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Resources of the Sea

THE SEA AND ITS RESOURCES AS AN ECOSYSTEM

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(with four text-figures)

ABSTRACT

Energy from the sun is transferred via marine plants, marine herbivores to primary and secondary carnivores and even man himself with some loss of energy at each stage. Inorganic materials from sea water are extracted and returned during this sequence of processes. Some data suggests that open oceans are only about twice as productive as deserts and that continental shelves are about ten times as productive. Coral reefs and estuaries may be as much as forty times as productive.

The interrelationships between changes in current patterns, fish, birds and man in the case of the Peruvian anchovy underlines the interdependence of various components in marine systems.

INTRODUCTION

Many people consider the science of ecology to be a relatively modern development resulting from the invasion of natural history by the mathematically more facile.

Ecology may be defined as the study of the interrelations of organisms or groups of organisms with each other and with the abiotic environment around them. These abiotic factors may be such variables as temperature, light, the amount of various nutrients, while the interrelations between organisms relate to who eats whom, who hides in what for protection, and other such important realities of day-to-day existence.

Odum (1959) notes that the German biologist, Ernst Haeckel, first proposed the use of the word 'ecology' in 1869, and Warren (1971) credits Tansley as being the first, in 1935, to define the term 'ecosystem' as it is now generally used. Warren further draws attention to Lindeman's (1942) paper, "The trophic-dynamic concept of ecology", as the first to elucidate the importance of nutrient cycles and energy transfers in ecological systems. Systems analysis and mathematical modelling techniques are, however, more recent additions to the range of tools available to the ecologist and they are being used increasingly in many ecological investigations varying from studies of specific aspects of the physiology of an animal to those of large-scale systems (e.g. Watt 1966).

A GENERALISED BIOLOGICAL SYSTEM

An analysis of the components of a generalised ecosystem must start with the input from the basic energy source, the sun. Energy and simple inorganic materials, the natural fertilizers, are utilised by plants possessing chlorophyll to produce the complex building-blocks of life. These the primary producers, then form the feedstock for the herbivores which use the energy stored in the plant tissues to synthesise animal tissue. In turn, the primary and secondary carnivores convert and transmit the energy first trapped by the green plants up the food web until a small part of it may be converted into the animal tissues of man himself. Each successive stage in a food chain or web is termed a trophic level from which there is a cycling of some energy back to the environment so that the longer the food chain the smaller the proportion of the original input to end up at the final level. The recycling of this energy and the basic inorganic materials is accomplished by the excretion of waste materials from the organisms at each of the trophic levels, and by those that escape predation or harvesting being broken down to complex organic materials by death and decay. The whole process, the building up and transfer of energy and materials and the losses and consequent recycling from the various trophic levels of the food web, can be described in terms of the laws of thermodynamics as energy transfers and conversions are the basic mechanisms of all natural systems.

A GENERAL MARINE SYSTEM

The primary producers of the seas are the pelagic plants, the phytoplankton and the benthic forms that constitute the micro-phytobenthos or bottom dwelling single celled plants, and the large algae. The chlorophyll bearing plants survive only in the photic zone which is limited to the top two hundred metres of the sea. Both groups of plants support grazing animals, which in the case of the plankton of coastal waters are mainly small crustaceans, while those of the benthic flora are largely mollusca and echinoderms and a few fish species.

In the marine environment, as with some terrestrial systems, another link of great importance is the detrital system which is based largely on the break-up of the macroalgae and to a lesser extent on the loss of cells from the phytoplankton. This detritus from the plant world is consumed by a whole range of animals with specially adapted mouth parts or other feeding mechanisms to enable them to utilise this particular food source. Typical examples of detrital feeders are to be found in most coastal environments; many of the shellfish that live buried in the beaches feed by 'vacuuming' detrital material with their elongate siphons. On death zooplanktonic organisms also rain down on the bottom living fauna and contribute their remains to the detrital cycle. Bacteria and fungi act on the material as it passes through the physical environment and may, if the detrital material gets harvested, enhance the meal or it may finally complete the breakdown process to return the basic building-blocks to the environment and in both cases complete the feed-back loop.

Carnivores are well represented in a typical marine system by both planktonic and benthic forms. In the holoplankton, the forms that spend their full life-cycle in the plankton, crustacea and arrow worms are supplemented by the transient plankton, or meroplankton, that are the larval stages of many benthic and pelagic animals. The first hours of larval life are crucial for most forms as they are particularly specific in their food requirements at that stage; if the prey species is not present in sufficient numbers, or the environment has favoured the growth of the prey species more than that of the predator the latter may not be able to ingest its food; both cases will give rise to massive deaths which, if the species is of commercial significance, will give rise in subsequent years to lean catches for the fishermen. Predators at a higher level in the food web of the groups most important to man such as fish, birds, and mammals are important in marine systems as are many molluscs and marine annelids that are of no direct consequence to man.

Productivity of ecosystems can be measured in many ways but the usual method of expressing the values is as grams of organic dry matter per unit time. Odum (1959) presents data suggesting that open oceans are only about twice as productive as deserts while continental shelf waters, at up to 5 grams per square metre per day which is similar to most forms of agriculture, are around ten times as productive. Coral reefs, many estuaries and intensive agriculture may produce up to 20 units and the maximum rates that may be maintained for short periods in both natural and cultivated ecosystems can attain some 60 units.

In terms of the ecosystem approach to the marine environment, man can be considered as a top-level predator. In many situations he is competing directly with birds, sometimes with marine mammals and often with fish for a share of a fishery resource. He has to fight the elements but has a greater degree of independence from the perturbations of the physico-chemical elements of the environment than do the stocks he seeks to exploit, and from those of the populations of his competitors. The latter may well be depressed by the same set of conditions that reduce the stocks of a fishery, thus relieving predation pressure on that population when it is in a highly stressed condition. Man, however, rarely has this information feedback from the environment and will tend to press on with his fishing in expectation that the catch will be bigger and better than the last years haul; a situation that has often given rise to 'over-fishing' of the stocks.

Each advance in technology that man develops allows him to become a more efficient catcher of fish, when measured in terms of tons of fish per dollar of expenditure, but it has yet to be developed fully in the area of sensing the status of both the exploited stocks and of their environment. Once this is achieved then an essential feed-back loop will have been established that will enable man to become more efficient in terms of the energy expended in fishing the resource compared with the recovery of energy represented by the catch.

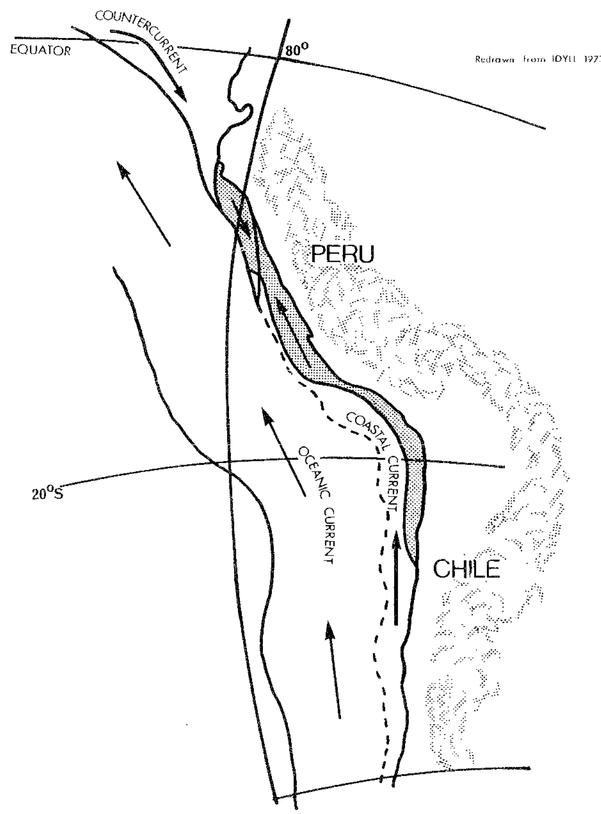

FIG. 36. - Sketch of the current systems of the western South American coast showing the distribution of the Peruvian Anchovy (*Engraulis ringens*) marked by the stippled area.

Another important feed-back loop between man and his ecosystem is the recycling of the waste products of his technological society. The disposal of sewage from large conurbations poses a problem as it is often discharged in vast quantities at a few locations and causes an over-loading of the natural systems in a limited area. In the last few decades this problem has been exacerbated by the presence of toxic materials that can poison natural systems either acutely when present at high levels, or chronically if the materials are accumulated by elements of the biota. Here again man has yet to pursue the development of his technology to the state where it fully utilises the dimensions of the natural systems and yet does not have long term effects that are counter-productive.

At this stage it is useful to turn to the consideration of a contemporary example of the interaction of a natural perturbation in evironmental conditions and an increasing exploitation of a fishery resource.

THE PERUVIAN ANCHOVY FISHERY

The dry western seaboard of South America has a current system (fig. 36) first described by von Humboldt after his visit there in 1803. It is a complex system composed of two north-flowing and two south-flowing streams. The oceanic current, some several hundred kilometres wide and up to 700 metres in depth, lies offshore and flows from the Southern Ocean to the equatorial region through some 40 degrees of latitude. Hugging the coast and also moving northwards is a weak, slow-moving body of water called the Coastal Current which varies in width and speed from season to season. Both currents are made up of cold nutrient-rich waters brought up from the deep oceans by the action of the south and south-east Trades that are the prevailing winds in the region. The resulting offshore surface-drift pulls up the high salinity, nutrient-rich water to form one of the major upwelling regions of the world. The high nutrient levels support such a massive development of phytoplankton that the amount of carbon fixed by photosynthetic activity ranges between 45 and 200 milligrams per cubic metre of water per day compared with 15 milligrams in the waters immediately adjacent (Idyll 1973).

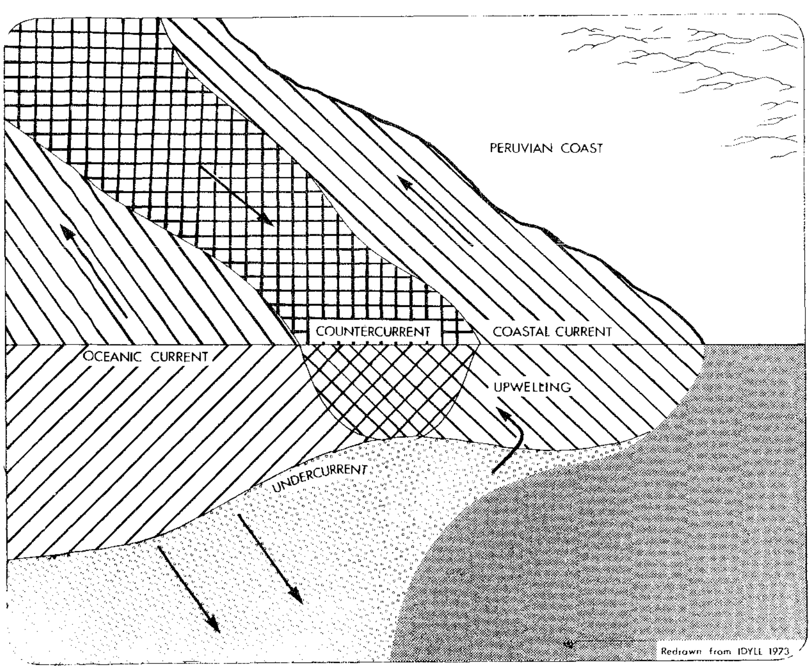

FIG. 37. - Cross section of the western South American coast to show the generalised structure of the currents.

The south-flowing streams are the deep Undercurrent that travel below the cold north-flowing currents described above and a surface (fig. 37) Counter Current originating in the equatorial regions. Normally the Counter Current does not penetrate far to the south, but in some seasons westerly winds slow down the Coastal Current and push the warmer, low-salinity and low-nutrient Counter Current to the south. This change, which usually begins around Christmas, is known to the Peruvians as *El Nino*, or the 'Christ Child', and it heralds a major disruption of the anchovy fishery.

The Peruvian anchovy *Engraulis ringens* is distributed within the Coastal Current between latitudes of 5° and 25° south. Spawning occurs throughout the year but with a pronounced peak in August-September and a lesser peak in January-February. The fish spawn about the end of their first year, at a length of approximately 11 centimetres and weighing some 150 milligrams, and they can produce up to 10,000 eggs; if they survive to a second spawning, at a length of about 15 centimetres (6 inches), they may produce some 20,000 eggs. Anchovy larvae have a very small yolk store, limited swimming power and a high metabolic rate, making them particularly susceptible to variations in their food source in the plankton. If environmental variables, such as light, temperature, salinity or nutrients, have deviated from normal and the preferred food items, which must be just the correct size in relation to the size of the larval mouth, are absent, present in reduced numbers, or at a different stage of development than usual, then the larval anchovy will die in massive numbers.

Just such a situation develops in an *El Nino* year. The warmer low-salinity and low-nutrient waters of the Counter Current push back the Coastal Current and cover it to a depth of up to 30 metres to produce conditions adverse to the survival of the anchovy. The fish are well tuned to the conditions of the narrow Coastal Current and they develop in enormous concentrations close to the shore of the continent. This species has evolved a life style that captures a very high proportion of the total energy available in the system and converts that energy into a biomass estimated to be of the order of 15-20 million metric tons, about 22 per cent of the tonnage caught throughout the world (Idyll 1973). In addition, before man's intervention this stock supported a high concentration of birds on the islands of the region (fig. 38).

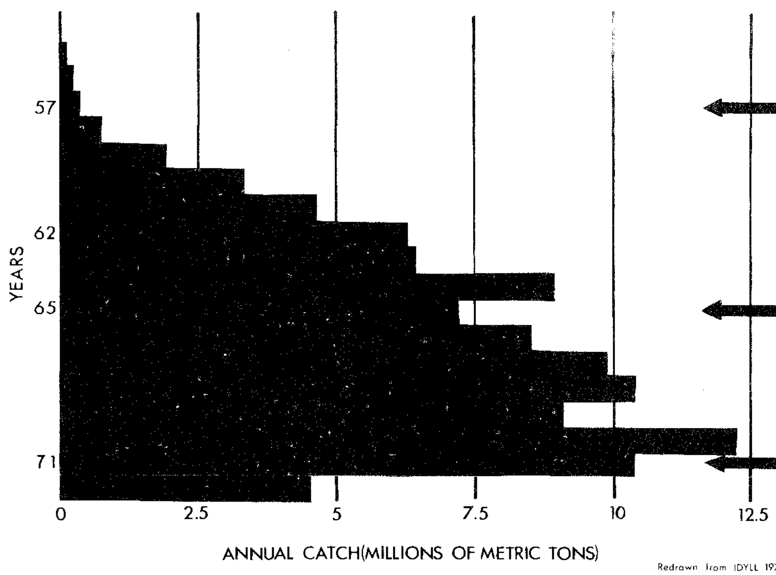

FIG. 38. - Annual catch of the Peruvian anchovy fishery for 1955-1972, in millions of metric tons, showing the occurence of *El Nino* conditions (by arrows at the right-hand side).

The guano birds, a collective name for three species, a cormorant (*Phalacrocorax bougainvillii*), the booby (*Sula variegata*) and pelican (*Pelicanus thagus*) have developed massive populations in the region; recent estimates have been as high as 30 million individuals. Between 80 and 95 per cent of the birds diet is made up of anchovies and one estimate of their food consumption, based on five million birds from a particular island, was put at 1,000 tons per day. A more recent estimate gave the average total annual consumption as 2.5 million metric tons, or about a fifth of the local commercial fishery catch (fig. 39).

In an *El Nino* year catastrophic changes are introduced into the system. The nutrient-poor waters cannot support the phytoplankton necessary to sustain the anchovy larvae, the warm low-salinity waters disturb the adult anchovy so that they disperse rather than form the massive schools close to shore. This may be a by-product of the introduction into the region of northern predators, such as the yellow-fin tuna, the dophin fish and others. Alternatively it may be that the conditions produce blooms of noxious phytoplankton species similar to the 'red tides' of Florida and these may disturb the anchovy. Associated with the noxious plankton blooms is the production of hydrogen sulphide to the extent that it blackens the paintwork of the fishermen's boats; hence the name the Peruvian fishermen give to the phenomenon is *El Pintor* (The Painter).

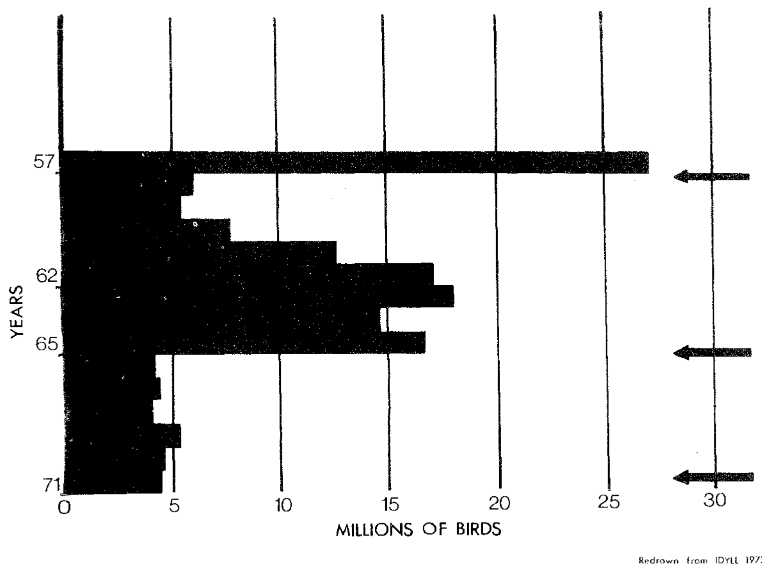

FIG. 39. - Estimated population of *guano* birds on the island off the western South American coast showing the occurrence of *El Nino* conditions (by arrows at the right-hand side).

The commercial fishery began to land its first big catches in 1957 and over the next decade it attracted large investments of capital in ships and shore plant. In 1960 the United Nations agency FAO began, with a grant from the UN Development Program, to introduce fisheries experts from around the world. An *El Nino* year was experienced in 1965 but the fishery continued to be expanded until it reached an all time high in landings of 12.3 million metric tons. Apparently the fishery biologists did not take note of the decline after the 1957 *El Nino* of guano bird populations which had dropped from an estimated 27 million to some 5.6 million by 1958-59, then recovered by 1962-63 to some 17 million, fell to 4.3 million after the 1965 event and still had not recovered by 1972. In April of that year when the fishery was only a few weeks into the season, the catches slumped and the season ended with only 4.5 million tons harvested. The catches in 1973 were again low but by now the fishery biologists were estimating the total population to be only of the order of two million metric tons compared with an estimated 20 million in 1970. In addition, estimates of recruitment have been the lowest ever observed - only some 13 per cent of the levels estimated in a 'normal' year.

The degree to which the *El Nino* in 1972, the severest ever observed, is to blame for the collapse of the fishery and the extent to which the enormous fishing pressure at a time of severe environmental stress can be said to be the cause, is still a subject for strenuous debate. Will the Peruvian fishery follow the Californian model in which the northern anchovy (*Engraulis mordax*) has replaced the sardine (*Sardinops caeruleus*)?

DISCUSSION

The example of the Peruvian anchovy fishery serves to underline the interdependence of various components of a marine system. The investigators failed to define the extent of the ecosystem that they were charged with managing and they thus did not have a full information feed-back from the totality of that system. The signs that are now evident in the population responses of the guano birds was missed because the research objectives did not recognise that they were a crucial component of the system being investigated.

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