ECOLOGICAL SYSTEMS

Nature never breaks her own laws - Leonardo da Vinci

INTRODUCTION

Ecology can be defined as that branch of science which studies the relationship of living organisms with each other within their physical environment. Organism and their physical environment form ecosystems. Human settlements also form ecosystems within larger ecosystems. At any point in time, ecosystems can be new or old, changing their boundaries and growing or declining, or in a form of climax or steady state. This section uses energy diagrams as developed by Howard Odum (1976) to help compare ecosystems and recognise equivalent roles in different systems, including that of human settlements.

PRODUCERS AND CONSUMERS

All ecosystems are solar based and have some common characteristics that abide by the Laws of Thermodynamics. Within an ecosystem there are the food producers, plants which use sunlight to produce food, and food consumers, both plants and animals that use this food. Both producers and consumers maintain an ecosystem by recycling the by-products given off by each other. Figure 1 shows a balanced ecosystem.

Figure 1 Balanced Ecosystem (Odum, 1976, p95)

Sunlight supports the photosynthetic process of the producers. Heat disperses into the atmosphere and oxygen is produced. The consumers use this oxygen and feed on the food of the producers giving off heat and carbon-dioxide as they do so. Carbon dioxide plus sunlight forms the food of the producers. The producer-consumer interaction of the two processes of photosynthesis and respiration are complementary - one provides what the other needs. This complementary interaction is called symbiosis.

Figure 2 shows this producer-consumer (P-R) symbiosis. Chemical components are isolated to show how they cycle in the P-R process. Each component contributes part of the energy requirement. The nutrients are shown coming out with the heat, but going on separately to be cycled and reused.

Figure 2 Producer-consumer symbiosis (Odum, 1976, p100)

Plants develop living biomass from the process of photosynthesis. Upon dying, this biomass falls to the ground as wood and forest litter. Some of this biomass is eaten by consumers before dying, or is consumed by insects and microbes after dying. These processes form a food chain. A plant eaten by one animal might in turn be eaten by another animal, and so on. Most ecological systems develop food chains with at least five stages. A food chain is linear and follows the generalized form of Plant - Herbivore – Carnivore. The quality of energy is upgraded at each step of the chain, but with an inevitable accompanying loss of energy to heat due to the Second Law of Thermodynamics.

In nature, the food and feeding relationships of plants and animals are rarely in the form of a simple linear food drain, but instead interconnects with a large number of other food chains to form a food web. This web can become extremely complex, and the discovery and description of a food web in any given habitat is an enormous task. This is why tampering with a food web can have some unexpected and undesirable effects.

Animals at the base of a food chain are relatively abundant, while those at the other end are relatively few in number. There is a progressive decrease in between the two extremes. In comparing the population of other carnivores and herbivores with that of humankind, it is clear that humankind does not have the same symbiotic relationship within the ecosystem. The reason why is because humankind has been able to tap the resources of energy and utilise this energy to sustain a larger population than that of other similar sized animals. Other parts of the ecosystem may not be able to tap external sources of energy other than sunlight but they too have inflows and outflows of mineral nutrients.

Figure 3 is representative of a typical ecosystem, with inflows of both organic matter and mineral nutrients so that both photosynthesis and respiration are stimulated to higher levels than they would reach without the inflows.

Figure 3 Steady state inflow and outflow of nutrients (Odum, 1976, p104)

GROWTH AND UNLIMITED ENERGY SOURCE

Whether a system can continue to grow or not depends upon whether the system can tap a source of energy that can maintain further growth. During a period of growth when the storage of structure, reserves of energy, population, information and order are expanding, the inflows of energy into the system exceeds the outflows. With a large energy source such as a rich oil well, energy users can tap whatever amounts of energy they can pump. With a limited energy source, energy users must divide up the limited flow as shown in Figure 4.

Figure 4 Comparison of energy sources (Odum, 1976, p47)

The Maximum-Power Principle first formulated by Lokta (1925***) explains why some energy systems survive others. This principle can be state as follows:

> *The systems that survive in competition are those that develop more power inflow and use it best to meet the needs of survival.*

According to Odum (1976, pp40-1), ecological systems which use the Maximum-Power Principle develop storages of high - quality energy, feeds back work from the storage to increase inflows, recycles materials as needed, organises control mechanisms that keep the system adapted and stable, and sets up exchanges with other systems to supply special energy needs. Figure 4 demonstrates these ideas.

Figure 5 Energy feedback loop (Odum, 1976, p41)

The more energy that is pumped into the storage C, the more is fed back to A. This energy-pumping feedback stimulates inflow from the source of energy, E. The steeply rising graph of growth produced by this feedback acceleration with a large source of energy is sometimes called 'Malthusian growth”. As long as the source is larger enough to maintain a constant force in spite of a greater drain of energy, the pumping will increase faster and faster until natural limits are reached.

Super - Accelerated Growth

Over the past 100 years economic growth as measured by GDP in the developed countries has grown at faster rate than population growth. The growth in GDP per capita has grown at the same time as the population has grown. The growth in GDP per capita has been due to a universal conviction that growth and expansion is a positive value. The profit motive, the protestant work ethic, and a capitalist system has enabled a unified effort in bringing together resources for a maximum rate of economic growth. By way of co-operation, a self-interaction process, super - accelerated growth has been enabled.

Figure 3-6 Super-accelerated growth. (Odum, 1976, p69)

Growth is faster with self-interaction pumping than with ordinary Malthusian feedback pumping. The A+B curve is the super-accelerated growth made possible.

A system that is able to accelerate its growth faster than another system is able, to capture the energy source flows from the other system. A system which has super - accelerated growth survives at the expense of another system as shown in Figure 7.

Figure 7 Competitive exclusion (Odum, 1976, p71)

GROWTH AND LIMITED ENERGY SOURCE

A limited energy source is where the source itself controls the energy flow. An example is the sunlight falling upon earth. The extent of the process photosynthesis depends upon this incoming flow of energy. Once this incoming energy has been used to the fullest, growth either declines - a situation in which outflows exceeds inflows and storages are decreasing - or the system maintains a steady state where the inflows of energy just keep up with depreciation and losses as shown in Figure 8.

Figure 8 Limited growth, (Odum, 1976, p68)
Example a - Economic growth on large newly discovered oil reserves.
Example b - Economic growth on solar energy.

Figure 9 shows the mechanics of decline. An example would be termites feeding off a log until the energy source is completely eaten away.

Figure 9 Mechanics of decline. (Odum, 1976, p72)

Growth of quantity (Q) accelerates at first until the source (T) begins to run out. The quantity of stored order (Q) then gradually declines as depreciation (D) and outflow of feedback (F) exceed production (P).

Most systems are able to tap a steady source of energy and during their period of rapid growth they have been able to tap a temporary energy source as well. Figure 10 shows a surge of growth and then a return to steady state.

Figure 10 Surge growth to steady state (Odum, 1976, p73)

HOMOEOSTASIS

All ecosystems have developmental stages corresponding to that of an organism - birth, early rapid growth, and maturity. Each developmental stage brings the ecosystem closer to steady state - that is a state of homeostasis in which there is a dynamic equilibrium interaction between the ecosystem and its physical environment.

Succession is a natural process where organisms within the same ecosystem succeed one another by maximising their energy inflow until a highly stable climax ecosystem develops. During this succession stage, energy and nutrients are added to the ecosystem with the result that the net ecosystem production is high. The ratio of gross production P to respiration R is greater than 1, and the food chains of the ecosystem are linear.

As an ecosystem approaches climax, the P/R ratio approaches 1, the net ecosystem production approaches 0, and the food chains of the ecosystem tend to be woven into food webs. A climax ecosystem is stable and in a condition of internal self-regulation where feed-back mechanisms enables the ecosystem to return to equilibrium following any stress of change in climate, energy, and nutrient resources.

There is a relationship between diversity or complexity and the stability of an ecosystem. Increasing the complexity of an ecosystem may or may not increase the stability of the system. The development of a high degree of diversity can favour the collection of energy and provides flexibility in cases where there are changes in the relative availability of energy resources. On the other hand, the energy required for organising diversity is large and can be either an aid or a drain on energy. During the succession stage there is a low diversity of species, but a high level of diversity of special adaptations within the species. At climax there tends to be a high level of species diversity. A careful evaluation of an ecosystem should be made before a change in diversity is considered and effected.

Humankind are omnivores and eat plants and meat. We no longer hunters and gatherers. We are now essentially grazers who either feed off grain directly or indirectly through the breeding of animals which we eat. Agriculture is an attempt to increase the P/R ratio for humankind consumption by preventing the natural process of succession and decreasing diversity. Humankind has been able to crop a high yield from an unstable agricultural ecosystem by feeding in energy in the form of fertilizer, weeding, and insecticides. Monoculture systems of growing crops, building dams, roads, and different types of pollution threaten the homeostasis of ecosystems. An eco-energetic approach should be used to determine whether instabilities will occur in ecosystems so that appropriate changes to original plans of development can be made. In other words, the eco-energetic approach allows an environmental impact assessment of proposed developments.

CARRYING CAPACITY

Carrying capacity is the maximum population that can be supported in a given environment. As has been shown in previous sections, organisms and ecosystems have developmental stages where there is initially a period of slow growth, a period of rapid growth and a stable period of non-growth where there is a steady state climax. This also applies to the growth of the population of an organism within an ecosystem as shown in Figure 11.

Figure 11 Carrying capacity

The limiting factor that prevents further population growth is the availability of nutrients. In climax ecosystems there are complex food webs where the cycles of nutrients are tightly interlinked. The carrying capacity of each organism in a given environment is limited by the stock of that requisite of life that is in shortest supply. The following simplified diagram shows the interdependence of the nutrient cycles.

Figure 12 Interdependence of Nutrient cycles. (Ehrlich et al., 1977, p77)

Herbivores feed on plants, and carnivores feed on herbivores and fellow carnivores. As can be seen, the ultimate limiting factor of total biomass (combined carrying capacities of all organisms) in an ecosystem is the process of photosynthesis carried out by plants, algae, and certain bacteria.

The total quantity of solar energy entering the Earth's atmosphere is in the order of 15.3 x 10^8 calories/m^2/year. Much of this energy is absorbed by the atmosphere, or reflected back to space by clouds. The actual quantity of solar energy available to plants ranges from 2.5 - 6.0 x 10^8 calories/m^2/year depending upon the geographic location. However much of this available energy is not used in the process of photosynthesis. As much as 95% to 99% of this available energy is lost from the plants in the form of sensible heat and heat of evaporation. The remaining 1% to 5% of energy is used in photosynthesis and is transformed into the chemical energy of plant tissues (phytomass). Even then not all this energy is continuously available to herbivores as this energy represents the Gross Primary Production (GPP) of the plant. The Net Primary production (NPP) which is continuously available to herbivores is the sum of the Gross Primary Production less the respiration (R) of the plant. The ratio of respiration to gross production can range from 0.20 to 0.75, depending upon the type of plant. Figure 13 shows an example of the available Net Primary Production available to herbivores.

Figure 13 Net production (Phillipson, 1966, p6)

The photosynthetic efficiency of plants which is the ratio of Net Primary Production to the amount of solar energy received while the plant is in leaf ranges from 1% to 5%. A plant with high photosynthetic efficiency may not necessarily produce more phytomass per unit time than a plant with a low photosynthetic efficiency. The latter plant may have a higher productivity factor as plants have a different ground coverage percentage and not all plants carry out photosynthesis during the entire year. Over one year an average Net Primary Production is approximately 0.25% of the incident solar energy for land plants, though under favourable conditions this may reach 2% over the growing season. Because of these intervening complexities, it is more useful to consider productivity rather than photosynthetic efficiency as a comparison indicator of different plants.

Herbivores feed on the available Net Primary Production. On average they convert approximately 10% of their food intake to growth. The individual Gross Growth Efficiency – (Calories of Growth)/(Calories Consumed) - varies from 6% to 37% among the species and a high Gross Growth Efficiency indicates an efficient assimilation of food energy for growth with little being voided as faeces or used in respiration.

The Gross Growth Efficiency of an organism reduces as the organism grows larger. Another growth factor is the Net Growth Efficiency - (Calories of Growth)/(Calories -Assimilated) - where a high Net Growth Efficiency indicates that a relatively small amount of the assimilated energy is lost as heat of respiration and that the remainder is used for growth. Tissue growth efficiencies tend to decrease as one goes up the trophic level food chain. Herbivores, in building up their body tissues, dissipate a large proportion of the phytomass energy they consume. The efficiency of energy transfer between trophic levels – (Calories Consumed by Predator)/(Calories Consumed by Prey) - known as Linderman's Efficiency is approximately 10%. This efficiency ratio accounts for why the total phytomass of plants is greater than the biomass of herbivores which is greater than the biomass of carnivores. The biomass pyramid in Figure 14 shows this relationship.

Figure 14 Biomass pyramid (Ehrlich et al, 1977, p134)

Although the biomass of bacteria and fungi accounts for only 0.58% of the community biomass, the following energy flow pyramid in Figure 15 shows that they account for approximately 17% of the energy flow because, in general, smaller organisms have a higher metabolic rate and reproduce more rapidly than larger ones.

Figure 15 Energy flow pyramid (Ehrlich et al, 1977, p134)

The Net Community Production (NCP) available to humankind as a food and energy source is that share of the Net Primary Production or net phytomass humankind shares alongside with other herbivores. Humankind also feeds on biomass and that which is available to humankind is what I term Net Community Secondary Production (NCSP). Humankind is concerned with maximising food and energy resources by maximising the NPP/GPP, NCP/GPP and NCSP/GPP ratios.

If humankind wishes to maximise food and energy resources, then humankind should remain exclusively a herbivore and feed directly off plants and use phytomass as fuel alongside with hydro-electricity and other solar based energy sources. In doing so, humankind would be sharing the available net phytomass alongside other herbivores. This raises the question of whether humankind should attempt to succeed other herbivores.

It is improbable that humankind will succeed bacteria and insects by taking over their share of the net phytomass which is available. However, humankind has caused birds and animals to become extinct at a faster rate than normally occurs within nature. Assume that humankind does monopolise a larger share of the phytomass available. Would he be able to return to the soil the necessary nutrient cycle? For humankind to attempt a monoculture of his own species would be to upset the balance of nutrient and energy cycles resulting in succession of humankind himself by the lower order species. Humankind needs to live in harmony with plants, animals, insects, birds, fish, and bacteria in order to survive. In striking a balance between food consumption and energy consumption from phytomass together with other forms of solar energy collection we need to understand more fully the patterns of energy flow within ecosystems and, in particular, our own energy flows and their effect on the environment.

SUMMARY TABLE

	ECOSYSTEM ATTRIBUTE	**GROWTH STAGE**	**CLIMAX**
Energetics			
1	Gross production/respiration (P/R) ratio	Greater than 1	Approaches 1
2	Net production (yield)	High	Low
4	Biomass supported/unit energy flow (B/E ratio)	Low	High
4	Food chains	Linear	Weblike
Structure			
5	Species diversity	Low	High
6	Stratification and spatial heterogeneity (patter diversity)	Poorly organised	Well organised
Life History			
7	Life cycles	Short and simple	Long and complex
Nutrient and Energy Cycling			
8	Mineral and energy cycles	Open	Closed
9	Nutrient and energy exchange rate	Rapid	Slow
Selection Pressure			
10	Growth form	For rapid growth	For feedback control
11	Production	Quantity	Quality
Overall Homeostasis			
12	Internal symbiosis	Underdeveloped	Developed
13	Recycling	Unimportant	Important
14	Stability (resistance to external stress)	Poor	Good
15	Entropy	High	Low
16	Information	Low	High

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FURTHER READING *** to be added

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