Energy and Environment in New Zealand

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I CAN'T
STAND IT...


... AND YET THERE IS A CERTAIN PERVERSE NOBILITY IN IT...

A Note to the Teacher

Modern Biology courses often have a wider aim than simply introducing students to the elements of biological science. More and more teachers and curricula designers are seeking to provide a course that enables students to use their biological training to evaluate the relationship between man and nature - between human systems and natural systems. This change of emphasis arises out of a recognition that the impact of human systems on nature has been badly managed and that this mismanagement has important implications for us all. The next generation will have to cope with a complex of problems stemming from interactions between population, resources and environment. The first step towards coping is a clear understanding of the problem.

An understanding of the working of natural and human systems can best be obtained by using system analysis techniques. Systems analysis seeks to develop a package of basic principles that govern the working of both natural and human systems. These are then used to analyse the structure of systems and to predict their performance under different conditions. Students using this text will, in section I, be introduced to the basic principles of a system analysis 'language'. Then in section II, they will apply this language to the analysis of New Zealand ecosystems, both modified and unmodified. Finally, in section III, they apply the same analytical techniques to human systems in an effort both to identify key problem areas and to explore remedial strategies.

The text has been developed with particular regard for the 7th Form Biology syllabus. Portions of Section A and much of Section C of the 7th Form Biology syllabus are well covered by this text - although in a way that may be unfamiliar to those unfamiliar with systems analysis. HOwever, because the workings of natural and human systems do not confine themselves to the contents of our 7th Form Biology syllabus, there is some 'spill over' of contents into areas normally associated with Geography, Economics and Computer Science. Thus, to a limited extent, the text is multidisciplinary. Teachers involved in classroom testing of the manuscript have suggested that it functions well as a self-instruction text, with class discussion of suggested activities.

The use of computer analysis in the text also deserves some comment. System modelling really comes alive when combined with a computer. When we asked high school teachers about the advisability of including computer-based exercises in the text, we got two sorts of answers.

Those that had never seen or used a microcomputer considered it unwise on several grounds. Those that had access to the relevant 'hardware', or had seen microcomputers used in schools, thought most schools would have them within a few years, and that consequently we would be unwise not to include some material requiring computer analysis. Therefore, we have introduced the use of the microcomputer as an optional aid to system modelling. Where schools have the equipment, students are provided with sufficient guidance to 'begin at the beginning', and to proceed from there to some simple computer modelling. Where no computer is available, the essential exercises can still be completed without such equipment.

Finally, we recognise that the text offers something of a 'voyage of discovery' for most teachers. The multidisciplinary nature of modern biology, the potential for computer-assisted teaching and the unfamiliarity of system analysis 'language' combine to produce a text that requires a certain amount of courage to use. We urge you to do so, however, since the text has the potential to make a significant contribution towards the education of the generation of New Zealanders that might devise a new and more sustainable relationship between our human system and our natural environment.

ACKNOWLEDGEMENTS

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The Ecosystems of New Zealand map is adapted from the poster produced by the National Conservation Campaign, 1979, and used with permission of the Post Office Savings Bank.

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Footrot Flats cartoons are used with the permission of Murray Ball.

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PART ONE: PRINCIPLES AND SYMBOLIC LANGUAGE

1: Systems and Symbols

The earth is covered with living systems that are constantly interacting. Molecules interact with each other within cells; cells interact within organisms; organisms interact within populations; populations interact within ecosystems; and ecosystems interact with each other within the biosphere.

We can develop *models* of these various interactions to help us understand better the ways in which various living systems function.

The ecosystem is one important model of a biological system. We understand the ecosystem model to include:

- populations of living things (producers, consumers, decomposers);
- cyclic flows of nutrients (like C.N.P.);
- non-cyclic flows of energy; and
- the physical attributes of the system.

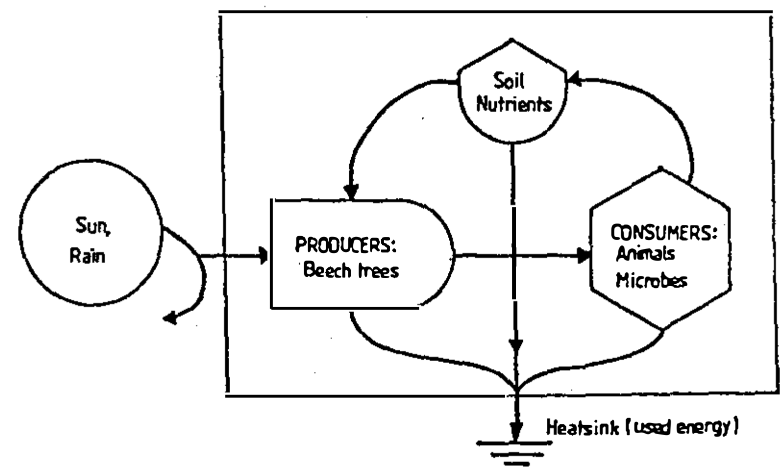


Figure 1.1 Beech forest ecosystem

1.1 A BEECH FOREST SYSTEM MODEL

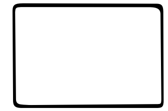
As an example of a typical New Zealand ecosystem, we have chosen a beech forest. A beech forest ecosystem is a system of interactions between trees, wildlife, microbes, soil, chemical cycles and air. Each of the many interactions is accompanied by a flow of energy. One useful way of representing the organisation of a beech forest ecosystem is to chart the flows of energy through the system, using a symbolic energy language. We have done this in Figure 1.1.

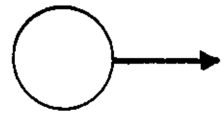
You can see the flow of sun and rain come together and interact with soil nutrients in the production process of the beech trees. Energy flows from the production of the trees are used by the consumer animals and micro-organisms to grow and to produce soil nutrients which are then recycled to the trees. Used energy from the processes and losses or *depreciation* from the storage flow out of the forest system as heat. The actual beech forest system has many inflows and outflows, such as nutrients coming in with the rain and water leaching out through the soil (Figure 2.1), but we have simplified the system to introduce the symbols.

Like any language, the language of system modelling needs practice before it can be mastered. This is not a difficult task, however, since you have already been introduced to the basic elements of our system language. The beech forest system model contains seven basic symbols from which our models will be built.

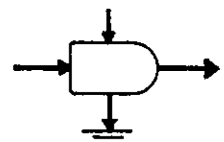
The rectangle formed by the solid lines shows the boundary of the ecosystem model. The circle of the sun and rain represents the energy inflow from outside the system. The lines with arrows show the directions of inflows and outflows. The symbol shaped like a bullet represents the production process of the trees. The hexagon is the symbol for consumption, in this case, by animals and microbes. The tank symbol indicates storage of soil nutrients within the forest. The heat sink is the symbol for the outflow of degraded heat energy and depreciation leaving the system.

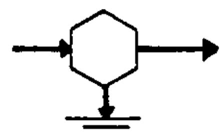
Remember:

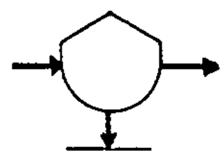

means boundary of ecosystem model

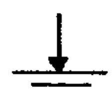

means inflows from outside the system

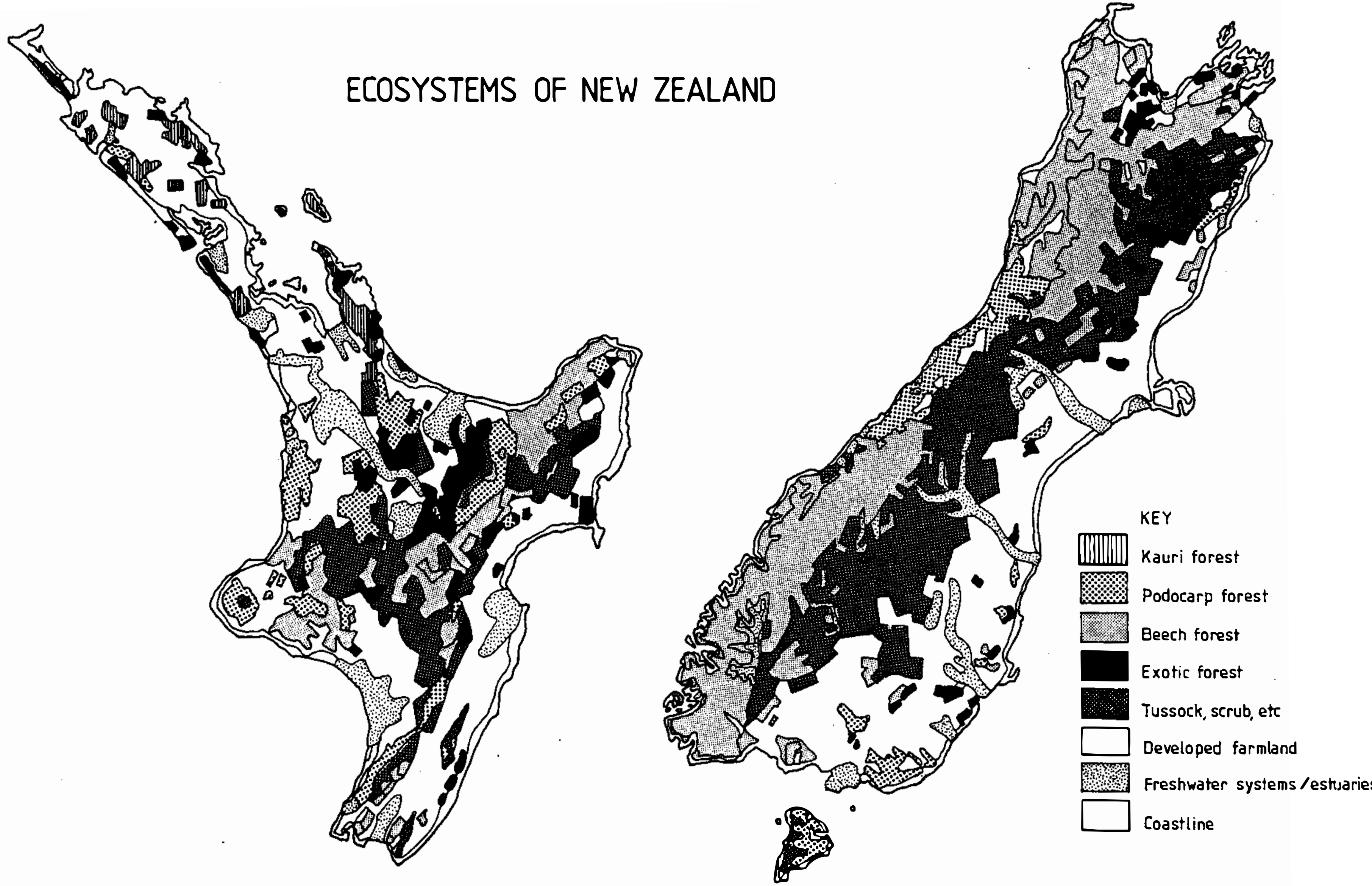

means pathway of energy flow


means production unit and process


means consumption unit and process


means storage


means heat sink - degraded energy


ECOSYSTEMS OF NEW ZEALAND
KEY
Kauri forest
Podocarp forest
Beech forest
Exotic forest
Tussock, scrub, etc
Developed farmland
Freshwater systems / estuaries
Coastline

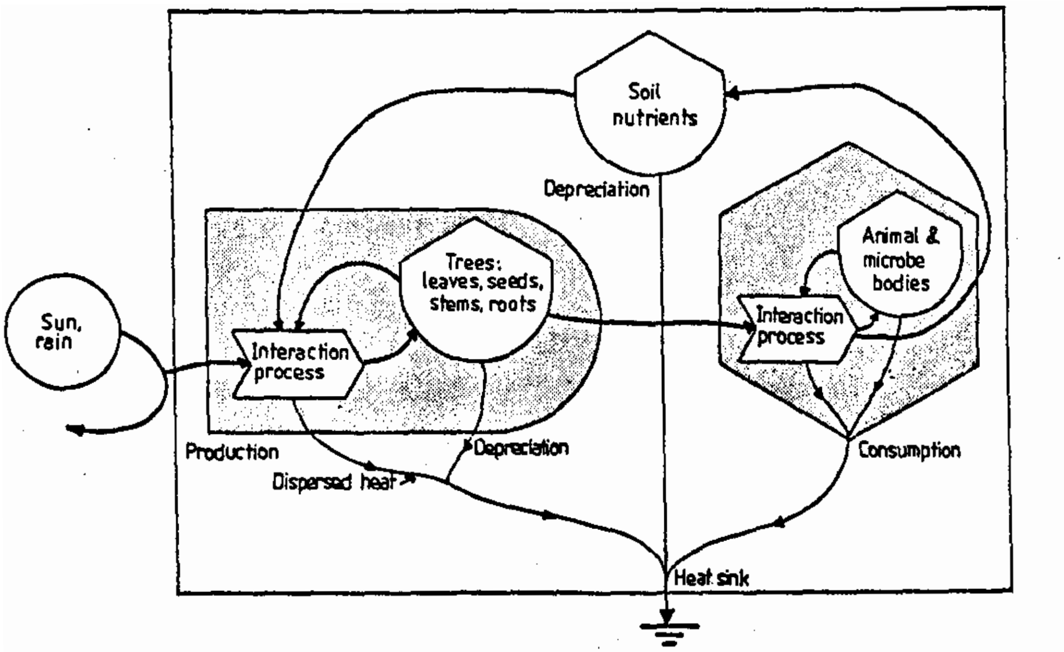


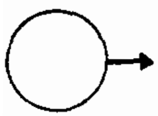
Figure 1.2 Beech forest with details of production and consumption

Next, look at this beech forest system in more detail with the interactions and storages that are part of production and consumption (Figure 1.2). In the production process the sun and rain interact with the soil nutrients to produce biomass of leaves, stems, roots, seeds. They feedback into the interaction to use more energy of the sun, rain, and soil nutrients. Some of the production products are consumed by the animals and microbes. There is energy degraded from the interaction and the storage. The flow of energy from the producers interacts with the biomass of the consumers to produce more consumer bodies which feedback to interact with more energy from the producers. Chemical wastes, like urea from the interaction process of the consumers, recycle to the soil nutrients and then to the trees again. Thus, materials like nitrogen and phosphorus cycle through the system, while degraded energy flows out from interactions and storages. Potential energy can be used only once.

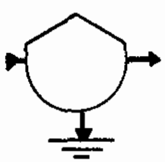
The beech forest has been used as an example to introduce the concept of energy flows and the use of system symbols. All ecosystems have similar patterns of outside energy sources, producers, consumers, recycling, and degraded energy.

1.2 SYMBOLS AND THEIR MEANING

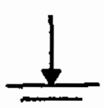
Here is a summary of the energy language symbols that we have introduced so far, together with some others that we will need later.



Energy Source The circle indicates a source of energy from outside the system under consideration. It may be a steadily flowing source like a river. It may be a large source with a constant pressure like the pressure of the sea. It may be a source that varies, as solar energy does from day to night. We can add words to the diagram to describe what kind of energy is being considered and how it is delivered.



Energy Storage Tank This symbol indicates a storage of some kind of energy within the system. The symbol could indicate energy stored in an elevated water tank, in an oil tank, soil nutrients, animal bodies, in the manufactured structures of a building, or in a library (information).

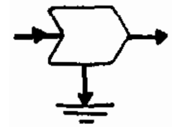


Heat Sink The arrow pointing downward, seemingly into the ground, symbolizes the loss of degraded energy - that is, energy which cannot do any more work - from the system. The pathway of degraded energy flowing out includes heat energy that is degraded as a by-product of work and also the dispersed energy of depreciation.

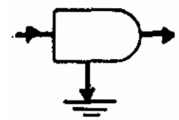
Heat is lost in friction, as when an automobile's tyres rotate over the road. It is also lost in the processes of photosynthesis and respiration. In the human body, heat flows out from the skin and lungs.

Concentrations of matter are energy storages. Energy is lost if the concentration is spread apart; this is depreciation. Depreciation of animal bodies is the loss of energy as they become old and less able.

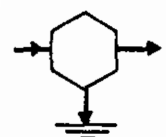
Heat sinks are required on all storage-tank symbols and all interaction symbols.



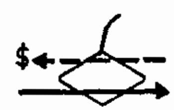
Interaction The pointed block is used to show the interaction of two or more types of energy required for a process. In the example of the forest, sunlight interacts with soil nutrients and storage structure in trees to produce more tree biomass.



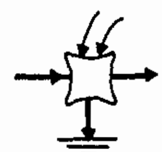
Production This symbol has one flat end and one rounded end. It indicates the processes, interactions, storages, etc. involved in producing high-quality energy from a dilute source like sunlight. It is used for producer systems like plants, forests, farms. The symbol can be used without interior details as in Figure 1.1, or with interior details as in Figure 1.2.



Consumption This symbol is hexagonal in shape with used energy outflowing at the bottom. It indicates that inputs are consumed and transformed into higher quality outputs. Examples are respiration in animal consumers, consumption by cities and the transformation of small clouds into large, more active clouds. The symbol can be used without interior details as in Figure 1.1 or with interior details as in Figure 1.2



Money Transaction The diamond-shaped symbol indicates the flow of money in one direction to pay for the flow of energy or energy-containing materials in the reverse direction. In Figure 10.3 we use the money-transaction symbol to indicate money obtained from the sale of fish and money paid for the boats, labour and nets.



Switching Actions This symbol turns pathways on and off according to controlling pathway, e.g. fire, as in Figure 9.2.

ACTIVITIES

1. *Prepare a list of energy symbols and their meanings.*

2. *Use the energy symbols to represent a simple ecosystem that you have studied. (Does your answer differ in any marked way from Figure 1.2?)*

   Each of you will have a slightly different diagram, but they can all be correct if they include the basic flows: outside energy sources, production, consumption, interactions, storages, heat sinks, and probably outflow.

3. *On the basis of your knowledge of a beech forest, explain the system in more detail. (Notice that our diagram does not show all the details that you may know about the forest, but it does include the overall basic pattern and necessary flows.)*

4. *In what ways does the modelling language help you to see how ecosystems function?*

2: The Flows of Energy and Materials through Ecosystems

In exercise 1 you studied a simple system diagram of the beech ecosystem. You have also used the energy symbols to make other diagrams. Now let us add more detail to the forest system model by including the nutrient inflows and outflows, the water inflows and outflows, the oxygen and carbon dioxide cycles, decomposers, and the recycling of materials. Follow Figure 2.1 carefully as we add these extra processes.

2.1 A MORE DETAILED BEECH FOREST SYSTEM MODEL

Figure 2.1 shows the understory plants included with the beech producers. These are mosses, lichens, low shrubs and herbs. They use the sun, water, and nutrients to produce plant matter. They are eaten by the consumers and their litter stays on the forest floor as *detritus*, to be consumed by the decomposers.

We have added the water cycle to the diagram. *Rain* is shown as an outside energy source. Inside the system we show a storage symbol containing water which is either in the soil or on the surface. The water is used by the trees and plants in photosynthesis. Their leaves *transpire*, which releases water vapour to the atmosphere. Water also leaves the system as *runoff*.

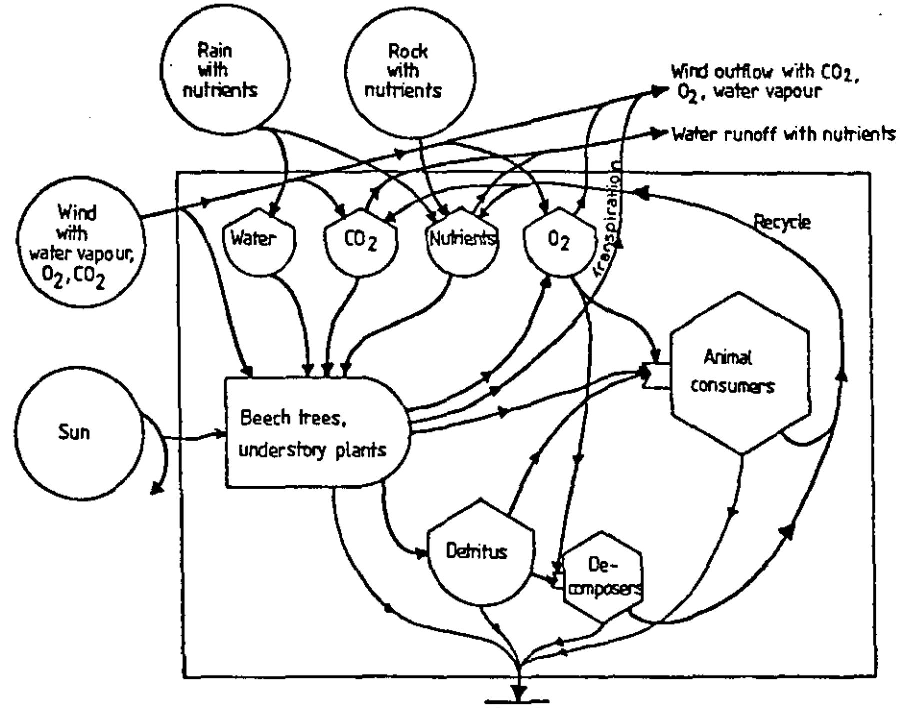


Figure 2.1 Beech forest with details of inflows and outflows

Wind is an outside energy source that blows carbon dioxide, oxygen and *water vapour* in and out of the forest. It also does other work, such as removing the water of *transpiration* from the leaves, spreading seeds, and blowing down dead tree limbs.

Carbon dioxide is shown in a storage symbol. The storage symbol represents both the carbon dioxide blown in by the wind and that produced by the respiration of consumers. Carbon dioxide is used by the trees and other plants in photosynthesis.

Oxygen is also brought into the forest by wind. It is shown in a storage symbol which includes the oxygen produced by the photosynthesis of the producers. Oxygen is used by the forest consumers in the process of respiration.

The outside source of *nutrients* is shown as an energy source within the rain. Some nutrients enter the forest dissolved in the rain, others are added to the soil by the dissolving of volcanic rock containing phosphorus, especially, and other minerals. These processes are all inflows to the soil nutrient store which is available to the forest producers. Outflowing from the nutrient store are materials leached from the topsoil and nutrients dissoved in the water runoff.

The *decomposer* cycle is important in all ecosystems. Dead leaves, branches, and other litter from the trees and plants fall to the forest floor as detritus. Feathers, excreta, dead bodies, etc., from the animals are also part of the detritus. The decomposers (microbes, worms, fungi) recycle these materials into phosphates, nitrates, potash and other inorganic chemicals which flow back into the store of nutrients in the soil.

Over the years this beech forest ecosystem has built up a balance - or dynamic equilibrium - between water inflows and outflows, nutrient inflows and outflows; growth, death, decomposition, and recycling of trees and other producers; and birth, growth, death, decomposition, and recycling of consumers.

2.2 QUANTITATIVE ENERGY FLOW

It is possible to *measure* the quantity of energy flowing along the various pathways within the ecosystem. Figure 2.2 shows the beech ecosystem with energy flow data added. These are quantities of joules calculated for inflows and outflows.

The joules of energy shown in Figure 2.2 are obtained from the actual flows in grams. Notice that the largest numbers are at the left where the dilute energies of sun, wind, and rain are flowing in. The smallest numbers are at the right, there are not many joules in recycling nutrients, but they are high quality energy which has a much greater effect. This idea of high quality energy is one that we will return to later.

The data on Figure 2.2 illustrates two energy laws that are fundamental to all systems - both natural and man-made. First, the *law of conservation of energy*, states that all flows into a system must be balanced by the stores in, and the outflows from, the system. Another way of stating the law is that energy can neither be created nor destroyed. In physics this is called the First Law of Thermodynamics.

The second energy law important to all systems is the *law of degradation of energy*, or the Second Law of Thermodynamics. This states that there is a loss of energy from every process and every storage. This degraded energy is energy that cannot do any more work. It appears as heat and is therefore shown flowing down the "heat sink" in all the diagrams. As you can see from the data on Figure 2.2, the quantity of degraded energy is large when compared to the energy that builds structure in the system. This is not wasted energy; its outflow is an inherent and necessary part of *all* processes, biological and otherwise.

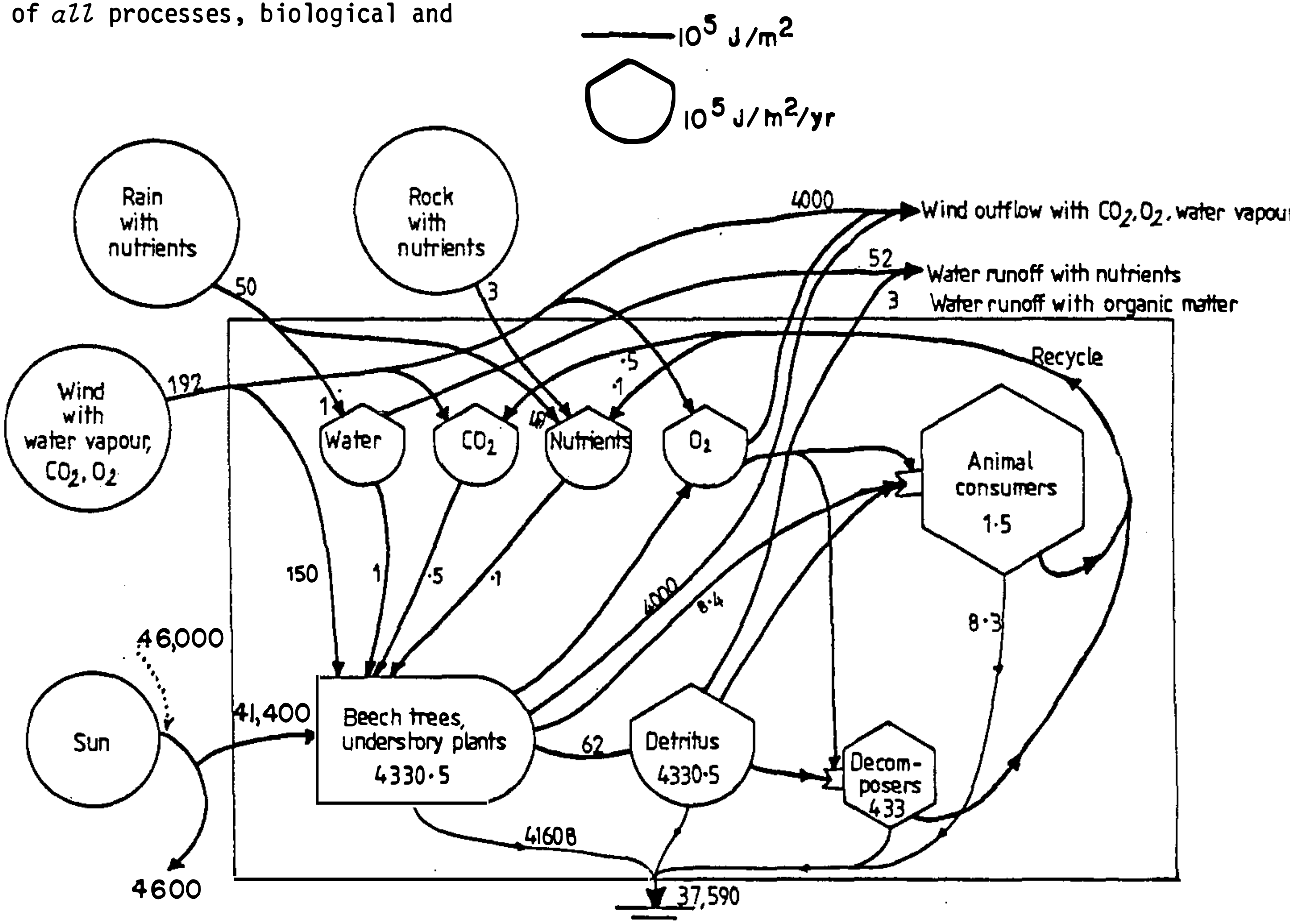


Figure 2.2 Beech forest with numerical data on flows and storages

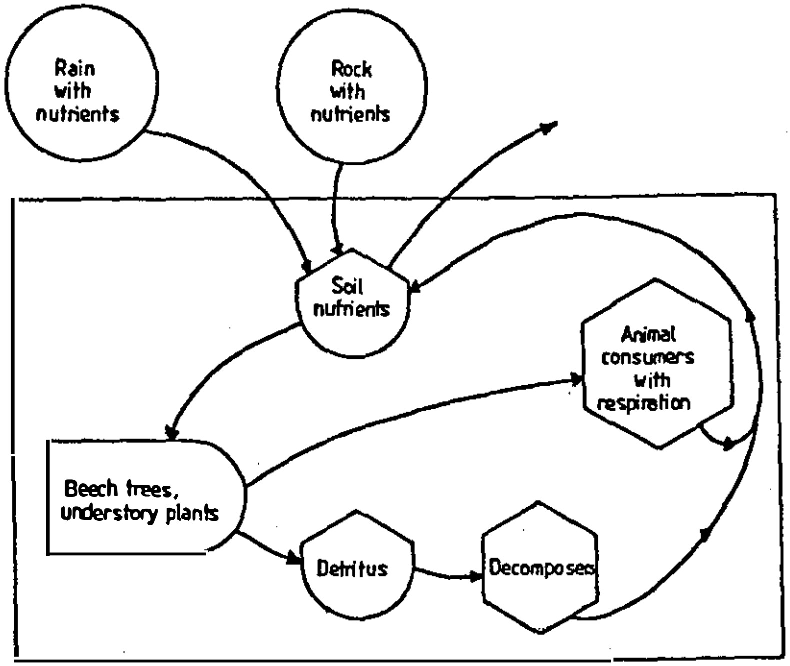


Figure 2.3 Diagram of phosphorus cycle - an example of a nutrient diagram. The diagram can be placed as an overlay of the general diagram that has energy and other flows in Figure 2.1.

2.3 THE PHOSPHORUS CYCLE

An ecosystem is a living system. To survive, it needs a continuing supply of materials. These may come from outside inflows, from recycling, or, more usually, from both. System diagrams can be used to trace the flow of any material cycling through the ecosystem. Figure 2.3 shows the phosphorus cycle as one example.

The phosphorus cycle has no gaseous phase corresponding to the atmospheric phase of the nitrogen and carbon cycles. Because of this, the phosphorus cycle turns very slowly. In addition, most common phosphates are insoluble. Consequently, phosphorus is often limiting in terrestrial systems.

Phosphorus, dissolved in the rain as phosphates and contained in the rock as particles, becomes part of the nutrients in the soil. The roots of plants take up water containing soluble phosphates from the soil. The phosphate is used to produce DNA, RNA, ATP, and other organic compounds containing phosphorus. Detritus from plants and animals contains organic phosphates which are decomposed by soil organisms, including phosphatising bacteria which are analagous to the nitrifying bacteria of the nitrogen cycle, into phosphates and other inorganic nutrients. These phosphates again become part of the soil nutrients. Phosphorus flows out of the system as phosphates suspended in water that leaches down through the soil or flows directly down hills.

ACTIVITIES

1. *Re-draw your answer to Question 2 in Section 1 and include details of the flow of nutrients and water, together with re-cycling processes. How does it compare to Figure 2.1?*

2. *Refer to Figure 2.2*

   (a) Add up the total quantity of energy flowing into the beech forest eco-system and the total quantity flowing out.

   (b) Compare the two totals. What law does this support?

3. *Do the data in Figure 2.2 support the law of degradation of energy? Explain your answer.*

4. *Calculate the percentage of incoming energy that is degraded for each of the following sub-systems:*

   (a) the producers;

   (b) the consumers;

   (c) the decomposers.

5. *Can you explain the differences between your answers in Question 4?*

6. *If a yield of trees was being taken from the forest, trace the effect this would have on the flows: producers to detritus and to consumers; detritus to decomposers; recycling from decomposers and consumers.*

   What effect would the smaller amount of nutrients recycling have on the production growth of trees? What would have to be added to regain the balanced steady state?

7. *Make an overlay diagram similar to Figure 2.3 for one of the other materials flowing through the forest system: nitrogen, potassium, carbon, oxygen, or water. How does it differ from Figure 2.3? Why?*

3: The Food Web of the Beech Forest

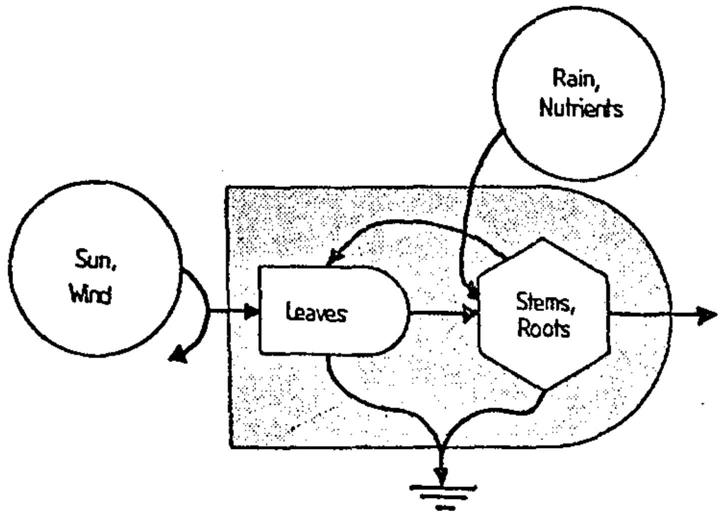


Figure 3.1 Plant photosynthesis and respiration

In exercise 2 flows of energy and materials in ecosystems were examined using the beech forest as an example. In this exercise we will study food webs, again using the beech forest.

3.1 PHOTOSYNTHESIS AND RESPIRATION BY PRODUCERS

As you know, plants carry on respiration as well as photosynthesis. In Figure 3.1, we show the plant involved in both photosynthesis (as a producer) and in respiration (as a consumer). The leaves perform photosynthesis and all parts of the plant perform respiration, as well as doing such work as support and processing materials from the soil. To show photosynthesis and respiration are *both* part of the production process of the plant, a large producer symbol is drawn around them. So Figure 3.1 represents the processes and part of the beech tree. Remember that when you come to study Figure 3.2

3.2 THE STRUCTURE OF THE FOOD WEB

The food web of the New Zealand beech forest is also shown in Figure 3.2 Comparing this figure with Figure 2.1, you will notice similar overall patterns with energy flowing in and out, and both energy and materials flowing through the component parts of the system. In Figure 3.2 some of the pathways have been left out, like the carbon dioxide and the oxygen, so that others may be added. In Figure 2.1 we were emphasizing inflows and outflows; in Figure 3.2 we are concentrating on the flows between the internal components of the web. Now, follow the symbols and flows in Figure 3.2 carefully as they are described. Imagine you are in the forest and are able to see and hear all the activity.

The producers have been divided into the trees (mostly beech), the epiphytes growing on the trees (lichen, mosses), and understory plants (herbs, shrubs).

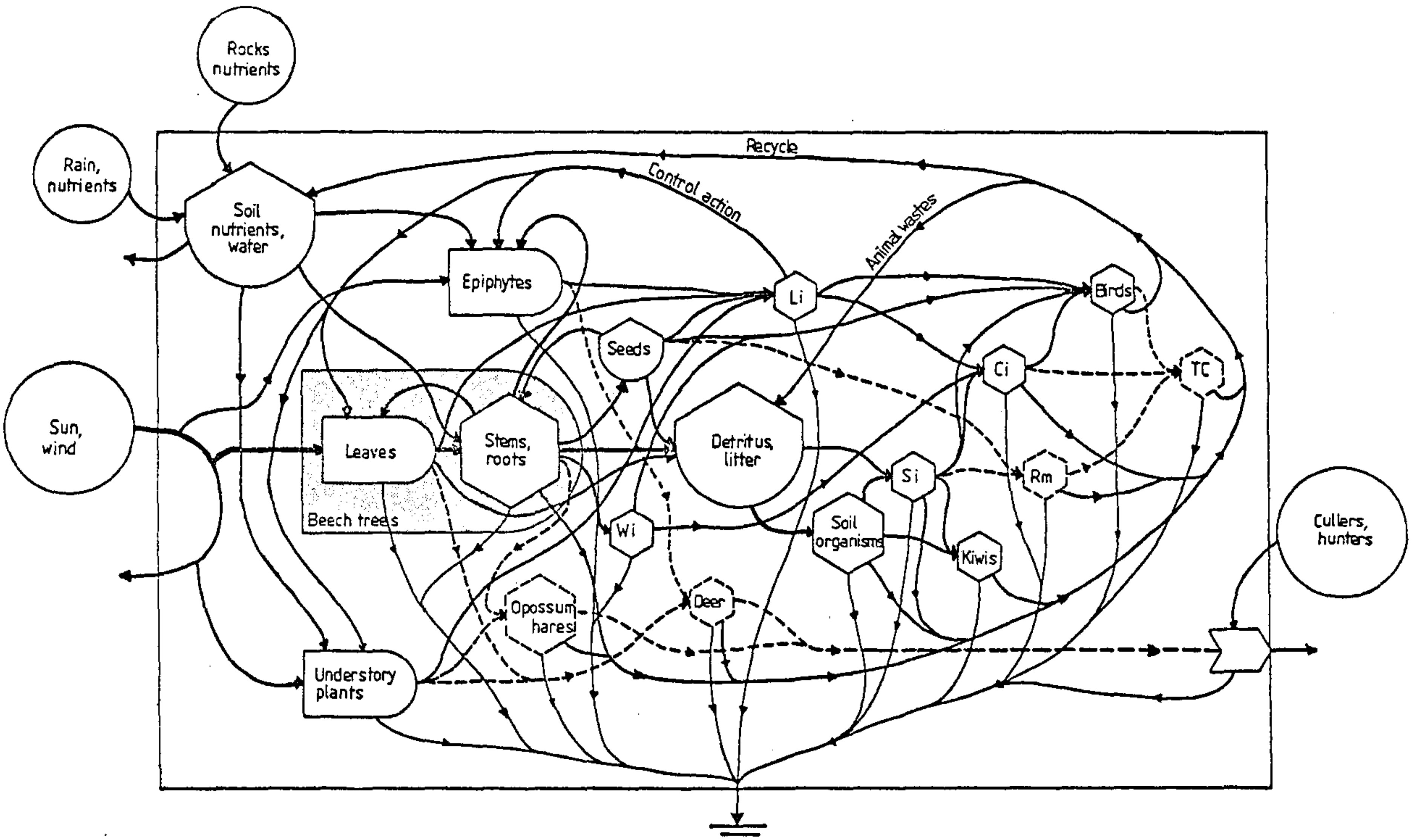


Figure 3.2 Beech forest food web. Dashed lines are exotic introduced species that have become a part of the ecosystem.

Wi = wood-eating insects, Li = leaf-eating insects,
Soil organisms = animals, microbes, fungi,
Si = Soil insects, Rm = Rats and mice,
Ci = Carnivorous insects, TC = ferrets, weasels, stoats.

The most important consumers in this forest are those feeding on the detritus (soil litter - mostly from the producers). These consumers are soil animals, microbes, and fungi. The lines are drawn more heavily from the sun to the trees, and from the trees to the detritus and soil consumers, because these are the pathways of greatest energy flow in this system. The litter from the trees, plants and animals builds up on the forest floor. If you pick up the litter you can see small animals, fungi and many kinds of soil insects. If you look at the litter under the microscope, you may find many microscopic organisms (microbes); these include bacteria, soil algae, protozoa, mycorrhiza, and viruses.

Primary consumers are animals that eat plants. These include insects which eat leaves, seeds and epiphytes; woody insects which eat stems and roots; and deer, opossum and hares, which eat understory plants and parts of the trees.

The secondary consumers feed on primary consumers. In the beech forest they include soil insects and kiwis which consume the soil organisms; carnivorous insects which consume the other insects; rats and mice; and birds which consume insects. As you can see from the flow lines, several of these secondary consumers (soil insects, rats, mice and birds) are also primary consumers, since they eat seeds as well as insects.

The insects are divided into four categories according to their food: woody, leaf, soil and carnivorous. There are hundreds of species in each category.

In Figure 3.2 the wastes are shown flowing from each consumer into two pathways; one directly to the soil nutrients, the other to the detritus to be consumed by soil organisms and thus converted to soil nutrients.

Many functions are carried out by birds in this forest. They include kea, kaka, parakeets, yellow heads, and white heads. There are larger birds (the harrier and New Zealand falcon) on the edge of the forest.

Tertiary consumers in this system are the ferrets, weasels and stoats. Cullers and hunters, who take opossum, deer and a few hares, are at the top of the food chain.

3.3 FEEDBACK CONTROL IN THE FOOD WEB

Notice the feedback loops of control action from the leaf insects to the epiphytes, tree leaves and understory plants. The term feedback control refers to the *service* that the higher consumers do for the lower organisms. An example of this feedback control is the relationship between bees and flowers. While the bees are collecting nectar, they pollinate the flowers.

Population control is another example of feedback control, or service. When one species of plant becomes numerous, the population of insect which feeds on it also increases. By feeding heavily on the plants, the insects regulate the numbers of that species. As a result, the forest maintains greater diversity and a better overall production. Such stability is necessary for long-term survival.

These mutualistic relationships of production and feedback normally keep the numbers of plants and insects in a steady or fluctuating balance - a situation that is known as "dynamic equilibrium".

3.4 EXOTIC ANIMALS

The storage symbols with dashed lines are exotic animals, those which were not part of the beech forest originally. Notice that there were originally no tertiary consumers and no deer, opossums, rats, or mice. These introduced animals have added diversity to the beech forest, but they are still causing changes in relative composition of plant species - some species being nearly eliminated because of selective feeding. The opossum and deer feed on understory plants, opening up the forest and allowing herbivorous insects to enter and damage the beech trees. Because the deer and opossum are considered pests, hunting is encouraged and cullers are paid by the Government to harvest them. There is continuous discussion as to whether the forest is being damaged by the exotic animals or whether they have become part of a balanced system.

ACTIVITIES

1. *Draw a diagram of a food web for another ecosystem. How does it differ from Figure 3.2?*

2. *Which is the most important subsystem in your diagram - the detritus, as in the beech forest, or another?*

3. *Describe one of the feedback control actions in your system.*

4. *What is the relationship of man to your natural system? Include human interactions in your diagram.*

5. *Are there any exotics in your system? Are they an advantage or disadvantage, in your opinion?*

6. *Discuss the role of exotics and their control in New Zealand, using other examples. (We will take this up in more detail later.) As fuel energy becomes less available, energy-intensive control measures like helicopters will be less possible.*

7. *Gather some litter from a forest. Place a small amount in water; look at it with the naked eye, then under a dissecting microscope, and finally under the binocular microscope from low to high power. List the kinds of organisms you find. There is a whole food web in the litter. Make a preliminary food web diagram, using the knowledge that green organisms are producers, and that large organisms usually feed on smaller ones.*

8. *To find evidence of micro-organisms and their work, mark some leaves and leave them in the forest to see how fast they decompose.*

4: Trophic Levels and the Quality of Energy

In exercise 3 a food web was studied. In this exercise, we consider food webs as chains of successive energy transformations.

In order to investigate energy exchanges within the food web, it is often convenient to aggregate the web into a single food chain. The food chain then can be divided into trophic levels categorised by the kinds of food the organisms consume. The food web of the beech forest is aggregated in Figure 4.1.

4.1 A QUANTITATIVE FOOD CHAIN

Energy relationships between the parts of the web can now be seen more easily. From Figure 4.1 you can see that about 4,600 x 10^6 joules (or 4,600 *mega*joules) of sunlight fall on each square metre of New Zealand per year. About 1% of this energy is transformed by the forest producers into plant organic matter. In other words, about 46 x 10^6 joules of new trees, epiphytes, and other plants are produced per metre per year. 4,595 x 10^6 joules go down the heat sink as necessary energy dissipated during the production process. The efficiency of this use of sunlight is, therefore, 46/4,600, or 1%.

Although that may seem low, the mature forest is, in fact, one of the most efficient systems in transforming energy to organic matter. However, most of the captured energy is used by the producers in maintaining their complex living structure.

The range of efficiencies for photosynthesis in different plant species is between 0.01-2%. These efficiencies are low because sunlight is very dilute, and many successive steps and extensive chlorophyll-containing cellular machinery are necessary to concentrate it into higher quality energy. Since plants have evolved the photosynthetic process over several billion years, it may be the most efficient conversion possible of sunlight, since it provides its own apparatus. This idea should be remembered when sunlight is considered as an alternative energy source for human systems.

At each level of our beech forest food chain, about 10% of the energy available to that level is converted to new biomass. The other 90% is dissipated down the heat sink. This ratio also applies to producers, which consume 90% of their own production during respiration. Thus, the 4,600 megajoules of sunlight that fall on 1 square metre of forest in 1 year become:

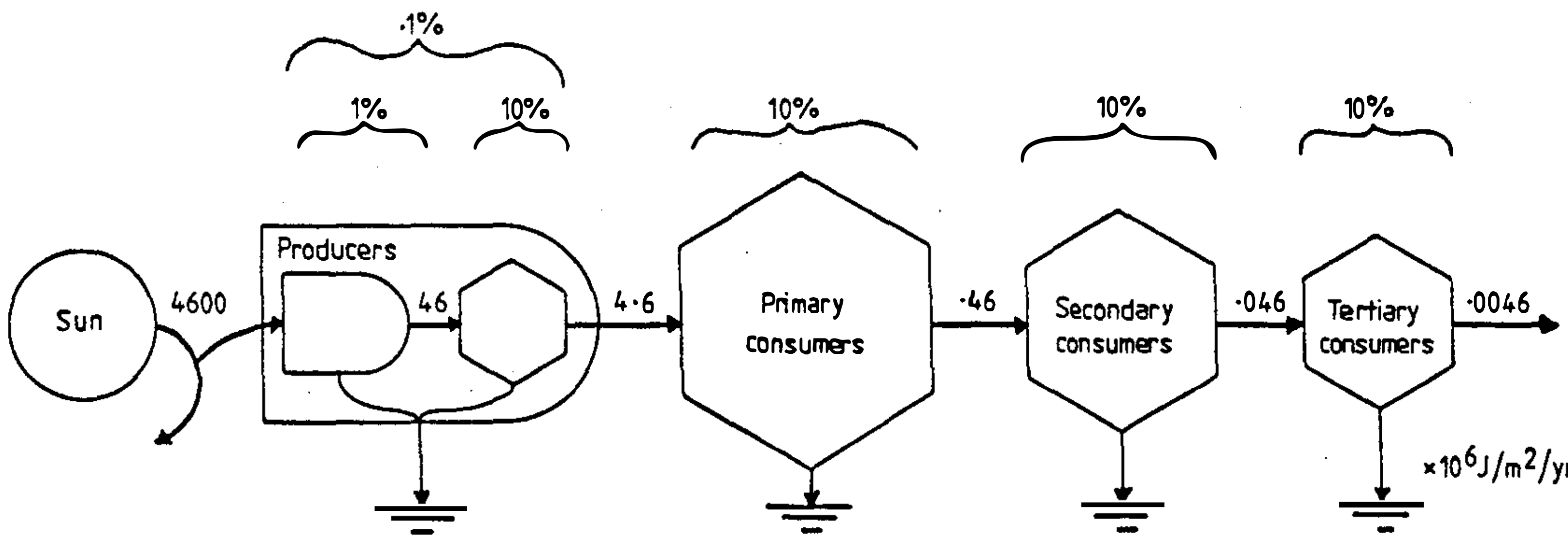


Figure 4.1 Beech forest food chain with levels of successive energy transformation. Feedbacks of service are omitted.

Primary consumers: leaf insects, wood insects, opossum, hares, deer, rats, mice, microbes;
Secondary consumers: carnivorous insects, birds, soil insects, kiwis, rats, mice;
Tertiary consumers: ferrets, weasels, stoats, birds.

- 46 megajoules of captured energy, of which:
- 4.6 megajoules is new producer biomass, which is consumed to become:
- .46 megajoules of new primary consumer biomass, which is consumed to become:
- .046 megajoules of new secondary consumer biomass, which is consumed to become:
- .0046 megajoules of new tertiary consumer biomass.

This may be easier to visualise if we say that to produce 1 megajoule of a ferret (or other tertiary consumer) it takes 1,000,000 megajoules of sunlight.

---

(1) 1 gram of protein (dry weight) = 2×10^4 joules.
Animals are about 20% protein (dry weight).

4.2 CARRYING CAPACITY

We can use this energy quality chain and the information in the footnote (1) to make some estimates about the carrying capacity of animals. For example, how many grams of tertiary consumers could be produced by the sunlight falling on one square metre of land in one year?

$$\text{Weight of tertiary consumer produced per } m^2 \text{ per year} = \frac{\text{Energy available for growth of tertiary consumers per year}}{\text{Energy content of 1g protein}} \times 5$$

$$= \frac{.0046 \times 10^6}{2 \times 10^4} \times 5$$

$$= 1.15 \text{ g}$$

This means that the top consumers use the production of sun, plants, detritus, insects, animals, etc. on one square metre of land in one year to make about one gram of biomass. It takes a lot of land and sunlight to produce one top consumer. If a ferret were the only tertiary consumer on an area and it weighed 2 kg, it would require 2,000m^2 (2ha) to replace its own weight in a year.

4.3 ENERGY QUALITY

Because it takes many joules at the left end of the chain to make a few joules at the right, we regard the energy at the right as being of *higher quality*. A gram of ferret took more energy to produce than a gram of beech tree; therefore, the ferret is higher quality energy. The energy quality is lowest at the left and rises with each step along the chain.

4.4 ENERGY RELATIONSHIPS IN A SIMPLE FARM SYSTEM

Imagine a pioneer sheep farm. The farmer grows grass, grazes sheep on the grass and uses the sheep as his only food source (he likes mutton). The only energy expended in managing the system comes from the farmer's labour. The food chain for this simple farming system is shown in Figure 4.2(a).

Notice the way in which the sheep have been drawn. The sheep really have two trophic levels within their bodies. They graze on the grasses which are first digested by microbes in their gut, then the microbes and remaining grass are absorbed by the sheep. We would expect the sheep to convert about 10% of the energy available to them into new biomass, but because of these two feeding processes the sheep actually convert only about 1% of the energy of the grasses into meat and wool. In this pioneer system the farmer converts 10% of the energy from the sheep into work with which he manages the system.

In the beech forest example you saw how it took 10^6 joules of light energy to produce 1 joule of ferret. In the simple farming system it takes the same quantity of light to produce 1 joule of farmer's labour. In other words, the ferret and the farmer are about the same level of energy quality. Both use the energy of their food chain to act as controlling managers of their system.

Notice the *feedbacks* in Figure 4.2(b) from the farmer to the sheep and the pasture, and the feedback from the sheep to the pasture. The feedback from the farmer represents management in the form of breeding, herding, protecting, shearing and culling the sheep; and of planting,

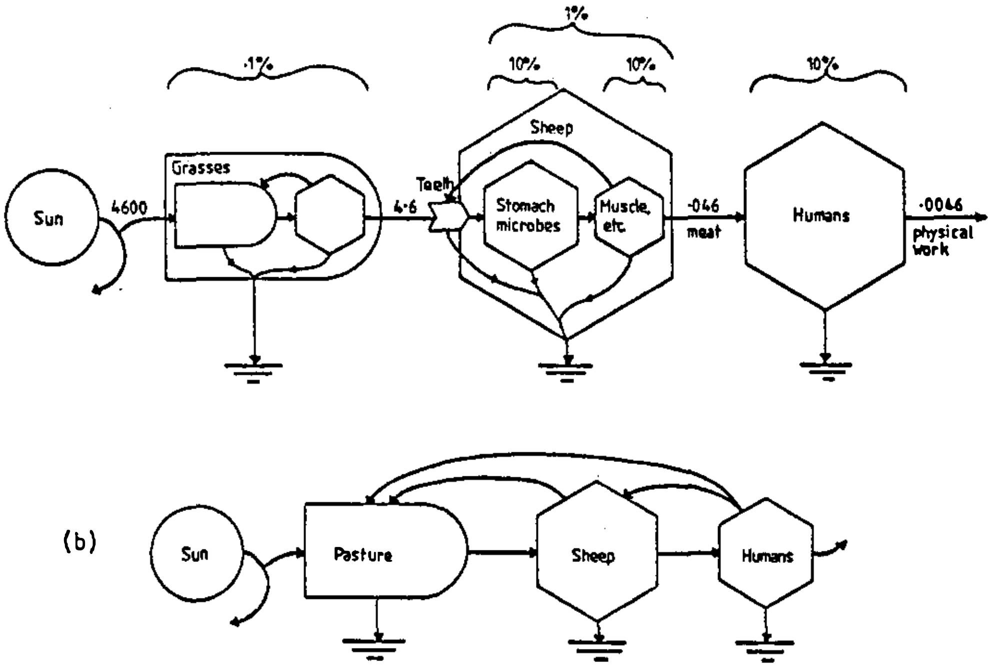


Figure 4.2 Food chain of a sheep farm.
(a) with levels of energy transformation
(b) with feedbacks of service.

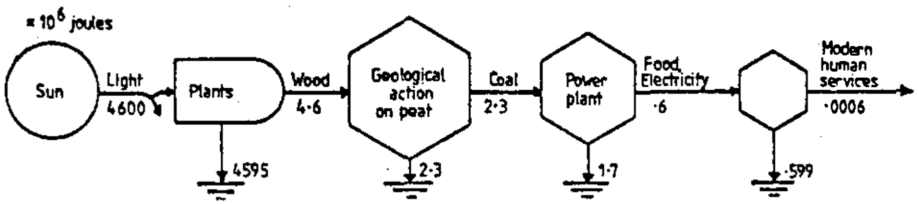


Figure 4.3 Modern human energy quality chain.

fertilising and protecting the pasture. The sheep also manage the pasture by eating the plants; this keeps the grass growth steady and prevents most shrub and tree seedlings from becoming established. These feedbacks, like those of the insects in the beech forest, seem to be necessary for the survival of all systems in the long run.

There are often suggestions that much energy could be saved by skipping the meat in the human food chain and having people eat only vegetation. When we look at the food situation in this world of hungry people, it is an appealing proposal. There is 100 times as much energy available in the grass as there is in the sheep in our simple farming example. However, as you can see from all food chains, energy is concentrated by work at each level. To get a balanced diet by eating only plants, humans have to do the work of gathering and concentrating energy which the animals now do. Growing and harvesting the cereals, vegetables, and nuts necessary for a healthy diet requires a great deal of energy. The high price of a vegetarian diet reflects this high energy input. In many cultures, however, humans may eat more meat than they need.

4.5 ENERGY RELATIONSHIPS IN A MODERN SOCIETY

The ideas of energy quality and energy transmission along food chains are useful for examining the way in which modern societies use energy. Consider the generation of electricity from coal (Figure 4.3). Starting with the same quantity of light energy as the beech forest and primitive farm (4,600MJ), we would expect to obtain about 2.3 MJ of coal, in the fullness of geological time. This quantity of coal could then be converted into 0.6 MJ of electricity (including energy for installations and human services). During the chain of events leading to the production of this electricity, a great proportion of the original energy has been degraded and dissipated as heat. Electricity, therefore, is high-quality energy.

Electricity and other types of energy support human society (and its machines), which culminates in humans and their educated services. Each joule of human service has 100 joules of coal energy making it possible. In Figure 4.3 about .0006 MJ of human work was obtained from 4,600 MJ of sunlight. Modern human services, therefore, represent very high quality energy indeed - many trophic levels higher than that of the top carnivores in the forest.

ACTIVITIES

1. *What feedback control service do deer provide in a beech forest? (Figure 3.2)*

2. *Discuss the proposition that a diet with meat is a more energy efficient way of feeding humans than a vegetarian diet. What does this mean in a world where many people are undernourished?*

3. *Considering the three systems introduced in this section:*

   Beech forest;

   Primitive sheep farm; and

   Modern society,

   list the following system components in order of energy quality - from lowest to highest.

farmers' labour	*ferret*
sunlight	*deer*
coal	*modern human labour*
soil microbes	*farmland grass*
sheep	*beech leaves*

4. *Use the method introduced on page 17 to calculate:*

   a) *the number of grams of secondary consumer capable of being produced by the sunlight falling on 1 square metre of land in one year;*

   b) *the number of grams of primary consumer produced by the sunlight falling on 1 square metre of land in one year;*

   c) *compare the answers for primary, secondary, and tertiary consumer. Is there a relationship between the numbers, and if there is, can you give an explanation for it?*

5: Production and the Maximum Power Principle

5.1 PRODUCTION

We had better begin by sorting out what we mean by the term *"production"*. We consider production to mean the process by which two or more ingredients are combined to form a new quantity of greater value. For example, soil nutrients, water, carbon dioxide, and sunlight are combined to form organic matter during photosynthetic production. Typically, industrial production involves the use of energy, labour, capital, and raw materials to form industrial products. In Figure 5.1 the production process is illustrated. Notice the pointed interaction symbol with its inflows of ingredients and outflows of products. Whenever this symbol is used, it indicates that a production process is occuring.

During a production process, each inflowing ingredient carries energy of different type and quality. During the productive interaction, these energies are transformed to a new form, and some energy is degraded to become used energy, shown flowing out through the "heat sink". Energy transformations, like those occurring during production processes, are referred to as *work.*

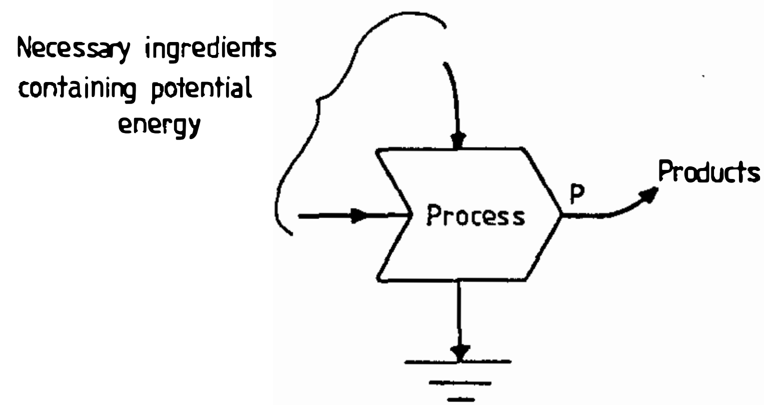


Figure 5.1 Production process (P) with two interacting ingredients.

5.2 GROSS AND NET PRODUCTION

Confusion often arises over the terms gross and net production. Where there is a production process followed by a consumption process - as in photosynthesis and respiration in plants - we must distinguish between immediate production and production minus the accompanying consumption. In Figure 5.2, *gross production* is the actual rate of generation of products - which is the flow at the point of the interaction symbol (5 grams per day, in this case). *Net production* is the production that is actually observed, where production and some consumption are going on simultaneously. In the figure the gross production rate is 5 grams per day and the consumption rate is 3 grams per day. What is observed is a *net* production equal to a gross production minus the accompanying consumption, or 2 grams per day.

In more complicated systems, such as the beech forest, where there are several stages of production and consumption there is more than one kind of net production. For example, net wood production, net litter production etc. Net production also depends on the time when it is estimated. For example, most plants use up at night much of the production they made during the day. Their day-time net production is large, but their net production including night-time

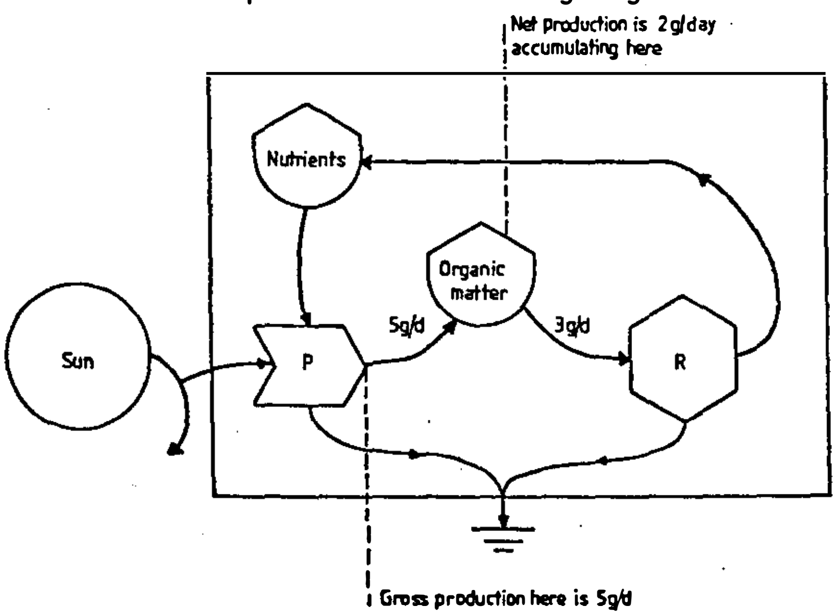


Figure 5.2 Gross and net production.

consumption is very small. If net production over a year is considered, it is often small or even zero.

5.3 LIMITING FACTORS

Most production processes are stimulated to go faster when the ingredients are available in larger quantities. However, a reaction can only proceed at a rate which is determined by the ingredient that is available in the least favourable amount. This ingredient is then called a *limiting factor*. For example, since light is necessary for photosynthesis, the process slows down and stops at night; sunlight is the limiting factor which controls the process.

In Figure 5.3, increasing the supply of nutrients causes light to become limiting. At

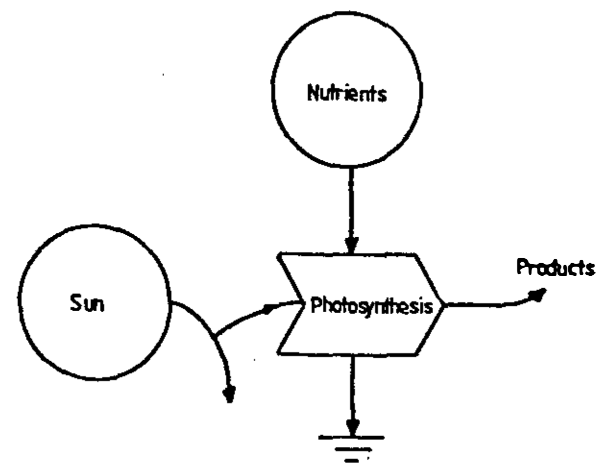


Figure 5.3 The sun, which has a limited flow, is the limiting factor in the process of photosynthesis.

that point, continued increase of nutrients will not increase production. This is an example of an *external* limiting factor. In Figure 5.2, increasing light causes the nutrients to become limiting because they get tied up in the organic matter produced and do not recycle fast enough. This is an example of an *internal* limiting factor.

5.4 THE MAXIMUM POWER PRINCIPLE

The maximum power principle suggests reasons why certain systems survive and others do not. The principle can be stated like this:

> *When there is competition between systems, those systems that survive are those that develop the largest energy inflows and use them most effectively to feedback and bring in more energy.*

This means maximising the use of resources both from the area and imported from outside. For example, consider a farm on which crops are planted at the best time in relation to rain and sun. The best fertilisers are applied to make the crops grow, and crops are grown that people will buy. This farm will produce enough financial return for the farmer to live well, maintain the soil, and repeat the process year after year. He may even be able to expand his system by buying up less efficient farm systems. The successful farmer's system will survive and will then be copied by other farmers. It is successful because it developed the largest energy inflows and used them in such a way as to further expand the quantity of energy flowing in.

In economics the maximum power principle appears as the survival of one company over another. In international relations it is the survival of one political group over another, as in World War II. When energy supplies are steady, maximum power may mean less competition and an increase in diversity and efficiency.

During times of abundant energy supplies, maximising growth maximises power. Thus during the early stages of succession, communities increase their biomass rapidly. When energy resources become limiting, developing efficiency through *diversity* maximises useful power. In a mature forest system each organism has its niche and there is very little competion. The organisms tend to have co-operative, rather than competitive, relationships. In the mature economic system, co-operation is again more common than competition. Hopefully, therefore, when fossil fuels are less available and countries are running on renewable energies, tendencies to expand and crowd each other will be less. Relations among nations may then be peaceful.

The systems that maximise power are those that use their energies to build the kind of structures that feed back to bring in more energies. They are also the systems that feed back to the larger system of which they are a part. For example, in the larger system of the forest, a tree uses the energy of the sun by growing leaves which increase in size and number to catch more of the sun's energy. This process of the tree feeds back to support the forest system by building soil, making a stable microclimate, recycling nutrients, and providing food for animals. Thus, the tree maximises both its own power and that of the larger system of which it is a part. Systems which maximise the use of energy available to them have means to meet all other shortages and limitations.

ACTIVITIES

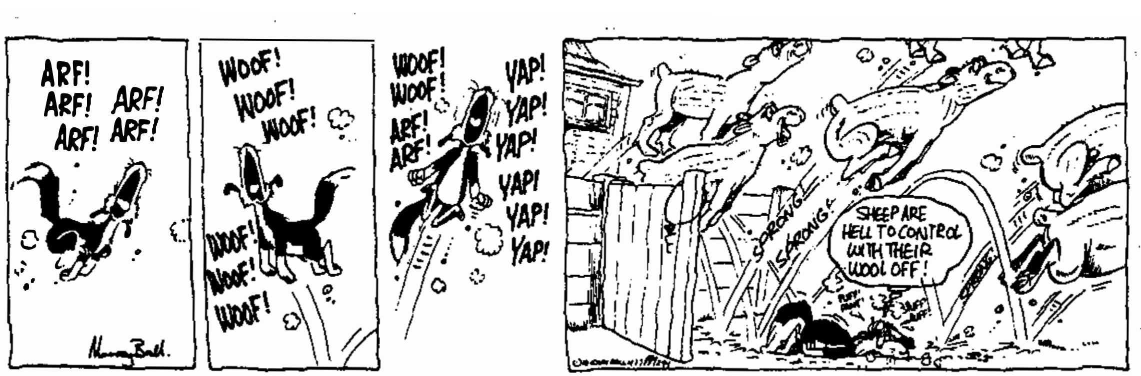
1. *Put some jars containing pond water in the window (do not use tap water because it contains chlorine and heavy metals). To each bottle add a pinch of fertiliser of a different type and label. If available, use some compounds containing phosphate, potassium, nitrate, and some manure. Leave two bottles as controls. After five - ten days bright green blooms of algae will appear, in some jars more than others. Explain this in terms of limiting factors: which nutrient was more limiting in the original pond water?*

2. *Cut the grass on a square metre of lawn and weigh the clippings. Estimate the time of growth since the last cutting. Calculate the net production per day per m². Now suppose that the grass respires at night one gram per m². What is the gross production? (Remember grass respires during the daytime also.) Express your analysis in the form of a diagram.*

3. *Which field is using more total energy: a paddock without fertiliser or one with super-phosphate fertiliser supplied? How does fertiliser represent the work of an out-side energy source? (Hint: fertiliser comes from islands where birds accumulate guano wastes from eating fish out of the surrounding sea.)*

4. *As weeds spread over a field, how do they maximise power so as to improve their ability to compete and survive?*

5. *What is the limiting factor in your own productive effort, which at your age may include learning effectively and developing ways of fitting in with society?*



6: Population Growth Models

All living things form systems. Natural systems and human systems can respond in many different ways, as time passes.

Some systems increase in both numbers and complexity with time. Others remain steady, and still others decline. The fate of a system depends on the energy supply that is sustaining it and the way in which the components of the system are organised. We can examine the organisation of a system by preparing a systems diagram of it. Such a diagram can also be referred to as a *model*. Figures 3.2 and 4.2 are examples of system diagrams or models of living systems.

In this exercise we will investigate models for three different systems. In each case we will use the model to develop a graph of the way the system might perform through time.

6.1 MODEL 1: EXPONENTIAL GROWTH

The first model is shown in Figure 6.1. It represents a population growing on a source that can supply as much energy as is needed. As an example, think of a population of rabbits growing on a hopper of food which is replenished regardless of how fast it is eaten. Follow the flows in the diagram to see that, as the rabbit population increases, it feeds back to bring in more energy (by eating more) to make even more rabbits. If the system starts with a male and female rabbit and they produce four bunnies, they pair and produce eight offspring; then at the same rate of increase the next generation will produce 16; the next 32; the next 64; and so on. As the number of rabbits increases, they use more of the energy source, and increase even faster.

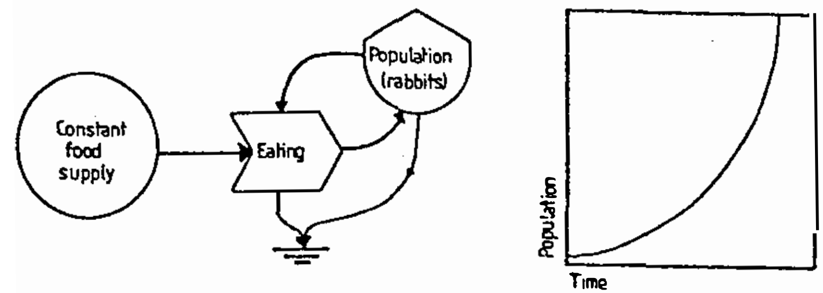


Figure 6.1 Model 1: Growth of a system with a feedback interaction with an energy source that maintains constant pressure.

You can see that there is no limit to the growth of the rabbit population as long as their food supply is maintained. We will refer to this as "growth on an energy source with constant pressure". As Figure 6.1 shows, the growth curve of a population under these conditions is exponential. Thus, exponential growth is the result of growth on a constant pressure energy source.

In practice, a constant pressure energy source cannot be maintained indefinitely, so that perpetual exponential population growth is impossible. However, during the early stages of population growth, when the demand for food is small (compared to the amount available), energy may be available at constant pressure and growth may be exponential. But eventually, food would become limiting and the situation would need to be represented by a different model.

6.2 MODEL 2: LOGISTIC GROWTH

Logistic population growth is common in nature. It shows how populations on a constant-pressure source become so crowded that growth levels. A small population is growing on a constant-pressure energy source; for example, a population of yeast in a fermenting brew. At first the growth of the population is exponential. Food is easily obtained, and as the population grows it feeds back to draw in more energy. However, as the yeast become crowded, their by-products begin to interfere with cellular function. The interference accelerates in proportion to the number of interacting cells until eventually the population stops growing and the numbers remain constant from then on.

This pattern of population growth is analysed in Figure 6.2. Notice that the model is basically the same as that in Figure 6.1. The energy supply is a constant-pressure source, and the population is drawing in energy and feeding back to draw in more. Population growth is therefore exponential - at first. However, as Figure 6.2 shows, the population, by interacting with itself, creates an accelerating energy drain which will eventually draw off enough energy to stop population growth. Thus, the graph shows: exponential growth which slows and eventually levels off to a steady state.

Another example of model 2 is the growth of a human population and its services in a city. Growth may increase exponentially until the crowding of houses, streets, stores, and cars starts to increase the negative factors of dirt, noise, crime and pollution and the cost of dealing with these becomes progressively greater. The more the population builds up, the greater the drain until the growth of the city levels off.

Notice that in model 2, the quantity in the storage symbol has been referred to as, the "quantity". We will continue to use this general term for the contents of the store. You should remember that, the "quantity" may refer to population numbers, biomass, energy stored or all of these.

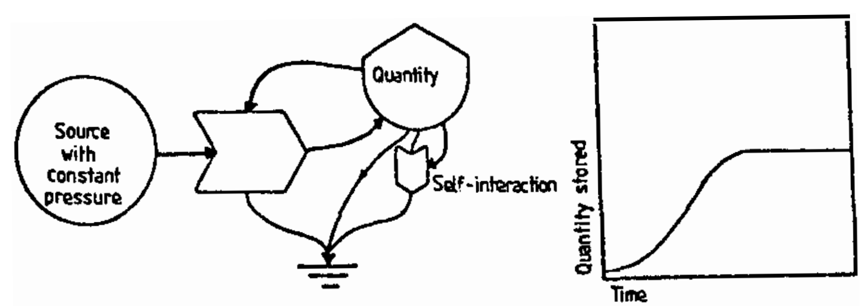


Figure 6.2 Model 2: Growth of a system with a constant-pressure energy source and a self-interaction on the outflow drain.

6.3 MODEL 3: A RENEWABLE SOURCE CONTROLLING FLOW

Ecosystems utilise sources such as the sun, rain, wind and flowing streams. These are sources that the system cannot control, they are controlled-flow renewable sources. In the case of Model 2, you saw how an exponential growth reached a steady state due to the energy drain of self-interactions. A curve of similar shape can also come about because of *energy shortages*.

Suppose that we have a population sustained by an energy source from which there is a steady flow of energy. (Figure 6.3.) The energy flowing from the source is beyond the control of the population - for example, the sun shining on a forest. There is nothing that the trees can do to increase or decrease the energy flowing to them. Some of the light energy is used by the trees; some of it passes out of the system.

When the forest is new, light energy will not be limiting. Thus, the growth of the trees will be rapid, and some of the surplus light energy passes by unused. As the forest grows, however, the trees use more and more energy, and

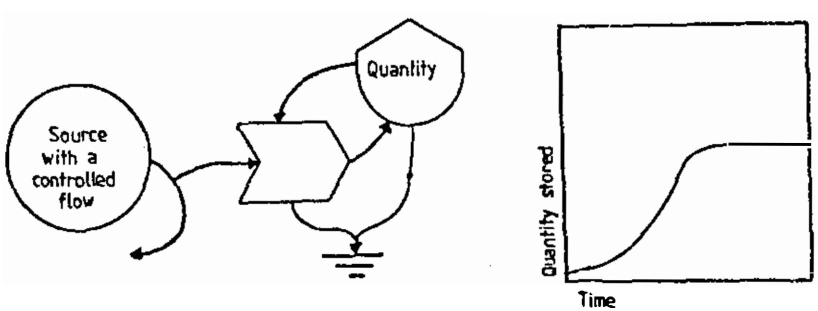


Figure 6.3 Model 3: Growth of a system in which a feedback uses a controlled-flow energy source.

less and less escapes unused. Eventually, light becomes limiting. Growth slows and stops. The forest becomes a balance between growing and decomposing. Once again the curve grows and then levels - but this time due to a source with a controlled flow.

Another example of growth on a controlled-flow source is the building of hydro-electric power plants along the river. New power plants can be built until all the energy in the mountain water flow is being used. Once this point is reached, new power plants cannot increase the energy obtained from the moving water.

These sources are often called renewable because they flow continuously and are not used up. This is in contrast to non-renewable sources like coal and oil which are being used up. The earth will eventually make more, but millions of years are required.

ACTIVITIES

1. *Find different examples for each model.*

2. *Is oxygen a constant-pressure source or a controlled-flow source: for the birds in the air over New Zealand, for fish in a pond with algae? Explain your answers.*

3. *Notice that in none of the graphs does the quantity start at zero; each storage starts with a quantity in it. Why is this so? Explain, using the rabbit model (Figure 6.1) as an example.*

7: Models of Ecosystems

In exercise 6 we introduced three models that are useful in understanding population growth. Now we will look at three other models for growth in systems that are limited by energy sources. These models are more typical of ecosystems.

7.1 MODEL 4: GROWTH IN A SIMPLE STORAGE TANK

The fourth model is one of a storage tank with an inflow from an energy source and an outflow. As an example, think of an empty water tank with a steady flow of water coming in and a drain through which water is escaping. As the water flows in, the tank will fill up. As it fills, water will be pushed out faster. Eventually, water will be flowing in and out at the same rate and the water level will stay the same. This situation is represented in Figure 7.1(a). The graph shows the change in quantity of the water as it increases quickly, then more slowly, and finally reaches a steady state - a position of dynamic equilibrium.

Suppose that the tank was full at the start instead of empty. What would happen then? As Figure 7.1(b) shows, if you start with the tank full, the level will decrease until the same steady state is reached. What would happen if the water inflow is turned off? As Figure 7.1(c) shows, the level in the tank decreases quickly at first, and then more slowly, because as the amount of water becomes less its pressure on the drain becomes less.

An example in nature is a stream flowing steadily into a pond that also has a stream flowing out of it. When the stream first starts flowing, the pond fills up to a level where the flow into the pond equals the flow out (Figure 7.1(a)). Figure 7.1(b) illustrates the situation of the pond after a large rainfall. The quantity of water stored in the pond is high (because of the rain) but soon comes down to the same level as before. If the inflow stream is suddenly diverted, the water in the pond will drain away until there is none left, as is shown in Figure 7.1(c).

Another example is the build up of litter on the floor of a forest as the leaves fall. They build up a layer which continues to grow until the rate of loss from decomposition equals the rate of gain from leaf fall (Figure 7.1(a)). If a sudden gale dumps a load of leaves on the ground, the change in litter quantity would look like Figure 7.1(b). In some forests the leaves stop falling in the winter; the pile of leaves in the forest would then decrease as shown in Figure 7.1(c).

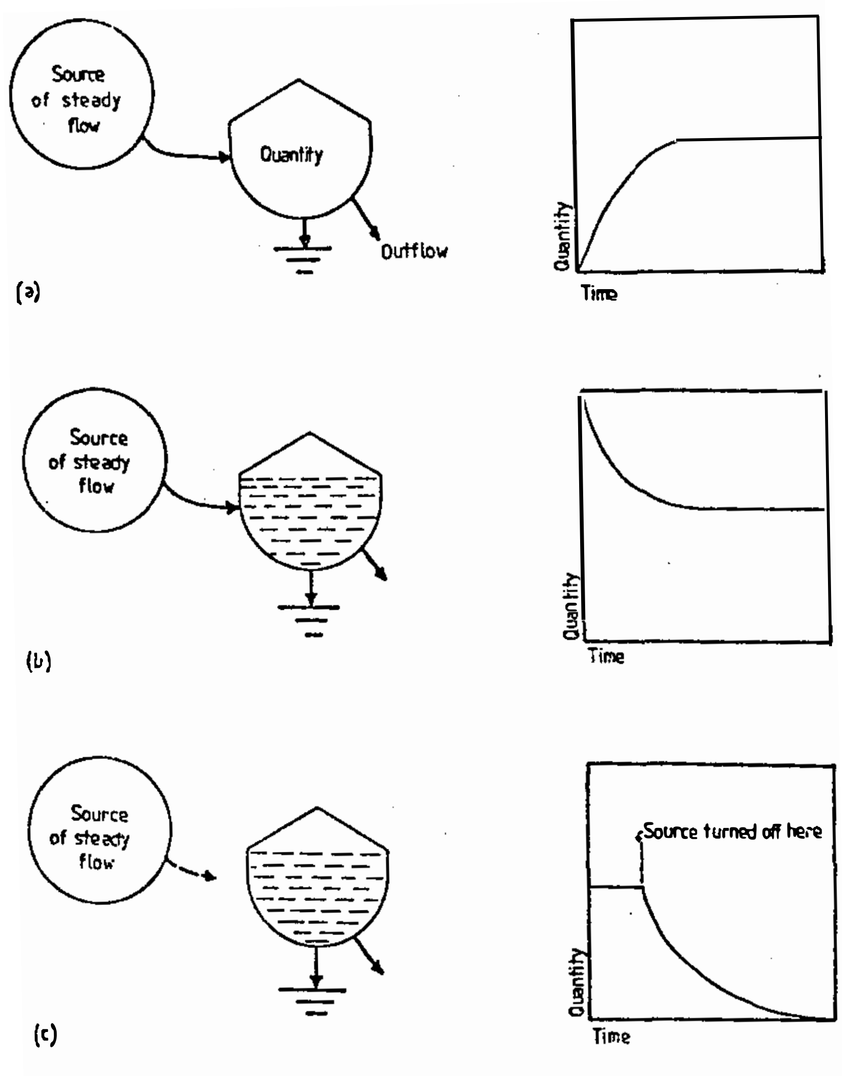


Figure 7.1 Model 4: Growth, steady state, and decline of a system of one storage tank and an energy source with a steady flow.

(a) Start with storage tank empty.

(b) Start with full tank.

(c) Start with steady state, then cut off energy source.

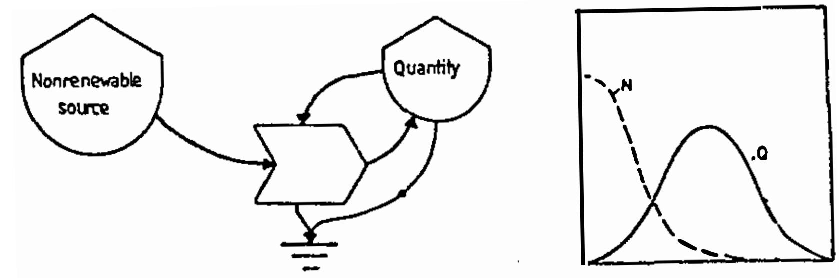


Figure 7.2 Model 5: Growth of a system with a non-renewable energy source.

7.2 MODEL 5: GROWTH ON A NON-RENEWABLE SOURCE

Some systems depend on resources drawn from a non-renewable source, for example, a population of beetles growing on the energy available from a decaying log (Figure 7.2). At first, when the population is small, there is ample energy and growth is exponential. Later, as the log begins to disappear, growth slows. As the log continues to get smaller, the number of beetles decreases until there is no more log - and no more beetles. On the graph, the solid line, Q, represents population numbers. The dotted line, N, represents the energy remaining in the log at any given time.

Some other examples of this pattern of growth are a mosquito population growing in a temporary pond, and a gold mining town growing on a deposit of gold and then declining into a ghost town when the gold is gone.

7.3 MODEL 6: GROWTH ON TWO SOURCES

Our sixth model has two sources, one renewable and one non-renewable (Figure 7.3). They both interact with feedbacks from the quantity so that it grows using both sources. As the non-renewable source runs out, growth declines until it reaches a steady state using just the renewable source. This model is formed by the addition of models 5 (Figure 7.2) and 3 (Figure 6.3).

An example is a population of fish living in a pond which has been fertilised. The two energy sources are the renewable solar energy coming into the pond, and the non-renewable energy available in the extra growth that has been produced by the fertiliser. The fish population will grow exponentially until the non-renewable energy is exhausted, and then decline to a level that can be supported by the unfertilised food chain in the pond.

Another example of a system that may perform in this way is the economic system created by human societies such as ours. Our economic systems have been growing on non-renewable fuels such as petroleum and on renewable sources such as sun, rain, and wind. These renewable sources support natural landscapes and oceans as well as agriculture, forestry, and hydro-electric power. As the non-renewable fuels are used up, our economic systems may decline and settle into a steady state using only renewable energies. Because this model has important implications for our future world, we will return to it at a later stage.

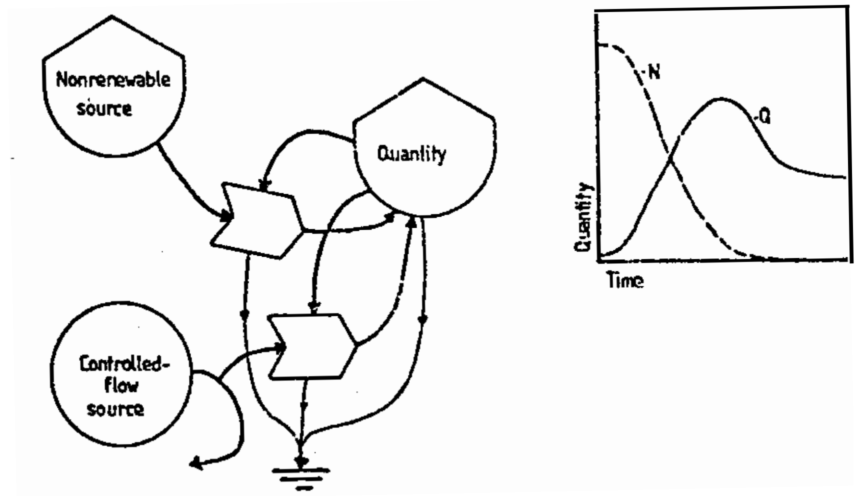


Figure 7.3 Model 6: Growth of a system with two energy sources, one a storage-limited source and the other a flow-limited source.

ACTIVITIES

1. *Set up a "model" of Model 4 (Figure 7.1(a)) in the sink at home and graph its performance.*

   a) Put an aluminium milk-bottle cap into the plug-hole of the sink. Punch a small hole in the milk-bottle cap.

   b) Turn on the cold tap and adjust it so that water flows into the sink a little faster than it is flowing out.

   c) Record the depth of the water in the sink at regular time intervals (say every 30 s) by placing a ruler in the water.

   d) Continue taking recordings until either your system reaches a steady state or it becomes clear that it is not going to. Either way, stop before your family faces the prospect of drowning!

   e) Graph water level (Y-axis) against time and conclude whether or not you succeeded in producing a "model" of model 4.

2. *Perform a similar experiment. This time, your aim is to duplicate the system illustrated in Figure 7.1(b). Graph your data and write a brief explanation of how you set up your "sink model".*

3. *Design a "sink model" experiment that would illustrate Model 6, using only the following equipment:*

   - *sink, milk-bottle cap and ruler (as for the previous experiment);*
   - *bucket, length of plastic tubing.*

4. *The Forrester computer model of the world human-support system makes the following prediction:*

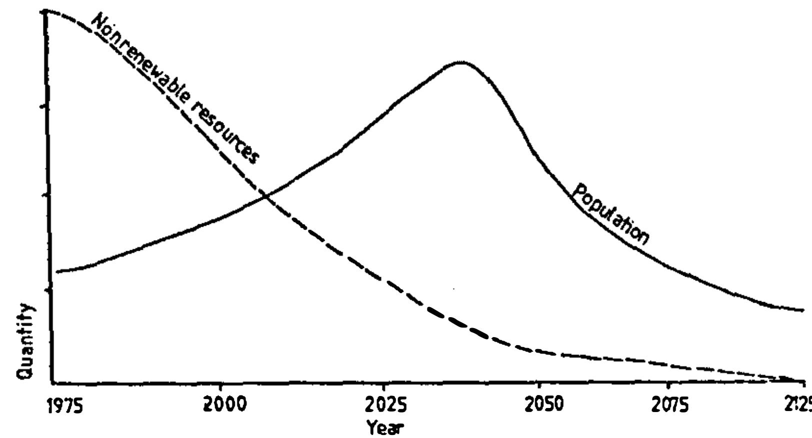


Figure 7.4 Forrester model.

   a. Describe in words the population future of the human species that is predicted by this model.

   b. Which of the six models that you have studied so far does this projection most resemble?

   c. Describe some of the likely energy resources that would be used by the human population in the year 2100.

5. *List the energy sources available to human systems. Mark each as to whether it is constant-pressure, renewable with controlled flow, or non-renewable. Be sure to include natural energies as well as fuels.*

6. *Find a new example for each of the three new models.*

7. *Prepare the electrical circuit shown in Figure 7.5(b) using wires, a solar photo-cell, an electrical storage tank (capacitor), a variable resistor, and a meter that reads electrical storage. This electrical circuit is an example of the model in Figure 7.1. See if you can reproduce the curves of growth on the meter by turning lights on and off, as shown in Figure 7.5(c).*

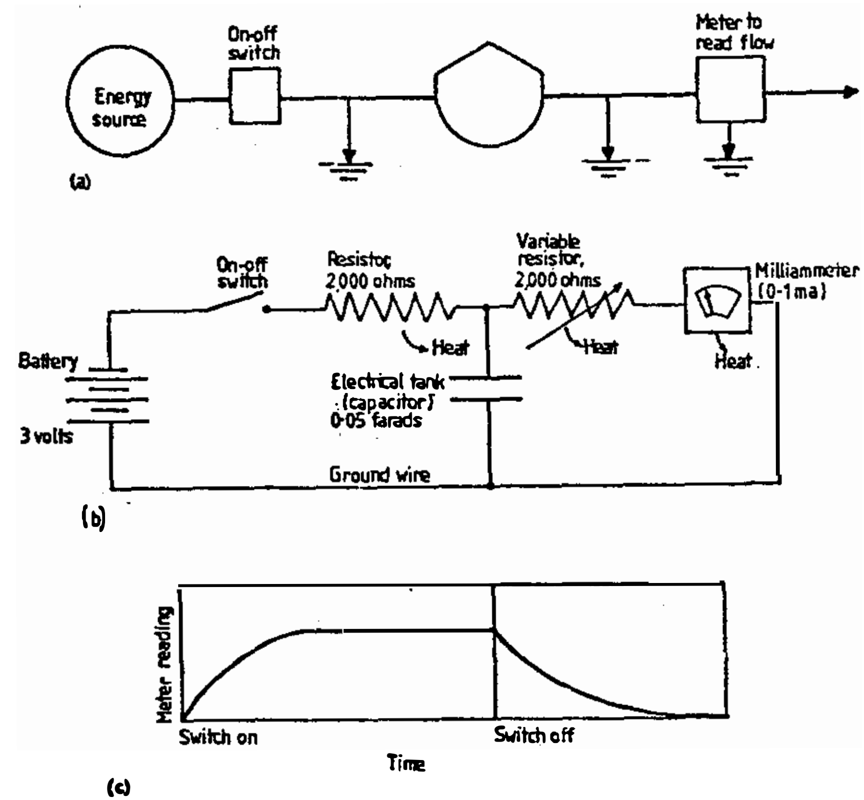


Figure 7.5 Suggested activity for an analogy with electricity; single tank being charged by a source.

(a) Energy diagram.

(b) Electrical wiring (electrical symbols and terms are used).

(c) Meter readings over time. Use battery or solar cell.

8: Simulating Quantitative Models

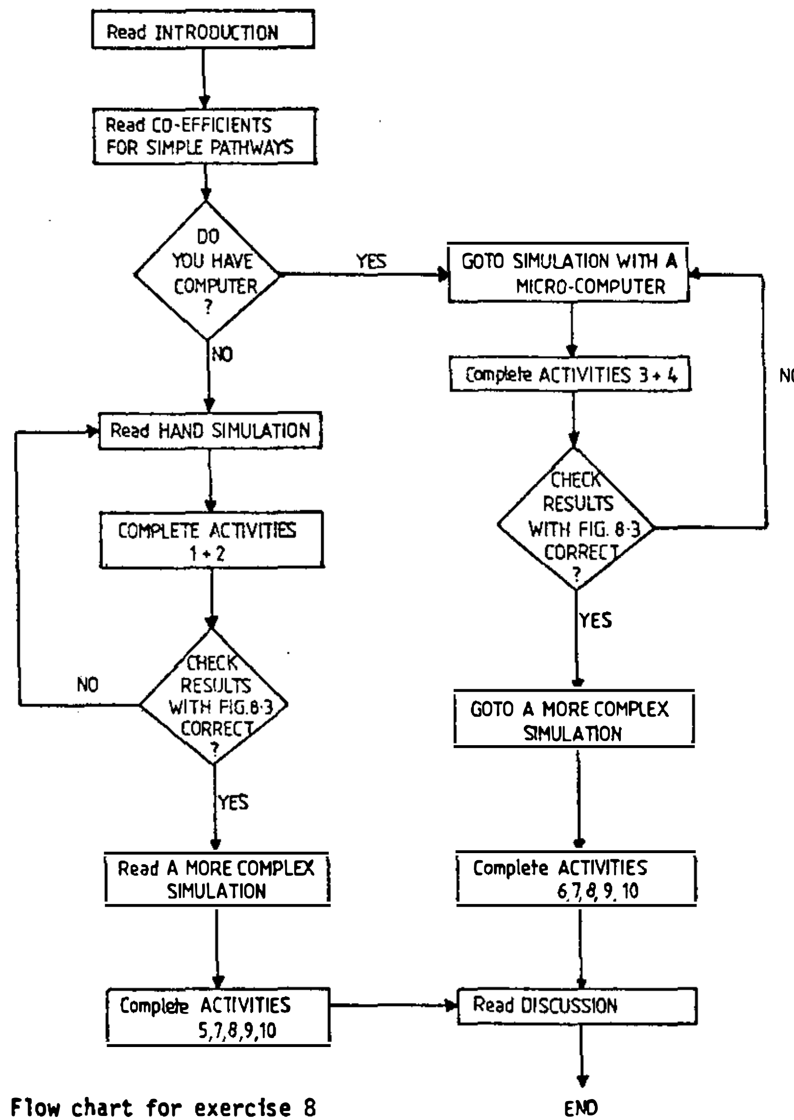
8.1 FLOW CHART FOR EXERCISE 8

In this exercise we will introduce you to the technique of simulating (or running) quantitative models of systems. The exact technique that you employ will depend on whether or not you have a computer available. To find out which sections you should complete, and in which order, consult the flow chart. Work through the readings and activities outlined in the flow chart until you reach the END.

8.2 INTRODUCTION

The energy language diagrams that you have been working with are a useful way of visualising the way systems respond. So far, we have introduced six models of systems with different types of energy sources and storages. We have been able to sketch semi-quantitative graphs of the way each system will respond through time. Our energy language becomes much more powerful, however, when quantitative calculations can be made to show the way systems respond.

The energy language diagrams that we have already used are mathematical statements. With them, we have been using *symbols* to represent *quantities* and *relationships*. They become



Flow chart for exercise 8

quantitative statements simply by noting the amount in each storage symbol and the flow-rate on each pathway. If we do this, we have a language that is very close to the language understood by computers. If you have access to a computer, and if you can learn to use it, you may be able to work the exercises in this section by computer simulation. If you haven't, don't worry, you can do just as well (for the present) with a technique that we call "hand simulation".

8.3 CO-EFFICIENTS FOR SIMPLE PATHWAYS

To represent quantitatively what is happening to a model at any one time, numbers are simply written on the diagram. Flow rates are written on the pathway lines and storage quantities are written in the storage symbols, like this:

Imagine a sink containing 20 L of water. The plug leaks so that 10% of the remaining water flows out each hour. During the first hour the sink will lose 2 L of water. Our quantitative energy language diagram for the system looks like this:

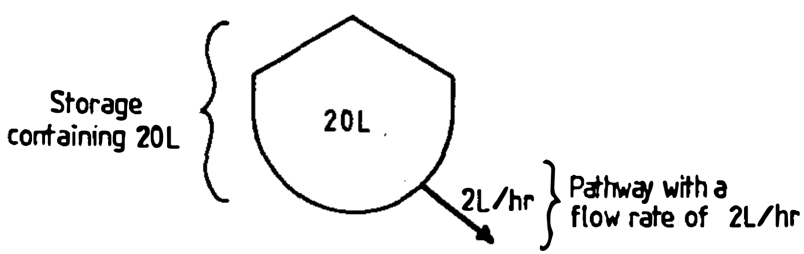


Figure 8.1 Tank model showing storage and outflow path.

This diagram is a *quantitative* description of the system at the start of the first hour. However, at the start of the second hour things are different. The quantity of water left in the sink is now 18 L and the rate of outflow is 10% of that, or 1.8 L/hr. Obviously, the first quantitative model will no longer do. Drawing a new quantitative model for the system at each instant in time could become a little tiresome. We can do two things to solve this problem.

- First, we can represent the quantity of water in the storage by Q (and understand that Q will change with time);

- Second, we can describe the outflow with a *pathway co-efficient*, called k, that indicates the fraction of the remaining water that leaks out each hour. Our pathway co-efficient is 10% or 0.1.

Notice that:

Outflow = pathway co-efficient x amount left in storage
= k x Q

and:

Pathway co-efficient = decimal fraction of storage flowing out per unit time.

Our quantitative model for the leaking sink now looks like this:

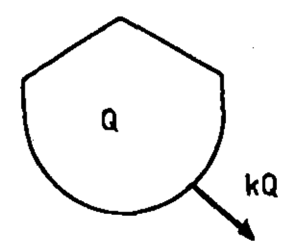


Figure 8.2 Tank model showing pathway co-efficient.

And all we need do to bring it to life is to add data.

8.4 HAND SIMULATION

Let's add some data and bring our quantitative model to life. In our discussion so far we have taken Q = 20 L and k = 0.1/h, so we will continue to use these figures. For the first hour:

$$\begin{aligned} \text{Outflow} &= kQ \\ &= 0.1/\text{h} \times 20\ \text{L} \\ &= 2\ \text{L/h (2 litres per hour)} \end{aligned}$$

and,

$$\begin{aligned} \text{remaining storage} &= \text{original storage} - \text{outflow} \\ &= 20\ \text{L} - 2\ \text{L} \\ &= 18\ \text{L} \end{aligned}$$

or, putting it in computer language,

$$\text{New Q} = \text{Old Q} - k \times \text{Old Q}$$

For the second hour:

$$\begin{aligned} \text{Outflow} &= kQ \\ &= 0.1/\text{h} \times 18\ \text{L} \\ &= 1.8\ \text{L/h (1.8 litres per hour)} \end{aligned}$$

and,

remaining storage (i.e. New Q) = original storage (i.e. Old Q) - outflow (i.e. k x Old Q)

$$\begin{aligned} &= 18\ \text{L} - 1.8\ \text{L} \\ &= 16.2\ \text{L} \end{aligned}$$

We have completed these calculations for the first five leaking hours. Here's the result:

Table 8.1

Time (since start) in hours	Quantity	Outflow, in litres
0	20	2
1	18	1.8
2	16.20	1.62
3	14.58	1.46
4	13.12	1.31
5	11.81	1.18

As you can see, we now have some quantitative statements about how this system is responding.

8.5 COMPUTER SIMULATION

Micro-computers make calculations like those in Table 8.1 easy, and plot the resulting graphs. (As well as being a valuable scientific tool, computers are a lot of fun.) The computer has a television-like display unit and a typewriter-like keyboard. You communicate with the computer through the keyboard and the computer communicates with you through the screen. The set of numbered instructions that you provide for the computer is called a *program*. When a program is typed into a computer, the instructions appear on the screen - just like typing on paper with a typewriter, and when the ENTER button is pushed, they also enter the computer's working memory. After the typing in of the program is completed, the instruction RUN causes the whole set of instructions to be executed. The results can appear either as a table, as in Table 8.1, or as a graph, as in Figure 8.3. When the computer is turned off, the storage in the working memory is lost. However, if you want to save the program or the results, you can instruct the computer to shift the information verbatim to a memory tape or disk which can be filed away.

Let's examine the calculations that were made to form Table 8.1. The process was one of repeating a series of step-by-step subtractions of increments from the storage. The process of making repeated calculations like this is called *iteration.* Iterations can also be described using a type of equation called a *difference equation.* For example, the process in Figures 8.1 and 8.2 could be stated in words, as follows:

The Quantity at the next time interval (Q_{t+1}) is the Quantity at this time interval (Q_t) minus the outflow (k times Q_t).

This is written as a difference equation:

$$Q_{t+1} = Q_t - kQ_t$$

The different ways of instructing computers are called computer languages, and for different computers different languages are required. Many of the new micro-computers use one of the simplest languages, called "Basic". The command words used in Basic are some selected common English words. The Basic commands needed to simulate the model are given in Table 8.2.

Our program for simulating the model in Figure 8.1 is set out in Table 8.3. (Our computer is a Compucolor - and if yours is a different make, it may require slightly different instructions.) Here's how we developed the program. Each instruction begins with a statement number. Statements are numbered, 1Ø, 2Ø, 3Ø, etc., in case we wish to add more instructions later, say between instruction 1Ø and instruction 2Ø. The computer will execute the instructions

Table 8.2

Some instructions in Basic language to which micro-computers respond

Command	What it does
LIST	Lists the program in the working memory.
RUN	Runs the program, working through the instruction in numerical order.
GO TO	Goes to a designated instruction number and performs it next.
IF	Provides a condition for doing something such as going to another designated line (e.g. IF t is less than 20, GO TO ...)
PRINT	Shows on the screen the numerical value of the quantities that you list after the PRINT command.
END	Stops running the program.
=	Sets a quantity equal to what is specified.
+	Adds the next quantity.
-	Subtracts the next quantity.
*	Multiplies the next quantity
/	Divides by the next quantity
<	Less than.

in the order of their numbers - even if they are typed out of numerical order.

First, we tell the computer the sizes of the quantities it will be working with at the start. Thus we have (in Table 8.3):

```
10  Q = 20  (quantity in storage = 20).
20  K = .1  (pathway coefficient = .1).
30  T = 0   (time = 0).
```

Then we tell the computer to print these numbers:

```
40  PRINT T, Q, K*Q
```

Next we tell the computer what to do with these numbers:

```
50  Q = Q - K*Q
```

which means, "new Q (Q_{t+1}) is equal to old Q (Q_t) minus K multiplied by old Q (Q_t)". (Note: * means multiply - to avoid confusion about what x means.)

Having done that, the computer is told to advance time by one unit:

```
60  T = T + 1
```

and then, if T is less than 20, it is told to repeat instructions 40, 50 and 60:

```
70  IF T < 20  GO TO  40
```

Our faithful computer repeats the calculations for each new time interval, prints out the results and advances the time until it gets to T = 20. At that point, when it gets to instruction 70 it does not go back to 40, but goes instead to 80, which says:

```
80  END
```

The whole sequence of calculations takes a few seconds; the results are neatly listed on the screen in tabular form. Beats hand-simulating, doesn't it?

Table 8.3

Program in Basic for rough simulation#
of model in Fig. 8.1

```
10   Q = 20
20   K = .1
30   T = 0
40   PRINT T, Q, K*Q
50   Q = Q - K*Q
60   T = T + 1
70   IF T < 20  GO TO  40
80   END
```

When ready to simulate, type RUN.

O is the letter O.

Ø is a zero.

To obtain a graph instead of a table of results, we can substitute the PRINT instruction in 4Ø by a PLOT instruction. Plot instructions vary from one type of computer to another.[1] The plot statement tells the computer to plot a graph of successive points with T on the horizontal axis and Q on the vertical axis. We obtained Figure 8.3 by giving the computer this instruction.

As you probably know, there is much more to computer programming even in simple Basic, but you already have enough to simulate the models in exercises 6 and 7 in an approximate manner.

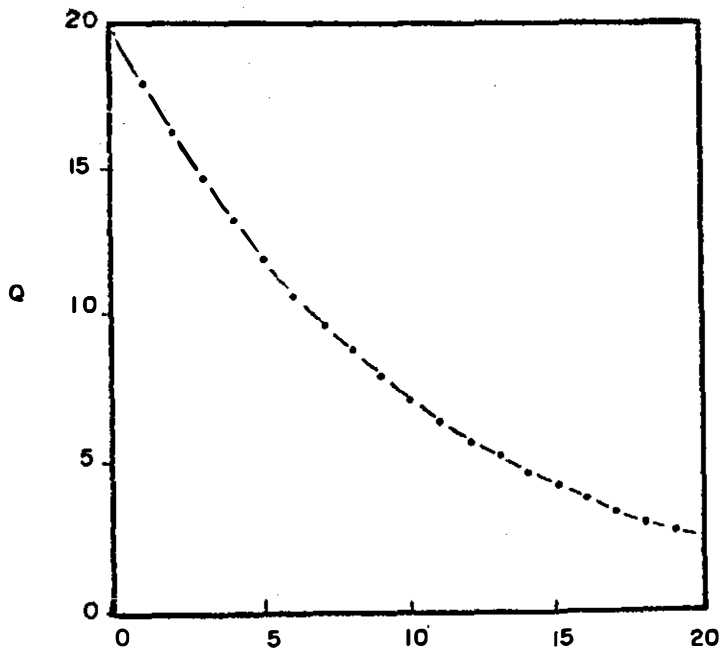


Figure 8.3 Simulation of model in Figure 8.1.

(1) On the Compucolor, instruction 4Ø would be:

```
4Ø  PLOT 2,T, Q, 255.
```

8.6 A MORE COMPLEX SIMULATION

If you were able to work through the simulation of the leaking sink without too much difficulty, you are ready for a more complex model, Figure 8.4.

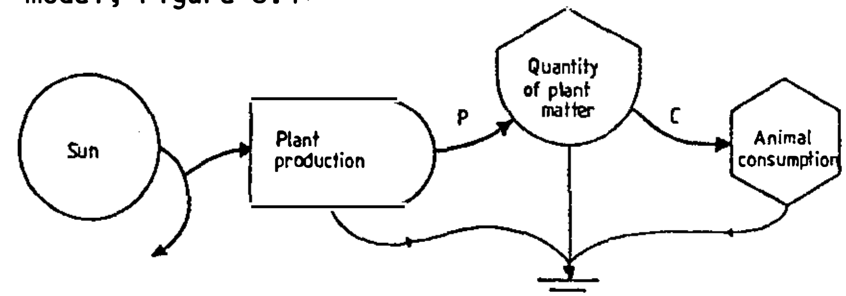


Figure 8.4 Ecosystem diagram.

It represents an ecosystem - any ecosystem. The model indicates that sunlight falling on the producers is captured during photosynthesis and stored in plant organic matter until it is consumed by animals. Now let's add some data. Sunlight varies during the year, and typically might provide the following quantities of energy:

Year	Season	Sunlight ($Joules/m^2/day$)
1	Winter	$5,000 \times 10^3$
	Spring	$10,000 \times 10^3$
	Summer	$15,000 \times 10^3$
	Autumn	$10,000 \times 10^3$

If the plants capture and store a steady 0.1% of the available light energy ($k_1 = .001$) and if animals consume a steady 20% of the energy in store in plant tissues ($k_2 = 0.2$), then a quantitative model looks like Figure 8.5.

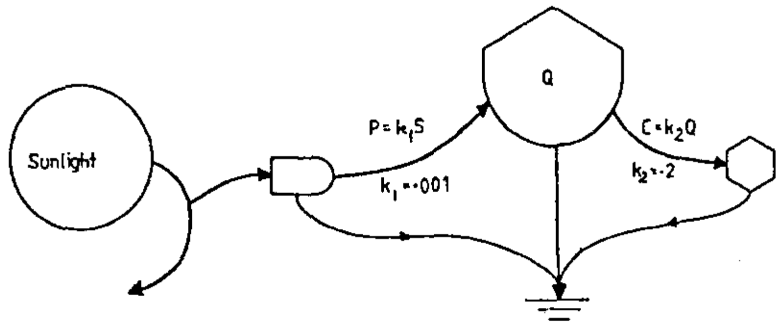


Figure 8.5 Ecosystem diagram with pathway co-efficients.

And a hand simulation of the systems response would begin like this: (We begin our hand simulation with Q = 0.1. To simplify writing, the numbers in the table are thousands of joules - and we are working to two significant figures).

Table 8.4

Hand simulation of Diagram in Figure 8.5

Year	Season		Sunlight $S \times 10^3 J/m^2/$ day	Plant production P = .001 x S	Animal consumption C = .2 x (old Q)	Quantity of plant matter (new Q) (old Q) + P - C
1	Start	-	-	-	-	.1
	Winter	1	5,000	5	.2 x .1 = .02	.1 + 5 - .02 = 5.1
	Spring	2	10,000	10	.2 x 5.1 = 1.0	5 + 10 - 1 = 14
	Summer	3				
	etc.					

You now know enough to complete the simulation of this model yourself. Choose your weapon - hand or computer - and go to it! Refer back to the flow chart for the correct activity.

8.7 DISCUSSION

Your graph of the quantity should show growth and then steady state like Model 3 (Figure 6.3). The sun is a steady renewable source with a controlled flow. Consequently, the production of plant matter increases rapidly at first, but since animal consumption is a steady percentage of the available plant matter, the consumers start to increase faster until production and consumption is a steady percentage of the available plant matter, the consumers start to increase faster until production and consumption are about equal. The growth is not smooth because of the up and down variation of the sunlight. The peak of plant growth is later than the peak of sunlight because there is a lag in building up storage.

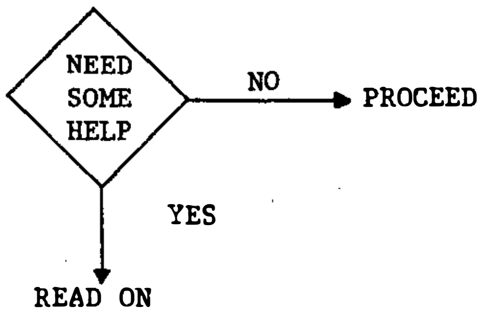
An example of this kind of growth is ecological succession. Rapid plant growth on an open field changes to slower net growth of shrubs and then trees, to a steady state climax forest, where trees and other producers are in balance with consumers.

ACTIVITIES

1. *Copy Table 8.1 and extend it to time = 20h.*
2. *Prepare a graph of Q (Y-axis) against time for the leaking sink.*
3. *Write a program in Basic (that is compatible with the micro-computer you have available) to simulate the model in Figure 8.1*
4. *RUN your program and from the output prepare a graph of Q (Y-axis) against time for the leaking sink.*

5. *Continue the hand simulation in Table 8.4 until you have data for 5 years' growth.*

6. *Prepare and run a program to simulate the model in Figure 8.5. Graph the results.*



The computer program for model 8.5 is basically similar to that for model 8.1. There is, however, one catch to it.

(a) *Begin by setting the starting value (Q = 0.1) and the season (or loop) counter (N = 1).*

(b) *Then comes the catch. You must instruct the computer to take a series of different values for S (sunlight), which varies in the regular series: 5,000; 10,000; 15,000; 10,000 etc. The following series of statements will do the job:*

```
: K = N - INT(N/4) * 4 + 1
: IF K = 1  S = 10,000
: IF K = 2  S =  5,000
: IF K = 3  S = 10,000
: IF K = 4  S = 15,000
```

(c) *The rest is easy. Give the instructions for the calculations to be performed, i.e. P = .001 * S; C = .2 * Q; Q = Q + P-C. Then provide a PRINT statement (you will probably want to know what is happening to : N, S, P, (and Q).*

Next, advance the season counter by one, include a conditional branch (IF N < 2Ø GO TO wherever), and END the program.

Congratulations, you have just become a system modeller.

7. *Copy the Figure 8.6 and graph the system's response and the available sunlight on these axes. Then use the graph to answer the remaining questions.*

8. *The graph indicates the response of this system. Which of the six models that you have studied so far is this response most like? Explain why.*

9. *We are not going to ask you to continue the hand simulation up until year twenty, but if we did, what might the completed graph look like?*

10. *Name an ecological process that you have studied that is illustrated by the graph.*

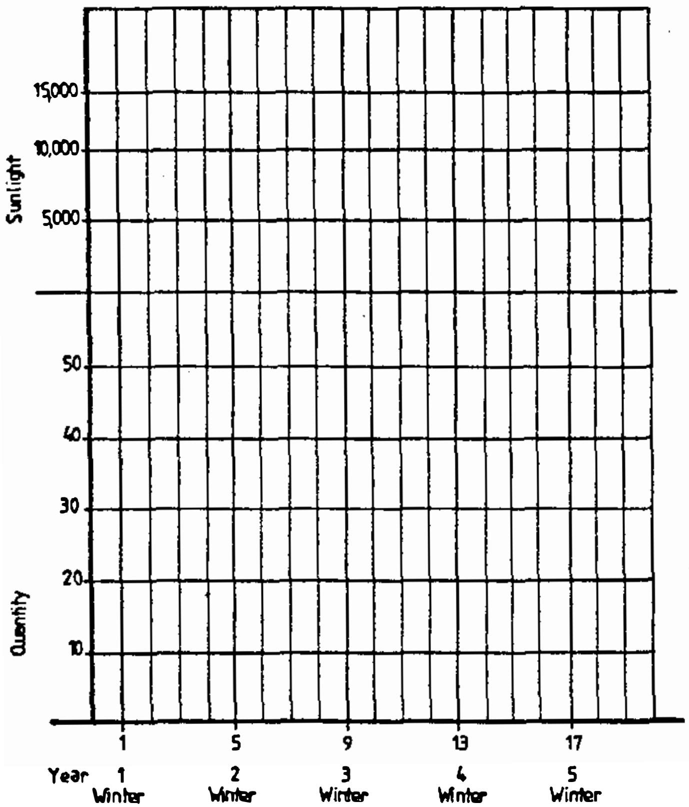


Figure 8.6 Graph for plotting the simulation of P-R system.

Table 8.2 - completed

Hand Simulation of Diagram in Figure 8.4

Year	Season	Sunlight S x $10^3 J/m^2$/ day	Plant production P = .001 x S	Animal consumption C = .2 x Old Q	Quantity of plant matter (New Q) = (Old Q) + P - C
Start					
1	Winter 1	5,000	5	.2 x .1 = .02	.1 = 5 - .02 = 5.1
	Spring 2	10,000	10	.2 x 5.1 = 1.0	5 + 10-1 = 14
	Summer 3	15,000	15	.2 x 14 = 2.8	14 + 15-3 = 26
	Autumn 4	10,000	10	.2 x 26 = 5.2	26 x 10-5 = 31
2	5	5,000	5	.2 x 31 = 6.2	31 + 5-6 = 30
	6	10,000	10	.2 x 30 = 6.0	30 + 10-6 = 34
	7	15,000	15	.2 x 34 = 6.8	34 + 15-7 = 42
	8	10,000	10	.2 x 42 = 8.4	42 + 10-8 = 44
3	9	5,000	5	.2 x 44 = 8.8	44 + 5-9 = 40
	10	10,000	10	.2 x 40 = 8.0	40 + 10-8 = 42
	11	15,000	15	.2 x 42 = 8.4	42 + 15-8 = 49
	12	10,000	10	.2 x 49 = 9.8	49 + 10-10 = 49
4	13	5,000	5	.2 x 49 = 9.8	49 + 5-10 = 44
	14	10,000	10	.2 x 44 = 8.8	44 + 10-9 = 45
	15	15,000	15	.2 x 45 = 9.0	45 + 15-9 = 51
	16	10,000	10	.2 x 51 =10.2	51 + 10-10 = 51
5	17	5,000	5	.2 x 51 =10.2	51 + 5-10 = 46
	18	10,000	10	.2 x 46 = 9.2	46 + 10-9 = 47
	19	15,000	15	.2 x 47 = 9.4	47 + 15-9 = 53
	20	10,000	10	.2 x 53 -10.6	53 + 10-11 = 52

9: Oscillating Systems

Many biological systems undergo a period of natural growth, after which they level out into a more-or-less steady state. Succession is an example of this pattern of growth. There are other systems, however, that behave in a different way. Instead of levelling out, they develop repeating oscillations. In the long run, this is a *kind* of steady state, but at any one time or place, quantities may be changing rapidly. So many phenomena in both natural and human systems have oscillations, that the oscillating system may turn out to be more typical than the steady state system.

9.1 PREDATOR-PREY OSCILLATIONS

Figure 9.1 shows a system with two components, each dependent on the other. It is a producer-consumer system. At first, both populations tend to grow exponentially, but as the first population becomes abundant, the consumer population accelerates its growth so fast that the first population is pulled back to a low level again. Then, with less to eat, the consumers decline in numbers, whereupon the producers increase, and the cycle repeats. The pattern in time is given in Figure 9.1(b). Oscillating patterns like this are observed in isolated simple ecosystems both in the lab-

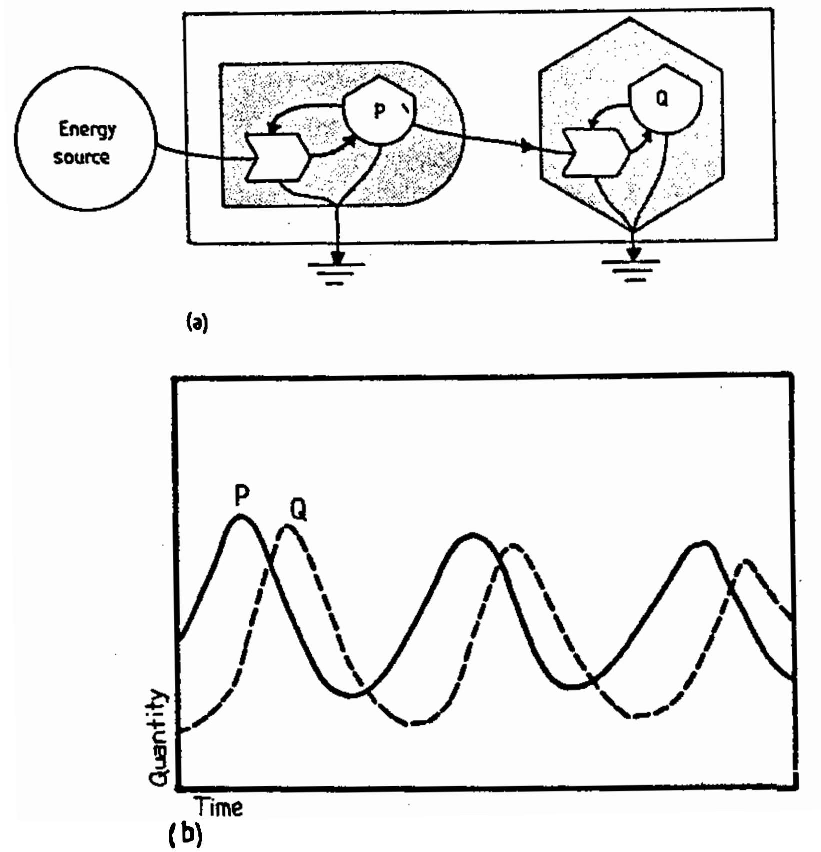


Figure 9.1 A producer-consumer system which oscillates.
(a) Energy diagram.
(b) Simulation.

oratory and sometimes in the wild. The oscillation of grass and lemmings (small mammals) in the Arctic is an example from the wild. Where this model is used for systems consisting of two interacting animal populations, it is sometimes called the predator-prey model.

Some scientists believe that animals introduced into New Zealand show oscillations of this kind. For example, opossums may eat all the palatable vegetation until their food supply is so low that population numbers decline. Another example, observed in Canada, which could develop here, involves conifers and defoliating insects that burst into epidemic growth and then die back as the conifers become defoliated. In this case, where the pattern has been repeating for a long time, the oscillation is not necessarily harmful to the climax forest, since rhythmic defoliation may help maintain seedlings and subcanopy components of the ecosystem.

Growth of grassland for several years, followed by extensive fire that recycles nutrients, is a characteristic pattern in many parts of the world. It may have been important in the drier areas of New Zealand in the past and may become important in the future. The heavy use of these lands for grazing has substituted farm animals for fire as an alternative consumer. There may even be oscillations in the growth of grass and populations of sheep on open ranges.

Human population growth has also been subject to oscillations. The patterns of disease epidemics alternating with human population growth is a familiar one in world history, a pattern modified in recent years by public health and medicine.

The model in Figure 9.1 is a standard one used in ecology textbooks to help explain population oscillation. However, the model does not show clearly the mutualistic effects of consumer feedback in helping the producer, such as the recycling shown in Figure 9.2.

9.2 COMPUTER SIMULATION OF AN OSCILLATING MODEL

Figure 9.2 is a model for a typical oscillating system with recycling included. In this case, the model describes consumption by fire or perhaps insect epidemic, or even the action of a farmer in cutting a pasture for hay after growth has reached a high level. This model is an interesting one to simulate by computer. The computer program is given in Table 9.1 and described in a flow chart in Figure 9.4. You don't have to be a computer-user to follow this model through.

This is how the model works: with constant environmental conditions, plant growth is in proportion to the available nutrients (N) such as phosphorus. Pathway F (F for fire) does not operate until the quantity of grass (Q) reaches a threshold value, called G_1. When it does equal

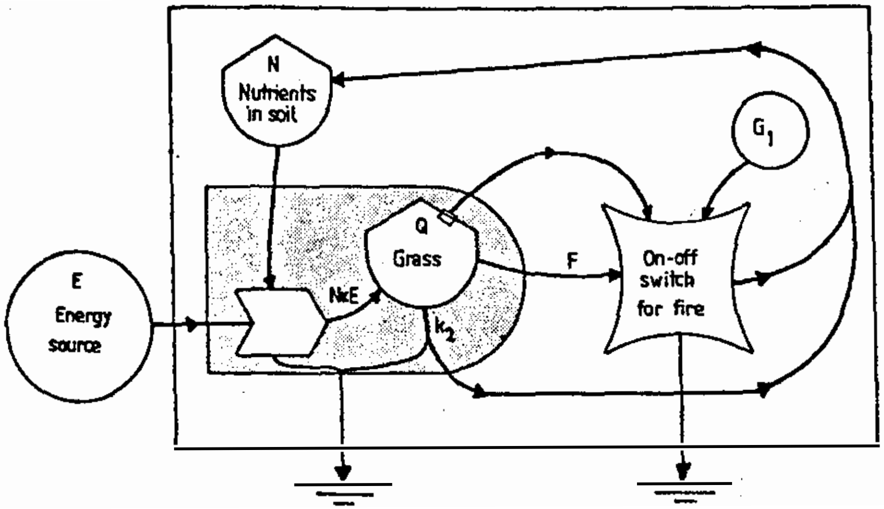


Figure 9.2 Grass-fire model. Q, quantity of grass per m^2; F, consumption by the fire; G_1, threshold amount of grass to turn fire on; N, nutrients in soil; NØ, total nutrients in soil and in grass (N+P*Q); P, proportion of grass that is nutrients; E, energy sources; N*E, rate of production of grass; K_2, percentage of grass that is respired and depreciates in one year; T, time in years; If $Q > G_1$ F turns on.

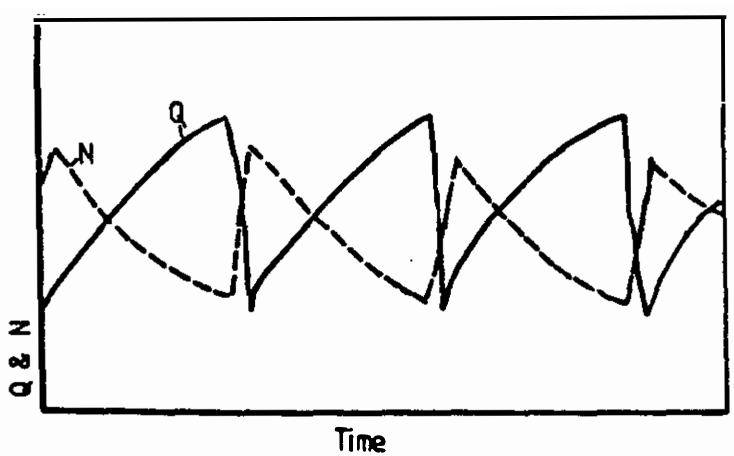


Figure 9.3 Results of simulation of Figure 9.2.

or exceed G_1, the pathway F consumes grass rapidly. When the rapid consumption process stops, the grass can regrow.

The results of the simulation are given in Figure 9.3. If you have access to a computer, try it yourself.

Table 9.1

Program in Basic

```
10   G1 = 18000
20   NØ = 25
30   Q  = 1000
40   E  = 150
50   K2 = 0.03
60   F  = 16000
70   P  = 0.001
80   IF Q > G1  THEN Q = Q - F : N = NØ
90   PRINT T, N. Q                        (NEEDED FOR PRINTING)
100  PLOT 29, 17, 2, T, N*2, 255          (NEEDED FOR PLOTTING)
110  PLOT 29, 18, 2, T, Q/300, 255
120  Q = Q + N*E - K2*Q
130  N = NØ - P*Q
140  T = T + 3
150  IF T < 127 THEN 70
160  END
```

Select either plot or print statements, not both. The plot statements are for a Compucolor microcomputer. Each computer uses slightly different commands.

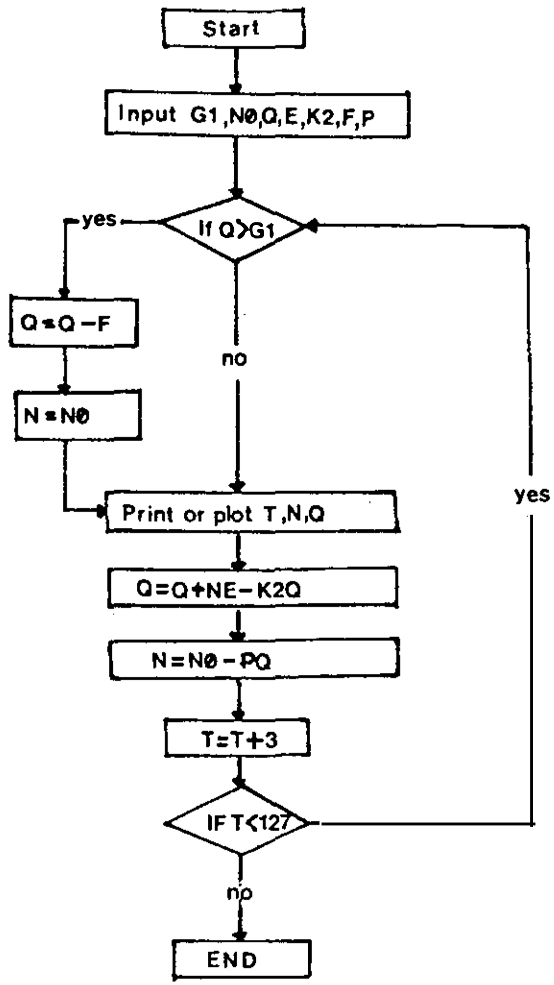


Figure 9.4 Flow chart for simulation of Figure 9.2.

ACTIVITIES

1. *Examine a grassy area that has been burned recently. Look for regrowth from roots and seeds.*

2. *Explain how the following processes may oscillate similarly to the prey-predator of fire models:*

   mechanical clock
   hunger
   inventory in a store
   earthquakes
   disease epidemic
   life of a single tree
   clover and grass grubs

3. (a) *If you have access to a computer, type in the program for an oscillating system, and then use it to determine the effect of increasing and decreasing the primary energy source (E). How do these changes affect the frequency of oscillation?*

   (b) *What is the effect of restricting the total amount of nutrients ($N_{\emptyset}$)?*

   How do these changes affect the frequency of oscillation?

PART TWO: NATURAL SYSTEMS

10: The Ocean

Three-quarters of the earth's surface is ocean; the ecosystems of the sea. The ocean system is especially important to New Zealand since none of our land is far from the ocean and much of our protein food comes from it.

10.1 TURBULENCE IN OCEAN SYSTEMS

Figure 10.1 is a diagram of an ocean ecosystem. The organisation of the ecosystem has the same basic pattern as other systems that we have considered, with outside sources, producers, and consumers. However, in the ocean system, turbulence is of special importance since it provides for both vertical and horizontal distribution of nutrients and gases. Turbulence is a circular motion of the water caused by wind. Tides and various currents also keep the water constantly stirring. These energies are shown in the system diagram as a kinetic energy storage in the ocean system.

Notice in the diagram the flows from the turbulence to phytoplankton and zooplankton. Turbulence keeps the plankton in motion, helping supply their needs and bringing to the surface those that sink. Phytoplankton are the producers of the ocean system: diatoms, dinoflagellates and other microscopic algae. Zooplankton are suspended animals most of which feed on the phytoplankton: they include many types of organisms from microscopic protozoa to fish eggs.

The ocean system diagram also illustrates the way in which circulation functions in the provision of nutrients. Materials lost from the ocean food web sink into deep water before decomposing. Upwelling sea water returns these lost nutrients to the surface where they stimulate the growth of phytoplankton, and hence the whole food chain. Such areas of upwelling water provide rich fishing grounds - such as those off the coast of Kaikoura in the South Island, and northwest of Auckland.

10.2 FISH YIELDS

It is sometimes suggested that if people harvested the sea more efficiently, it would produce much more food. This is exaggerated. Most of the open oceans have very few nutrients and sparse food webs. High fertility is found in upwelling zones and on the continental shelves where detritus consumers on the shallow bottoms are the beginning of diverse food chains.

The tonnage of marine fish caught around the

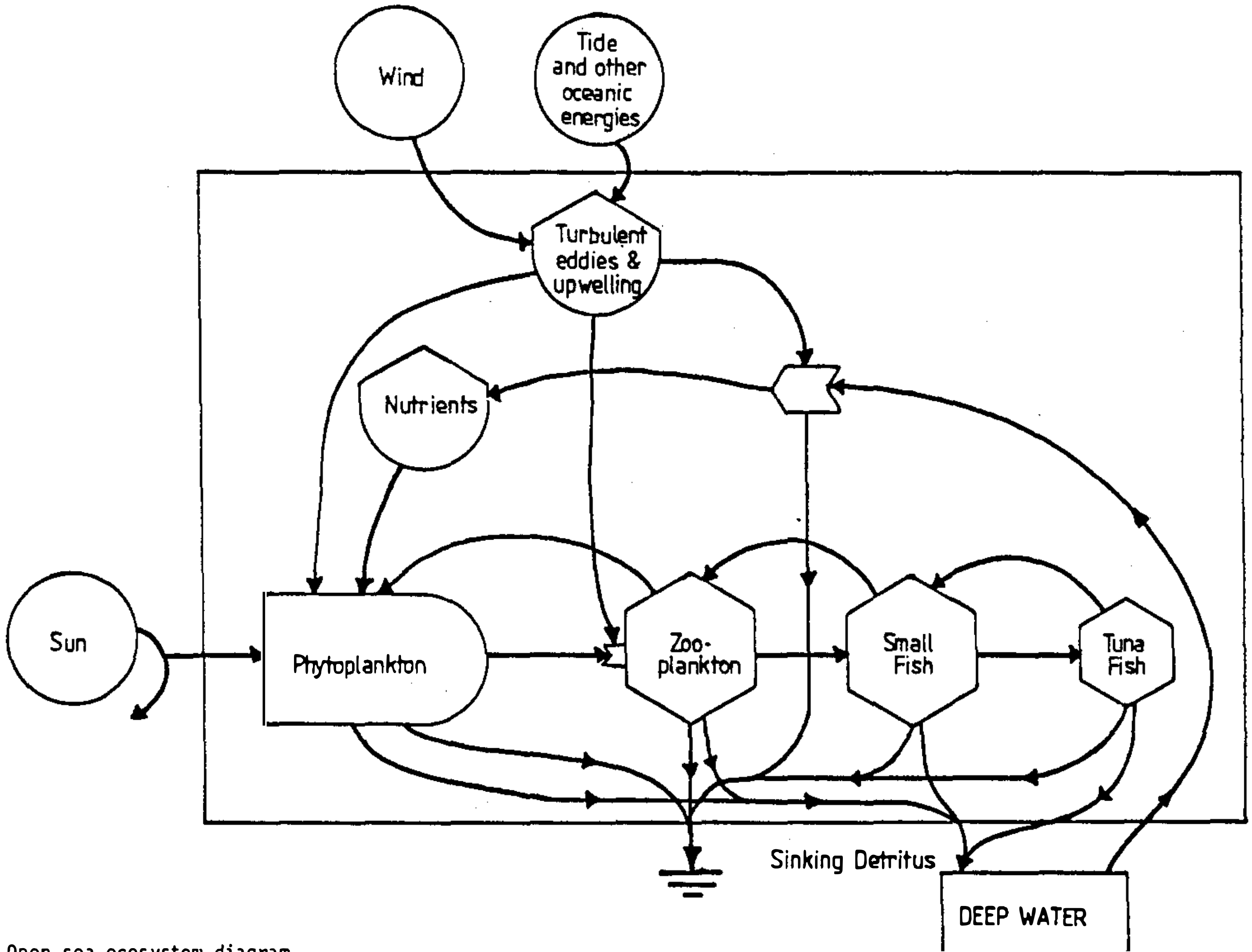


Figure 10.1 Open sea ecosystem diagram.

world showed a sharp rise in harvest from 1900 to 1970, after which it declined again, indicating that harvesting may have gone beyond the maximum sustainable yield. (Figure 10.2) Mechanical trawling devices bring up so many fish that the stocks of some species have become seriously depleted. When fuels become so hard to get that the large ships are no longer economical, fish stocks may rise again.

Every renewable system which supplies energy needs controlling and recycling feedbacks if it is to survive. As seen in Figure 10.3, humans have been taking yield from the oceans, but have not been putting much back to replenish the system. However, even under the best management, the oceans cannot solve the food problems of our over-populated world.

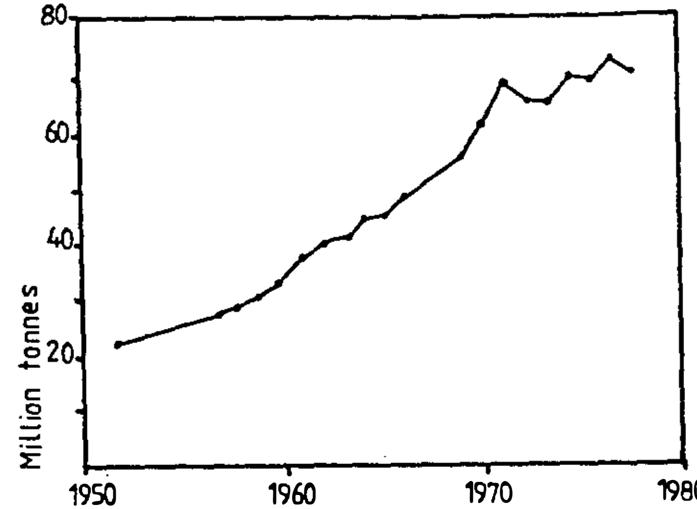


Figure 10.2 Growth in world fish catch, 1960-77.

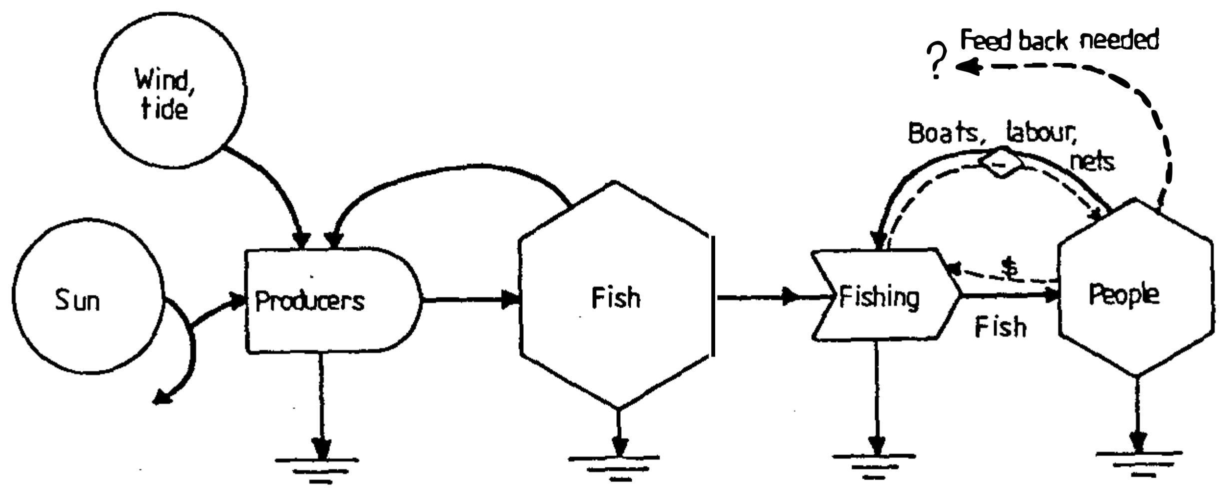


Figure 10.3 Fish yield from the sea with no feedback of people to the fish system.

10.3 WHALES AND WHALING

Many of the small numbers of whales that now survive in our oceans depend, as they always have, upon large zooplankton like krill, for food (Figure 10.4). Normally, we would expect that the energy passing through a food chain would require several intermediate steps in order to pass from organisms as small as krill to organisms as large as whales. Ecologically, the function of those intermediate organisms would be to concentrate the energy available in the food chain. Whales have been able to do without the middlemen by learning to harvest a small number of rather special ocean areas where currents help krill concentrate in large, tight masses. Thus, the ocean currents perform the same ecological function as first or second order consumers.

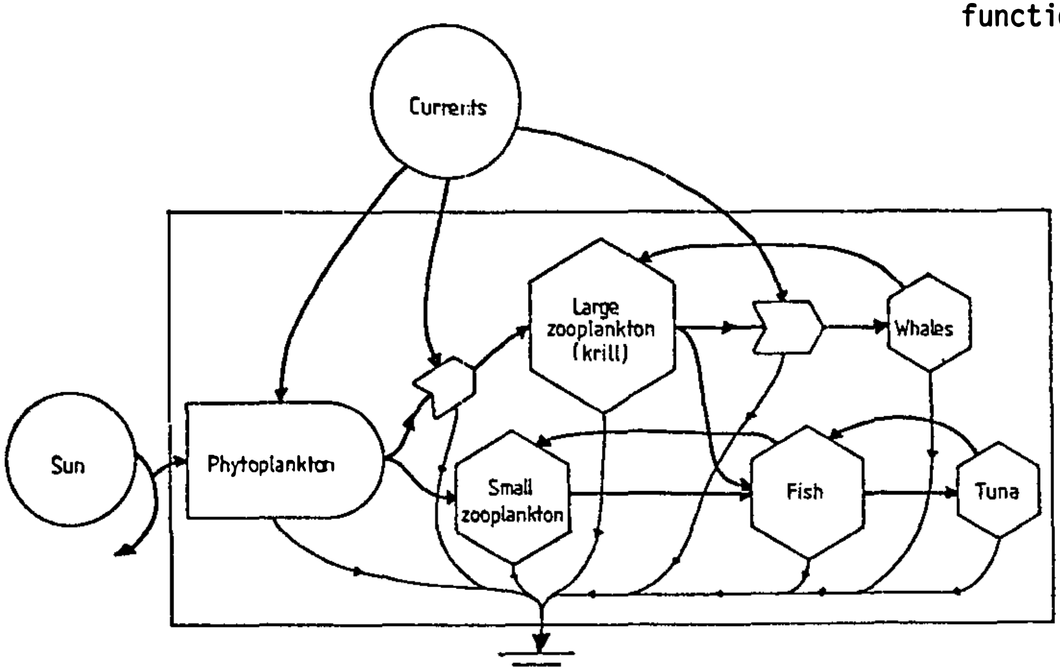


Figure 10.4 Whale and tuna food web showing the special role of currents.

ACTIVITIES

1. *The next time you visit Cook Strait, notice the swells and waves; these are driven by winds far away. Notice the convergence streaks where debris floats in lines. These convergence streaks are lines in the water where large perpendicular eddies meet, bringing together everything floating in the area.*

2. *Go to your nearest fishing port. When the fishermen bring in their catch, make a diversity count. Count 1,000 fish keeping a record of the number of different kinds. This number is called a diversity index. A count of about 30 different species in 1,000 means the system has a high diversity; six per 1,000 is a low diversity.*

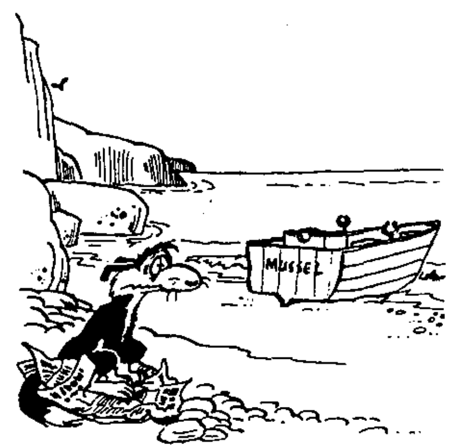
   Then go to the beach and count the number of species in 1,000 sea shells. These represent a sample of the molluscs at the bottom of the sea. What is its diversity index?

   Compare the diversity of the open sea with the sea bottom. Discuss why they are the same or different.

   Later we will do diversity counts on other systems.

3. *What kinds of services do you think people can feedback to the oceans to bring the fish yields back?*

4. *Draw a diagram of another fish food web. Be sure to include the physical energies like winds and currents.*



11: Pond and Stream

Because of its abundant rainfall, New Zealand has many freshwater ecosystems in ponds and streams. However, the geographical isolation has limited the number of larger animals and plants that have been able to immigrate or evolve in our freshwaters. New Zealand is nearly 2000 km from Australia, which is the nearest land mass.

11.1 PONDS

The most numerous ponds are small farm ponds excavated in pasture and used for watering stock. They are shallow and may become dry over the summer months. In parts of the South Island, kettle-hole ponds are common. These are formed in depressions in mounds of glacial debris. Even though different ponds vary in water levels, nutrients and temperature, they have the same basic ecological pattern which is illustrated in Figure 11.1(a) and (b).

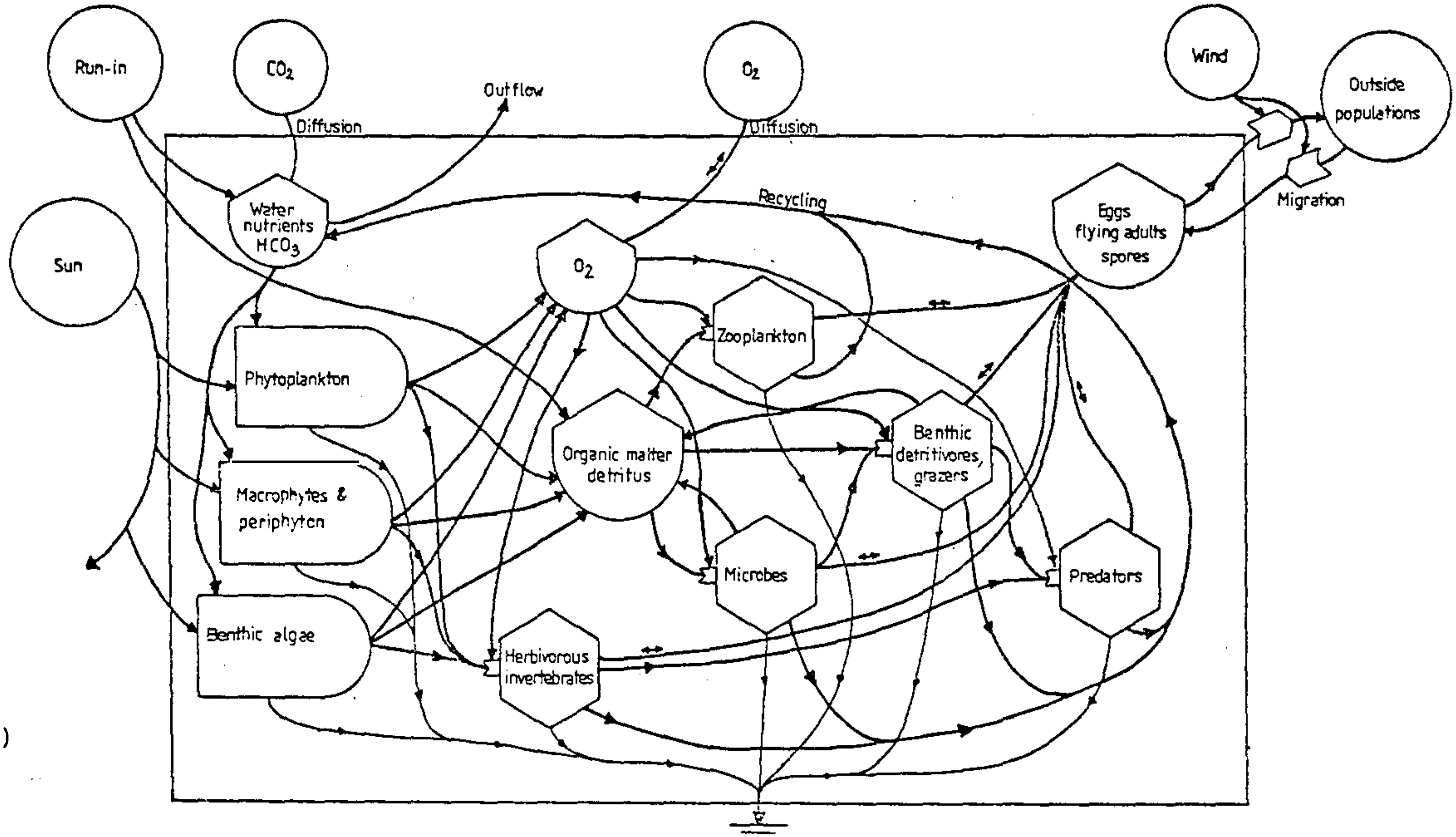
Most ponds are shallow enough so that light penetrates to the bottom. There are three groups of producers: *phytoplankton*, *macrophytes* (large leafy plants) with their *periphyton* (algae attached to the leaves and stems), and *benthic* (bottom) algae. Although there is usually no stream input, the run-off from the surrounding pasture brings dissolved organic matter, detritus and nutrients.

The carbon dioxide needed for photosynthesis comes into the water from the air, from decomposing organic matter, and from bicarbonates leached from rocks. Where limestones are drained, bicarbonates and calcium are high and the ponds are said to have *hard water*. However, most waters in New Zealand are dilute and said to be *soft water*.

Follow the food web flows and you will see that there are many microscopic and small creatures in the pond feeding on the plants and algae. However, there are no animals larger than frogs, which are, in fact, the top carnivores. Fish rarely live in these ponds because they often dry up for part of each year. Populations of other organisms such as eggs of zooplankton, seeds of plants, spores of algae and micro-organisms, and flying insect adults are carried in and out by the wind.

11.2 EUTROPHIC AND OLIGOTROPHIC WATERS

Waters with high nutrient levels are called *eutrophic*. Others, low in nutrients are called *oligotrophic*. Eutrophic water has more life but develops extreme oxygen conditions.



(a)

Figure 11.1 Pond ecosystem; details of the food web are shown.

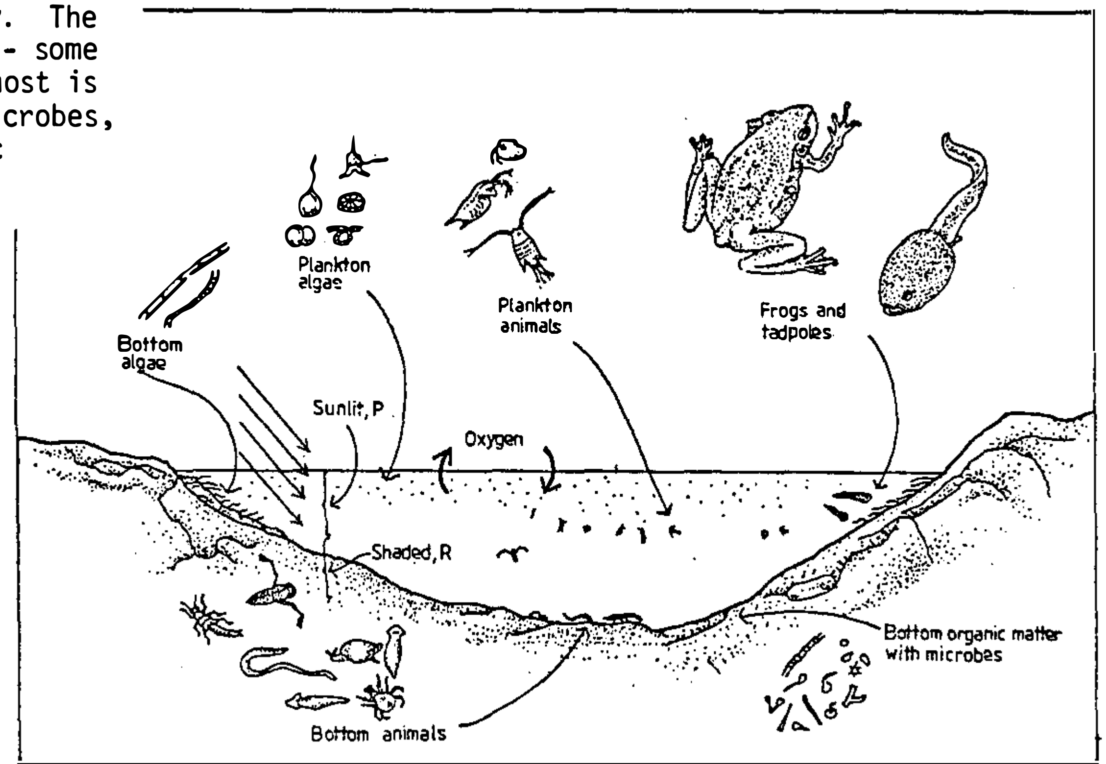
(a) Energy diagram.

Zooplankton: *Daphnia*, copepods and rotifers.
Herbivorous invertebrates: insect larvae, caddisfly, *Culex*, snails.
Benthic detritivores and grazers: ostracods, worms, chironomid larvae, mussels.
Predators: insects, mites, flatworms, frogs.

The maximum amount of any gas that can dissolve in water (the *saturation* level) depends on temperature. For example, freshwater saturated with oxygen at 21°C (70°F) contains 8 ppm (parts per million) of oxygen. When the temperature increases, the amount of dissolved oxygen that can be held in the water decreases causing the surplus to diffuse out of the water. If the temperature decreases the saturation potential of the water increases.

During a sunny day in eutrophic water, there is rapid photosynthesis. Consequently, both oxygen and organic matter build up quickly. The amount of oxygen may rise to 30 or 40 ppm - some of which diffuses out of the system, but most is used in plant and animal respiration. Microbes, decomposing detrius, and dissolved organic

(b)



(b) Pond; location of the main organisms of the food web. Illustrator Kathryn Gregson

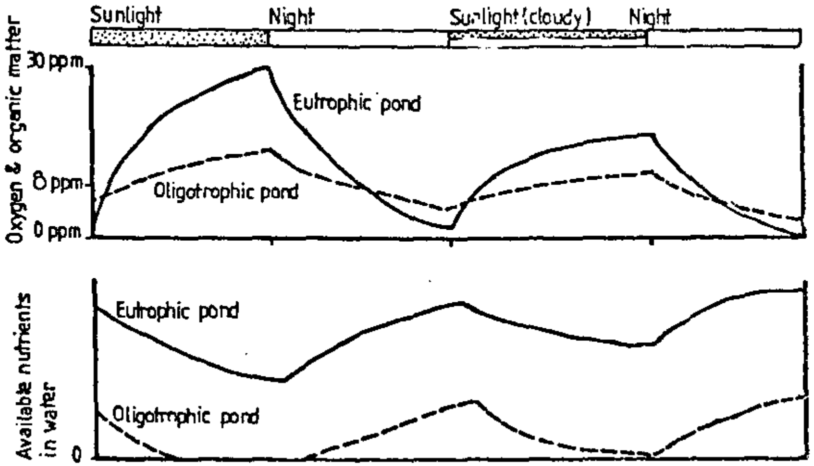


Figure 11.2 Changes in oxygen, organic matter, and nutrients in an oligotrophic (solid lines) and a eutrophic pond (dashed lines) through day and night. Data for oxygen variation from 0 ppm to 30ppm.

matter use up most of the oxygen produced during the day, bringing the oxygen level down to 1 or 2 ppm by the end of the night.

You can follow the changes in the graphs in Figure 11.2. The variations in an oligotrophic pond are less drastic since there are fewer nutrients to stimulate photosynthesis. Because the second day was cloudy with less sunshine falling on the pond, the photosynthesis was less, causing less oxygen and organic matter to be produced using fewer nutrients. Both animals and plants respire all day and night, using oxygen and organic matter to produce nutrients.

In eutrophic ponds, many fish, especially sports fish like the introduced brown and rainbow trout, cannot survive the low oxygen levels. Water fowl, like ducks, come to eutrophic ponds to feed on the rich biota. Some euthrophic waters have naturally high nutrient levels, but in New Zealand a very common source of high nutrient levels is the run-off which carries farm fertiliser, stock waste, industrial waste, or highway debris.

Oligotrophic waters with low nutrient levels have less total life. Clear lakes with few algae and bottom plants do not have the great variation in dissolved oxygen and so are usually good habitats for sports fish. Fishermen, take note.

11.3 MOUNTAIN STREAMS

A diagram of a mountain stream is shown in Figure 11.3. In this system turbulence and rocks are very important. Geological uplift forms mountains from which rocks fall and are worked into the streams. The rocks interact with the flowing water from the stream bed and its banks. The force of rushing water breaks rocks down steadily, eventually into fine sediment.

Animals and plants are adapted so that they can either withstand or avoid turbulence. Thus, the principal producers are algae which grow in a slime on the surface of the rocks. Insect larvae live under the stream rocks for protection from predators and from the turbulence. The rocks and banks channel the flowing water with its turbulence, carbon dioxide, oxygen, and nutrients, transporting materials downstream. Carbon dioxide, oxygen, and nutrients flow in with the water, become part of the stream water, are used by the organisms, then flow on downstream.

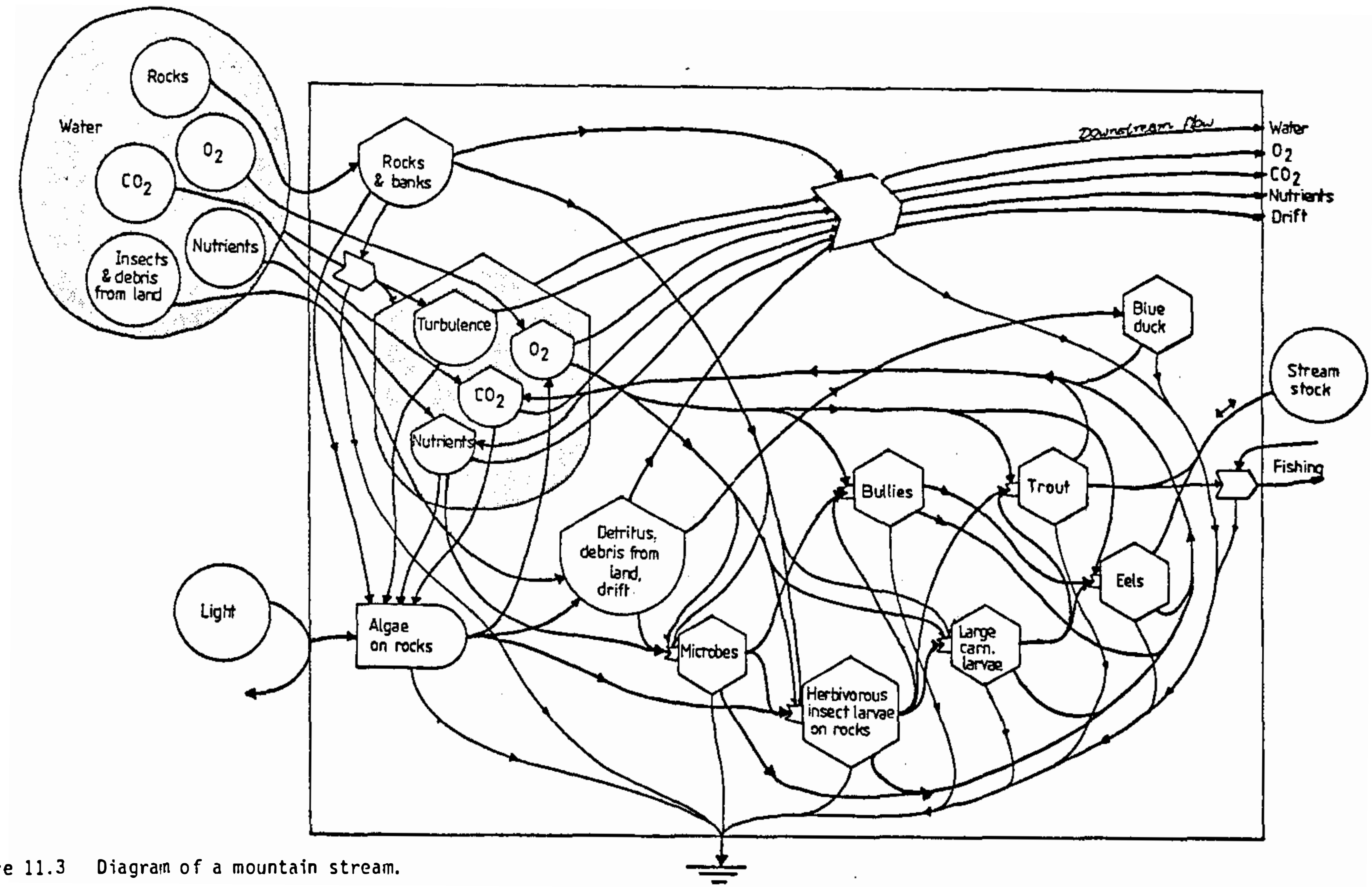


Figure 11.3 Diagram of a mountain stream.

The food web starts with the algae on the rocks; mountain streams are too swift and rocky for many rooted plants. Nutrients are absorbed by algae for photosynthesis and are also used directly by the microbes. Most mountain streams are distinctly oligotrophic, but they can be eutrophic if they receive enough nutrients. Organic matter from the land is an important source of stream detritus. Some of it is decomposed by the microbes, and some flows on downstream. The organic matter that flows downstream is called *drift*. Organic matter from the land is especially important in forest areas, where leaves and insects, such as beetles, butterflies and moths, fall into the stream. Populations get back upstream by having flying stages in their life cycles.

Freshwater stream insects spend most of their lives in the water as larvae in many different development stages. When mayflies, for example, mature, they fly in a large swarm over the water. After mating, the females oviposit the eggs in the water; and in two or three days the adults, who do not eat, die. The trout rise to the surface to feed on mature nymphs, emerging adults and ovipositing or spent females. Insect larvae feed on the organic slime of detritus and microbes, and may in turn be fed on by large carnivorous larvae.

Bullies and other small fish remain in small, calm sections of the stream; they live on microbes and insect larvae. The trout, which are small since they use the mountain streams as nurseries before migrating to rivers, also feed on insect larvae. Trout include both indigenous mountain trout and introduced rainbow and brown trout. Eels live near the bottom of the stream, eating small fish and competing with the trout for insect larvae.

Eels reproduce in the sea and return to the freshwater streams when about 1m long. Salmon, which have been introduced in many streams, travel in the reverse direction. They reproduce among the gravels of mountain streams. Their young then move to the sea where they live out their lives before returning to their stream for reproduction.

Blue ducks occasionally feed on floating organic matter and insect larvae. They are becoming scarce, perhaps because of competition for food with the introduced trout.

When waters reach the lowlands their velocity decreases and sediments are deposited. A flood plain develops which can grow wetland plants.

ACTIVITIES

1. *Compare a general fresh water system (Figure 11.1) with a general land system (Figure 3.2). Which components are the same, which different? Explain.*

2. *Draw a diagram of a pond or stream that you are familiar with. How does it differ from the diagrams in this exercise?*

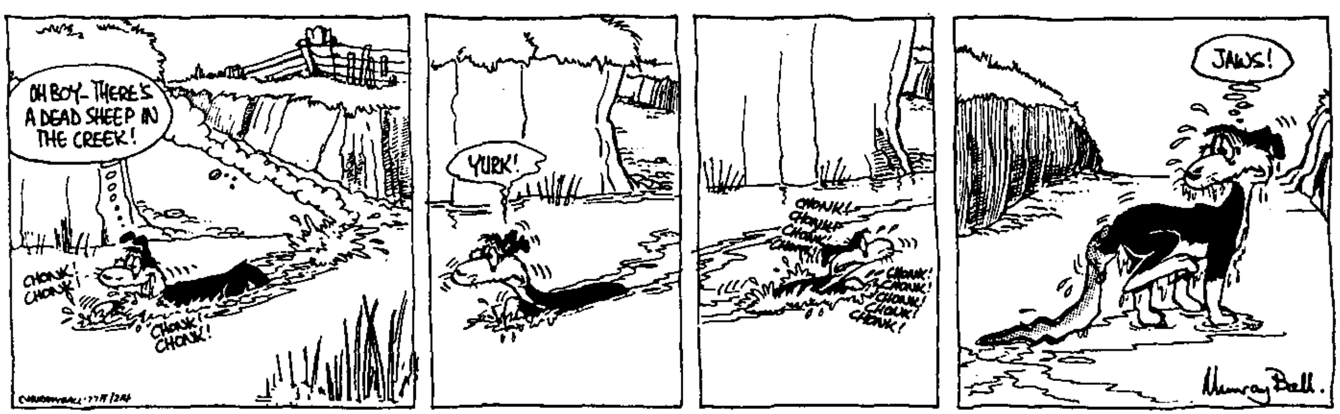
3. *Consider a eutrophic pond or stream near you. Where are the extra nutrients coming from? If it is polluted, what measures could you suggest to reduce the pollution?*

4. *With a Winkler kit or oxygen probe, take oxygen measurements. Groups of students can be assigned different parts of the investigations.*

   (a) *Measure the dissolved oxygen in the same pond or stream at regular intervals over a 24-hour period. Then make a graph showing the variation of dissolved oxygen with time. Explain the results.*

   (b) *Measure the dissolved oxygen in several ponds and streams. Explain the differences in results.*

5. *Trout, eels and salmon all have a life cycle that involves living in one environment and reproducing in another. This seems to be such a common pattern amongst mountain-stream fish that it must serve some clear biological purpose. Suggest what that purpose might be.*



12: The Estuary

12.1 ESTUARINE SYSTEMS

An *estuary* is the area along the sea coast where a river joins the sea. It is thus an area where freshwater and saltwater mix. Estuaries are often edged with *wetlands: marshes* with salt-tolerant grasses or *swamps* with mangrove trees standing in water much of the time. The special inputs to the estuarine system are the fresh-waters of the river mixed with the saltwaters of the ocean. Because of these inflows the estuary is often rich in energy, nutrients and has large numbers of plants and animals.

The outside energy sources of tidal inflow and the river are shown in Figure 12.1. The *kinetic energy* (motion) of the water in the estuary is created by tides flowing in and out, the river flow, and wind. This kinetic energy increases production by keeping the nutrients stirred among the phytoplankton, sea weeds, and marsh grasses. Food is moved to animals; zoo-plankton are also moved with their food, the phytoplankton.

Estuaries have a burst of productivity in spring and a high growth rate in summer. Many animals found in coastal waters, like shrimp and flounder, migrate back out to sea later in the year. Others, like mullet, migrate out to breed offshore, but the larvae return to the estuary where the young grow up. Still others, like salmon, breed in headwater streams and have young that pass through the estuary on their way to the sea, often growing rapidly during their time in the estuary. Because the larvae of many marine species grow up in the estuary, it is often referred to as a nursery. It is not where breeding and hatching occur but a place for rapid early growth.

The marsh is an area around the estuary whose size depends on the slope of the land. Because of the tides, its bottom is under water part of the day. Many burrowing invertebrates live in the marsh mud. The marsh is a protected area for larvae and small fish which come in and out with the tides.

Notice in the food web of Figure 12.1 that the mullet consume plant matter and detritus. Some bottom invertebrates like clams, cockles, oysters and mussels, are filter feeders, consuming bits of organic matter suspended in the water. Others, like worms, digest the organic matter in the ooze of sediment, detritus and microbes.

Small fish, shrimp and crabs consume zoo-plankton and bottom invertebrates. Flounder and

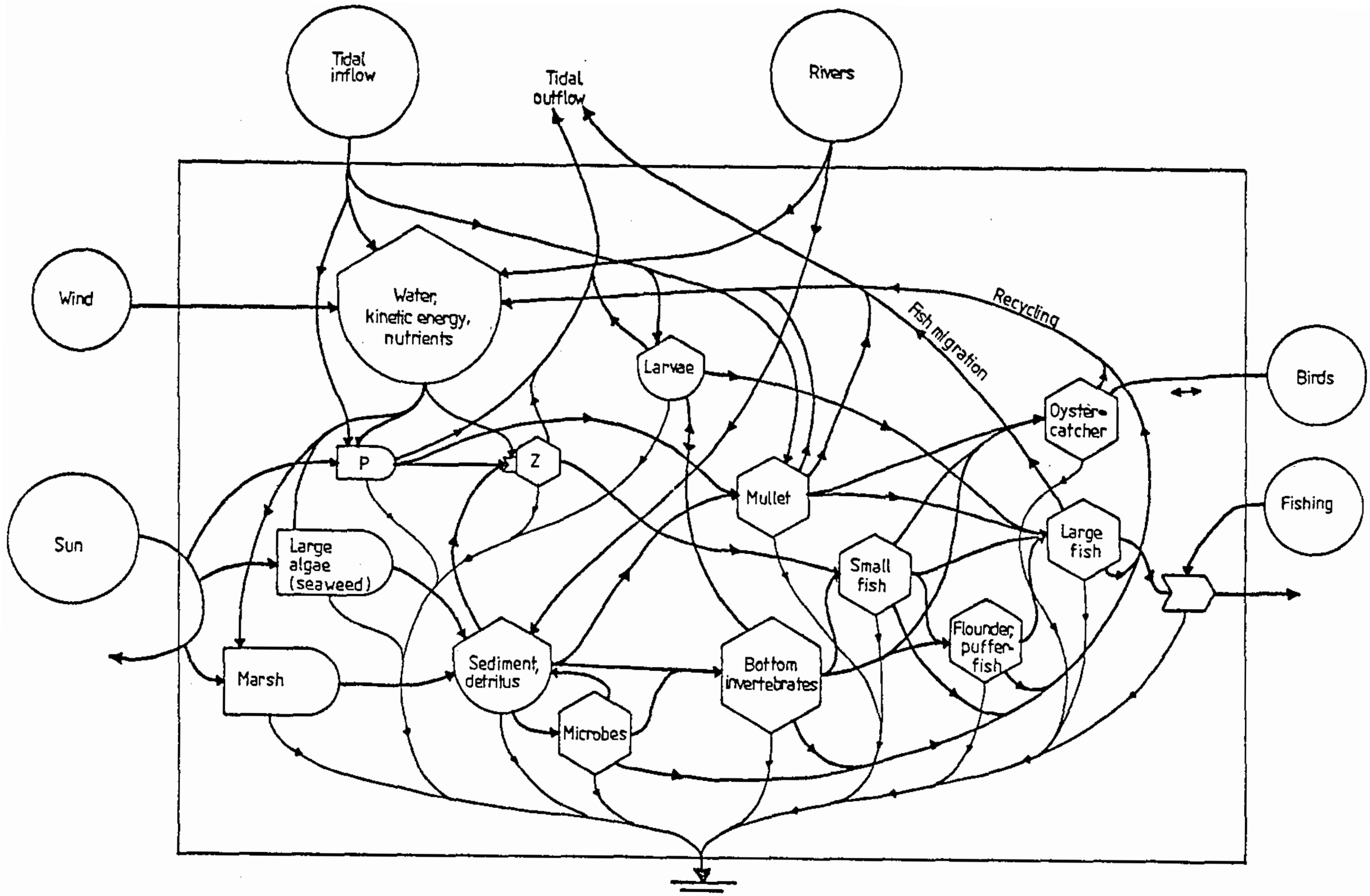


Figure 12.1 Energy diagram of an estuary.

P=phytoplankton; Z=zooplankton;
Bottom invertebrates=cockles, mussels, clams, worms;
Small fish=small fish, shrimp, crabs;
Large fish-barracuda, kahawai;
Oyster catcher=oyster catcher, wading birds.

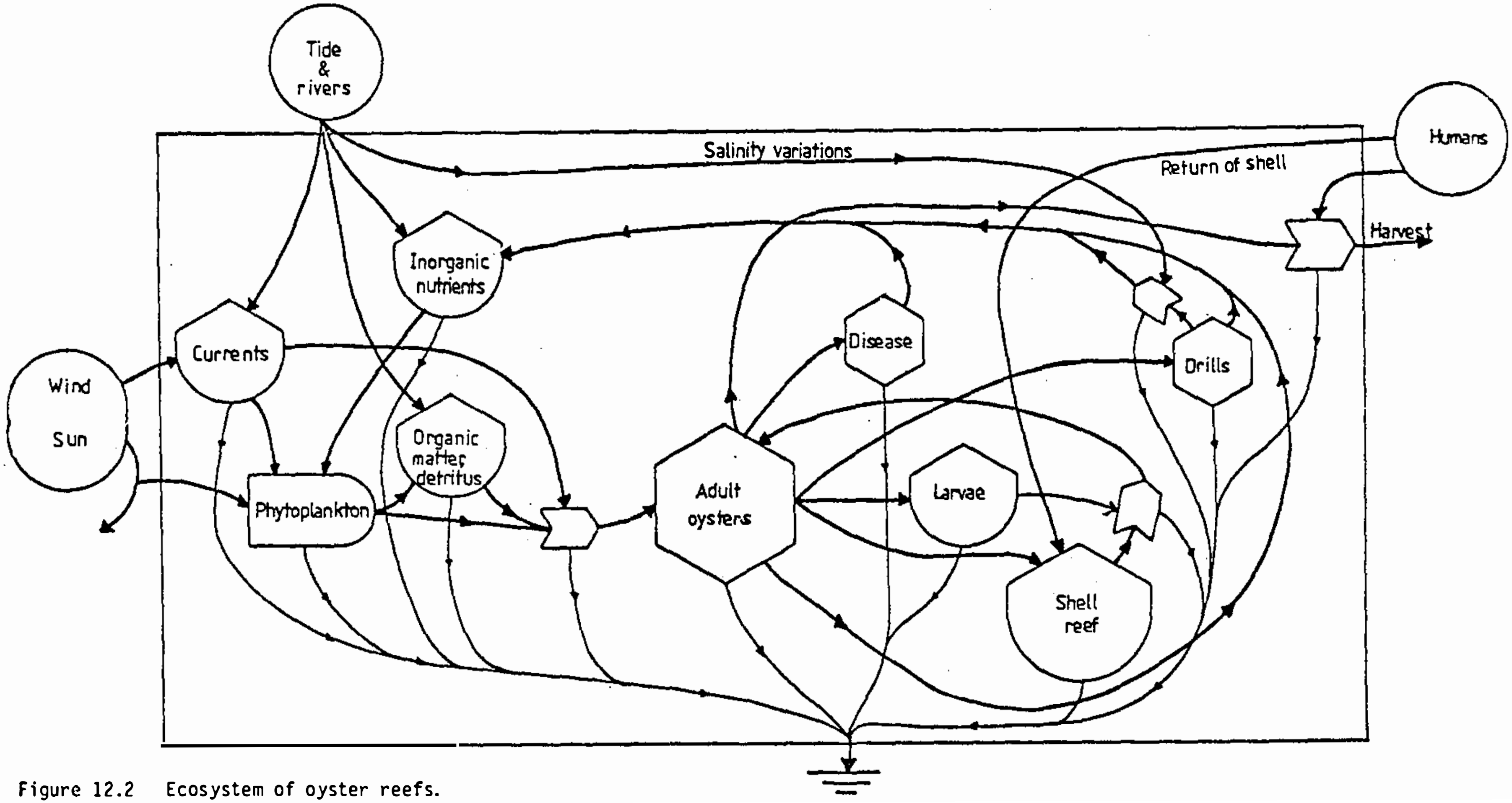


Figure 12.2 Ecosystem of oyster reefs.

pufferfish are bottom fish which feed on shrimp, crabs and bottom invertebrates. Large fish, which sometimes come into the estuary, include kahawai and barracuda; they feed on smaller fish and molluscs.

Many species of birds are a part of the estuary ecosystem, flying in and out. The oyster-catcher and gull feed on animals in the estuarine mud and on the beach at low tide. Wading birds like herons, feed in the marshes, and diving birds like the gallinule and cormorant, feed in the water.

Constant variations in *salinity* are a stress on estuarine organisms. They must all have special adaptations to survive salinities from 0 ppt (parts per thousand) salt in the fresh water from the river, to 36 ppt salt in the salt water of the incoming tides, and changing salinities in between. Because energy is used for special adpatations rather than for diversity, there are very few species in an estuary. But since the fertility of the area is high, there is high productivity in the few species present. When there are large numbers of a few species, they are easy prey for other organisms. You will often see estuaries where the mud flats are covered with cockles and oyster-catchers eating them.

12.2 OYSTER REEFS

Estuarine oysters (sometimes called rock oysters) grow their own cities. Oysters attach to each other, building up large mounds of shell. As bottom oysters die, larvae attach to old shells, increasing the size of the reef. As the mounds build up, the oysters have better access to currents which bring food and carry away wastes. Industries that harvest oysters usually put the shells back, in order to maintain the size of the reefs. This is one part of the fishing industry that feeds back to the natural system.

The same inflows are shown in Figure 12.2 as in Figure 12.1, but with different detail. Notice in Figure 12.2 the tides and rivers cause currents and bring in inorganic nutrients and organic matter. The interaction of the currents and the organic matter produces a flow of food to the adult oysters. The adult oysters make the shell reef, which is used by the larvae to produce adult oysters on the reef. The oyster populations are kept down by drills, disease and harvesting. Drills are snails that drill through the shell of the oyster, eating the insides. Drills increase in numbers when the salinity of the reef is fairly constant, as when the river is low. When the fresh water flow causes great variation in salinity, drill numbers are reduced.

12.3 AQUACULTURE

In the Marlborough Sounds near Nelson, oysters are cultivated on ropes tied to wooden rafts floating in the water (Figure 12.3). The high fertility of the estuary is an example of competition for the use of resources. The estuary already has both recreational use (with pleasure boats and sports fishing) and oyster culture. There is a new proposal for a logging enterprise, under which logs will be brought down the rivers into the estuary. This has caused concern for the possible pollution of the water with wood particles and wood chemicals, since sugars from freshly-cut trees grow large populations of slime bacteria.

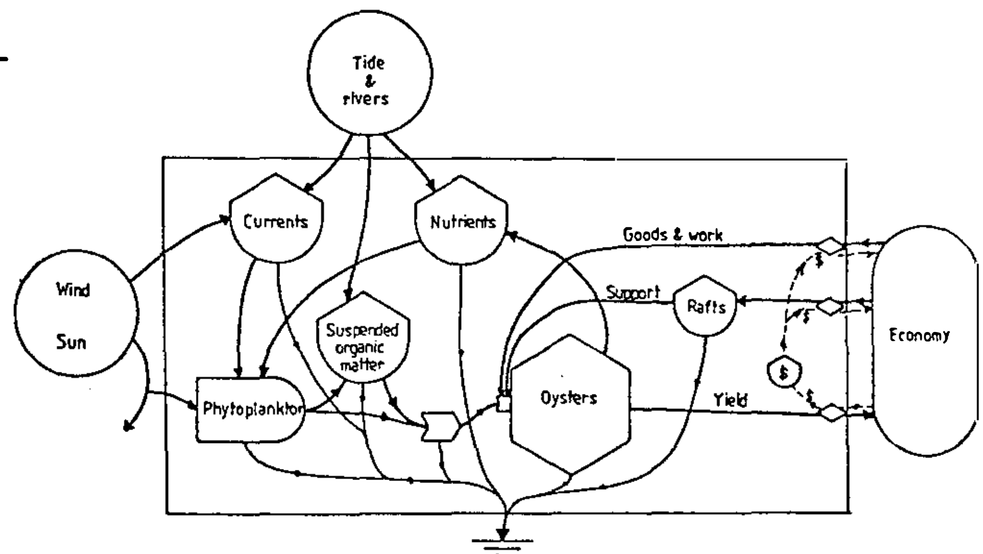


Figure 12.3 Oyster aquaculture.

ACTIVITIES

1. *If possible, take a field trip to an estuary. Collect as much information as you can about it.*

   Divide into groups to investigate:

   (a) *Outside sources: sun, wind, tide, rivers, pollution.*

   (b) *Producers: algae, seaweed - look for patches of seaweed.*

   (c) *Marsh: is there a marsh? If there is, how big an area, what kinds of plants, animals; if not, what is at the edge?*

   (d) *Bottom organisms: at low tide dig in the mud; look for oyster mounds.*

   (e) *Fish: look, and ask any people around what they catch.*

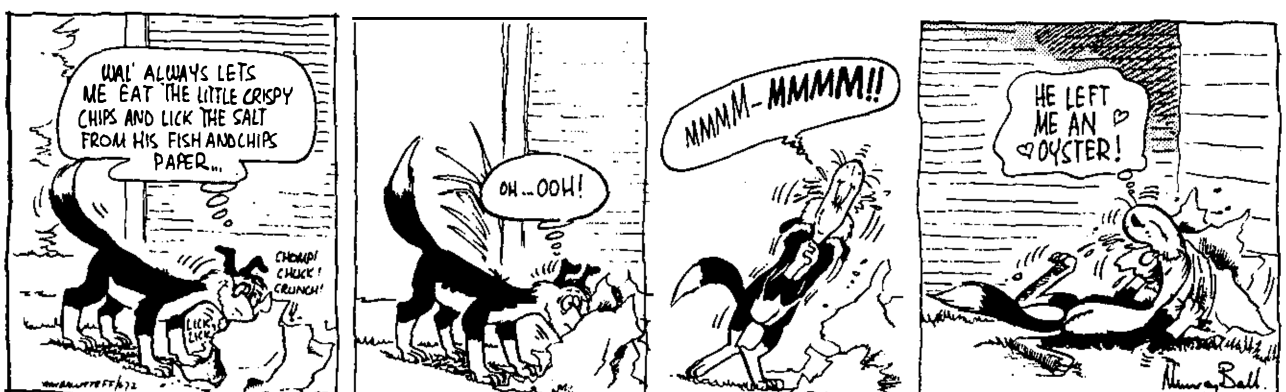
   (f) *Birds: be quiet and watch - field glasses and a bird identification book are helpful.*

   Put all the information together. With some assistance from your teacher, draw a diagram of your estuary on the blackboard. How does it compare to Figure 12.1? Explain the differences.

2. *If you cannot take a field trip, talk to someone who knows about your nearest estuary, then prepare a diagram of it, or find a description of an estuary in a book and draw it. What necessary parts of the system did your source leave out? Be sure to include them. How does your diagram compare to Figure 12.1?*

3. *How would you decide what human activities would be best for an estuary like the Marlborough Sounds? Prepare an outline management plan for your chosen area. How might you get your ideas considered?*

4. *List the seafoods you eat. Which of them spend some time of their life in an estuary?*



13: Lowland Podocarp Rain Forest

Imagine yourself standing in a lowland rain forest on the West Coast. Just in case you have never been there, this is the sort of thing that you would be experiencing:

- it is probably raining or dripping;
- your feet are wet from standing in the layers of wet litter and soft moss;
- there are many large trees with huge buttress-like exposed roots, all covered with mosses;
- it is dark and when you look up you see a canopy of deep green leaves with only a few specks of light shining through;
- you can hear several different types of bird song; and
- you find it hard to walk because of the many fallen logs.

This is an ecosystem with high species diversity because of a favourable combination of a number of energy sources. Notice in Figure 13.1 that the mountains cause the moisture in the winds from the moving air masses to fall as rain. There is also regular sunshine all year, and enough dry air from winds blowing down the mountains to carry away the water vapour from transpiration of the trees.

13.1 PRODUCERS

The great diversity can been seen in the numbers of canopy species - *podocarps* and *broad-leaved trees*, all covered with a green blanket of epiphytes. Many trees have large broad bases, called *buttresses*, and extensive roots which cover a wide area in the top soil. These adaptations give trees the extra support needed to stay erect in soft, wet earth. The understory and forest floor have a great variety of species too. This diversity means that with a number of species each using a small part of the energy, most of the available energy is captured and becomes a part of the system; hence, the forest is dark because almost all the light is being absorbed by the many layers of leaves.

The canopy trees take a long time to grow. They have high-quality wood that has considerable value. Consequently, most New Zealand rain forests have been lumbered at one time or another. There is now much controversy about how much of the remaining 5% of largely untouched forest should be preserved. Since native trees grow without management and rebuild valuable wood and

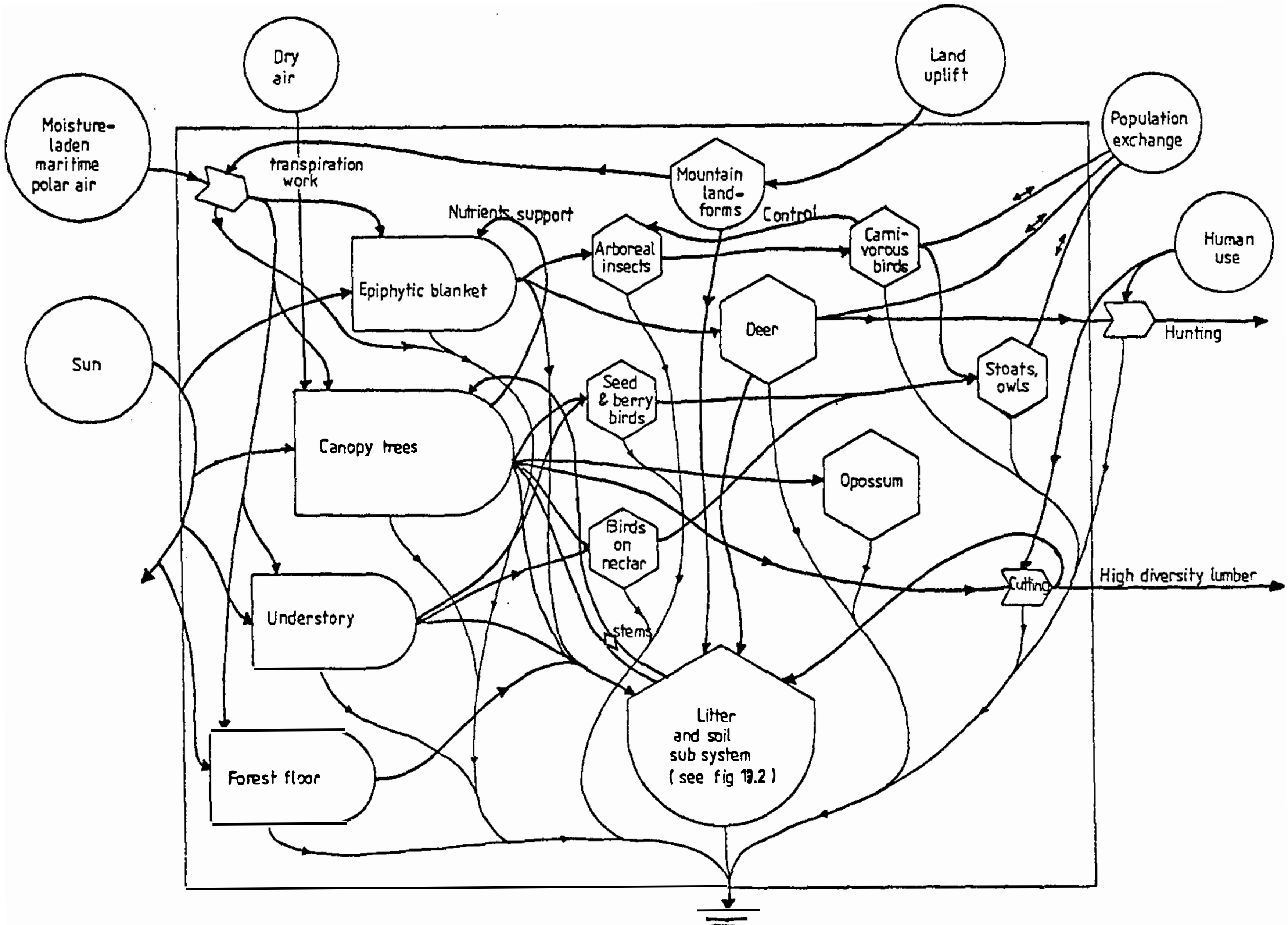


Figure 13.1 Lowland podocarp rain forest.

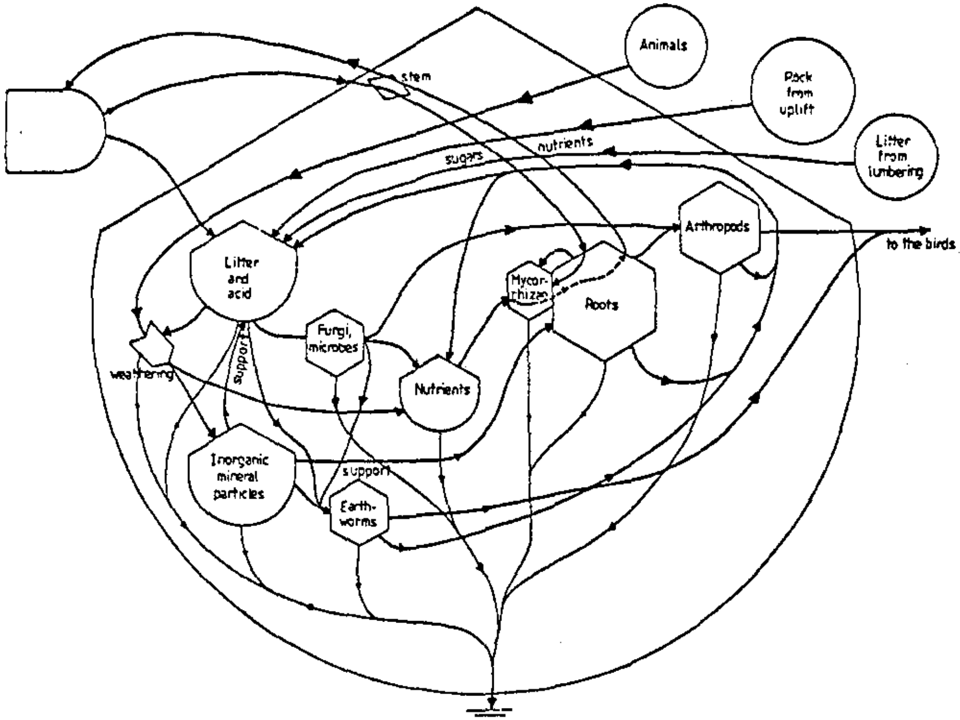


Figure 13.2 Litter and soil subsystem of lowland podocarp rain forest.

soil, most biologists believe that more native forests need to be restored and preserved. When external sources of phosphate are used up, native forests may be the only method available to future generations for rebuilding soils depleted by intensive agricultural use.

13.2 CONSUMERS

Different insects feed on different parts of each kind of tree and plant. Insects are adapted to the role of eating back anything in excess. In a diverse forest, even if one kind of tree succumbs to disease or an insect infestation, the ecosystem is not destroyed. There is a balance of consumers and producers; if any plant increases to excess, its consumer insects or disease organisms will increase until the species is again in stable balance with the other species. Since most insects and diseases are specific to certain species, their numbers also decrease when the plant species is back to normal density.

Berry and seed-eating birds, like the native pigeon, the kaka, and small parakeets feed on the trees and shrubs. Tuis, bellbirds and waxeyes consume the nectar in the flowers. Birds such as tomtits, riflemen, and blackbirds feed on insects in the vegetation and in the litter on the forest floor.

The birds regulate insect diversity and help distribute seeds. The bright-coloured fleshy parts of podocarp fruiting twigs encourage dispersal by birds.

Deer browse on the low plants, while opossums live mostly in the trees feeding on twigs and shoots. Stoats and owls prey on the birds. There is an exchange of birds, stoats and deer in and out of the system, excesses in one area repopulating low-density areas elsewhere. The owl is the only native top carnivore. Deer, opossums and stoats are exotics, having been introduced from overseas. Some introduced species have become a part of the balanced forest system, providing their numbers are controlled by culling and hunting.

13.3 THE DECOMPOSER SUB-SYSTEM

The sub-system of the litter and soil is shown in Figure 13.2. As the litter from the trees and plants builds up, the fungi and microbes decompose it, producing carbon dioxide and nutrients. The carbon dioxide interacts with water to produce acid, which breaks down the underlying rock into soil particles and nutrients. The soil particles form the basis of the soil which supports the litter and the tree roots.

Mycorrhizal fungi which coat the roots of the trees have a symbiotic relationship with the roots. Fungal hyphae extend from each root into the soil. The water and nutrients they absorb aid the growth of the tree. In return, the fungus obtains photosynthetic products from the cells in the tree roots.

The diversity of the rain forest system extends to earthworms. The largest species - a native earthworm which can grow to 2 metres in length - is found at a depth of more than 2 metres. Earthworms are important in breaking up the soil. As they ingest soil particles, litter, and microbes, they make passages which allow excess soil water to drain away.

A great diversity of arthropods feed on the microbes and roots and are consumed by birds. Kiwis are nocturnal consumers of earthworms and other invertebrates that they can probe with their long bills.

13.4 KAURI FORESTS

Kauri forests are a special variety of native forest found in warmer climates of Northland. They have a high diversity of trees, but there is a top overstory level provided by old and giant kauris that form a canopy 50 metres above the ground. The trees are between 200 and 2000 years old, and some have trunks up to 6 metres in diameter. The trees help maintain their structure by secreting a gum that plugs any wounds in limbs or roots. The diversity of life supported by the giant trees and by fallen logs is very large. Kauri forests resemble some tropical rain forests in their diversity and variety of structure at many levels, except the leaves are smaller and tougher, being adapted to drier air.

Because the kauris spread out their crown to form a large photosynthetic area per trunk, their individual tree growth rate is rapid. Forest plantations of kauri trees are being cultivated because the wood is high quality and the growth rate is comparatively good. A high diversity kauri forest with many ages and high diversity of other trees should not be confused with a kauri plantation. The first has great value for aesthetic use, self-renewal, tourism, gene pool storage, and rebuilding of the wild sector of the economy. The plantation is for cutting and wood products. Both uses of the kauri are important.

ACTIVITIES

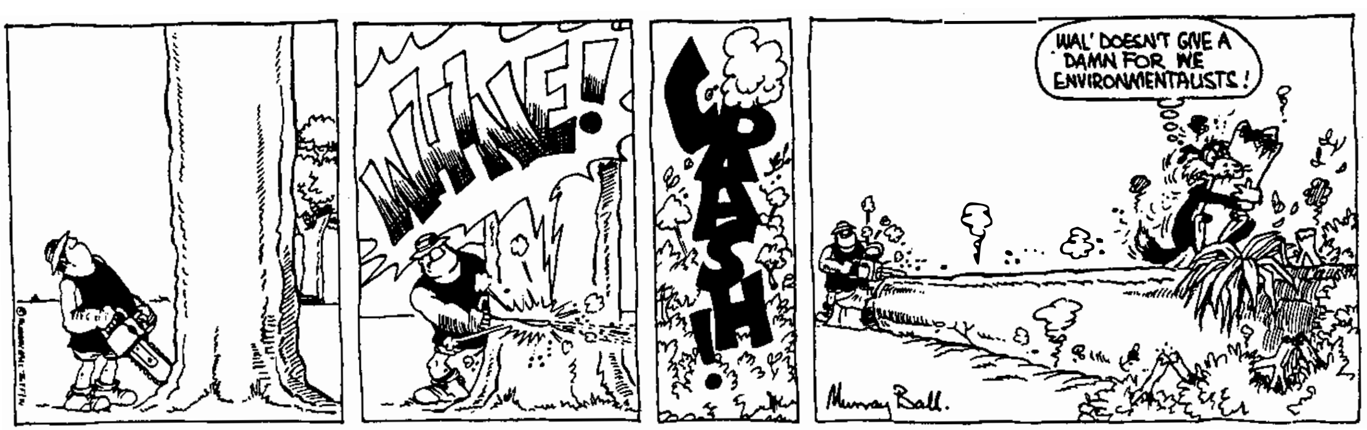
1. Visit your nearest lowland forest. Count the numbers of different species of trees. Remembering that 20 species per thousand individuals is high diversity and 6 per thousand is low, what kind of diversity do you find? Do the same count in a planted exotic forest and in any other available forests. How do their diversities compare? Explain the variation.

   If there is no convenient native forest, take diversity counts in any forests, - compare them, and discuss the variations in diversity and their reasons. Can you see any advantages in the more diverse forests?

2. Compare the <u>leaf area index</u> of the forests you visit. Look up and count the number of leaves directly between you and the sun, then look down and count the number of leaves between you and the soil. Add these. The more diverse forest will have the highest leaf area index: 5 - 8 indicates high diversity, 1 - 2 low diversity. Do these results agree with your results from Question 1?

3. Compare the lowland rain forest diagram (Figure 13.1) with the beech forest (Figure 3.2). Compare the quantity and kinds of producers, then compare the soil components, and finally the consumers. What outside energies account for the differences? (Note - they are not all shown on both diagrams.)

4. Do you think these native forests should be replanted, lumbered, or preserved? Defend your answer.



14: Exotic Forest Plantation Systems

Much of New Zealand was originally covered with several kinds of forest ecosystems - beech, kauri and rimu-matai. Most of these forests have now disappeared - either burned or cut for timber. These native forests produce valuable wood, but they grow very slowly, taking between 100 and 300 years to mature. Early this century it was discovered that stands of exotic (or introduced) timber species grow much more rapidly. Plantations can be harvested in 24 years, producing wood useful for paper, construction, and export. The productivity and growth of introduced species often increases dramatically in the new area, because they have been separated from their natural controls of disease, insects, predators and competitors.

One of the fastest growing exotics in New Zealand is Monterey Pine, or *Pinus radiata*. Radiata pine grows rapidly under New Zealand conditions (much faster than in its native California where it has a different role), produces a large volume of usable wood, and is adaptable to the climatic variations in New Zealand. Radiata is exported mostly as logs, boards, and wood pulp to Australia, the Pacific Islands, and Japan.

The diversity of organisms in a natural forest provides the management necessary to maintain production, as we saw in the rain forest system (Figure 13.1). In a planted monoculture, like the pine plantation, where diversity is minimised in order to increase the production of material useful to man, humans must take over the role of management.

14.1 MANAGEMENT OF EXOTIC FORESTS

Management involves coping with pests and diseases. Monocultures, like the forest plantation, are susceptible to disease and insect destruction. When an epidemic gets started, it can spread easily and devastate the whole forest. Potentially devastating pests of radiata forests include caterpillars that cause severe defoliation, insect larvae that feed on roots, and the large wood wasp (*Sirex noctilio*) which is a parasite on the trunk and branches. Consequently, management requires heavy applications of pesticides. Deer and opossums are widely distributed through pine plantations, feeding on leaves, branches, bark and twigs of the trees. They are controlled by culling and hunting.

Management may also involve the application of fertilisers. With fewer natural microbial consumers in the system, recycling is reduced.

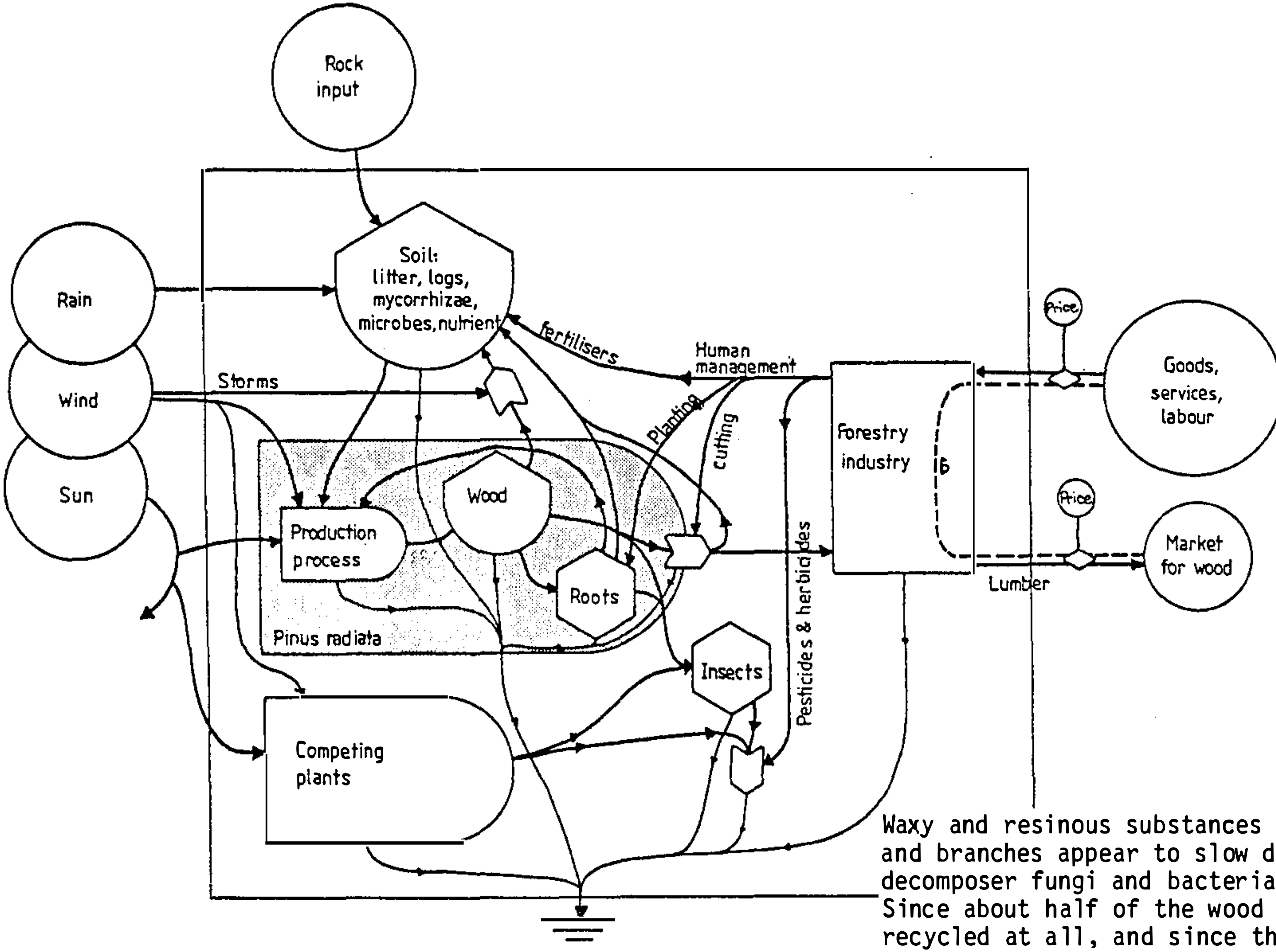


Figure 14.1 *Pinus radiata* forest plantation.

Waxy and resinous substances in the fallen needles and branches appear to slow down the rate at which decomposer fungi and bacteria cause their decay. Since about half of the wood is taken off and not recycled at all, and since the natural processes of rain and weathering of rocks restore soil nutrients slowly, fertiliser has to be applied to grow another crop. Pesticides and fertilisers are sometimes sprayed from aircraft.

Management may also involve the use of herbicides to kill the natural vegetation before seedlings are planted. This keeps the vegetation down so that the young seedlings may become established without competition from other species. The man-managed *Pinus* system is shown in Figure 14.1. Management techniques that use pesticides, herbicides, fertilisers, and aircraft are energy-intensive and sometimes destructive. For example, there is concern in New Zealand at present about the possibility that 2,4,5-T herbicide, which has been used in forest management, may cause birth defects in humans.

To avoid these problems, biological ways to control pests and replenish nutrients are being researched. For example, lupins, which are nitrogen-fixers, can be planted before seedlings are put in. Since lupin seeds will survive in the soil during forest growth, the nitrogen-fixing plants may reappear after the forest is harvested. Thus they become a permanent, useful part of the system. Nursery-grown seedlings, already inoculated with mycorrhizae, can be planted. The mycorrhizal fungi increase the seedlings' capacity to absorb nutrients from the soil, thus further reducing the need for fertilisers. To reduce the need for herbicides, trees can be planted very close together. The close planting shades out competing plants and at the same time allows the weaker disease-prone and pest-prone plants to be thinned out later.

Exotic trees may not be so well adapted to natural disasters as the native trees. For example, in the high winds of August, 1975, many exotic pine trees on the Canterbury Plain were blown down.

Because of the fast rich production of these forests, radiata pine plantations have been the basis of a very successful industry based on environmental energies. The price of the timber pays for the goods and services needed for this system, leaving a money profit. The value of New Zealand's exported forest products in 1977 was $220 million.

There are, however, several questions for the future. One is whether the soil is being depleted so that successive plantings will be less and less productive. Another is whether the fantastic growth of these exotic trees will continue as local pests become better adapted to them. Another is whether prices can remain low as fuels for machinery, helicopters, pesticides, and phosphorus become scarce and expensive.

14.2 NATIVE AND EXOTIC FORESTS COMPARED

A comparison between a native forest and an exotic plantation forest is shown in Figure 14.2. Notice that the native, self-maintaining forest has five times more *gross* photosynthesis (510×10^3 joules/m^2/day), than the exotic forest (100×10^3 joules/m^2/day, but less than half the *net yield*. In the native forest almost all the production goes into various kinds of work that favour gross production, such as diversity and recycling. All the nutrients needed are obtained by microbial action on the litter. Planting is done by natural reseeding. Diversity of trees and other organisms protects against epidemics of disease, insects, or overpopulation of any one species. Except for protection, native forest management costs almost nothing. Therefore, the yields are very high in terms of money spent, but longer periods are required for regrowth after cutting.

As Figure 14.2 shows, the plantation forest needs management's input of fertiliser, planting, cutting and other work: a total of about

22 x 10^3 joules/m^2/day, investment. In return for this investment, the managed forest produces about 42 x 10^3 joules/m^2/day. Thus twice as much energy is produced from the system than has to be put in from the economy. This calculation is a way of showing that pine plantations are a good contribution to the economy. Since calculations are done on an energy basis they will still be valid as prices vary and as fossil fuels become scarce, providing phosphate does not become short or costly.

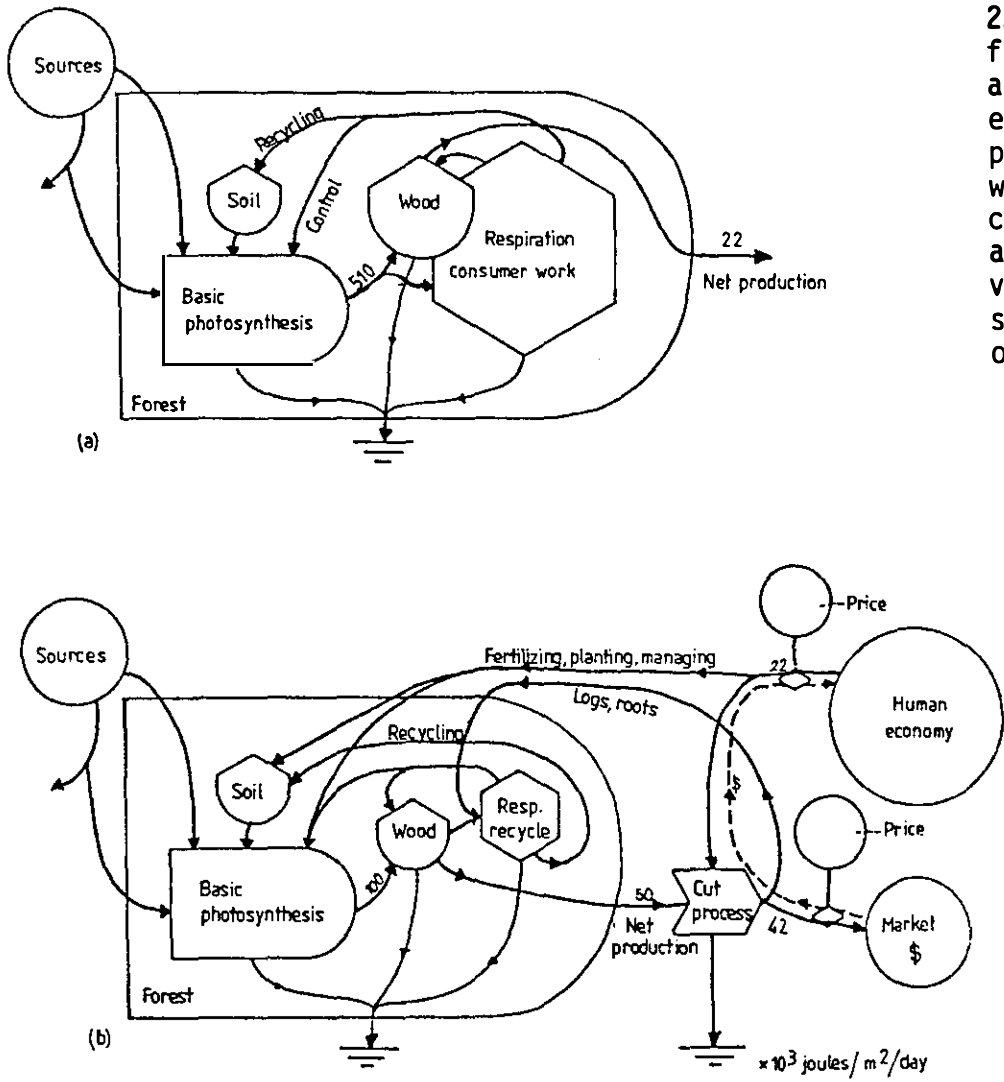


Figure 14.2 Comparison between self-maintaining and yield forests

(a) Self-maintaining native forest. Respiration processes built soil, diversity, animals, microbes, control, storage, recycling.

(b) Exotic forest plantation.

14.3 THE FUTURE OF FORESTRY

Forested land comprises 6.8 M ha (or 26%) of New Zealand's total land area. 6.2 M ha (or 92%) of this is classed as indigenous (forests like the beech and lowland rain forest which we have studied). The majority of this indigenous forest is on steep, broken and often erodable country where protection forest must be maintained, and where access for logging is almost impossible anyway. Only 1.05 M ha (17%) of the native forests - nearly all lowland forests - are considered to be available for any yield.

New Zealand's lowland forests have already been heavily exploited, and there is considerable concern about the rate and manner of exploitation of the remainder. At present, about 10% of our remaining stands of lowland forest is protected in reserves. Of the rest, about half has already been logged. Our present use of native timbers far exceeds the sustainable supply, so that the remaining unlogged lowland forest is being steadily eliminated.

Sustained yield management techniques involve "selective logging", the removal of only small numbers of selected mature trees, thus ensuring that the forest always remains in its climax stage. However, removing cut timber from mature forests without damaging other components of the forest system is very difficult. In addition, it seems possible that even very selective logging of forests can seriously disturb the habitat of native birds, some of which are already endangered species. Another problem is that selective logging usually takes the best trees, leaving the inferior genetic stock for seed production.

To live up to the forestry principle of cutting no more basal area (cross-section of wood at the base of the tree) of trees than is being planted, we believe that a moratorium should be placed on native tree logging until forests with trees of equal basal area are planted.

In 1978 there were about 0.74 M ha of productive exotic forests. Radiata pine is the dominant species (about 82%) with Douglas fir accounting for most of the rest. Forestry research suggests that another 1.7 M ha would be suitable for exotic production. This area is currently unused cutover native forest and marginal farmland on hill country. In these areas forestry may be more profitable than agriculture.

Large areas of New Zealand have now been cleared of native forests for more than 100 years. They thus have no easy access to seeds, microbes, and other organisms that are required to regenerate the forest. When lands are not in use for agriculture or plantation forestry, they could be generating valuable native forests and soils. We believe that small native forest plots should be established all over New Zealand so that the seeding for automatic reafforestation is widely available.

ACTIVITIES

1. *Take a field trip to a radiata pine plantation. Sample the diversity by counting numbers of species and by obtaining the leaf area index. (Refer to exercise 13 for methods.) How does it compare to the diversity of other forests?*

2. *Investigate other exotic forests, such as Douglas fir or* Pinus contorta. *How do they compare to radiata pine?*

3. *Make an energy diagram of the food web of the radiata pine system. How does it compare with the beech forest web (Figure 3.2) and the lowland rain forest (Figure 13.1)? How do you account for the differences?*

4. *What proportion of New Zealand's land do you think should be used for forest plantation, native forest, and agriculture? On what basis should this be decided?*

5. *Decide from the data on Figure 14.2 which system has the most gross production and which the most net production. What are the advantages of each? (Refer back to exercise 5 for a discussion of gross and net production.)*

15: Sheep Production Systems

Much of New Zealand's economy depends on the production of sheep from a pasture agricultural system. In this example of an economic agro-ecosystem, solar energy is transformed into yields of wool and meat.

15.1 SHEEP SYSTEM PROCESSES

Follow the sheep system process in Figure 15.1. Phosphorus comes in from the rain and from weathering of the rocks, as well as from fertiliser. Nitrogen (N_2) is shown being brought in by the wind and fixed into nitrates by clover. Grass grub is an example of natural control of diversity. If the growth of clover increases in excess, the reproduction of grass grubs is stimulated, which then increases their rate of destruction of clover. With less clover, space is available for the regrowth of ryegrass, keeping the balance stable.

In late autumn, ewes and rams (in the proportion of 50 to 200 ewes per ram) are put into enclosures for mating. Lambs are born in the early spring. Notice the two processes in the diagram of the ewes; the two interactions represent metabolism and reproduction.

In the high country the sheep graze on indigenous tussock grassland which is not as productive as the exotic ryegrass and clover, but requires less management. However, in these areas, because of the winter cold and snow, much supplementary feeding is necessary.

At the right of the diagram are the flows to and from the economy. Inputs of equipment, fertiliser, pesticides, selenium etc. are paid for by the money obtained from sales of wool and meat. You can see the money from the sale of wool, the sale of meat, and government subsidies going into the farmer's money storage. Subsidies keep the farmer's costs and income from fluctuating with severe market changes.

New Zealand currently produces 80% of the sheep meat entering world markets. Lamb is sold to the United Kingdom, specially-slaughtered lamb to Iran, and hogget to Japan and the United States. The total value of exported sheep products was over $900 million in 1977. The financial return from the sale of sheep products is used to pay for fertiliser and human and mechanical work, with which the sheep economic agroecosystem is managed.

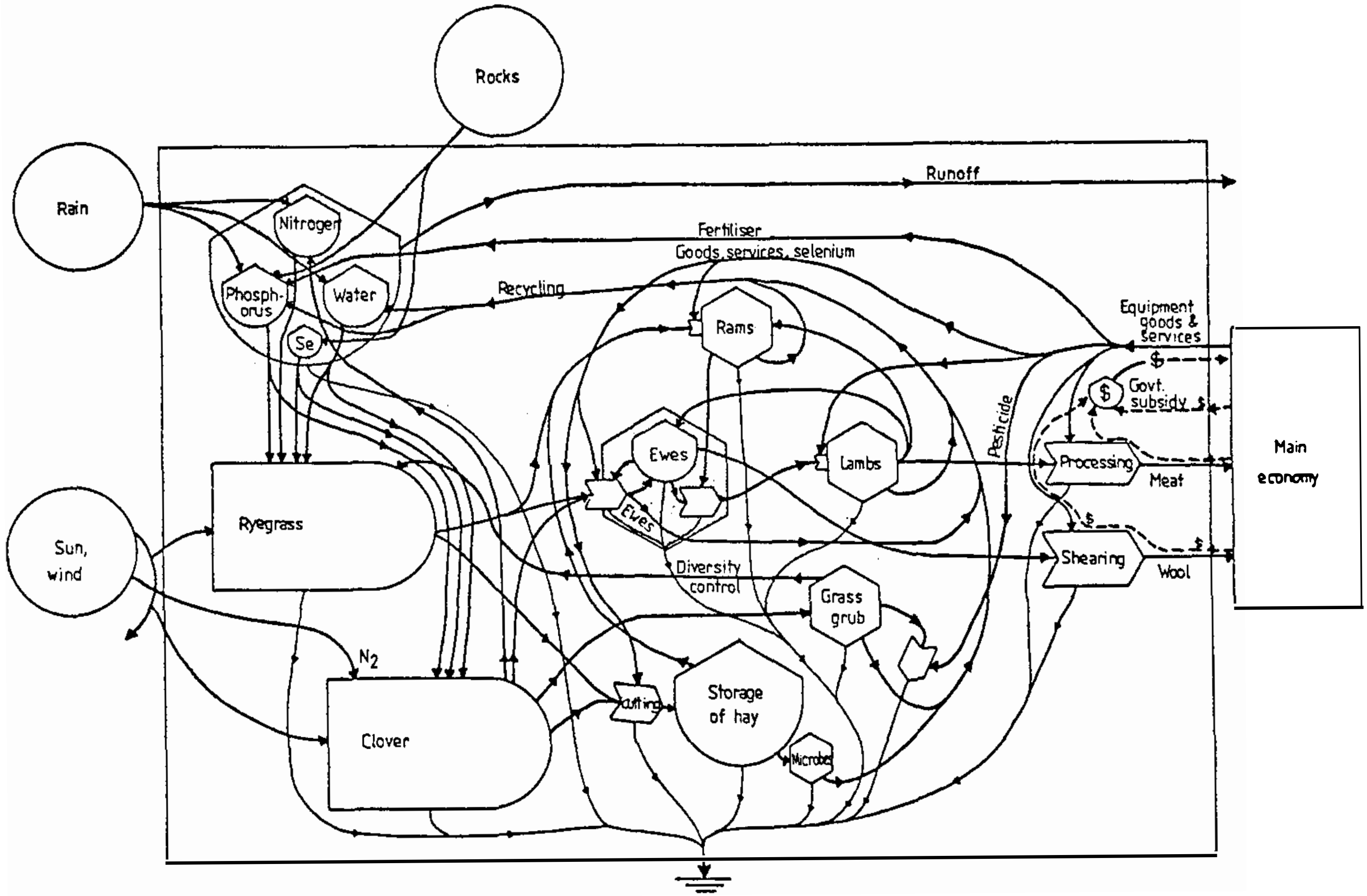


Figure 15.1 Sheep pastoral system.

15.2 MANAGEMENT STRATEGIES

Effective management of pasture land is required to produce the greatest weight of healthy sheep in the shortest time. Two particular limiting factors require careful management:

- the nutrient levels of many New Zealand soils are low, especially nitrate and phosphate levels: and
- grass does not grow at the same rate throughout the year, hence the carrying capacity of the pasture varies seasonally.

Additional phosphate is provided by applying superphosphate fertiliser which is manufactured from rock phosphate imported from Nauru and Australia. Nitrogen levels are supplemented by growing nitrogen-fixing clover with the pasture grass. In some areas the trace elements cobalt and selenium must also be provided to avoid nutritional diseases of stock.

On lowland farms the seasonal pattern of grass growth looks like that in Figure 15.2. Low temperatures reduce the growth of grass in winter, and lack of rain limits production in summer. However, farmers are able to maintain higher stocking rates than winter grass production would normally allow by cropping some of the surplus grass production from the spring and autumn peaks, turning it into hay and feeding it out in winter - and in some areas in summer too. Some areas are irrigated in summer. Such management practices as aerial topdressing with fertilisers and haymaking are highly mechanized, and therefore require an investment of fossil fuel energy.

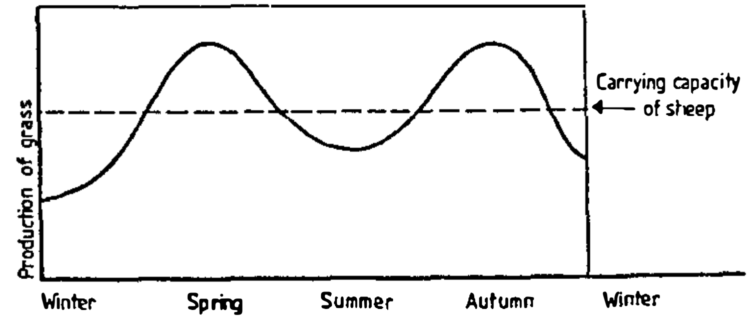


Figure 15.2 Seasonal pattern of grass and sheep production.

Electricity is used for charging fences.

As the cost of fossil fuel energy increases, some New Zealand farmers are finding that it is more economic to employ a low-energy management strategy. This involves doing away with haymaking almost entirely and carrying only as many sheep as can be supported by the natural carrying capacity of the pasture. Soil nutrient levels and winter feed levels are monitored very carefully, so that the sheep receive a subsistence-level diet in winter - no more, and no less. The yield from such management strategies is lower, but the investment in production is also lower, so that the financial return is the same or better than that from the more usual high-energy management strategy. The investment of human labour, however, is considerably higher.

As fuel supplies continue to decrease, the use of machines may become even less and the use of human labour greater. How will this happen *here* in New Zealand? Will farmers hire much more labour to take the place of machines? Will electric power replace some fuel-based machines?

Will the large holdings be divided into small farms to accommodate more people? Will there be a system of share-cropping where a small farmer raises sheep on a farm belonging to the owner, gives part of his production in payment for the use of the land - with perhaps a proviso that in time he can pay enough this way to own the land? Or, since forest management is less intensive than stock or crops and therefore requires less energy input, will farming become more diversified, with one farm containing some sheep pasture, some forest, and some land in crops?

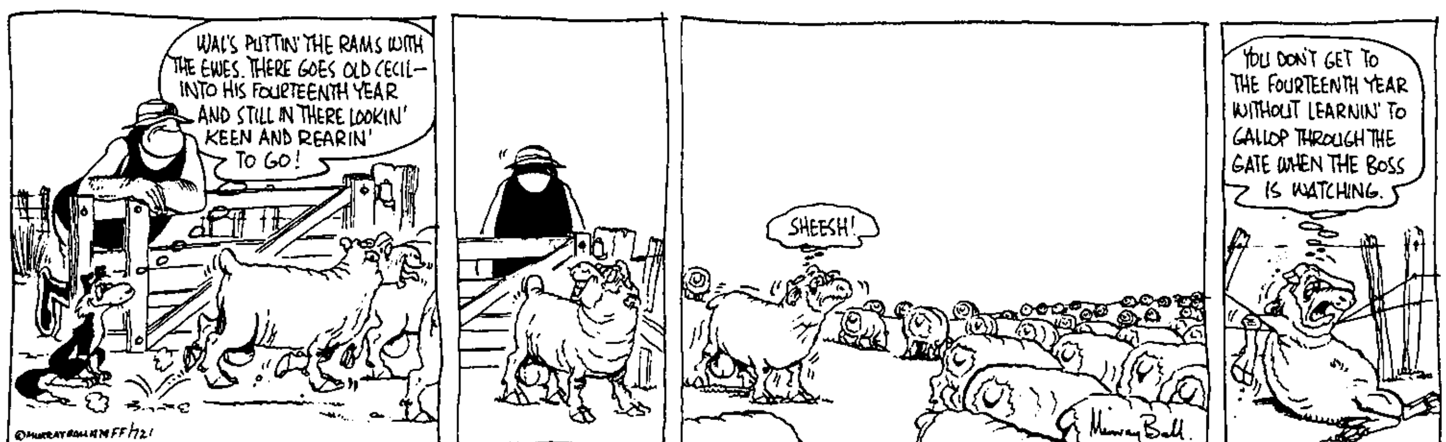
ACTIVITIES

1. *Make an energy diagram of another agricultural system, such as crops, beef cattle, dairy cows, wine grapes, or fruit orchards. Be sure to include all inputs from the economy. Find real figures for the energy flows and money if you can.*

2. *How does government subsidy to the farms affect the price of their products charged to poor people and to foreign countries buying the products?*

3. *Dig up, dry, and weigh one square metre of pasture grass. Count the number of sheep on a measured area, either by using an aerial photograph of sheep on pasture, or by taking a trip into sheep country, perhaps estimating the area by the kilometre counter on the car. One sheep weighs about 50 kg. How many kg of grass are required to support 1 kg of sheep?*

4. *If you were a sheep farmer, how would you cut down on your fuel energy inputs? What do you think will be the future of sheep farming in the lower energy world - one of the possibilities suggested in this exercise or another? Explain.*



16: Tussock Grasslands

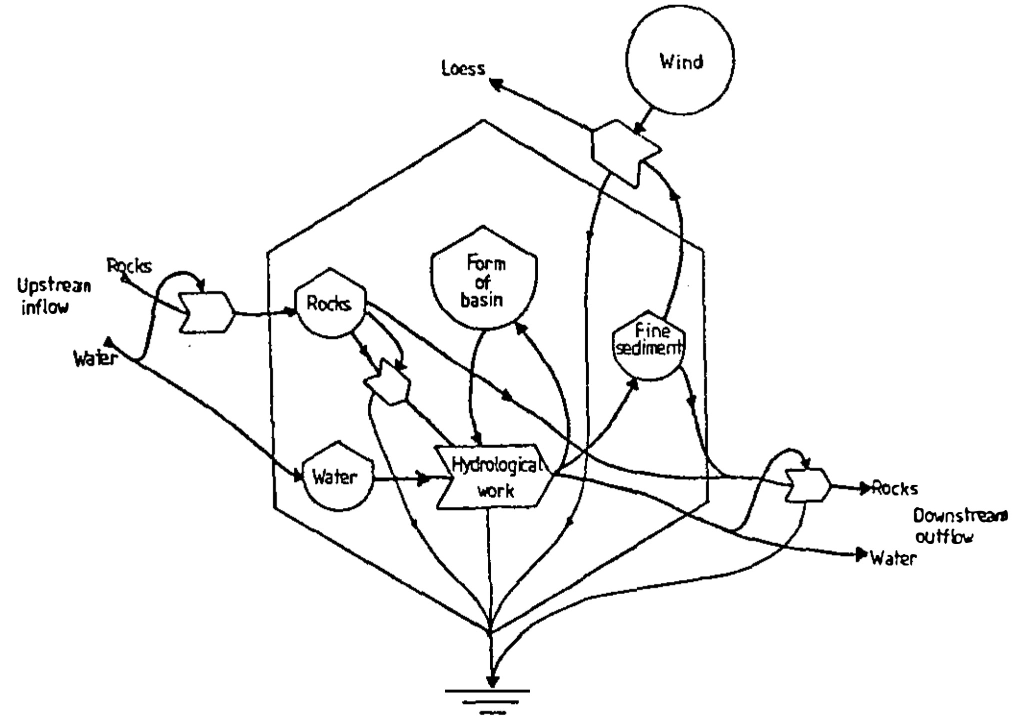


Figure 16.1 Rocky streams and basins subsystem of tussock grassland mountain region.

Much of New Zealand's mountain areas are covered with tussock grassland. *Tussocks* are highly adapted grasses which grow in a clump. Individual leaves may each live two or three years, and a total plant may live between one and two hundred years. The tussocks are a tawny colour because dead leaves remain upright around the green leaves and shoots.

16.1 THE ECOLOGICAL ROLE OF TUSSOCK

Tussocks have a critical ecological role in their system because they catch and retain the loess (blowing sediments) which maintains the production of the fields. Tall snow tussocks project above the winter snow and provide food for sheep when all other grasses are covered. In the fertilised and managed high country pastures, the tussocks are surrounded by *swards* (close growth) of shorter indigenous and sometimes exotic grasses which have been induced by grazing.

In Figure 16.1, the tussocks and other grasses receive water from rain and melting snow. Some of the water comes from storage in glaciers.

In Figure 16.2, follow the flow of rocks brought into the stream by the rushing water. The conversion of rocks to sediment is done by the power of the stream water cracking the rocks against each other. The shape of the basin is also formed by the water and rocks. Where strong winds blow, *fines* (fine sediments) are carried into the hills where they are caught by the tussock grasses. Rocks and sediments are swept downstream by the water.

Nutrients enter the mountain soils in rain and also in loess blown up from the rocky streams by the wind as is shown in Figure 16.1. Ultimate fertility depends upon levels of phosphorus and sulphur. Some phosphorus and sulphur enter the

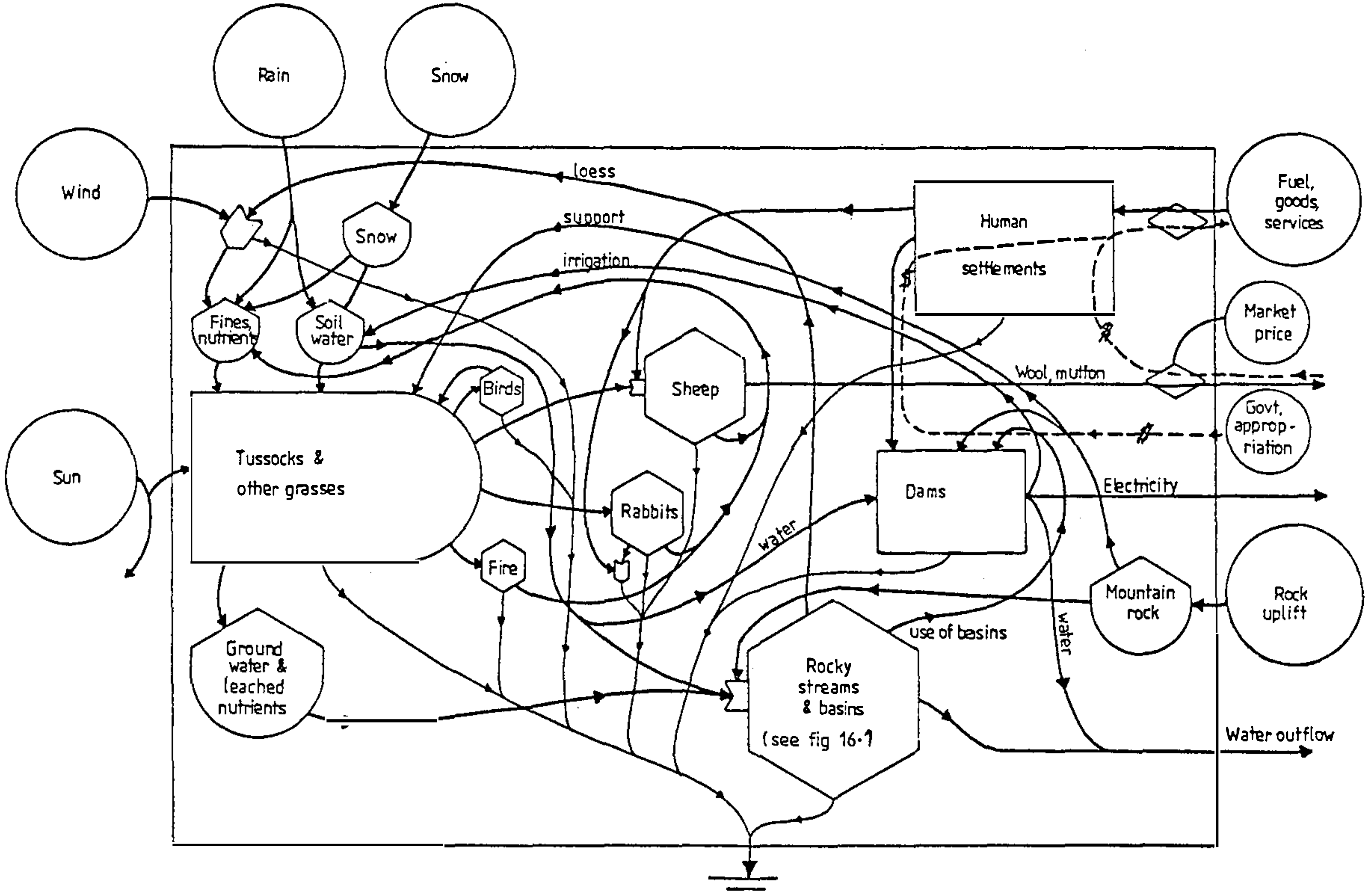


Figure 16.2 Tussock grassland mountain region ecosystem.

mountain system in rain, more enter from the breakdown of rocks in the soil, but most from the loess. In managed mountain tussock grasslands, the greatest gain is from applied fertiliser. Nitrogen is also an important nutrient, but not limiting. When phosphorus levels are adequate, nitrogen-fixing plants, such as native broom and matagouri, can provide enough nitrogen.

Birds are a part of the system, eating and spreading seeds of the grasses. The build-up of fertility in these fragile soils is slow and can easily be destroyed. Fire and over-grazing by rabbits and sheep contribute to loss of fertility by leaving the ground bare. Nutrients are then washed through the soil, through the porous rocky substrate underneath and into the ground water one to two hundred feet below the surface. Many New Zealand high country areas have suffered from these events.

16.2 MANAGEMENT OF TUSSOCK-GRASSLANDS

Under current management practices where capital is available, fertiliser is added to the land, to produce a thicker grass cover. The grass is then intensively grazed for a short time so that recycling of the sheep wastes maintains the improved nutrient status of the soil. The continuing high nutrient level keeps the ground covered with vegetation, and the vegetation reduces leaching.

At least part of New Zealand's mountain tussock grassland area has enough rainfall to support forest ecosystems. There is evidence that part of it was covered with forests several hundred years ago, some with beech and some with mixed podocarps. When forest trees are planted on these areas, they show rapid growth. Thus, it may be possible to return some tussock grassland to forest ecosystem, if it proves to be both ecologically and financially desirable to do so.

Historically, human settlements have exploited mountain lands for the production of sheep. More recently, dams have been built to transfer the energy of the torrential streams into electricity. This latter use of mountain areas converts the stream's energy into gentle flows which no longer bounce rocks into each other - something that is necessary to provide the fine sediments for soil development. However, there is a large net energy in hydro-electric plants. As we will see in exercise 20, this means that much more energy is yielded as electricity than is invested in the goods and services used to build the hydro-electric installation.

Controversy still exists about a number of issues related to the management of New Zealand's fragile tussock grassland ecosystems. Among them are:

- the degree of over-grazing of unfertilised lands;
- the long-range effect of dams on generations of fine sediments;
- the best ways to use electricity to increase the economy of agriculture;
- the possibility of using planted native vegetation as a soil-building alternative; and
- the ability of exotic forests to grow and seed themselves in the low-nutrient areas.

ACTIVITIES

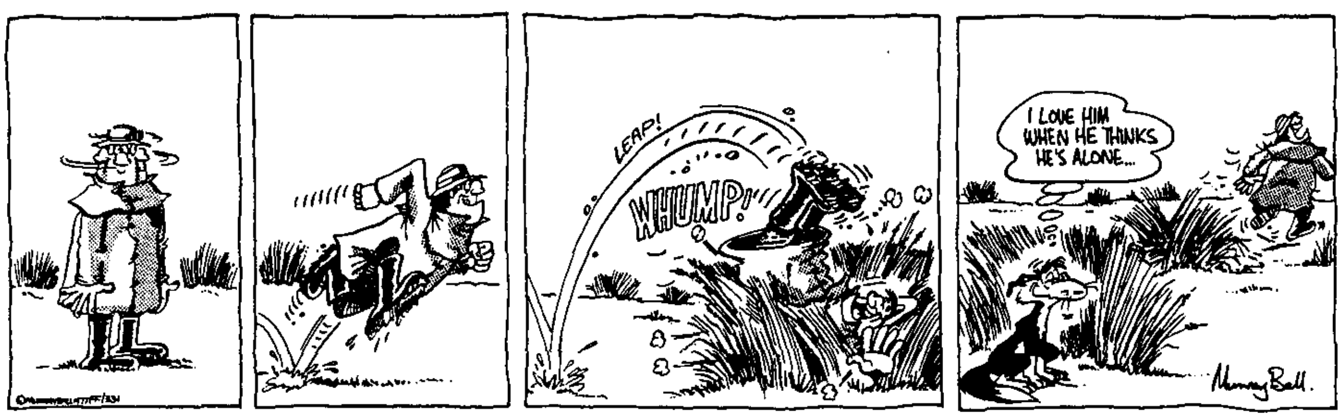
1. *Visit a tussock grassland area or find a picture of one. Compare your area to the diagram in Figure 16.1. Draw a diagram of your area, adding or subtracting organisms or processes as necessary.*

2. *Draw a food web diagram of this system.*

3. *Compare this sheep system with the lowland one in Figure 15.1. How do they differ - consider grasses, nutrients, water, and management?*

4. *As fossil fuel fertilisers become harder to get, what kind of management will be possible for the tussock grassland farmer?*

5. *Discuss one of the controversies in the last paragraph. Collect more facts, then suggest some possible solutions to the problem. Those in the class who choose the same problem can prepare a combined report to be presented to the rest of the class.*



17: Early New Zealand Maori Culture

You have learned in many courses about the early settlements of Maoris in New Zealand. Figure 17.1 is a way of looking at the culture as a system. The Polynesian system, as it became adapted to New Zealand, developed agriculture to produce the principal carbohydrate source (root crops such as kumara) with the protein being supplied from fish, shellfish and birds. The distribution of population in tribal groups was determined by territorial war struggles. Wood carvings, bird feathers, greenstone ceremonial war implements, and wooden canoe-ships were symbols and implements used to reinforce the feedback of control and dominion over the landscape.

As shown in the diagram, the resources of the environment converged to the human culture at the top. The Maoris managed the land, as shown by the switch indicating various alternatives. They burned or cut some forests, turning some land into wet marshes to grow flax or farm plots to grow root crops. Some of the land was left to return to forest through normal succession - grasses and herbs, shrubs like Manuka, then trees. Kauri trees were cut and crafted into beautiful long boats used for travel and fishing, covered with carvings which had religious or cultural significance. Trees were also cut for huts and

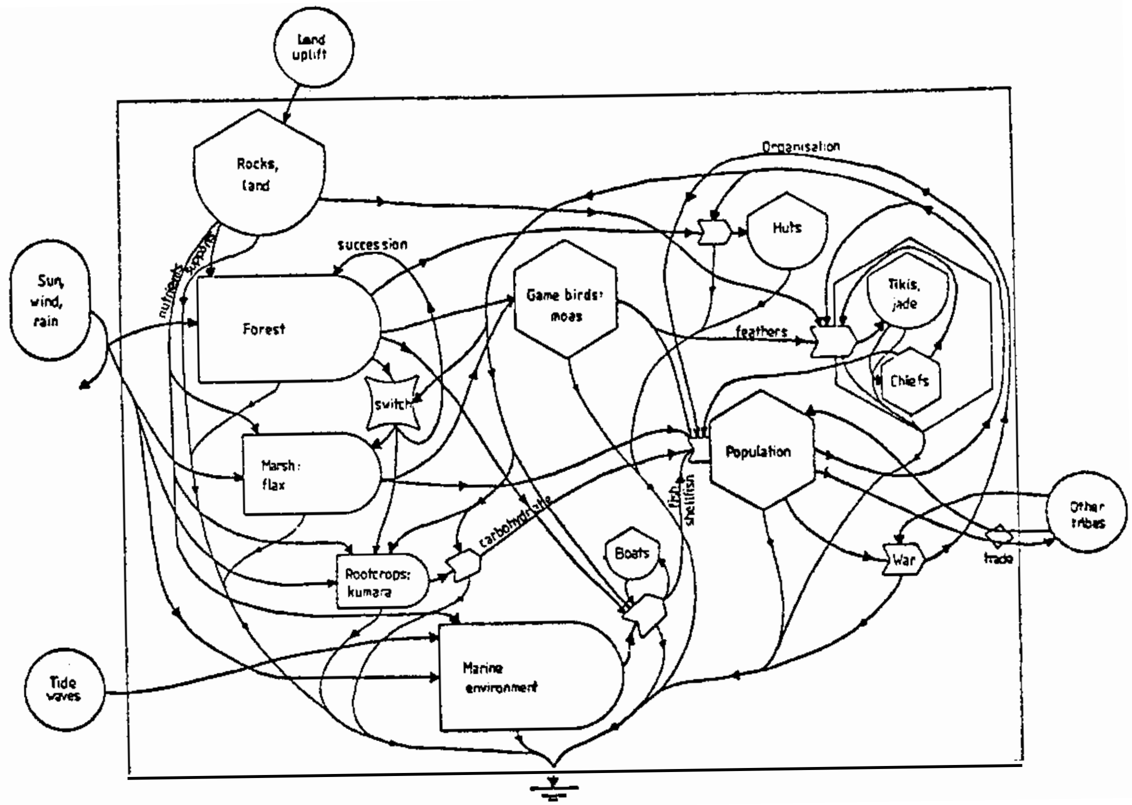


Figure 17.1 Early New Zealand Maori culture.

meeting houses.

Any group of people needs internal organisation to keep co-operative relationships going. Products contributing to the quality of the culture included the weaving of clothes from flax, using sharks' teeth for cutting tools, crafting greenstone into weapons and axes, and creating ornaments from paua shells. The hierarchy of leadership was recognised by the quality of the symbols. Maoris of rank had special carved tikis, greenstone amulets, and capes made of moa feathers. Relationships between tribes were a combination of trade and war.

At the time of the Polynesian discovery of New Zealand, the top of the ecological food chain was occupied by birds. There were flightless birds like the kiwis and moas of forests and grasslands, and the blue ducks and wading birds of the streams. Much energy, accumulated over long periods of time, was available in the high quality woods of kauri, kahikatea, and beech. Similarly, the geological landscape provided sources of high-quality energy - volcanoes and hot springs together with some forms of rock such as greenstone. These were joined to the culture of the Maori by the symbolism of mythology.

In exercise 5, we introduced the principle of the feedback provided by the higher quality consumer to sustain the pattern of basic productivity in the system. Examples were given of farmers fertilising their crops and seed-eating birds spreading seeds. In a similar way, the pattern of man and nature emerging here may have involved human actions with a cultural basis resulting in stability for the human consumer. The consumer, in return, may have performed special work for the environment - work that required intelligence, ability to travel, and persistence over long periods of time. Developing diversity through clearing, patch-burning, spreading seeds and shifting agriculture are examples of Polynesian roles in organizing the landscape.

The principles involved in the relationship between modern man and nature are basically similar. Men and women return services to the landscape in order to maintain productivity, diversity, stability and a pattern of long-range survival.

ACTIVITIES

1. *Add other details that you know to Figure 17.1. Be sure you put in the feedback flows.*

2. *Divide the class into groups, each studying and making a diagram of a pre-industrial society; for example, early European settlement in New Zealand, Polynesian Islands at the time the Maoris left, England in the 1700's, or early U.S. settlements.*

3. *Discuss boundary tensions between countries because of energy changes. Do you think war is a legitimate way of recognizing these changes? Can you think of other ways - perhaps including energy analysis by an international body like the United Nations?*

PART THREE: NEW ZEALAND'S HUMAN SYSTEM

18: Energy and Economics

Each and every one of us is bound together by being part of the earth's biological system. This system is the product of millions of years of biological evolution. At the same time we are also linked together as part of an economic system which is the product of cultural evolution. The circulation of money through human business, interacting with resources from the environment, constitutes the economic system. Diagrams help us to understand economic systems, and the way energy makes them possible. In diagramming economic systems, we must include another quantity, money.

18.1 PRINCIPLES OF ECONOMIC SYSTEMS

The first basic principle of economic systems is that money and energy flow in opposite directions. Consider the example in Figure 18.1. Farmers produce wheat and meat and sell them to people in town. Energy (in the form of meat and grain) flows from farm to town. Money (possibly in the form of a cheque) goes from town to farm. Later, the farmer can pay off his debt for tractors and buy some fertiliser. Energy (in the form of machinery and fertiliser) goes from town to farm, and money flows the opposite way.

Figure 18.1 analyses these exchanges: the

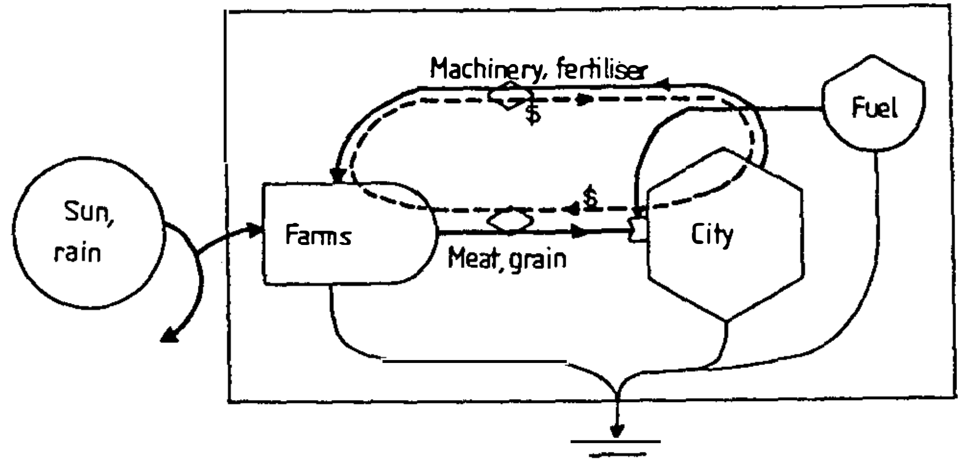


Figure 18.1 Energy and money flow in opposite directions.

farm is drawn as a producer; the city as a consumer. The flows of energy are represented by solid lines, and the flows of money by dashed lines. The small diamond symbol linking the flow lines for money and energy indicates that a transaction has taken place. As you would expect, considerable energy is degraded to heat as a result of the processes associated with these transactions.

Another basic principle of economic systems is that money pays for human work - and not for nature's work (natural resources). When you fill the car with petrol, you pay the service station attendant for the service. When the service station owner buys more petrol, he pays the refinery for the refining and distribution. The refinery pays OPEC (Organisation of Petroleum Exporting Countries) for the exploration, drilling and extraction of the petroleum. But no-one pays the earth for manufacturing the petroleum

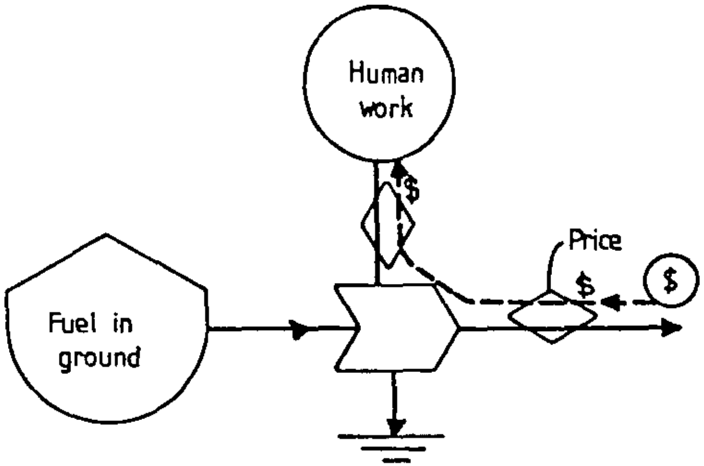


Figure 18.2 Money pays for work to bring fuel to users.

- no-one throws money down the oil well. Consequently, in Figure 18.2, we show energy and money flowing in opposite directions, except that no money flows into the ground to replace the oil. Money pays for human work, not for natural resources.

18.2 THE NATIONAL ENERGY-DOLLAR RATIO

Since the energy flow drives the money flow through economic systems, it should be possible to estimate the energy required to circulate one dollar, by dividing the total dollar flow by total energy use. As shown in Figure 18.3, in 1977, 13.2 billion dollars circulated through the New Zealand economy, while 1882 petajoules of (coal equivalent) energy was used and degraded to heat. The ratio of these two flows was *143 megajoules ($143 \times 10^6 J$) per one dollar*.

This energy-dollar ratio is very helpful for revealing the energy that is being spent to support human economic activity. Suppose a person makes and spends \$6,000 a year. Multiplying 6,000 by 143×10^6 joules, we find that 858×10^9 joules of energy is dissipated each year in support of that person. Since his personal budget for food energy is probably only about $4 \times 10^9 J$ (2500 Calories x 365 days), the difference represents work by farm machines, power plants, industry, and also the natural energies of sun, rain, wind, and even geological uplift.

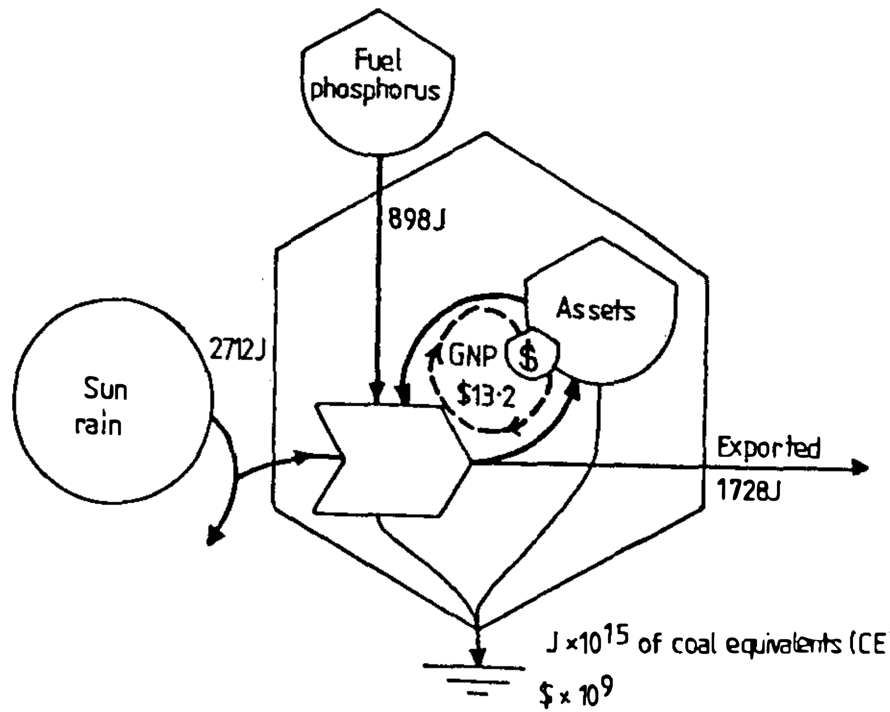


Figure 18.3 Energy flow and money circulation in New Zealand.
Energy-dollar ratio is $\frac{(2712 + 898 - 1728) \times 10^{18} J}{\$13.2 \times 10^9} = 143 \times 10^6 J/\$1$

18.3 COAL EQUIVALENTS

When we are considering the ability of different energy forms to contribute to the economy, we must take into account the *energy quality* of each form. One way to do this is to replace each energy source, in our thinking, by the amount of coal that would be necessary to do the same work. This is referred to as the *coal equivalents* (CE) of that energy source. As Figure 18.4 shows, it takes about 2000 joules of sunlight, acting through plants and geological action, to produce one joule of coal; and one joule of coal can be used to produce ¼ joule of electricity. These ratios can be used to convert sunlight and electricity to coal equivalents: the coal equivalent of 2000 joules of sunlight is 1 joule; the coal equivalent of 1 joule of electricity is 4 joules. An easy way to talk about the series is to refer to energies as low quality on the left and high quality on the right, since we arrange our diagrams in this way.

A system that is efficient uses high quality energy for purposes where the effect is large, since the solar energy required to develop the high quality energy was large. High quality energy is usually used where it can be an *amplifier* of lower quality energy. For example, electricity is used on farms to control and facilitate human work - but not as a source of light, in place of sunlight, to drive photosynthesis.

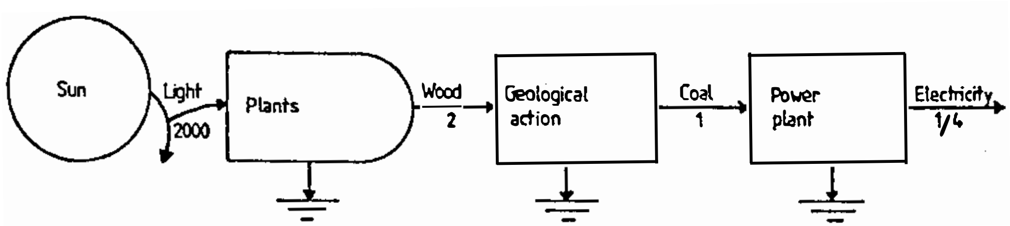


Figure 18.4 Energy quality chain, used to calculate coal equivalents.

In Figure 18.3 the total energies of sun and fuel are expressed in coal equivalents (CE). The joules of sun and rain falling on all of New Zealand averages 2712 x 10^{15} J-CE per year, which you see written on the flow from the sun and rain. The coal equivalents (CE) of total fuels and phosphorus are 898 J.

18.4 ENERGY AND INFLATION

The idea of the energy-dollar ratio also enables us to explain inflation. This is how it works: the buying power of the dollar is the amount of goods and services you can buy with it. The energy-dollar ratio expresses this buying power. In 1977 one dollar purchased 143 megajoules (CE) of goods and services. Now look at Figures 18.1 and 18.3 and imagine what will happen if the energy flowing into the economy *decreases*. Obviously, there will be less energy flowing for the same number of dollars: the energy-dollar ratio has changed. One dollar is "worth" less energy and, therefore, buys less. The loss of buying power of money is called *inflation*.

Of course, it is also possible to change the energy-dollar ratio by changing the number of dollars circulating. People and governments tend to borrow money, which increases the number of dollars circulating, without increasing the quantity of energy flowing. This increases the rate of inflation further. In the late 1970's New Zealand experienced both a decrease in the

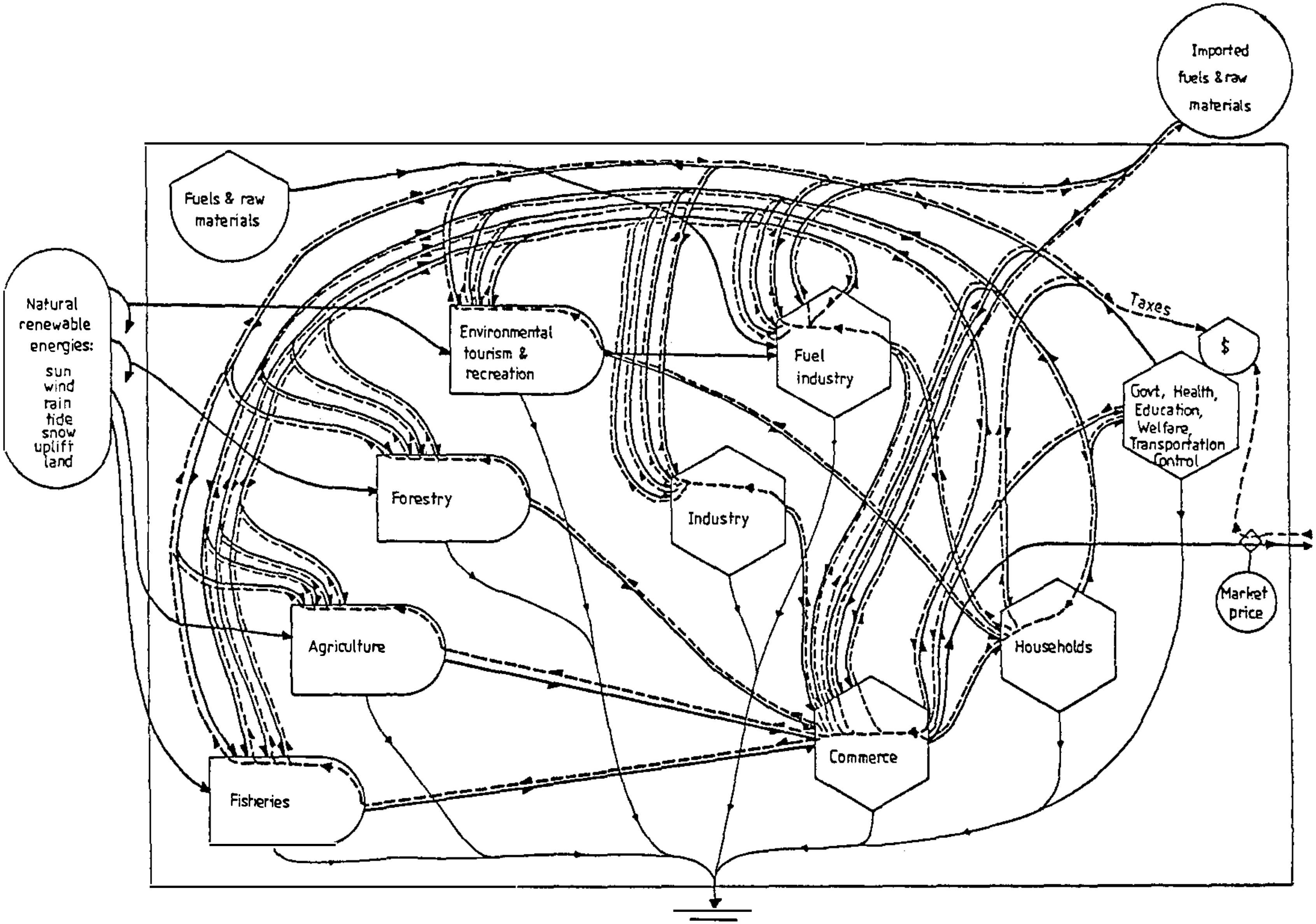


Figure 18.5. The economic web. Solid lines are energy flows; dashed lines are money flows.

amount of fuel used and an increase in the money flow - and an increase in inflation.

18.5 THE ECONOMIC WEB

The economy forms a web which converges to the high quality sector, just as an ecosystem forms a web which converges on the top consumers. In figure 18.5 we have divided the economy into nine sectors, with energies flowing towards the highest quality sectors, which are government and households. Now follow the flows: the renewable natural energies flow into four production sectors - fisheries, agriculture, forestry, and environmental tourism and recreation. Internal fuels (like coal and gas) and raw materials (like sands, gravel, limestone, and iron) are included in a storage symbol becuase they are non-renewable (renewed only by very long term geological processes). These, with imported fuels (like oil) and raw materials (like fertilisers, plastics, and chemicals) are used in the industrial sector to manufacture items like machinery, appliances, and clothes. The fuel industry includes electric power which is about 2/3 hydro-electric and 1/3 thermal using coal, oil and gas. Most imported petroleum is refined into petrol to be used for automobile transportation in the household sector. Production of goods by all sectors is distributed through the commercial sector to the households. The government controls the other sectors through laws and regulations, as well as by giving services like police, health, welfare, education, transportation, and subsidies.

The amount of money which flows along with each energy pathway within the economy, except towards government, is determined by the price. For example, people go to a hot spring for a day's outing: the solid line from the environmental sector to the people has an accompanying dashed money line flowing in the opposite direction representing the fee paid.

The money flow through the government sector is more complicated. Flows from the government are determined through political mechanisms rather than by price. Taxes are collected from most of the sectors into the money storage, and are then distributed as services. The flows of money do not follow the goods and services since the amount of government money from each sector does not relate directly to the amount of government service to that sector. When people (through their politicians) want to stimulate some part of the economy, the government supplies services. For example, subsidies given to agriculture are shown in the diagram as the dashed line flowing from the government sector to agriculture. In the household and agriculture sectors, the services by the government are of greater value than the taxes collected.

ACTIVITIES

Using Figure 18.3:

1. *What is the ratio of money to fuel energy in the New Zealand economy? Suppose a sheep farmer has to buy $500 worth of electric fencing. How much fuel energies have been spent for the fence in work across the whole economy?*

2. *How could you decrease inflation if you cannot change the rate of energy flow? Can you think of specific government policies which would do this?*

3. *How could you increase energy flow by changing energy sources? In what specific ways might this be done?*

4. *Calculate the ratio of money flow to energy flow in N.Z. if there were no inflowing energy from fuel resources. How would this affect the standard of living?*

19: Energy Sources and their Net Energy

Early human societies, like the Maoris, were relatively low energy users. They lived within modified ecological systems and were supported by the steady energy flows of air, ocean, and sun. Modern cultures are much more intensive in their use of energy. We have built many special systems for tapping the energy storages and renewable flows of the earth and diverting them from their former ways of maintaining life to new ways that increase the energy available to human societies.

19.1 NEW ZEALAND'S CURRENT ENERGY RESOURCES

The energy resources currently being used by New Zealand society are shown in Figure 19.1. Figure 19.2(a) is a more detailed analysis of the fuel and electric energy in industrial and urban uses. Figure 19.2(b) is an energy diagram with the numbers in PJ's on the storages and flows. (PJ stands for petajoule, 10^{15} joules.) Notice how much energy has to be dispersed into heat for each process. Oil is imported; hydroelectric and geothermal are renewable; gas and coal are storages within the country.

Modern societies have developed large industrial activities for obtaining, processing, and using energy - coal, oil, the sun (through

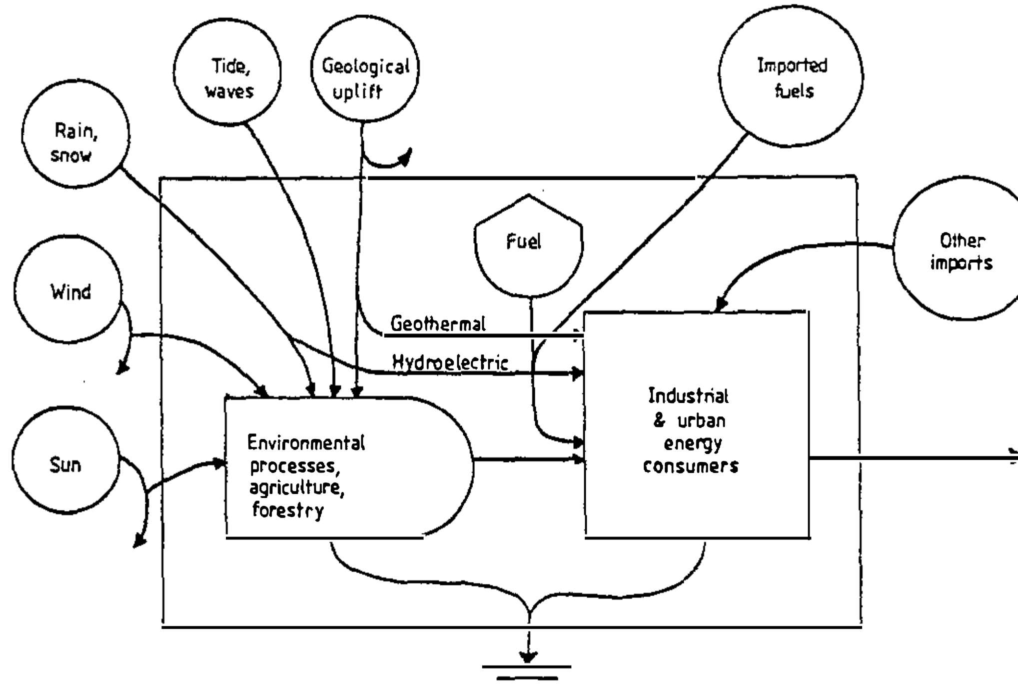
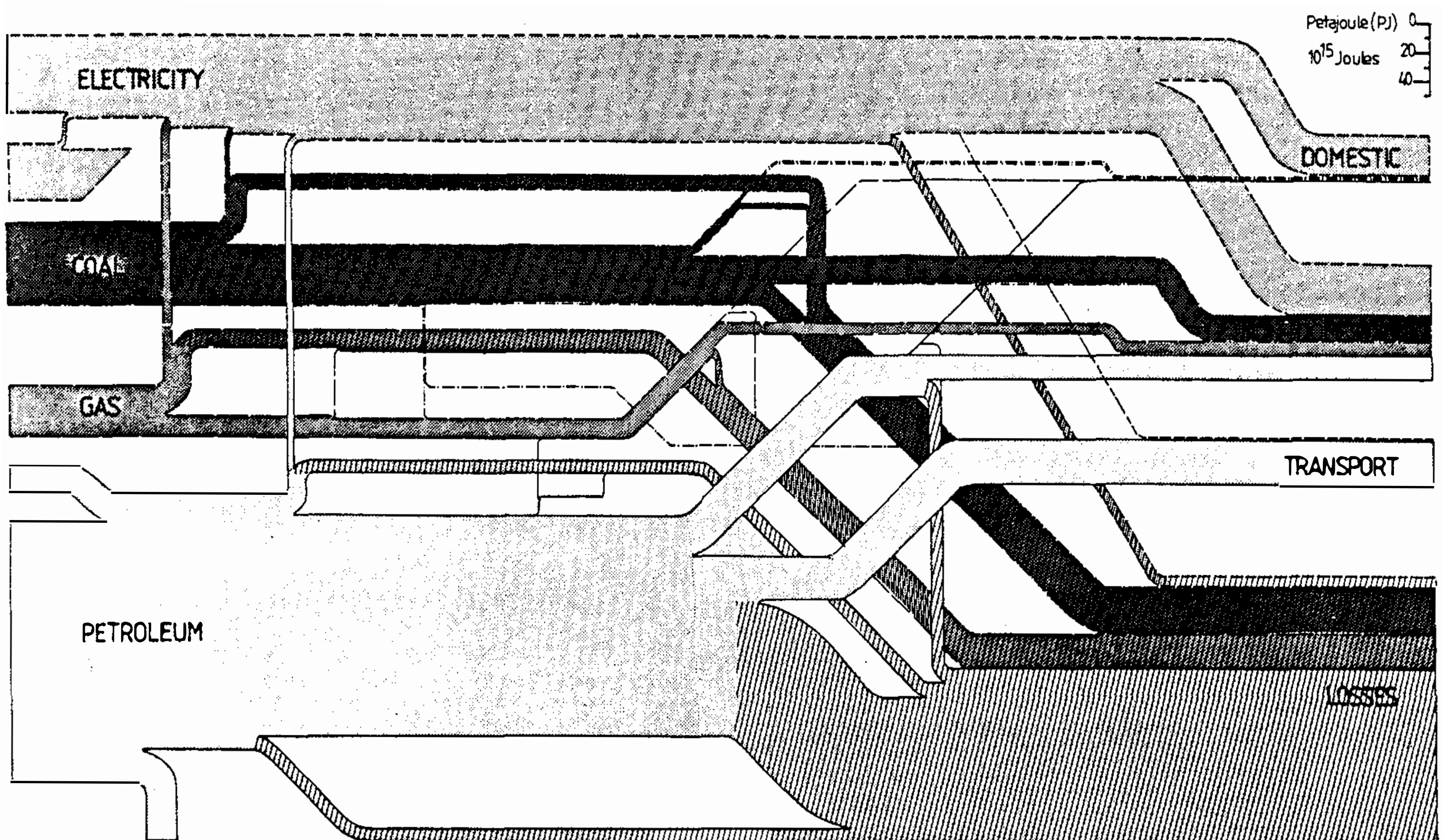


Figure 19.1 Energy flows to New Zealand. See Figure 19.2 for detail on industrial and urban energy subsystem in the square.

agriculture and forestry), winds, water, volcanic heat, nuclear energy, and many other forms. Because all these energy systems require *the use of* energy to get energy, we must be sure that we understand how much energy we are spending in order to obtain new energy. It is possible to spend more energy developing an energy source than it will ever repay. When we consider the declining reserves of fossil fuels, the question of which energy sources are capable of producing net energy is vital.

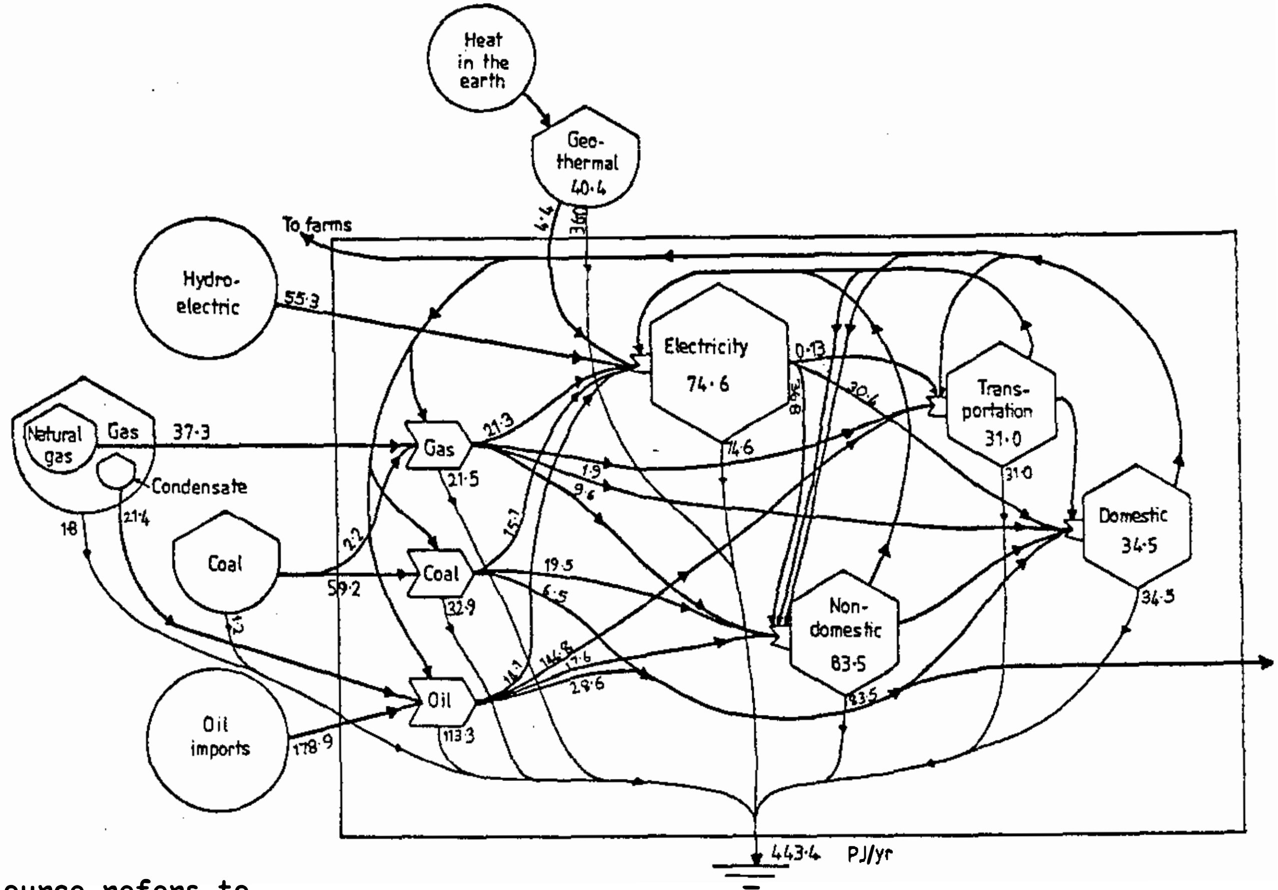


(a)

Figure 19.2 Energy flows in the industrial and urban sectors of New Zealand in 1976.

(a) Flow graph: width of pathway indicates size of flow. The term <u>losses</u> is misleading; energy is not lost but goes into heat as a necessary cost of upgrading the quality of energy (Minister of Energy, May 1978).

(b)



(b) Energy diagram with flows of PJ per year. (PJ = 10^{15} J).

19.2 THE NET ENERGY OF SOURCES

The term *"net energy"* of a source refers to the energy yielded over and beyond all the energy invested to obtain and process it. Figure 19.3 is a simple net energy diagram. It shows that, based on a 30-year life, a gas field (possibly like the Maui field) producing 385 CE petajoules of energy per year, with a feedback of 9.5 CE petajoules per year, has a net energy of 376 petajoules per year. The 9.5 CE petajoules of work by the main economy include the energy used for planning, discovery of the field, buildings, equipment, human labour and skills, maintenance etc.

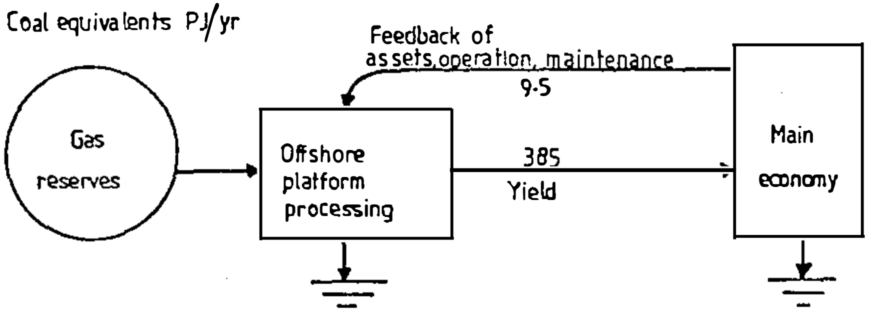


Figure 19.3 Diagram of net energy involved in utilizing a gas reserve which has a capital cost of $30 million spread over 30 years and an equal cost for operation each year. Net energy ratio = 39/1.

Notice that in comparing feedback and yield energy, it is necessary to use two of the ideas introduced in exercise 18. These are: *coal equivalents* - to ensure that we compare energies of the same quality, all are expressed as coal equivalents; and the *energy-dollar ratio* - to reveal the energy utilized by the economy in developing the feedback.

A useful way to compare the net energies of different sources is to express them as a *net energy yield ratio.* This is the ratio of energy yielded to the energy invested. The net energy yield ratio of the gas field in Figure 19.3 is 385PJ/yr to 9.5PJ/yr or 41 to 1, which is a very favourable ratio. The net energy yield of this gas can be used by the economy in manufacturing processes to produce goods; it can be transformed into liquid fuel for cars; or it can be used in heaters to keep people warm so that they can work to produce other goods and services.

Fossil fuels - gas, oil and coal - are all good net energy-yielders; consequently, they have been the basis of the world's industrial growth during the twentieth century. However, in most areas of the world natural gas supplies are running out. In New Zealand the Maui and the small Kapuni gas fields are estimated to have recoverable reserves of natural gas, condensate, and liquified petroleum gas which will last at least another 15 - 20 years. New Zealand's most important use for natural gas may be to replace increasingly expensive imported oil.

19.3 IMPORTED OIL AS A NET ENERGY SOURCE

Consider the yield of energy from buying Middle East oil, shown in Figure 19.4. In 1979 1 barrel of oil from Saudi Arabia cost $23. If $1 represents 143 megajoules in coal equivalents (the energy-dollar ratio), then paying $23 for 1 barrel of oil is equivalent to sending 3.2×10^9CE joules of our energy to Saudi Arabia in exchange for it. Since a barrel of oil contains about 9.6×10^9CE joules, the yield ratio is 9.6×10^9 divided by

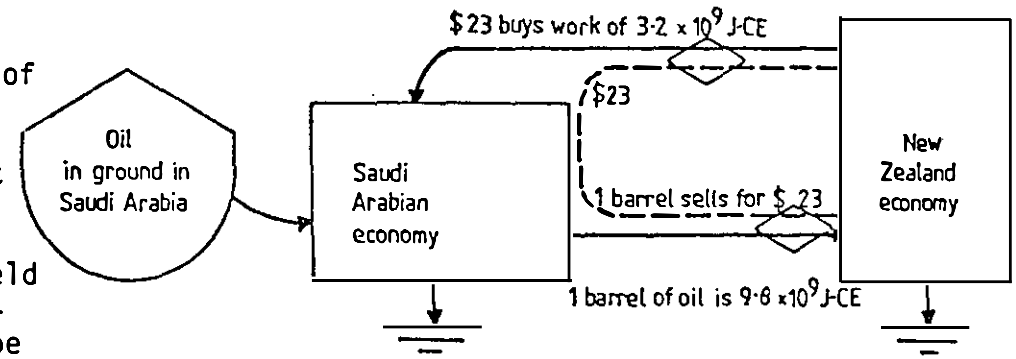


Figure 19.4 Diagram of net energy of buying oil from Saudi Arabia in 1979. Yield ratio was 3 to 1 ($9.6 \times 10^9/3.2 \times 10^9$).

3.2 x 10^9 or about 3 to 1. In 1974, when the price of a barrel of oil was $10, the net energy ratio was 6 to 1. Even though the net energy ratio of oil has decreased drastically, we will see that many other sources currently available have a ratio of less than 3 to 1. Consequently, despite rising prices, oil continues to be a sought-after fuel. Before the tremendous rise in prices in 1973 and 1977, there was such a high return from oil for energy invested (40 to 1) that all the world became dependent on this fuel. With the reduction of the net energy available from oil, many industrial countries are diversifying by using more coal.

As the oil becomes harder to get - deeper in the earth in the Middle East, the U.S.S.R. and the U.S.A., or farther out to sea as in the North Sea and the Gulf of Mexico - its net energy ratio becomes less. No oil has been found in New Zealand, although there is continued exploration.

19.4 COAL AS A NET ENERGY SOURCE

It is not hard to understand why coal is becoming an attractive alternative to oil. Figure 19.5 is a net energy diagram of New Zealand coal. The yield per year is 2,368,909 tons, or 79.3 x 10^{15} J, the net energy yield ratio at the mine is 29 to 1. However, the coal must still be transported to the consumer. The additional energy investment involved in transportation lowers the ratio to about 12 to 1. As you can see this is still a great deal higher than purchased oil, at 3 to 1. In parts of the world, like N.Z., U.S.A., Canada and U.K. where high energy yield ratios are available, industries and households are switching from oil to coal. In New Zealand the indicated reserve of available coal is about 12.5 x 10^3 PJ, enough to last about 120 years at the present rate of use. However, since other sources are becoming less available the use of coal can be expected to increase, depleting the reserve faster.

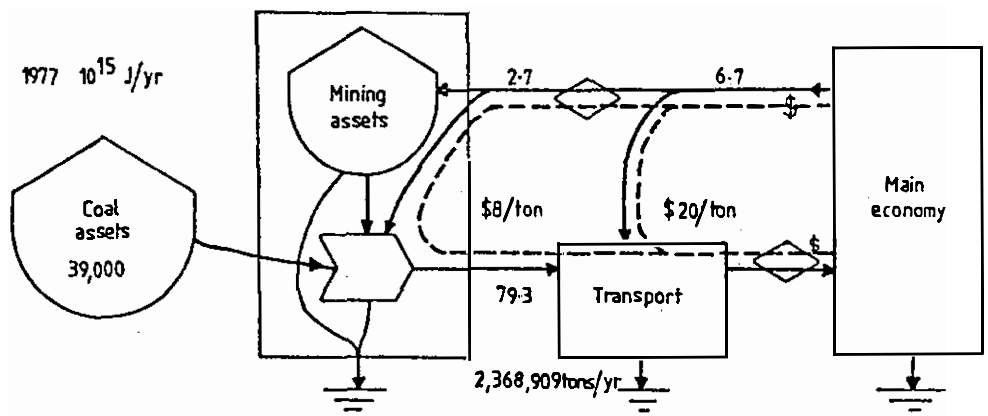


Figure 19.5 Diagram of net energy of coal mining and transport in New Zealand. Net energy yield ratios: at mines 29/1; transported in New Zealand 12/1/

With fossil fuels being used up, the world is looking for alternative energy sources. In the next exercise, we will examine some of these to see whether they have positive net energies, and how their yield ratios compare with fossil fuel energy sources currently available.

ACTIVITIES

1. *Collect pictures from magazines that illustrate the processing of gas, oil, and coal, preferably in New Zealand. Explain the significance of each picture to the total system of this energy source.*

2. *What will the net energy of imported oil be if the price is $30/barrel? (Figure 19.4). At what price will imported oil have such a low net energy that New Zealand should not buy it?*

3. *As imported petrol fast becomes unavailable, discuss what you think will happen to transportation by car. Consider both the possibility of petrol being produced from gas, coal, or other materials temporarily, and the possibility of none of these alternate processes yielding net energy.*

4. *If refining takes 10% of the fuel energy to transform raw petroleum to petrol, diesel fuel, etc., what change in net energy would result?*

20: Alternative Energy Sources

As fossil fuels become scarce, people are looking for other energy sources to run their highly industrialized world economies. Some possibilities are: hydro-electric energy from mountain water flows, geothermal energy from hot earth close to volcanoes, tidal energy, wave energy, wind, forest biomass, plant biomass, solar photo-electric cells, thermal engines running on ocean temperature differences, nuclear fission, breeder reactors and nuclear fusion. We will discuss these sources from the point of view of their net energies - since, if a source does not have a high yield ratio, greater than competing sources, it may not be worth developing as a primary energy source. See exercise 19 for a discussion of the importance of net energy, if you have not already done so.

20.1 HYDRO-ELECTRICITY

New Zealand is in a very advantageous position because the combination of mountains with rain and snow can be used to produce hydro-electric power. Taking the Benmore Power Station in the Upper Waitaki Basin as an example (Figure 20.1), the yield ratio for hydro-electric power produced in 1979 is 9 to 1 at the dam. Transmitting the electricity long dis-

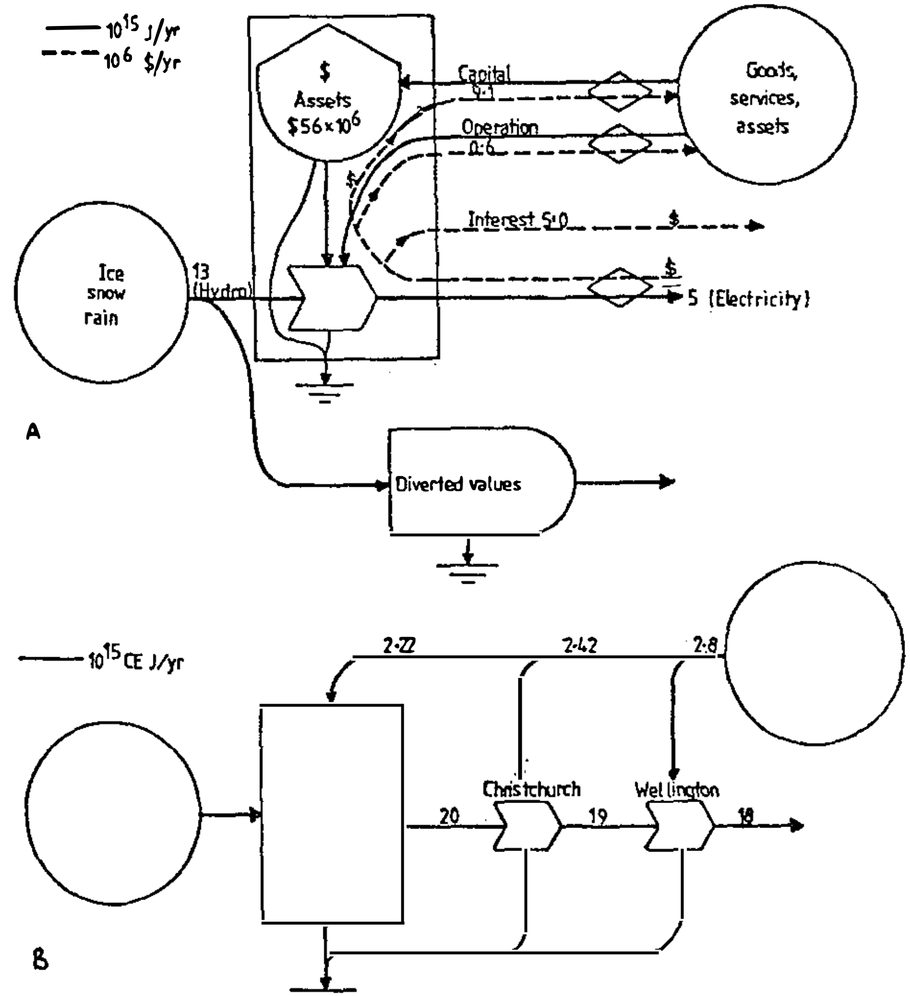


Figure 20.1 Net energy diagram of hydro-electric production from the Benmore Dam in the Upper Waitaki Basin.

(a) Diagram with data on the flows

(b) Data in coal equivalents showing net energy yield ratios.

tances dissipates some of the energy, and this reduces the yield ratio somewhat, but it is still large. Similar ratios have been obtained from other hydro-electric power stations. In 1977 68% of New Zealand's electricity (a total of 52 PJ) was hydro-electric. The potential for the development of further hydro-electric sources in New Zealand has been estimated to be 105 PJ per year, almost twice as much as is being used now. However, development of valleys for hydro-electric power takes energy and land away from other uses, so that the energy transformed is not all gain.

20.2 GEOTHERMAL ENERGY

In 1977 geothermal steam at Wairakei Power Station generated 5.5% (or 4.19 PJ) of the country's total electricity. A rough estimate of the total electrical energy available from geothermal resources is 40 PJ per year. Geothermal energy (steam and hot water) also provides some heat for homes and industry. However, tapping geothermal steam draws it away from natural springs and can cause loss of tourist attractions.

Small natural temperature differences are used in many of the earth's processes, like production of wind from differential heating of the earth and atmosphere. Tapping the heat of the earth for man's industrial processes has been economically successful only in the vicinity of volcanoes (in New Zealand, California and Iceland), where temperatures are high and the net energy large. The amount of energy that can be obtained from heat sources is proportional to the temperature difference between the source and the environment. As shown in Figure 20.2, the volcanic heat in the earth changes groundwater into steam which is tapped to run an electrical generator. In the area of volcanic heat, the net energy ratio is about 13 to 1. Transmission of the geothermal electricity decreases the ratio somewhat, but it is still favourable.

20.3 WIND ENERGY

Wind is another natural renewable energy source that has been used for some purposes in New Zealand. Windmills can grind grain, pump water, and generate electricity. A strong steady wind would have a yield ratio for making electricity of more than 1, but, as you see in Figure 20.3, light wind of 16 kph used in a wind electric generator does not have a favourable yield ratio. It yields only 1 unit of energy for an energy investment of 3.5 units. Such winds are not a good primary source.

Many areas of New Zealand have high winds, by world standards, especially Cook Strait, the Rakaia Gorge (west of Christchurch) and elevated

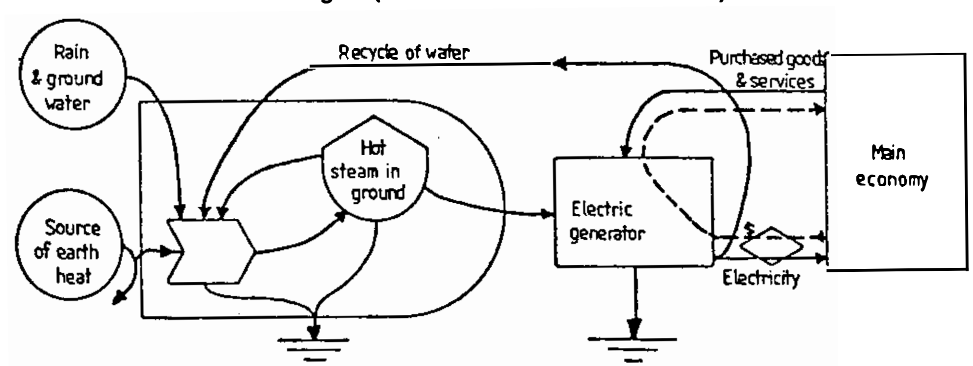


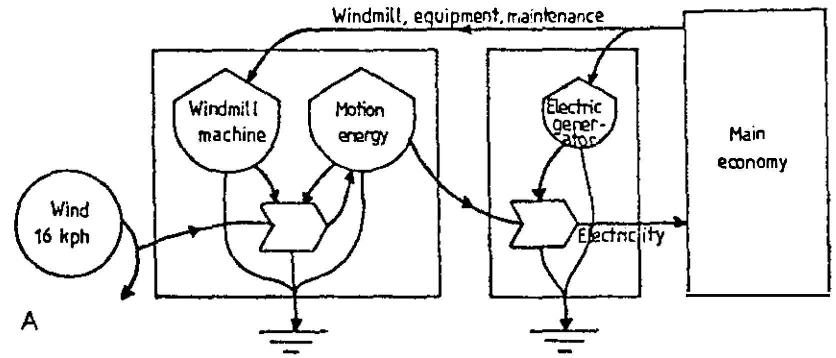
Figure 20.2 Geothermal electrical process. Net energy ratio of a case analysed in California was 13 to 1.

areas of inland Otago. However, they are very variable and would supply irregular output. Hydro-electric energy is a higher net energy and steadier. Small windmills may be used to pump water for stock-watering or irrigation in many areas, as in the past. Simple windmills and sailboats, if built from low energy materials, do yield net energy.

20.4 SOLAR ENERGY THROUGH BIOMASS

Many people hope the sun may be a solution to energy shortages. Biomass is the organic matter produced by plants in photosynthetic production, such as wood, leaves, grass, vegetables, etc. In exercise 21 we show that native forests have a large net energy yield ratio (320/1), because they require so little work from the economy. Production of exotic wood in New Zealand plantations has only a small net energy yield ratio (about 2/1) depending on the energy required in fertiliser (Figure 14.2). Production of bulky agricultural products such as fodder beets has a net energy yield ratio of about 1.3 to 1. The net energy of biomass depends on how intensively it is managed.

By processing these organic materials further, it is possible to manufacture methanol and ethanol, on which automobiles can be run. After adding the extra goods, services, equipment, fuels, and electricity requirements for this manufacture, the yield ratios are less than one. This means that fuels can be made from agricultural and forestry production, but the processes would have to be subsidised by the rest of the economy. At present, more fuel can be obtained per unit of energy used in the process from coal,



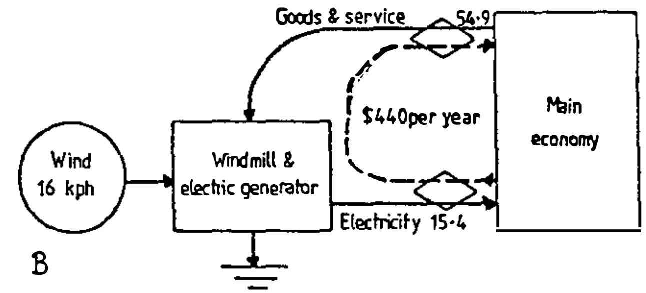


Figure 20.3 Energy flows for windmill, receiving 16 kilometre per hour wind, driving an electric generator.

(a) Energy diagram

(b) Summary with energy flows generating 1,200 kilowatt hours of electricity. Numbers are GJ (gigajoules: 1 GJ = 10^9 J) of coal equivalents.

Maui gas or foreign purchase. Later, when these sources are unavailable, fuels made from the organic produce may be the only way. However, there may be strong demands on the same land to produce food, clothing, housing, and household fuels, as well as petrol.

20.5 LIGNITE

Very substantial reserves of lignite are found in Southland. Lignite is former peat from swamps that is partly processed towards coal formation. Its energy is intermediate in concentration between wood and coal. It has to be naturally dried to yield net energy, such as drying in summer winds and sunlight. However, many deposits are under valuable lands that now yield in other ways, such as agriculture. Also some of the energy gained may have to go back into restoring land after strip-mining the lignite.

20.6 DIRECT SOLAR TECHNOLOGIES

Much discussed are the potentialities for use of the sun through solar technology, which includes solar heating panels and solar electric cells. However, the sun's energy is so dilute that the energy required for glass, plastics, pipes, wires, and equipment to concentrate it is four times its yield. Solar water heaters, as consumer technology, use less energy than electric heaters, so that they are a way of saving energy even though they use more than they yield. The best use of the sun may be in simple net energy yielding forestry and agriculture.

The principle emerging from this discussion is that dilute energy sources that require much invested energy are not good sources. Thus, other projects being experimented with that use dilute energies, like the small heat differences in the ocean, may also prove to have uncompetitive energy yield ratios.

Harnessing tides requires damming estuaries, which reduces many of their existing values for fisheries, navigation, and waste disposal. Tide levels in New Zealand are less than in those areas where tides have been dammed successfully for hydro-electricity.

Wave energy coming ashore in New Zealand is large in total quantity, and it does much daily work forming beaches and making sediment from rock. However, it is hard to use because it is spread out along a great length of coastline.

20.7 NUCLEAR ENERGY

Nuclear energy, unlike solar energy, is too concentrated and too hot, to use without cooling. Much of the excess heat energy must be dispersed to cool the process down to temperatures that will not melt the machinery. The nuclear power plants currently producing electricity in many parts of the world have a yield ratio of about 3 to 1. However, this ratio does not include the feedback energy from the economy necessary to deal with serious accidents or radioactive waste disposal. Consequently, very few new plants are now being constructed.

Apparently the breeder reactors have too much energy required in fuel recovery and complex safety measures to be positive net energy producers. Fusion processes are much hotter than fission reactors, so that the energy to control and use the fifty million degrees of a fusion process may be too great to be a positive net energy.

20.8 THE NET ENERGY OF ALTERNATIVE SOURCES

A summary of net energies of various sources is shown in Figure 20.4. Sources range from dilute sources like small heat differences and the sun on the left, to very concentrated hot sources like fusion on the right. Those above the line have positive net energies, with the ones on top, like natural gas, the highest.

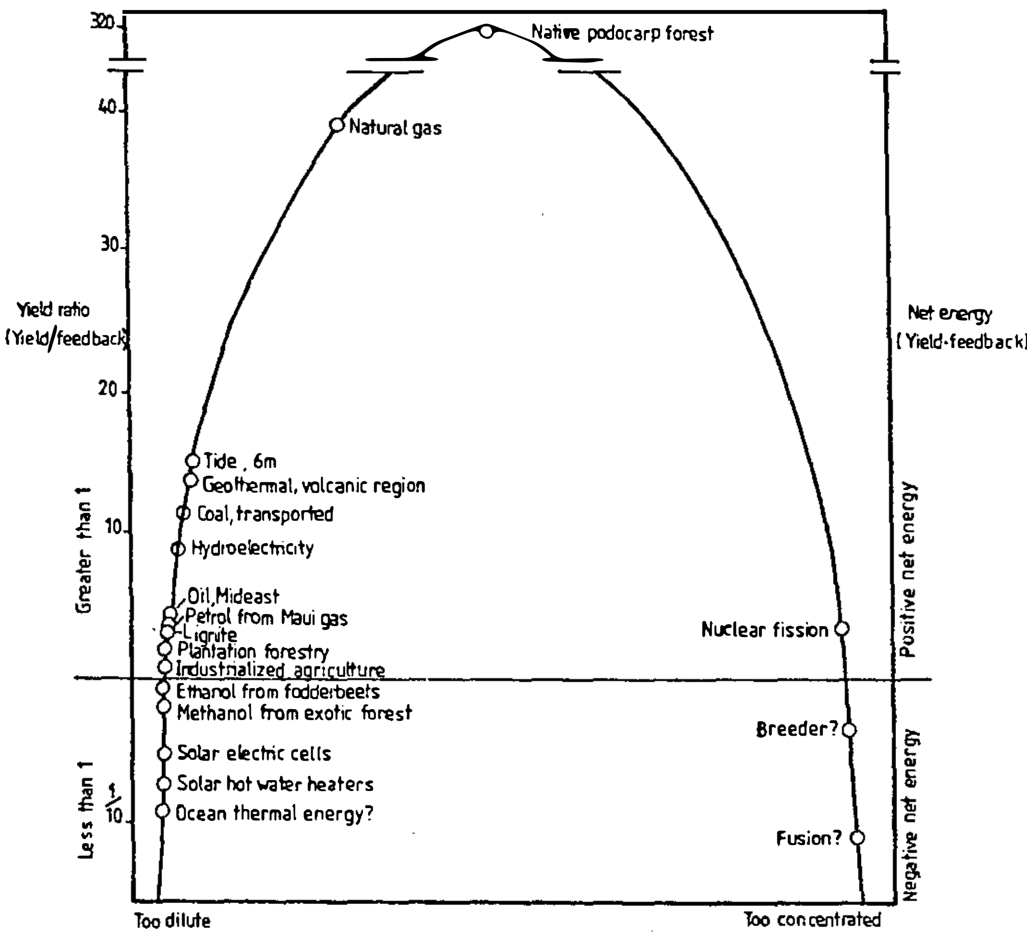


Figure 20.4 Net energy of sources.

Table 20.1

Energy Equivalents

Type of Energy	Joules of heat to make one coal equivalent joule	Coal equivalent joules (CE-J) per heat joule
Sunlight	2,000	0.0005
Plant production	5	0.2
Wood	2	0.5
Coal	1	1
Oil	0.7	1.5
Electricity	0.25	4

Energy/dollar ratio, 1977 = 143×10^6 joules/$1

ACTIVITIES

1. *Try to list the energy sources in exercises 19 and 20 in the order of their net energies.*

2. *Which fossil fuel will run out first in New Zealand? What will be the consequences of this?*

3. *Discuss the reasons why New Zealand has decided not to build nuclear power plants. Do you agree?*

4. *List three fossil-fuel energies, five energy sources directly based on the sun, one source within the earth, and one source which used the atom. Which of these are good net energy yielders now?*

5. *Why do solar technology devices have a poor yield ratio? What are proven ways of supporting human beings on solar energy?*

6. *The net energy calculation of hydro-electricity does not have the loss of productivity due to damming and diverting land and water uses. How could you evaluate this? (Hint: what area, other sources of energy, and money are no longer flowing, and what is their coal equivalent flow per year? Table 20.1).*

7. *Make a collection of pictures and articles about alternative energy sources. (A group of students could work together on each source - and give a report to the class.) Evaluate the articles: do the data from different articles agree? the conclusions?*

21: Environmental Evaluation

Environmental energies, like sun, wind, rain, and geological uplift are at work every day, contributing value and developing the assets of the land. Natural systems use these environmental energies to build the landscape with its form, sediments and rocks. Over long periods of time, a natural selection has created associations of living and non-living things that use these available environmental energies in the most productive manner. For example water interacts with plants, animals, and rock to build soils; snow and ice interact with uplifted rock to produce sediment; wind interacts with plants and water to draw in nutrients by the pull of transpiration; and all these interact to develop the diversity and stability of natural systems, which we regard as having aesthetic beauty. In assessing the value of natural systems, we often disregard the amount of work that has been invested by environmental energies. We should not disregard these investments, however, since taking them into account makes sure we use the products of environmental work in a way that recognizes their value to the economy, something that prices rarely do.

21.1 EVALUATING KAURI FORESTS

Consider the example of our few remaining stands of Kauri forest, which contain trees ranging from 200 to 1200 years old. The stored work represented by these assets can be calculated by multiplying the yearly flows of environmental energy into the Kauri system by the number of years necessary to form mature Kauri trees. Some of these energies are dilute, like sunlight, and others are more concentrated, like the rain. Consequently, we convert all inflowing energies into energies of the same quality, by expressing them in coal equivalents. As Figure 21.1 shows, the solar work alone entering a Kauri system is 64×10^9 CE J per hectare per year. Using the energy-dollar ratio, you can see that the dollar value of that input of environmental energy is

$$\frac{64 \times 10^9 \text{ CE joules/hectare/year}}{143 \times 10^6 \text{ CE joules/dollar}}$$

$$= \$450 \text{ per hectare/year}$$

If a Kauri forest is 200 years old, its accumulated work in soil, structure, diversity, trees, genetic organization, etc. is the annual valuation calculated above, times 200 years - or $90,000 per hectare. Many Kauri forests are much older than 200 years. A 1000 year old forest would have accumulated solar work to the value of $450,000 per hectare.

When natural resources are utilised, the money obtained from their use is not paid to nature in return for the environmental energies invested, but to the human developers. If a 200 year old Kauri forest is harvested for wood, the cost of cutting is around $300 per hectare - which is a very small proportion of the value of the invested natural energies. As Table 21.1 shows, the net energy ratio is correspondingly high at 320 to 1. This indicates that from a *money* investment point of view, the harvesting of Kauri forest is a bargain. Small wonder that the early European settlers in New Zealand disposed of most of the Kauri forests in a very short time.

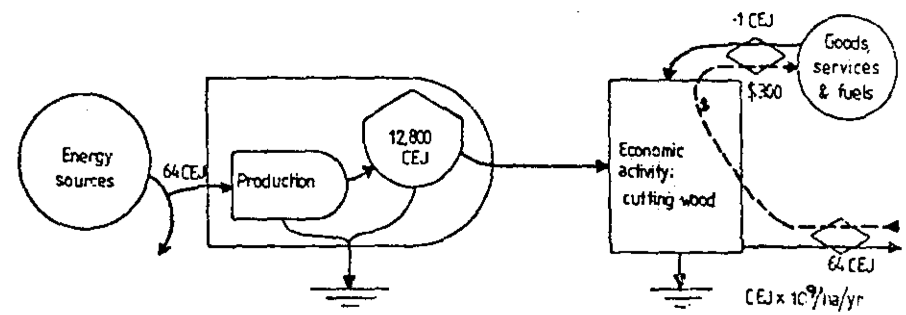


Figure 21.1 Productive work in one hectare. Dollars spent for goods and services in use of environmental values (continual production and stored value) do not reflect the very large energy contributed by nature's work. Stored energy is

$$(64 \times 10^9 \text{ CEJ/ha/yr})(200 \text{ years}) = 12{,}800 \times 10^9 \text{ CEJ}$$

21.2 THE VALUE OF NATIVE FORESTS

The ecological pattern of living organisms in native forests required thousands of years to develop its organization of relationships (since the ice age 9,000 years ago), so the value of the last remnants is many times that estimated above. The remaining high diversity native forests are now so rare that they have great aesthetic value as tourist attractions. More important still, the remaining forest stands represent irreplaceable gene pools and life associations that are essential for the re-establishment of native forests on now fallow lands. We must also remember that there is a minimum size for a forest system below which the stable maintenance of the larger species (which do important work in the system) becomes doubtful.

Future generations of New Zealanders may well place a higher value on native forests than does the present generation. The very least that we can do, therefore, is to ensure that adequate stable genetic reserves are maintained, and that these are sufficiently large and sufficiently dispersed to *ensure* their survival - despite possible future ecological disasters, like fires and serious drought. Once such reserves are established, native trees should be harvested on a continuing yield basis only - which means that the amount of timber cut each year is no more than the amount of growth each year. Native forests will thereby provide an economic activity with the same high net energy ratio, not just for one generation of New Zealanders, but for all generations into the foreseeable future.

21.3 ECONOMIC DEVELOPMENT

In general, the most financially rewarding land-use activity is that which taps into the largest store of free environmental energy. When New Zealand forests and soils were rich and virgin, they contained large quantities of free environmental work. Consequently, the utilisation of the resources provided early settlers with

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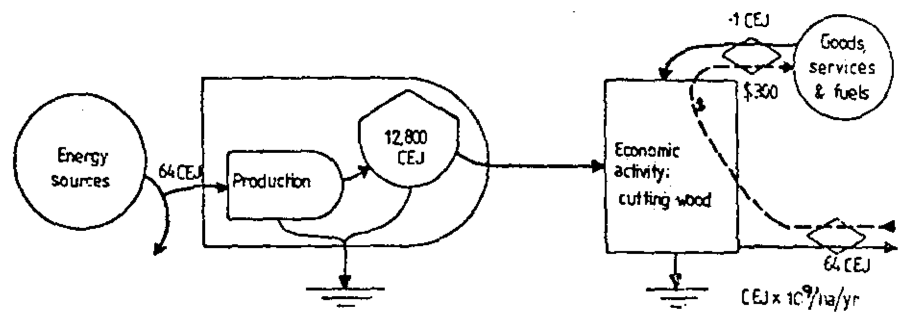

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Another example of this pattern of events can be found in high country farming. New Zealand's high country soils are very fragile. They contain relatively low nutrient levels - which is to say that they contain rather low stores of environmental energy. At first, the productivity of high country farms was good. The stores of environmental energies available in these soils ran down very quickly, however, to the point that high country farms are now of marginal profitability. Many high country farmers have already returned their land to forestry or to natural tussock grasslands. The long-lived tussocks have some of the properties of trees in holding soil, nutrients and water and in adaptations to the severe climate.

Table 21.1

Steps in Calculating Net Energy of Native Forest

Date given: 64×10^9 CE-J/ha/yr of sunlight, rain, wind, falls on N.Z.
$300/ha to cut forest trees.
One hectare of native forest, average 200 years old.
143 CE-J/$ is the energy/$ ratio.

How the calculations are made:

Yield is the environmental energies: 64×10^9 CE-J/ha/yr

Feedback: the only cost is for cutting; the forest takes care of itself.

$-cost of cutting:

$$\frac{\$300/\text{ha}}{200 \text{ years (average tree age)}} = \$1.50/\text{ha/yr}$$

Cutting work in CE:

$$(\$1.50/\text{ha/yr})\ (143 \times 10^6 \text{ CE/\$}) = 0.2 \times 10^9 \text{ CE/ha/yr}$$

Accumulated stored value:

$$\frac{(200 \text{ yrs})\ (64 \times 10^9 \text{ CE yield})}{143 \times 10^6 \text{ CE/\$}} = \$90{,}000$$

$$\text{Net energy} = \frac{\text{Yield}}{\text{Feedback}} = \frac{64 \times 10^9}{0.2 \times 10^9} = \frac{320}{1}$$

21.4 THE PROFITABILITY OF LAND-USE INVESTMENTS

We can determine in a rough way whether an investment in a land-use activity is likely to be profitable. This is done by calculating the ratio of natural energies harvested to invested money for the particular project being contemplated, and comparing this ratio with the national average. In New Zealand, the national average is about 205 x 10^6 CE J of environmental energy harvested per one dollar of purchased fuels, goods and services. A proposal that involves harvesting less environmental energy per invested dollar than this national average ratio would be obtaining too little environmental support, and therefore would be unlikely to be profitable. In addition, such a proposal makes too much economic activity relative to natural life support, with risk of pollution and other harmful environmental impacts. A proposal that would gain a greater amount of environmental energy per invested dollar would probably give a good economic return. Thus, the concepts of environmental value can guide us in the making of economic as well as environmental decisions.

Economic development is attracted to areas where there are still free environmental energies and unused fuel resources. However, if systems become too crowded and overdeveloped, shortages of environmental support and negative effects like pollution and crime cause the economy to compete badly and deteriorate. You can see how this works when you think of the overcrowding in some parts of the world's cities (New York, Glasgow, London).

If you were considering investing in a part of New Zealand, you would probably choose an activity made competitive because of natural resources. For example, a competitive area might be near fuel resources, with clean water, or open space. Since New Zealand has untapped resources of coal, gas and hydro-electric power and is relatively uncrowded, investors from more crowded countries are coming here with proposals for economic development.

21.5 INTERNAL OR EXTERNAL USE

Valuable products from the external environment like native woods and agricultural products, because they have net energy, contribute more to the economy than they take from it. This assumes the product is used within the country. But, if sold abroad at the regular price, it sends value away; this stimulates other economies but hurts the local economy. See exercise 24.

ACTIVITIES

1. *Consider Figure 21.1 and Table 21.1; the figures there are for trees of 200 years old. Calculate the following assuming that the trees were an average of 1200 years: yield per year, cutting cost in dollars per year, feedback in CE per year, value in dollars for 1200 years, and the net energy.*

2. *Complete a similar set of calculations for a hectare of exotic forest. They are cut in 24 years, and the total feedback cost is $1392, which includes planting, fertiliser, and thinning, as well as cutting. Begin by drawing a diagram similar to Figure 21.1, putting the data on it. Then calculate: yield per year, feedback cost in dollars per year, feedback in CE per year, value in dollars for 24 years, net energy.*

3. *From the answers to the last two questions, estimate the relative contributions of native and exotic forests. Why, then, are exotic forests planted? Would you favour a programme to save and replant native forests on vacant land? What proportion of native and exotic forests would be best for this country if the economy were a self-sufficient one (not based on exports)?*

4. *If you can find some similar data for another endangered environment, calculate its contribution and net energy in the same way. If possible, distribute your discoveries to help decisions concerning the area.*

5. *If 9000 years and 10,000 ha were required to develop the organisation of a forest ecosystem, how much solar energy was required? How many coal equivalents? If there is only one tract of such forest left, what is its replacement energy requirement? Using an energy/dollar ratio, estimate the dollar equivalent of the work.*

22: Using a Model to Simulate the Future

Our current human system runs on a mixture of renewable resources (like sunlight and wood) and non-renewable resources (like petroleum and copper). Our economic system uses these resources and converts them to materials that have financial value, called assets.

22.1 THE NEW ZEALAND MODEL

We have developed a simple model (Figure 22.1) that relates supplies of renewable and non-renewable energy available to New Zealand, to the quantity of assets available to our human society. Starting with New Zealand data for 1977 - fuel reserves, rate of use, rate of natural energy input, and depreciation - we will calculate and plot the changes in dollars of assets in ten year intervals of the whole economy. By running this model into the future, we have a basis for making some predictions about what the future holds for our economic system. From inspecting the diagram, what do you predict will be the shape of the graph?

If you have access to a computer, we suggest that you use Figure 22.1 and Table 22.1 to develop and run your own program. Refer back to procedures in exercise 8. If you do not have a computer available, Table 22.1 is set up for a hand-simulation. Whether or not you use a comput-

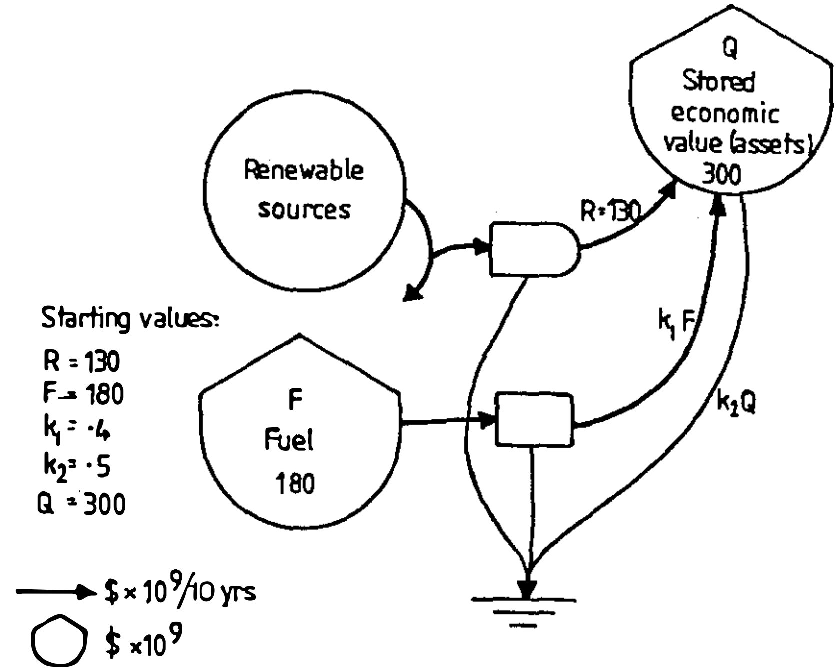


Figure 22.1 Model for simulation. Flows and storages are energy expressed as dollars of value generated. Time is in ten year intervals.

er, you will need to know what the various quantities in the model are:

Q is the dollar-value of the assets available to New Zealand's society.

R is the steady flow of renewable energies, in dollars.

F is the dollar-value of the non-renewable energy in storage.

K_2Q is the dollar-value of the depreciation of assets in storage.

All quantities have been converted to 10^9 dollars for storages, and 10^9 dollars per ten years for flows.

22.2 RUNNING THE MODEL INTO THE FUTURE

Some advice for computer programmers:

Set the starting values for each of the quantities;

Set time at the start to 0 (i.e. T = Ø);

Table 22.1

Data for Model in Figure 22.1

Time (T) T = T + 10	Renewable sources (R)	Production from fuel (K_1F) $K_1 = .4$	Fuel (F) $F = F - K_1F$	Depreciation (K_2Q) $K_2 = .5$	Stored economic value (Assets, Q) $Q = Q + R + K_1F - K_2Q$
0-1977	130	180			300
10-1987	130	.4 x 180 = 72	180 - 72 = 108	.5 x 300 = 150	300 + 130 + 72 - 150 = 352
20-1997					
30-2007					
40-2017					
50-2027					
60-2037					
70-2047					
80-2057					
90-2067					
100-2077					
110-2087					
120-2097					
130-2107					

Write the statements for the operations that must be carried out (i.e. $F = F - K_1*F$);

Include a PRINT or PLOT statement for T and Q;

Advance the time (i.e. T = T + 10);

Include a statement to repeat the calculation (i.e. IF T< 15Ø GO TO 1ØØ);

Some advice for hand-simulators:

Copy Table 22.1;

The calculations that you must perform are shown at the head of each column;

Work across, completing each line before starting the next;

The first line has been completed, as an example.

ACTIVITIES

1. *Continue the hand simulation until you have data for 130 years. Use calculators if available.*

2. *Draw a graph putting time on the x-axis and changes in assets on the y-axis. Then use the graph to answer the remaining questions.*

3. *Does the shape of the graph agree with your prediction? Which of the models in exercises 6 and 7 does it resemble?*

4. *Consider this as a predictive model of New Zealand's future. What proportion of the highest assets are those of the steady state? (i.e. by how much will people have to cut their standard of living (energy per person) when we are living only on the renewable resources?)*

   What proportion of this year's assets are the steady state assets, i.e. by how much will the standard of living drop?

5. *What will be the approximate date of the peak of growth? When will the economy hit a steady state?*

6. *Do you think that this mini-model correctly predicts the economic future of New Zealand? If you think it does, might it also predict the economic future of the world?*

7. *This model assumes no major new energy sources become available. If new non-renewable sources became available, how would the curve be affected? How would the curve be affected if new renewable sources were developed?*

8. *To obtain detailed data on a two-year basis for the next thirty years, change the values for calculation to:*

   $R = 26$

   $F = 180$

   $K_1 = .08$

   $K_2 = .1$

   $Q = 300$

   This will give you data more predictive of the near future. Draw a graph in the same way. (This will differ from the original graph because of the way the calculations are made.)

9. *Assume that the population of New Zealand continues to increase. Calculate the assets available per person at 20-year intervals during your anticipated lifetime.*

   (a) *Copy and complete the table below.*

   (b) *Write a paragraph describing changes in your lifestyle that you would anticipate, should your analysis of this issue prove to be substantially correct.*

Year	*Population projection x 10^6 people*	*Total assets* \$ x. 10^9*	*Assets per person*
1977	*3.1*		
1997	*3.8*		
2017	*4.0*		
2037	*4.1*		
2057	*4.2*		

*See Table 22.3

Table 22.2

Computer Program for Model in Figure 22.1

Statements	Explanation
10 Q = 300) 20 K_1 = .4) 30 K_2 = .5) 40 R = 130) 50 F = 180)	These give initial conditions and co-efficient values from the diagram.
100 PRINT T, F, Q	Omit if plotting
110 PLOT 29, 18) 120 PLOT 2, T/1.2, F/5, 255) 130 PLOT 29, 23) 140 PLOT 2, T/1.2, Q/3, 255)	Omit if printing
150 DT = -K_1*F) 160 DQ = R + K_1*F - K_2*Q)	These calculate the changes
170 F = F + DF) 180 IF F<0 THEN F = 0) 190 Q = Q + DQ) 200 IF Q<0 THEN Q = 0)	These calculate F and Q for the next time interval.
210 T = T + 10 220 IF T< 150 GO TO 100 300 END	

The program is specifically written for a Compucolor micro-computer, but the "Basic" is similar for other computers.

In the plot routine time is divided by 1.2 so as to space 150 years evenly over the Compucolor screen which is 127 points wide. Similarly F and Q are scaled to fit the screen.

Table 22.3

Completed Calculations for Table 22.1

Time	R	K_1F	F = F - K_1F	K_2Q	Q = Q + R + K_1F - K_2Q
		K_1 = .4		K_2 = .5	
0-1977	300		180		300
10-1987	130	.4 x 180 = 72	180 - 72 = 108	.5 x 300 = 150	300 + 130 + 72 - 150 = 352
20-1997	130	.4 x 108 = 43	108 - 43 = 65	.5 x 352 = 176	352 + 130 + 43 - 176 = 349
30-2007	130	.4 x 65 = 26	65 - 26 = 39	.5 x 349 = 175	349 + 130 + 26 - 175 = 330
40-2017	130	.4 x 39 = 16	39 - 16 = 23	.5 x 330 = 165	330 + 130 + 16 - 165 = 311
50-2027	130	.4 x 23 = 9	23 - 9 = 14	.5 x 311 = 156	311 + 130 + 9 - 156 = 294
60-2037	130	.4 x 14 = 6	14 - 6 = 8	.5 x 294 = 147	294 + 130 + 6 - 147 = 283
70-2047	130	.4 x 8 = 3	8 - 3 = 5	.5 x 283 = 142	283 + 130 + 3 - 142 = 274
80-2057	130	.4 x 5 = 2	5 - 2 = 3	.5 x 174 = 137	274 + 130 + 2 - 137 = 269
90-2067	130	.4 x 3 = 1	3 - 1 = 2	.5 x 269 = 135	269 + 130 + 1 - 135 = 265
100-2077	130	.4 x 2 = 1	2 - 1 = 1	.5 x 265 = 133	265 + 130 + 1 - 133 = 263
110-2087	130	.4 x 1 = 0	1 - 0 = 1	.5 x 263 = 132	263 + 130 + 0 - 132 = 261
120-2097	130	.4 x 1 = 0	1 - 0 = 1	.5 x 261 = 131	261 + 130 + 0 - 131 = 260
130-2107	130	.4 x 1 = 0	1 - 0 = 1	.5 x 260 = 130	260 + 130 + 0 - 130 = 260

23: The New Zealand System

People who enjoy jig-saw puzzles will probably like this section, because we are going to put one together. In previous sections we have introduced the various components of the New Zealand system. Now we will assemble these to form a model of New Zealand as a system. This *aggregated* model will allow us to make some comments about the current state of the economy and to extend our discussion of how New Zealand might develop in the future.

23.1 THE FIRST OVERVIEW MODEL

The first overview model is Figure 23.1. All the flows in New Zealand have been combined, or aggregated into three sectors: the *natural environmental resources* of land, mountains, waters, and vegetation, including coal and gas reserves; the *yield systems* of agriculture, fisheries, and forestry; and the *human sector* with its urban, industrial, and commercial components. Outside energy sources have been combined into renewable sun, rain, wind, and geological uplift; non-renewable imported fuels; and imported goods and services. Figure 23.1 also shows the energy flowing out of New Zealand in exports and waste heat.

The environment is used by the human sector to provide clean air, land, water, sunshine, wind to blow away smoke from industry, rivers to carry away wastes, geothermal power, and hydro-electricity. Because there is almost no feed-back of service from the human sector to the natural environment, its production is gradually being run down. For example, hydro-electric power dams divert the energy of swift flowing rivers away from the production of sediments (which build soils) to the production of electricity. Consequently, soil-building is reduced. Resources such as coal and gas are also mined from the environment with no replacement.

The production yield from agriculture, forestry, and fisheries is consumed by the cities. There are inflows to the yield sector from the environment (land, soil, and nutrients) and from the human sector (fertiliser, pesticides, and labour).

An example of flows from the environment to the yield sector is phosphorus which is a critical nutrient element needed for agriculture. It is now added as fertiliser made in the human industrial sector from imported phosphate rock. The phosphate rock was concentrated from the sea by fish-eating birds, in nesting colonies, releasing wastes (guano). When phosphate rock becomes unavailable or too expensive, agriculture will have to depend on the natural phosphate-concentrating processes, like those of native forests which slowly concentrate phosphorus from rain and weathering of rocks. Land can be allowed to go into native forests to renew the soil nutrients, be rotated to agriculture or yield forestry, and then back to native forest when soils again become depleted. This will be like the shifting agriculture of pre-industrial times. However, at present, there is enough phosphate rock for at least another 10 - 20 years at present rates of use.

In Figure 23.1 we have also added the money flows. In Figure 18.5 we showed how money flows to all the sectors in the economy, but in Figure 23.1 we show only the basic outline of the money flows across the borders between one sector and another. Money is shown coming in as payment for exports, circulating through the economy, and going out to pay for imported fuels and goods. Notice that slightly more money is spent for imports than is received from exports. This is said to be a poor balance of payments. The resulting deficit increases inflation, whether it is paid by borrowing or by devaluing the dollar.

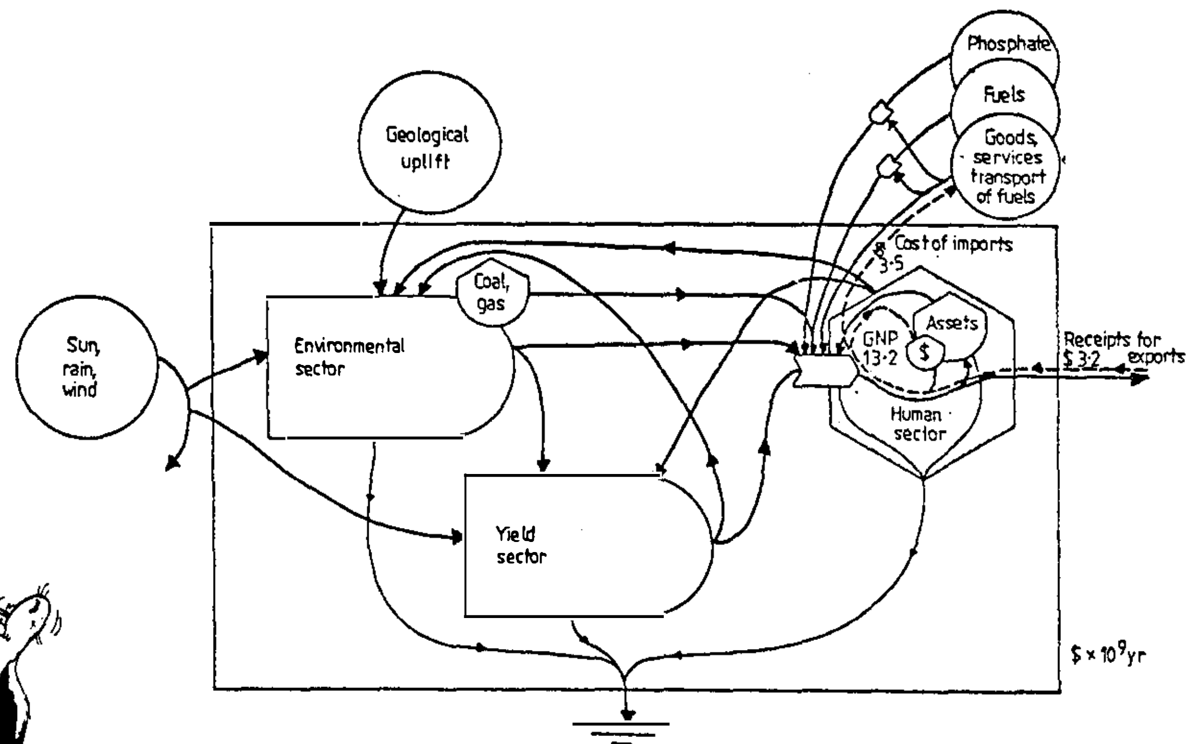


Figure 23.1 New Zealand money flows of imports, exports and GNP (1977).

When you compare the total money circulating within the economy (the Gross National Product or GNP) with international trade, you see that international trade is more than 25% of New Zealand's economic activity. This proportion is larger than for most developed countries. In the U.S.A., for example, the corresponding figure is around 10%. A figure of 25% is more typical of the economic systems of Third World countries.

23.2 THE SECOND OVERVIEW MODEL

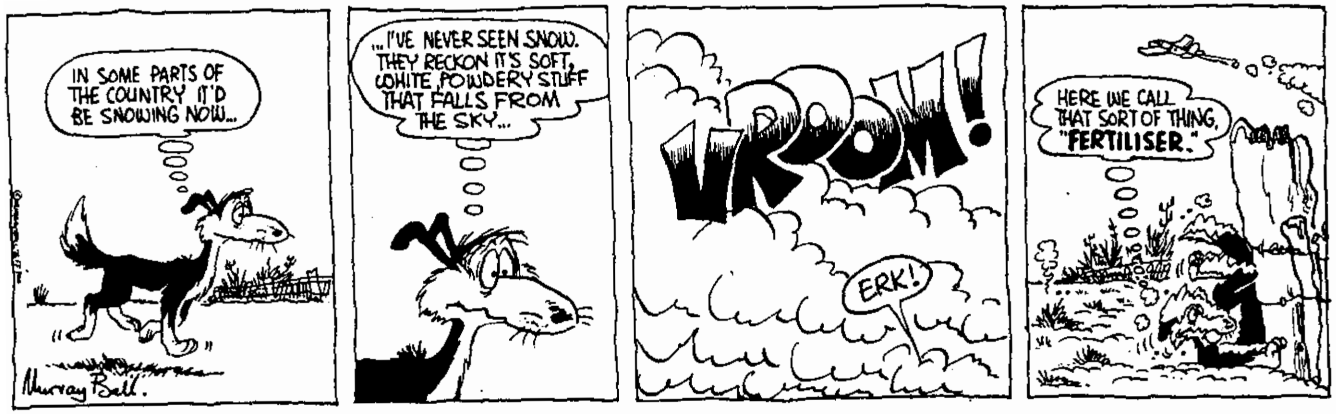
In Figure 23.3, flows of energy (in coal equivalents per year) have been written on the pathways to answer other questions about the New Zealand economy. For example, how much of the economy is based on non-renewable energy sources? Renewable sources are sun, rain, wind, uplift, tides, waves etc., and hydro-electric plants that get their power from the mountains, glaciers, and rain - 2712 CE-PJ per year. The non-renewable energy sources are the internal sources of gas and coal, and the imported fuels and phosphate - a total of 898 PJ per year. At present, therefore, more than one-third of the economy runs on non-renewable energies. As non-renewable sources become used up, the New Zealand economy may decrease down to a steady state supported by the energy available from renewable sources alone, as you have already discovered in Exercise 22. However, since New Zealand has the potential for a considerable expansion of our present hydro and geothermal electricity generation, we will be able to have a higher standard of living than those nations without volcanoes, mountains, oceans and good rainfalls.

23.3 ENERGY RELATIONSHIPS IN INTERNATIONAL TRADE

What are the energy relationships in international trade? The imports of fuels and phosphate, their transport, goods and services per year, total 1011 CE-PJ; the coal equivalents of exports is 2014 PJ. Commodities like meat, dairy products, wool, hides, fruits, vegetables, and wood products use more energy in their development than is represented by money received. They contain the work of many direct environmental inputs. By using them at home, their net energy could stimulate the New Zealand economy. By doing more processing and then exporting manufactured goods, fewer goods and services would need to be imported. Our exported raw wool now stimulates industries in Japan and England, which sell finished wool goods to us. The more we make jerseys, carpets, and other finished goods here, the more *our* economy will be stimulated.

23.4 THE AGGREGATED MODEL

Finally let's put it all together. Figure 23.3 is a more detailed diagram of the New Zealand system. The various component parts that we have introduced separately are aggregated in this diagram. The renewable outside energy sources are shown coming from the action of solar energy in driving the atmosphere and oceans. The total renewable energies include 948 PJ-CE falling directly on New Zealand and 1764 PJ-CE of sunlight elsewhere. The outside energy sources include tide, waves, and fish which flow into the fishing industry. Phosphate and other raw materials are shown being imported. People come in and out carrying dollars with them. The human sector shows the production and feedback of its many parts.



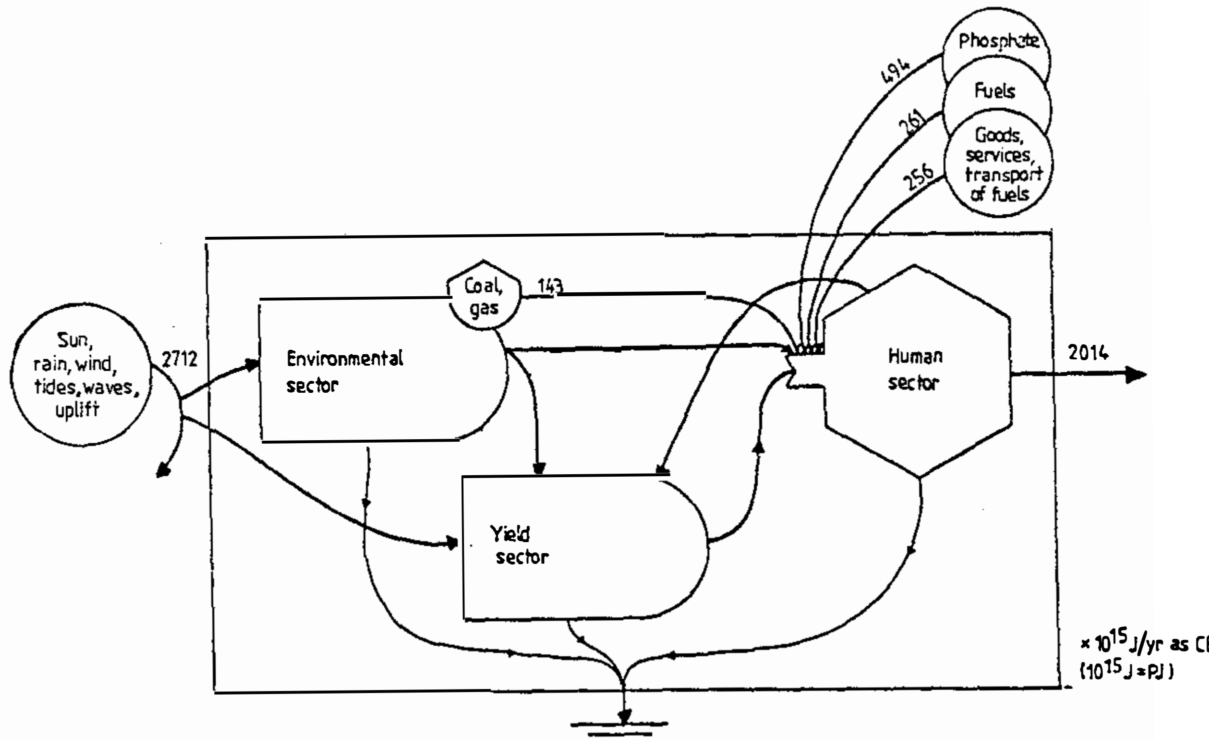


Figure 23.2 New Zealand energy flows in coal equivalent joules.

ACTIVITIES

1. *List in detail and discuss two of the following flows: (Figure 23.2)*

   a. *environmental sector to the human sector,*
   b. *environmental sector to the yield sector,*
   c. *human sector to the yield sector,*
   d. *yield sector to the human sector,*
   e. *feedbacks from the human sector which could help keep the environmental sector from deteriorating,*
   f. *feedbacks necessary from the yield sector to keep the environmental sector from deteriorating.*

2. *Find an article in a newspaper or magazine containing suggestions about the New Zealand economy. Discuss it in relation to the analysis in this exercise: that money and energy should be used to promote more internal technological development and fewer exports of primary unprocessed products. Explain why you agree or disagree with the suggestions in the article.*

3. *Explain how the import-export deficit increases inflation. (Remember inflation is caused by an increase in amount of money flowing per unit of energy flowing.)*

4. *How do native forests renew the soil? (Refer to exercises on forests, especially 13 and 14.) What nutrients are involved?*

5. *Consider the human sector in Figure 23.2. Pick two of the parts and show how they interact and feedback to each other.*

6. *Discuss the following controversial statement. Do you agree or disagree? Explain.*

   Government support in the form of guaranteed prices and subsidies on equipment and fertilisers, are given to the productive yield sector of the economy. These subsidies, which come from general taxes, make it possible for farmers to sell their products at prices lower than they could without the subsidies. More of the value developed from environmental work on the farms goes abroad with less received in return. If the subsidies were decreased, we might not be able to export so much meat and wool. This would be a disadvantage to the farmers in the short run, but it might encourage them to diversify into products that are saleable without subsidies, and New Zealand industries to process more farm products before export.

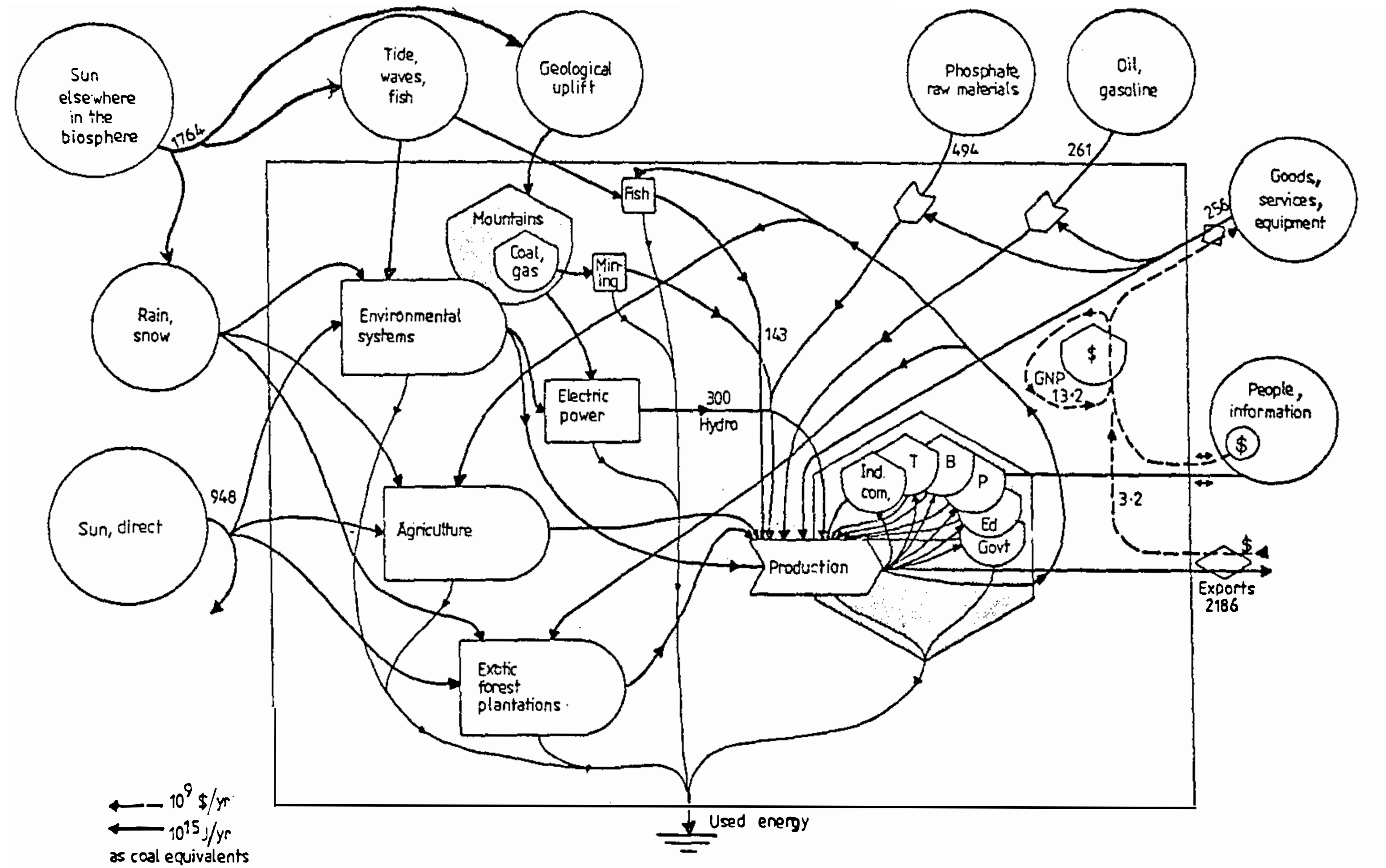


Figure 23.3 New Zealand with dollar and energy flows.

Units in human sector are: Ind.com=industry and commerce
T=Transportation, B=Buildings, P=People,
Ed=Educational Institutions, Govt=Government.

24: The Future Revisited: New Zealand's Carrying Capacity

By now you understand well the way in which living things are totally dependent upon the energy sources available to them. You also understand that human systems are no exception to this rule. When a population's demand for energy exceeds the available supply, it first decimates the storages in its food chain, and then its numbers crash. If the species is to survive, mechanisms must develop somewhere in the system to keep the population from exceeding its resources. The average size of a population that can be supported over long periods of time is, therefore, determined by the environmental resources available and the stability with which they are transformed. The size of a population that can be supported on an area's energy sources at a given standard of energy per person is called the *carrying capacity* of that area.

At present, New Zealand has a population of a little over 3 million people. Some people, extrapolating past trends, predict it will rise to 4 million by the year 2000-2020, and that it may stabilise at between 4 and 5 million by, perhaps, 2040. Can New Zealand support that many people? Just what *is* the carrying capacity of New Zealand?

Table 24.1

Energy per person in different countries

Country	Population (millions)	Sunlight, fuels, and electricity used per person per year* $\times 10^{15}$ CE-J
New Zealand	3.1	375
United States	240.0	522
United Kingdom	56.0	210
Japan	114.0	209
India	626.0	31
World	4,100.0	98

*Fuels, electricity and solar energy are each expressed in coal equivalents embodied in their flows. This does not include all of the energies such as rain, wind, waves, etc.

24.1 ENERGY AND HUMAN POPULATIONS

Human populations demand more from their environment than just sufficient energy for basic sustenance. We turn any additional energy that is available into a higher *standard of living*. The standard of living of a human population can be measured by its per capita energy consumption. As Table 24.1 shows, the developed countries (including New Zealand) use about ten times as much energy per person (per year) as does India. The carrying capacity of New Zealand depends on two factors: first, the amount of energy available in the future, and second the population which develops to divide up that energy; in other words, the per capita energy consumption. Let's examine the first of these two factors.

24.2 NEW ZEALAND'S CURRENT ENERGY BUDGET

New Zealand's current energy budget is outlined in Table 24.2. It includes renewable environmental energies (like sun, rain, etc.) flowing in; non-renewable fossil fuels (both indigenous and imported) flowing in; imported materials (like phosphate rock and finished products) flowing in; and exported products flowing out. The energy flowing out must be subtracted from the energy flowing in to reveal the total quantity of energy available to our society. Estimates for these various inflows and outflows are shown. The numbers represent the embodied energy of these goods. Embodied energy is the energy required to develop or concentrate a product. For example, a piece of exported furniture carried with it a share of the environmental energies that were used by the growing forest, the energy required to harvest and transport the wood, and so on.

Notice the very high embodied energy of New Zealand's exported sheep products. In 1977 New Zealand exported sheep products and timber with an embodied energy content of 1728 petajoules, for which we received $1,100M. In the same year, we imported $513M worth of petroleum fuels, with an embodied energy of only 261 petajoules. From an energy point of view, this is a great loss.

Because our trade is based on dollar values and not on embodied energy values, we are sending more value abroad than we are receiving in return.

Table 24.2

Energy Balance Sheet for Now

		10^{15}CE J/yr*
Renewable environmental energies+	) Indirect	2496
	) Hydro-electricity	200
	) Geothermal electricity	16
Natural gas		30
Coal and lignite		38
Imported fuel		261
Imported phosphate		494
Net exported energy		-1930
Total available for use		1605

* Units are coal equivalent petajoules per year, 1977 data.

\+ Environmental energies not only include direct sunlight but the work of the sunlight over the oceans contributing to New Zealand more rain, wind, waves, and geological uplift work than is the average for other countries.

With our current pattern of exports and imports, our total energy inflow is 3535 petajoules per year; our total outflow is 1930 petajoules per year; so that our net available energy is 1605 petajoules per year. If New Zealand were to revise its terms of trade with the rest of the world, stop *exporting* so many raw products like sheep, timber and coal, and stop *importing* finished products (make our own), the result would be many additional petajoules of energy available to the New Zealand system each year. In the following energy balance sheets for the future, we have assumed that New Zealand does, in fact, go in this direction.

24.3 AN ENERGY BUDGET FOR THE YEAR 2000

Meanwhile, let's return to our basic question - how many people can our likely future energy resources support? An energy budget for *now* is given in Table 24.2. Next consider the situation that may exist in your lifetime, when the available petroleum, phosphate, and natural gas are being used. An energy balance sheet for New Zealand in the year *2000* might look like this (Table 24.3).

Notice that hydro-electric generation has doubled, that geothermal electric generation has increased 2½ times, and that the amount of fuel imported has dropped substantially. However, the most significant change involves the drop, to about half, in the amount of embodied energy being exported. New Zealand, we have assumed, is becoming more self-sufficient.

Increases in hydro-electric power are made at the expense of losses in indirect environmental energy because lands are diverted from agriculture and life support. If the present large energies embodied in export balance from New Zealand are reduced, then the overall energy in use is higher. In other words, there is economic growth and the carrying capacity will have increased. If our standard of living does not increase, New Zealand could support 60% more people than at present. Alternatively, if our population does not increase, the present number of people could have a standard of living up to 60% higher than today's (Table 24.4). However, if, as seems likely, our population increases to around 4M by the year 2000, the available energy may allow a standard of living around 25% higher than the current level.

Table 24.3

Possible Energy Balance for Year 2000

		10^{15}CE-J/yr
Renewable environmental energies	) Indirect	2282
	) Hydro-electricity	400
	) Geothermal-electricity	30
Natural gas		200
Coal and lignite		300
Imported fuels		50
Imported phosphate		400
Net exported energy		-1000
Total used		2662

Table 24.4

Energy per person in N.Z. in Future Scenarios

Time	Present population 10^9CE-J/person	Rising population* 10^9CE-J/person
Present	1605PJ / 3.1M = 518	
2000	2662PJ / 3.1M = 858	2662PJ / 4M = 666
2100	2312PJ / 3.1M = 746	2312PJ / 4.5M = 514

* Based on population prediction.

Table 24.5

Possible Energy Balance for Year 2100

		10^{15}CE J/yr
Renewable environmental energies	) Indirect	2182
	) Hydro-electricity	500
	) Geothermal electricity	30
Natural gas		20
Coal and lignite		20
Imported fuels		10
Imported phosphate		50
Net exported energy		-500
Total used		2312

24.4 AN ENERGY BUDGET FOR THE YEAR 2100

Next, let's look ahead to around the year *2100* - when much of the non-renewable energies will have been used up both in New Zealand and throughout most of the world. (Table 24.5) New Zealand is then much more self-sufficient. Considerably fewer exports are necessary to buy essential needs. The total energy available is lower than in 2000 but higher than at present. Consequently, the carrying capacity may be up to 44% higher than now. If our population has stabilised by then at around 4.5m, the available energy per capita is almost the same as it is today. Our standard of living may be similar to that today, except that by then we may well have learned to "do more with less". In a low energy world, New Zealand may well be a most favoured nation. The nature of life, however, will be very different, as we explore in the next exercise.

ACTIVITIES

1. *Estimate how much land is necessary for your personal carrying capacity (area of New Zealand, 269 x 10^3 km^2; population, 3.1 x 10^6).*

2. *What is the carrying capacity of sheep on paddocks that are receiving purchased inputs from the economy? What is the carrying capacity without receiving inputs from the economy? (Hint: find out from an agriculturist what their stocking rate is with fertiliser and without fertiliser.)*

3. *What happened to the introduced rabbits at the turn of the century when they were most abundant in New Zealand? What does this tell you about carrying capacity? What is their situation now?*

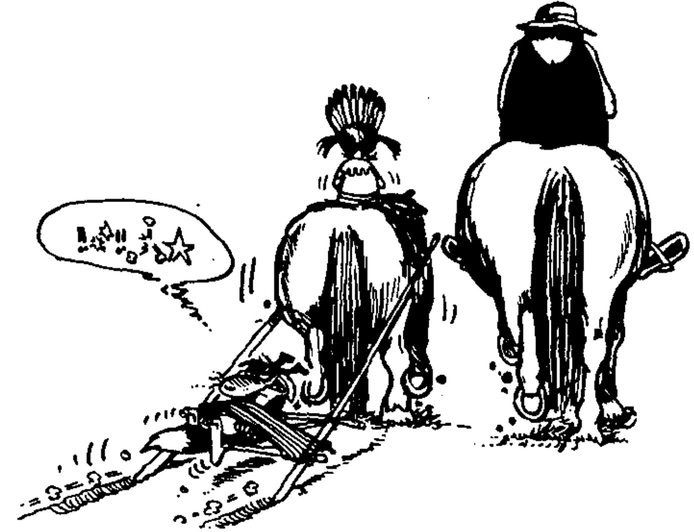
4. *Based on Figure 24.1, what percentage of the useful work derived from flows of energy in New Zealand would be stopped if imports of phosphorus were cut off?*

5. *Considering the data on energy per person in Table 24.1, in which direction do you think migration is most likely?*

6. *Discuss the idea of equality of people in the world community and the present pattern of energy flow. How do your conclusions relate to New Zealand?*

7. *In considering international trade, explain the difference between balance of payments of money and the energy flows they pay for.*

25: Epilogue: the Lower Energy World



Our current human systems are running on massive inputs of non-renewable energies. World populations have been growing excessively compared to available resources, with many countries experiencing a low standard of living.

We know that the non-renewable fuels that sustain our current systems must eventually run out, although the exact fuel reserves remaining and the timing of their depletion is unclear. And when they do run out, we must either support a large human population with the much smaller quantities of energy likely to be available from renewable sources, or populations must decrease, perhaps catastrophically. Thus, we face a *transition* from our current high-energy, high-growth world with unequal division of resources between societies, to a low-energy, steady state world of more equal societies, supported by renewable resources alone.

25.1 TRANSITION SCENARIOS

In New Zealand this may mean a higher standard of living (energy per person) than in many countries, because of the rich renewable resources of sun, rain, and mountains - combined with low population. How might this transition come about? There are several possible ways. Figure 25.1 illustrates these possibilities.

In the first scenario (Figure 25.1(a)) there is rapid, unlimited use of the remaining non-renewable resources. We drive our cars as fast and as far as we can, cut all the remaining forests, and degrade our soils by excessive production. Consequently, there might be a short-lived boom, followed by a very painful period of disruption, while the human system re-organises, based on renewable resources, and a steady state is eventually established.

In the second scenario (Figire 25.1(b)) we imagine that some new, unlimited energy source becomes available. Armed with this unlimited energy source, we continue world growth with further extraction, consumption, and pollution, until the whole biosphere and human survival might be threatened. Fortunately, there seems little chance of a high net-energy-ratio, unlimited energy source being developed.

In scenario three (Figure 25.1c) energies go into transition activities that make sense for the future, such as developing renewable-resource, low-energy technologies. This scenario produces perhaps a small amount of further growth, followed by a slow decline to a steady state. The steady state may involve oscillations. There are several possible pathways, each depending on the degree of limitation of consumtpion of non-renewable resources, and the speed with which renewable technologies are developed.

So, two of the three scenarios that we have presented result in a transition to a steady state human system - one possibly more comfortably than the other. The second scenario, however, presents us with grave dangers.

Let's assume that we succeed in making a safe transition to a steady state society. What will it be like?

25.2 CHARACTERISTICS OF THE STEADY STATE SOCIETY

The structure of a system running only on environmental energies is shown in Figure 25.2. The energy flows are steady. If no additional money is created, the energy-dollar ratio would remain constant, and there would be no inflation. As we have less fuel and less steel, *transportation* may change - fewer planes may fly; some roads may not be repaired; trains may be used more, since they can use available electricity; more sailing ships may appear instead of fuel-burning ships.

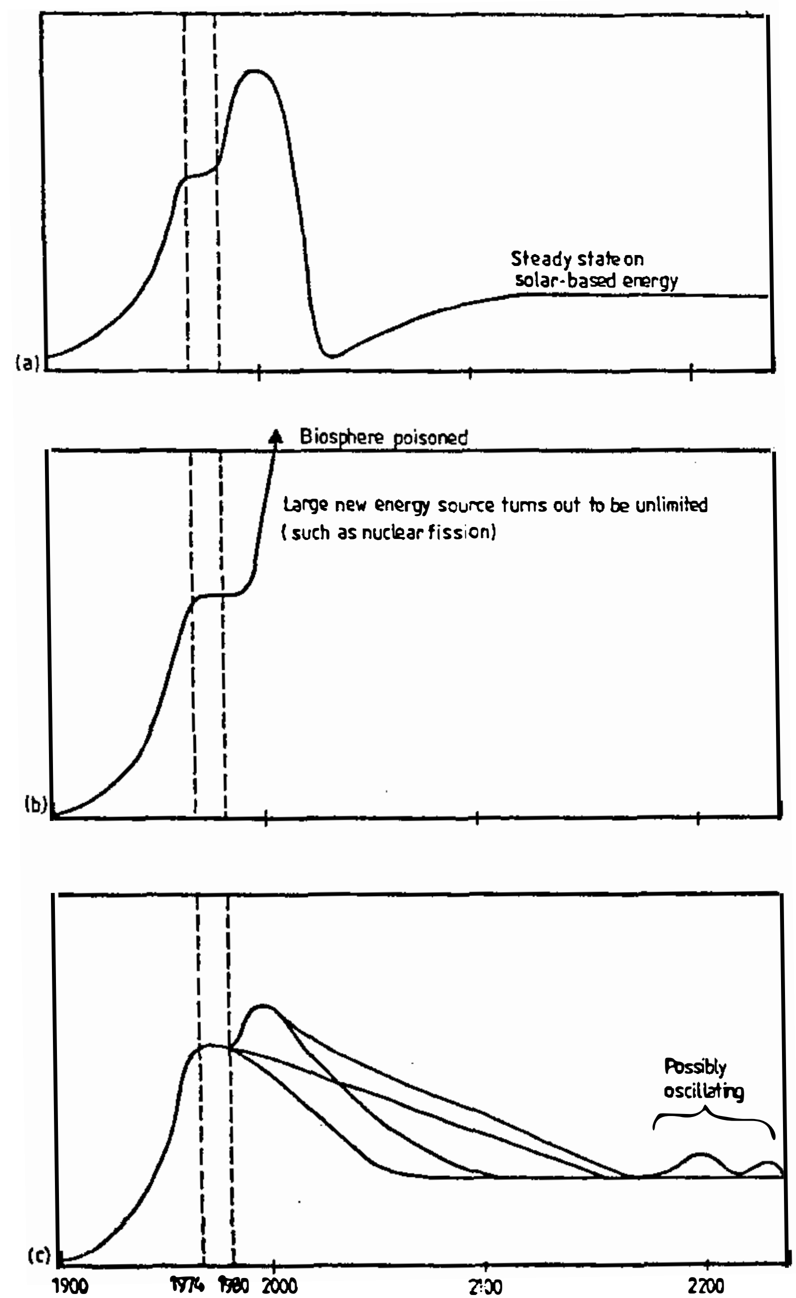


Figure 25.1 Alternative New Zealand futures
(a) Continued boom and bust on present energy sources
(b) Unlimited growth
(c) Patterns that make gradual transitions.

In *business* there may be less competition and more co-operation. In a mature natural ecosystem there is very little competition; each organism has its niche. This may also be true in a mature steady state human society. There may be less *advertising* because it is energy-intensive and less necessary with fewer new types of goods to sell. Money will still need to be borrowed for replacement, but in a *no-growth economy* there may no longer be profits from large new investments. With no new net growth, money may not make much money; the rich may not automatically get richer. There may be more pride in *efficiency* and performance. Goods may be built to last rather than with a planned obsolescence. So, we may have fewer, more durable goods. As fuels get scarce, there may be fewer machines and more people working. This may help solve the *employment* problem. People are already changing their life-styles to include making their own bread, crafting furniture, and growing their own vegetables.

A steady state means no *net* growth. In a forest at steady state, when a tree falls, new ones take its place. In a steady state economy, when a steel mill becomes obsolete, it is renovated or closed down and a new one built; the output of steel remains the same.

In human society perhaps the biggest change in going to a steady state may be in attitude - from "bigger is better" to "small is beautiful", or "moderate is modern". Change may no longer be a goal, but pride in doing the best possible. This involves a significant change in people's attitudes, because our society has been built on values of progress and growth.

Generally, a lower-energy society will *reuse* and recycle. There may be less rubbish thrown away, fewer junked cars. A windmill made of old machine parts and ingenuity may pump water at low cost, whereas a new one would not provide net energy. *Miniaturization* takes less high quality material energy while still using high quality technology - small calculators, computers, radios, cars. There may be less choice in all areas - consumer goods, jobs, vacations.

Construction may change from the building of large houses and new developments to building small houses, and repairing and remodelling old ones. Already buying a new house is impossible for most young working couples; they rent, build a house with their own labour, or buy an old house. House planning is changing to take advantage of the natural energies of trees, sun, and wind. Deciduous trees can be planted on the north to shade the house in the summer; in winter when the sun is needed for warmth, the trees shed their

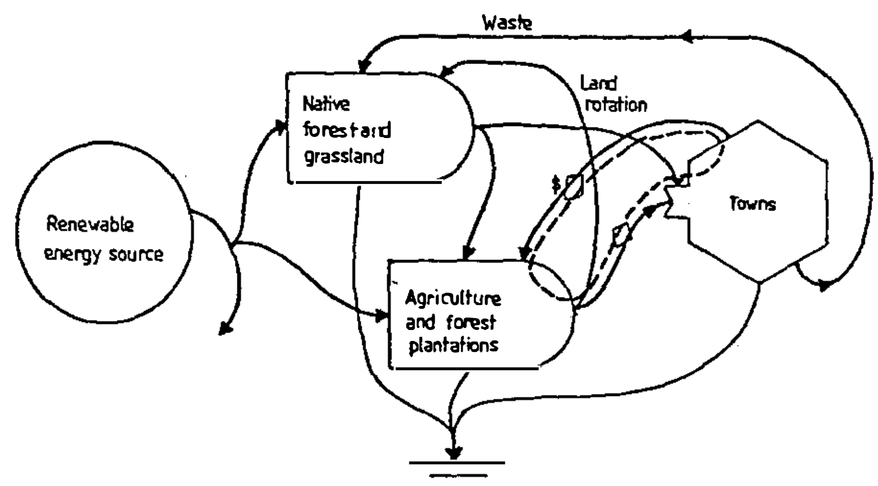


Figure 25.2 Economy run on renewable sources.

leaves. Insulation can save energy, and heat pumps use less electricity than electric resistance heaters. Lawns may be turned into gardens or tree plots, with more native and fewer energy-intensive exotics. Large projects like hydro-electric dams will be postponed; the Ministry of Works may spend more time on repair of roads than in new construction.

The power of *government* may become more local, less central. Large centralised government takes much energy for transportation, communication, and co-ordination - an example is the tremendous amount of governmental paper work. The lower-energy government may spend less on regulations and subsidies; the budget is likely to be balanced. Taxes may be less, and more of them used for local projects. Welfare services may be provided by voluntary care - less government money required. There may not be the energy for government inspections of schools, for instance, so local school boards may have greater autonomy.

Agriculture, in some areas, is already becoming less energy-intensive and more land- and labour-intensive. Farmers, especially those with small farms, are using fewer pesticides, fertilisers, and machines; they are expanding the use of land and people. The trend is toward organic gradening with more emphasis on recycling and composting. *Local production* of wool clothes may increase, as imported synthetic fibres become harder to get and more expensive.

Forestry may change from the growing of very large, energy-intensive, exotic-tree plantations to self-seeding areas with a diversity of species, which are harvested in rotation. Management may use more labour and fewer helicopters, large trucks, fertilisers, and pesticides. With expansion of the use of land for low-energy agriculture and forestry, there may not be much land available for production of alcohols for transportation.

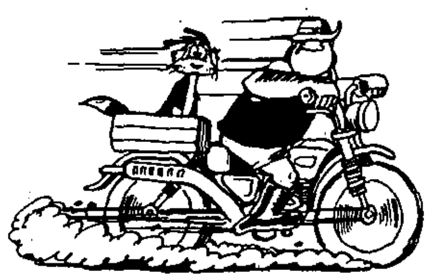
Those concerned about the *environment* can relax their worry about *pollution* in the long-run future. Most pollution is caused by concentrated burning of fossil fuels in cars and industry or their use as chemicals. These will decrease as the fuels decrease, and population concentrations will disperse. Technological anti-pollution devices may be used less, and natural recycling may increase.

With fewer national regulations, local *schools* may become more individual. Programmes may be planned to fit local needs, involving the teaching of skills needed by local industry or farming. *Universities* may become smaller with more emphasis on teaching and less on research. They may have the responsibility of storing the special knowledge developed in the last century. There may be less exchange between countries of knowledge, staff and students.

Society in lower-energy times may become more stable with smaller units of government, less moving around, and more *local control*. The trend may be that religion and social customs will decide *values* rather than laws. As people know more of their neighbours, there may be less crime and more caring. These changes are easier in the towns than in the cities. People are already moving out of the cities and suburbs. Those left in the cities may become social units, and may even start farming the vacant lots.

A growth society needed an expanding *population*, but now population growth is slowing in developed countries. *Women* are already changing from a completely child-home orientation to work in the money economy. One of the fascinating questions is the future of the *family*. Recently, with much energy and greater opportunities for women to have jobs and fewer children, the family seems to have become less stable. Soon there may be less energy for moving and new jobs, but women will probably still have few children and be in the work force. Will families become extended - with parents; one or two children, and several non-related members - living in a small house in the country with several members working in a neighbouring industry? Or will some other pattern evolve?

The lives of *individuals* will be affected by all these changes. With less pressure for progress, there may be better mental health. As technological jobs decrease, pride in work may increase. Handcrafted goods may become popular; more time may be spent on gardening for self-sufficiency.



25.3 MAKING THE TRANSITION EASIER

Although the steady state looks like a happy time, the transition may be difficult and disruptive. The biggest problem is to explain to people what is happening and why their way of life is changing so drastically, so they can plan and not be apprehensive. Education should be especially important now, to help people understand what to expect and why. If total energy goes down faster than populations decrease, and energy per person decreases, people may have to accept either lower salaries or higher unemployment.

In the transition, before people move out of the cities, pollution from the burning of coal may increase. If the world's extensive coal reserves are fully used to replace petroleum, carbon dioxide levels in the atmosphere may become a serious problem. However, coal smoke when it is dispensed from houses in rural areas, may add needed nutrients like sulphur to the land. There will be pressure to turn wilderness and forests into agricultural land without fertilisation, causing overgrazing and depletion of soils. If this becomes the pattern, the future would become like the first graph in Figure 25.1 instead of the third. Social disruptions increase in uncertain times; crime, mental distress, violence may all become worse, before they decrease as people settle into small stable communities.

You can think of many ways to ease this transition from our high-energy growth society to the lower-energy steady state. Here are several suggestions:

- Explain to friends and parents about the possible future.

- Plan your education to learn all you can about how the world functions, and also become skilled in several specific areas.
- Plan for your future employment - perhaps one job to fit in to the economy as it seems now, and flexibility for the transition and your possible lower-energy job. People may have two places of work - the city and at home on the farm.
- Decide what is really important to you.
- Consider working to obtain land.
- Plan your life-style to fit the possible futures.

ACTIVITIES

1. *Try a week of a diet with small amounts of protein (i.e. ¼kg high quality meat) and no packaged foods. Think of other ways to experience the lower-energy world and try them.*

2. *The steady state can be defined as a system in which energy inflows equal energy outflows. Give examples from the physical world, ecosystems, and early human societies. What are the inflows and outflows in each example?*

3. *What do you think the lower-energy steady state will be like for you? What will you miss most from your present life? What least?*

4. *What sort of retraining should be given to New Zealanders to prepare them for the lower-energy life? How should formal schooling be changed.*

5. *Collect pictures of low-energy and high-energy activities, and make a collage of each. Be prepared to use them to explain your ideas about the changes to the class.*

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