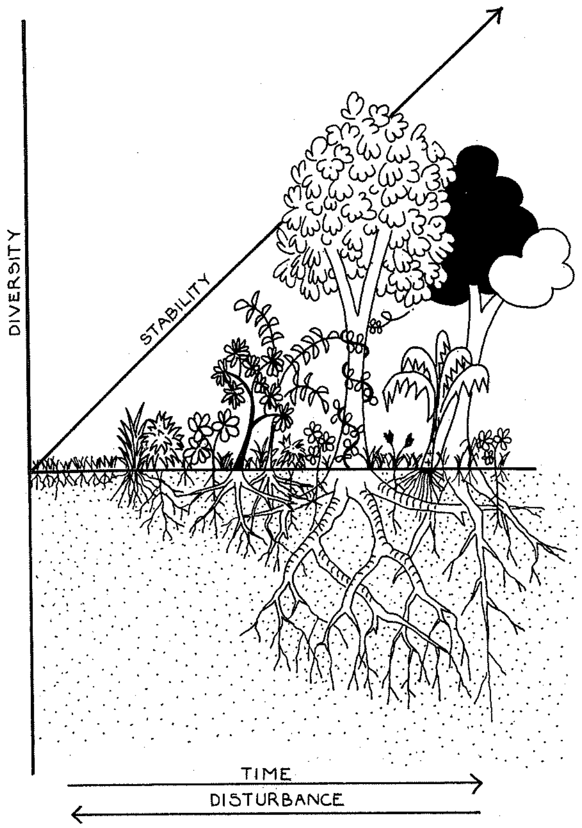


Figure 3.6 Succession.

reduce, inhibit or slow down growth. Climate is the main determinant of the vegetation of an ecosystem and soil is generally second in importance.

Figure 3.6 shows species diversity on the vertical axis and time on the horizontal axis. After a natural or man-made disturbance the ground will be bare. In time this will be colonised by grasses, and these will be succeeded by herbs, shrubs, small trees and bigger trees. Finally, there will be forest. This process is called succession. Succession happens because each type of plant changes the nutrient levels in the soil preparing it for the next type of plant.

Any disturbance drives succession backwards. On the other hand, as more and more species are added ecosystem stability is strengthened. For example, pioneer planting will provide windbreak protection for later wind-sensitive plants.

In permaculture you start successional planting with local species of plants and animals that do well in your region. Then, to increase the number and variety of species, you design features that moderate the limiting factors. Remember that every ecosystem is embedded (nested) in other ecosystems and does not exist alone. What you design will impact outside the site you are working on.

Stacking

Stacking is using space and time economically by packing in species. You can do this by:

- Planting so densely you can't see the ground and so shade out weeds. Shade-loving species are planted under tree canopies, vines are planted to climb orchard trees, and crops are inter-planted. This is called stacking in space.
- Growing different crops with each other, so that as the clover finishes the lucerne is already coming up. This is called stacking in time.

Another way to stabilise ecosystems is to use space more effectively by omitting the grass and herb succession and moving directly to planting shrubs (look again at Figure 3.6). These shrubs are known as pioneer or nurse species because they can live in degraded soil, improve soil nutrients and protect the new seedling trees. This is the main technology in rebuilding rainforests.

Your goal in designing landscapes is to move as far along the time axis and against the disturbance axis as possible.

Ecotones

The edge where two or more ecosystems meet, known as an ecotone, is extraordinarily rich and productive. Take the estuary where the ocean meets the land, or the edge where rivers meet land, or where the road meets the bush. At each of these there are many more factors of heat, warmth, water, temperature and species than in the middle of the ecosystem itself.

Ecotones impact on harvesting and design. Pest management, weed control and our relationships with wildlife are also affected. In permaculture we try to increase edge effects to create more microclimates, by providing wavy edges to garden beds, aquaculture systems and grey-water delivery techniques.

Guilds and relative placement

'Guild' is the permaculture word for co-operative groups of plants that support each other and thrive when grown together. Usually, they have evolved in the same place and under the same conditions. For example, beans, corn and pumpkins support each other. They occur naturally and also in wild systems. Acacias and eucalypts grow well together; legume and cabbage families help each other thrive. In one Aboriginal language this concept is described by the word *waru*. The bird, the worm, the tree and the spider all form a *waru*.

Relative placement occurs when you place elements relative to each other and to other parts of your overall design. For example, if you plant your vegetable garden close to your kitchen and where you walk through it every day, you will look after it better and harvest it more often. You can have your compost bin there and also send recycled water to it. When all parts save time, work and resources, the relative placement is effective. If you place your vegetable garden in one corner and your compost far off in another, the relative placement is poor and you will work harder.

The human role

We know we are consumers, but is that all we are? With our capacity to reflect, it seems as if our role could be as custodians of land and resources. Custodians 'have care of', or are keepers. This is an old familiar idea for people who live close to the earth. By taking on a new role of guardianship, perhaps we could successfully husband our Earth through this crisis.

Permaculture is not the only design system that takes into account our new understanding of the uniqueness and fragility of Earth's present biosphere and our role within it, but it is the most comprehensive.

Try these:

The following exercises will help the theory you have just read come alive.

1. Sit in your garden and look for a food chain or part of one. If you find it difficult, watch a bird and see what it eats, or look for an eaten leaf on a plant and see if you can find the organism eating it.
2. Look in your compost bin and describe some of the inhabitants there. Draw them or just write a list of them. Are they the same in winter and summer?
3. Do seasonal counts of all the species in your garden. Start now and do it again every three months. As the numbers fluctuate you will have an indication of the stability of your ecosystem. You can draw up your page like this:

Season	Number of Animal Species	Number of Plant Species
Spring	6	30
Summer	22	31
Autumn	25	43
Winter	8	19

4. Go back to the principles of permaculture and decide which have an immediate impact on reducing your ecological footprint and how you will apply it.
5. For the next month record every single thing you bring into your garden from outside your boundaries, that is, seed, water, fertiliser, plants, mulch and so on. This is a measure of how open, or closed, your system is.
6. Do you know your ecological footprint? If not, find out now, and then ask others what theirs is.