73

7

The Functioning of the Antarctic Marine EcoSystem A Fragile Equilibrium

Gilles Billen* and Christiane Lancelot*

INTRODUCTION

While the possibility of the exploitation of Antarctic mineral resources—the resources, existence and the economic profitability of which are still far from proved—is currently provoking a heated debate, it is too often forgotten that the living resources of the Antarctic ocean have been the subject of intense exploitation for more than a century.

In the context of the current fisheries crisis, where sea catches—amounting to some 70 million tonnes per annum—have practically reached their limits in traditional fishing zones, and where numerous countries of the northern hemisphere have an excess capacity in their fishing fleets, the Antarctic fisheries could become the object of significant development.

Biological resources, renewable by their very nature, are in theory perpetually available for a form of exploitation which respects the equilibrium of the natural system which produces them. History shows, however, that his has not always been the case in the Antarctic and that man's activities have often led to the rapid depletion of stocks of the exploited resources.

The object of this chapter is to analyse the conditions for rational exploitation of the Antarctic marine ecosystem and its sensitivity to disturbances resulting from intense human activity. This analysis is based on the recent findings relating to the ecological functioning of the Antarctic marine system, which have come notably from the Belgium Programme of Scientific Research in the Antarctic.

THE APPARENT BIOLOGICAL "WEALTH" OF THE ANTARCTIC OCEAN MASKS A GREAT FRAGILITY

The ecosystem of the Antarctic ocean is characterized by the presence, at the higher levels of its food chain, of large organisms in comparison with those occupying similar levels in temperate or tropical ecosystems. Thus, krill, which is the principal herbivorous invertebrate in the Antarctic ocean, feeding on phytoplanktonic algae of 20–200 μm, reach a size of 2–6 centimetres, whereas herbivorous zooplankton of temperate marine systems rarely exceed a millimetre. The main consumers of

* Translated from the French by Philippe Sands and Emma Chown.

The Antarctic Environment and International Law (J. Verhoeven, P. Sands, M. Bruce, eds.; 1-85333-630-0; © Graham & Trotman; pub. Graham & Trotman, 1992; printed in Great Britain), pp. 39–51.

krill (Figure 7.1), birds, seals, fish, cephalopods, and rorquals, vary between 10 centimetres and 30 metres, whereas in temperate seas the size of first-order carnivores, such as herring, is only a few decimetres.

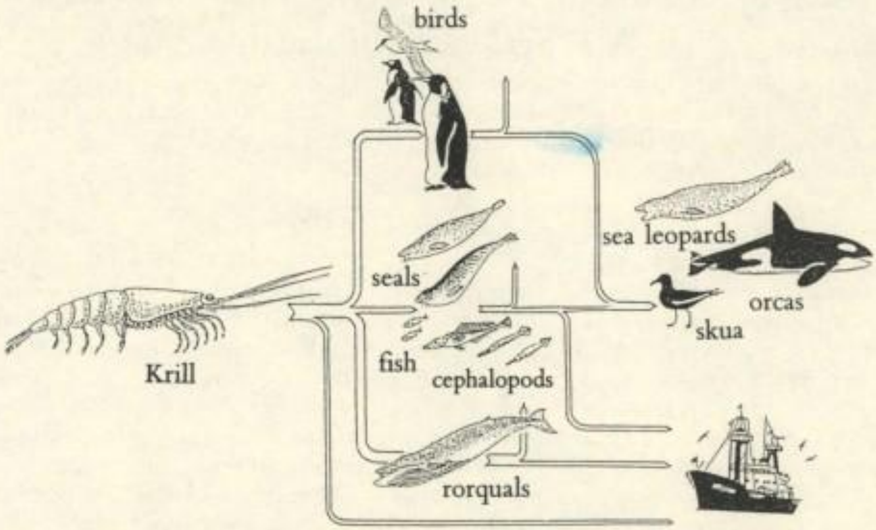

Figure7.1 The Antarctic EcoSystem

The top of the food chain in the Antarctic Ecosystem is characterized by the presence of large animals, many of which depend directly or indirectly on krill.

Moreover, the large size of these organisms is matched by their considerable abundance. Even if estimates of stocks of these animals is subject to some uncertainty, current figures show in effect a biomass which is comparable to, and sometimes well over, that found in temperate marine environments. Thus, estimates of krill stocks in the whole of the Antarctic ocean (an area of 36,000,000 square kilometres) varies depending on the author between 44 and 1,000 million tonnes[1], which represents a biomass of 100 and 2,200 mgC/m^2, compared with an estimated biomass of zooplankton in the North Sea, a system which is far richer than the average global marine environments, of 300 mgC/m^2.[2] Stocks of whales in the Antarctic ocean at the beginning of the century were estimated at about 45,000,000 tonnes, that is to say, a biomass of some 80 mgC/m^2, which is of the order of those fish stocks found in the most productive fishing zones. In the North Sea, the fish stock is estimated at 400 mgC/m.[2]

This abundance of large animals gives the impression of a great richness which very early on captured the imagination. The Antarctic ocean began to appear like

[1] G. A. Knox, "The Living resources of the Southern Ocean: a scientific overview", in F. Orrego-Vicuña (ed.), *Antarctic Resources Policy* (Cambridge University Press, 1983), pp. 21–66.

[2] G. Hannon, C. Joiris, "A seasonal analysis of the Southern North Sea ecosystem", *Ecology* (1989), 70, 345–350.

an inexhaustible reservoir of fauna. Paradoxically, however, successive periods of exploitation undertaken in the last two centuries have always resulted in the exhaustion of the resource in question within a few decades.

Thus towards the end of the eighteenth century, the hunting of seals, wanted for their fur and fat, developed in the sub-Antarctic islands. It ended within fifty years in the virtual extinction of the two most widely caught species, the fur seal and the sea elephant, from all sites which were accessible to ships at the time. It took more than a century for populations to recover. The current catches of crab, leopard, and weddell seals still amount to about 200,000 of each per annum, a biomass of 42,000 tonnes.[3]

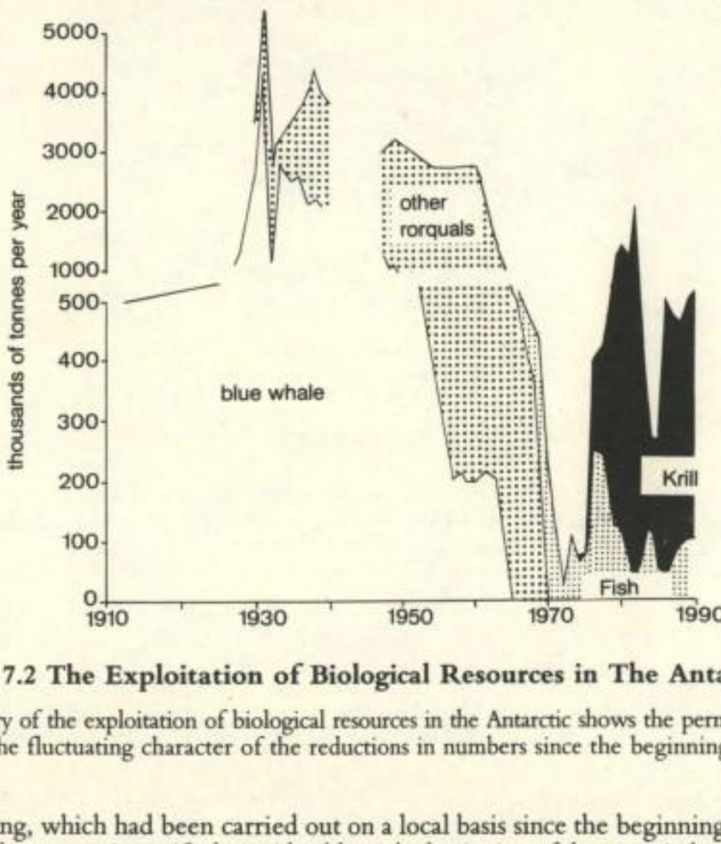

Figure 7.2 The Exploitation of Biological Resources in The Antarctic

The history of the exploitation of biological resources in the Antarctic shows the permanence but also the fluctuating character of the reductions in numbers since the beginning of the century.

Whaling, which had been carried out on a local basis since the beginning of the nineteenth century, intensified considerably at the beginning of the twentieth century, when ships were armed with cannon-harpoons. Over half the stock of rorquals at this time (45,000,000 tonnes) consisted of blue whales. This species also constituted the majority of catches (at least by tonnage) up until 1935 (Figures 7.2 and 7.3). The drastic decrease in stock, however, forced the whaling industry to turn successively towards other smaller species. Thus the common rorqual and the Rudolph rorqual were in their turn eliminated, despite various measures to regulate hunting. Nowadays, stocks of rorquals still existing in the Antarctic have been reduced to about

[3] Op cit. n.1.

7,000,000 tonnes. Antarctic whaling activity, having reached its limit, has practically stopped since the beginning of the 1970s. Today there are only three Japanese and Russian whaling ships left.

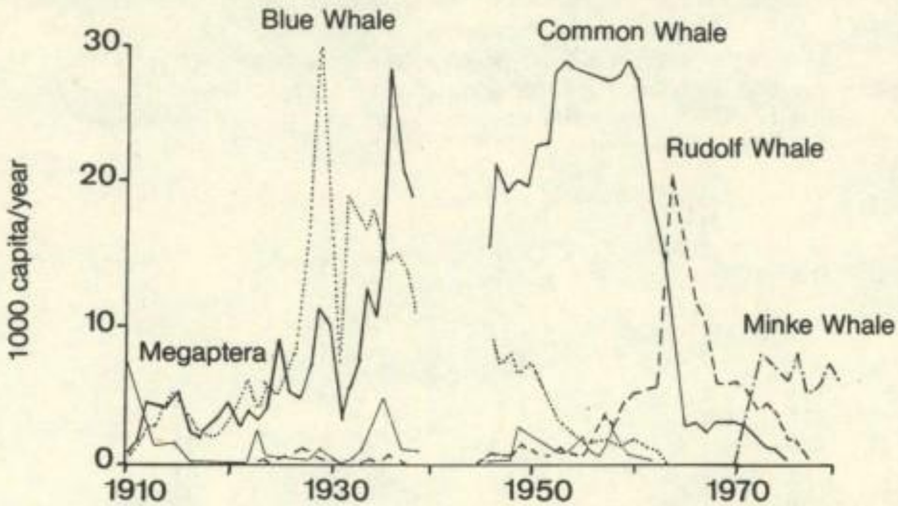

Figure 7.3 Catches of Large Cetaceans

The table relating to catches of large cetaceans in the Antarctic since the beginning of the twentieth century shows that the hunting has been aimed at a succession of different species as the stock of each has been exhausted.[4]

Commercial fishing for several species of fish, especially demersal species, developed in its turn in the 1920s. The large catches in the early years (more than 400,000 tonnes per year, in 1970, principally in South Georgia) could not be maintained beyond two seasons. In the case of fish, too, available statistics show clearly a progressive movement in fishing efforts from one species to another as the stock of each runs out (Figure 7.4). In the 1980s, keeping catches at equivalent levels to those at the beginning of the 1970s was only possible by a trebling of fishing efforts, for which the net yield was in decline (Figure 7.5).

Since 1976, krill has been the subject of significant exploitation and now constitutes the largest part of biological takings in the Antarctic, with an average of 400,000 tonnes per year (Figure 7.2). Estimates of the potential catches available vary considerably depending on the author. While the FAO has suggested a figure of 5 million tonnes per annum, others, basing themselves particularly on an estimate of the surplus made available by the reduction of predators linked to the elimination of whales, estimate that an annual taking of 100 million tonnes could be

[4] Op cit. n.1.

sustainable.[5] This would represent more than 200 times current catches and would constitute a tonnage greater than all of the traditional world fisheries together. In this context one can understand the economic stakes represented by the increase of catches in krill. Only the absence of a viable market allowing the sale of greater quantities limits such an increase for the time being.

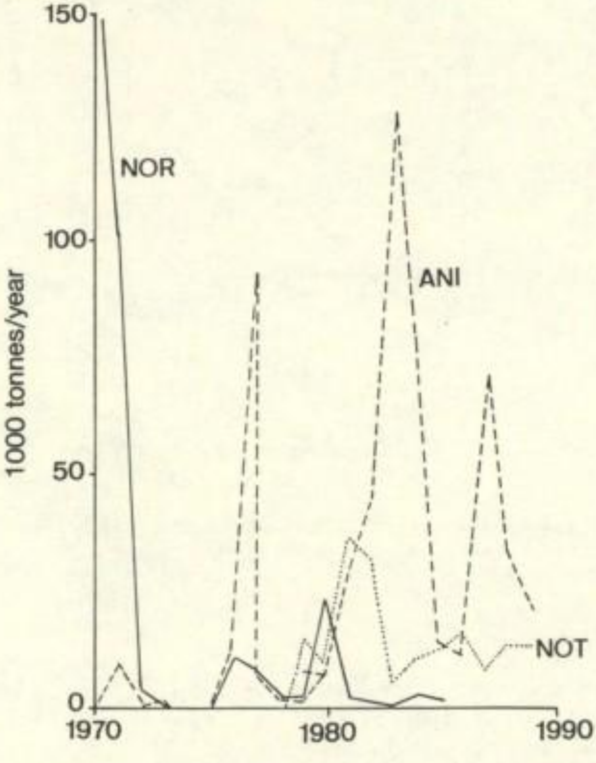

Figure 7.4 Fish Catches in South Georgia

Fish catches in South Georgia (the main fishing zone in the Antarctic) show clearly the fluctuating character of these catches, despite sustained fishing efforts, and the rapid movement from one species to another as stocks run out (NOR, Notothenia rossii; NOT, Patagonothoten brevicauda guntheri; ANI, Champsocephalus gunari).
(Source: CCAMLR 1990).[6]

[5] T. Nagata, "The implementation of the Convention on the Conservation of Antarctic Marine Living Resources: needs and problems", in F. Orrego-Vicuna (ed.), *Antarctic Resources Policy* (Cambridge University Press, 1983), pp. 119–138.

[6] CCAMLR (1990), Draft Statistical Bulletin, Vol. 2 (1980–1989), SC-CAMLR-IX/BG/2.

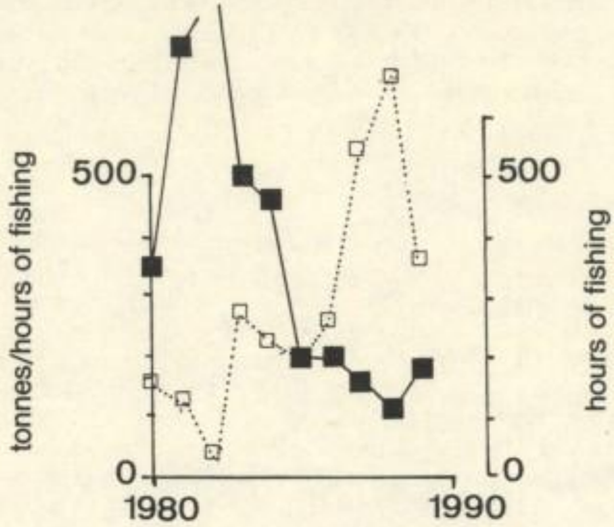

Figure 7.5 Fishing Efforts and Net Yield

During the 1980s, fishing efforts in South Georgia grew considerably (dotted line), with a decrease in the net yield (solid line), demonstrating thus the exhaustion of stocks. (Source: CCAMLR 1990).[6]

However, research is currently being carried out, notably in the USSR, to develop krill proteins industrially in order for them to become a more important market in human and animal foodstuffs.[7]

Ecological upheavals resulting from past examples of uncontrolled exploitation of certain biological resources of the Antarctic ocean should lead us to be extremely prudent about increasing the exploitation of krill. This is particularly so given that this essentially herbivorous organism constitutes a kind of turntable between the primary production of microscopic algae and higher organisms—from penguins to whales—which, for the most part, depend directly or indirectly on krill for their food (Figure 7.1).

The eventual establishment of krill quotas should be based on a better understanding of the principles which govern the functioning of the Antarctic marine ecosystem. In this regard, progress in recent years in the ecological study of the Antarctic ocean throws light on the characteristics of the functioning of this ecosystem which make it particularly vulnerable to excessive takings.

[7] A. Fokin, S. Rogozhin, Y. Vainerman, "Protein from krill", Science in the USSR, (1988) 4: 54–56.

THE FUNCTIONING OF THE ANTARCTIC MARINE ECOSYSTEM

AT THE BOTTOM OF THE FOOD CHAIN, RESOURCES ARE LIMITED IN TIME AND IN AREA

The food for krill is constituted mainly of microplankton of a size between 20 and 200 µm. These are dominated by algae which develop either in the ice or in the water. The first are only accessible to krill at the moment the ice melts.

Antarctic minus algae are remarkably adapted to the extremely low temperatures (−2°C to +2°C) to which they are permanently subjected. The main factor limiting growth is the availability of light, in spite of the significant amounts of sun which characterize the spring and summer in the Antarctic. This limitation is explained depending on the area of the Antarctic ocean, by the size of the ice cover, or by the turbulence induced by the violent winds which occur in this part of the globe. In areas covered by ice, in effect 95% of the sun's rays are reflected back, leaving only a very small amount of energy to penetrate down to the water column. Only those communities of algae associated with the ice are able to develop. In areas free of ice, on the other hand, losses due to reflection on the surface of the water amount to only 15%. The level of light in the water is therefore significant, but the increased turbulence induced by the winds which constantly stirs up the algae found in the lower depths, prevents them from benefiting sufficiently to grow into a large population (Figure 7.6). On the other hand, in the zone on the edge of the retreating ice field, the production of low-saline water resulting from the ice melting which starts in the spring leads to the formation of a layer of surface water of a lower density and which is therefore very stable. The phytoplankton circulating in this layer encounters optimal conditions of light. It can therefore develop rapidly and reach extremely high levels of concentration. These crops of algae are nevertheless very ephemeral: the violent winds which ravage these regions destroy the vertical structure of the water column, no longer protected by the ice cover, and dilute the phytoplankton which had accumulated in the surface layer into the depths.

Optimal conditions of lighting for the growth of phytoplankton only exist in the Antarctic ocean temporarily in the marginal zone of the melting ice, where the weaker salinity of the surface layer of the water column ensures a certain stability in the face of the turbulence induced by the winds.

A high concentration of algae in the Antarctic only occurs, therefore, in the neighbourhood of ice fronts, thus following from October to March and at a distance of 300 to 800 kilometres behind the retreat of the ice field (Figure 7.7).

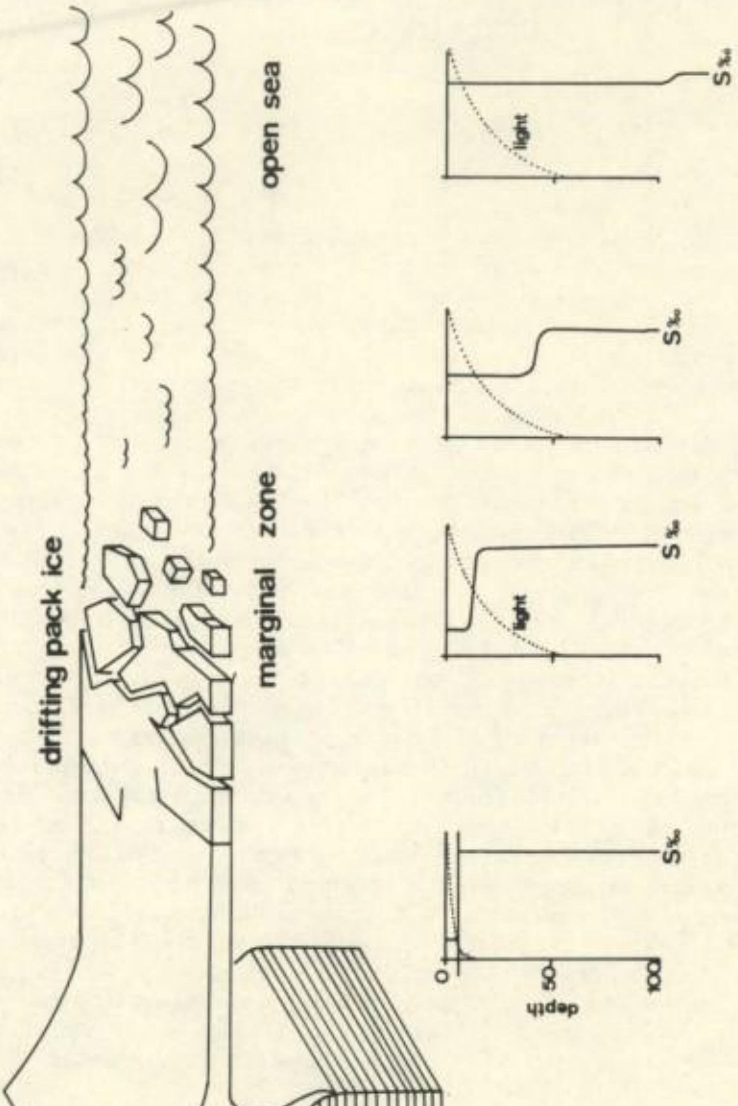

Figure 7.6 Lighting Conditions in the Antarctic

Optimal conditions of lighting for the growth of phytoplankton only exist in the Antarctic Ocean temporarily in the marginal zone of the melting ice, where the weaker salinity of the surface layer of the water column ensures a certain stability in the face of the turbulence induced by the winds.

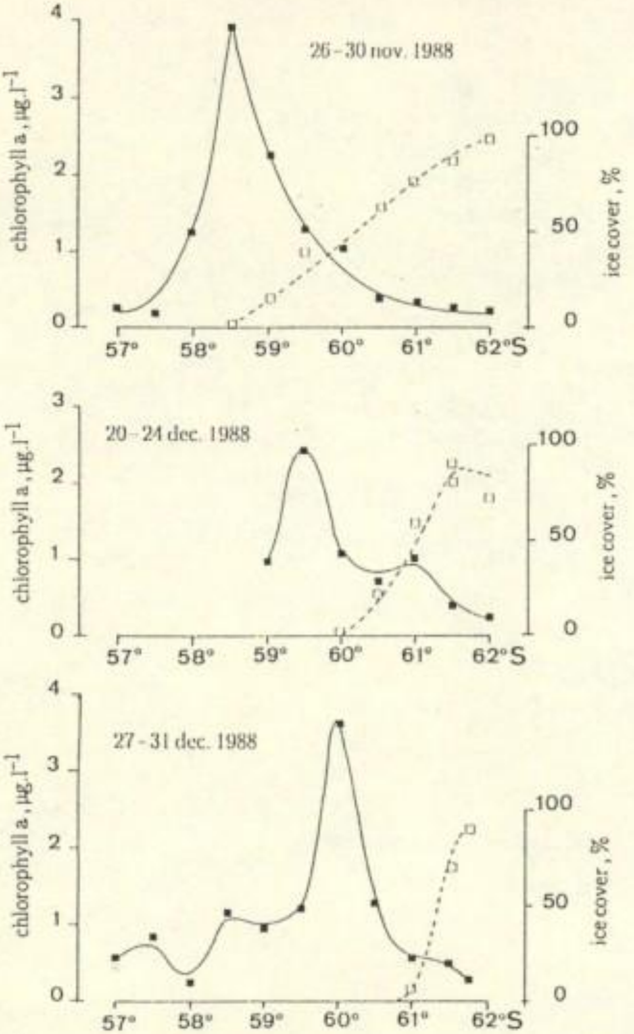

Figure 7.7 Seasonal Variations in the Biomass of Phytoplankton

Seasonal variations in the biomass of phytoplankton (measured by the concentration of chlorophyll) during the retreat of the ice field in the Weddell Sea.[8]

[8] C. Lancelot, G. Billen, S. Mathot, "Ecophysiology of phyto- and bacterioplankton growth in the Southern Ocean", in S. Caschetto (ed.), *Belgian Scientific Research Programme on Antarctica*. Vol. 1: *Plankton Ecology* (Prime Minister Services Science Policy Office, 1989), pp. 1–97.
C. Lancelot, C. Vetn, S. Mathot, "Modelling ice edge phytoplankton bloom in the Scotia-Weddell Sea sector of the Southern Ocean during spring 1988", *Journal of Marine Systems* (1991) 2: 333–346.

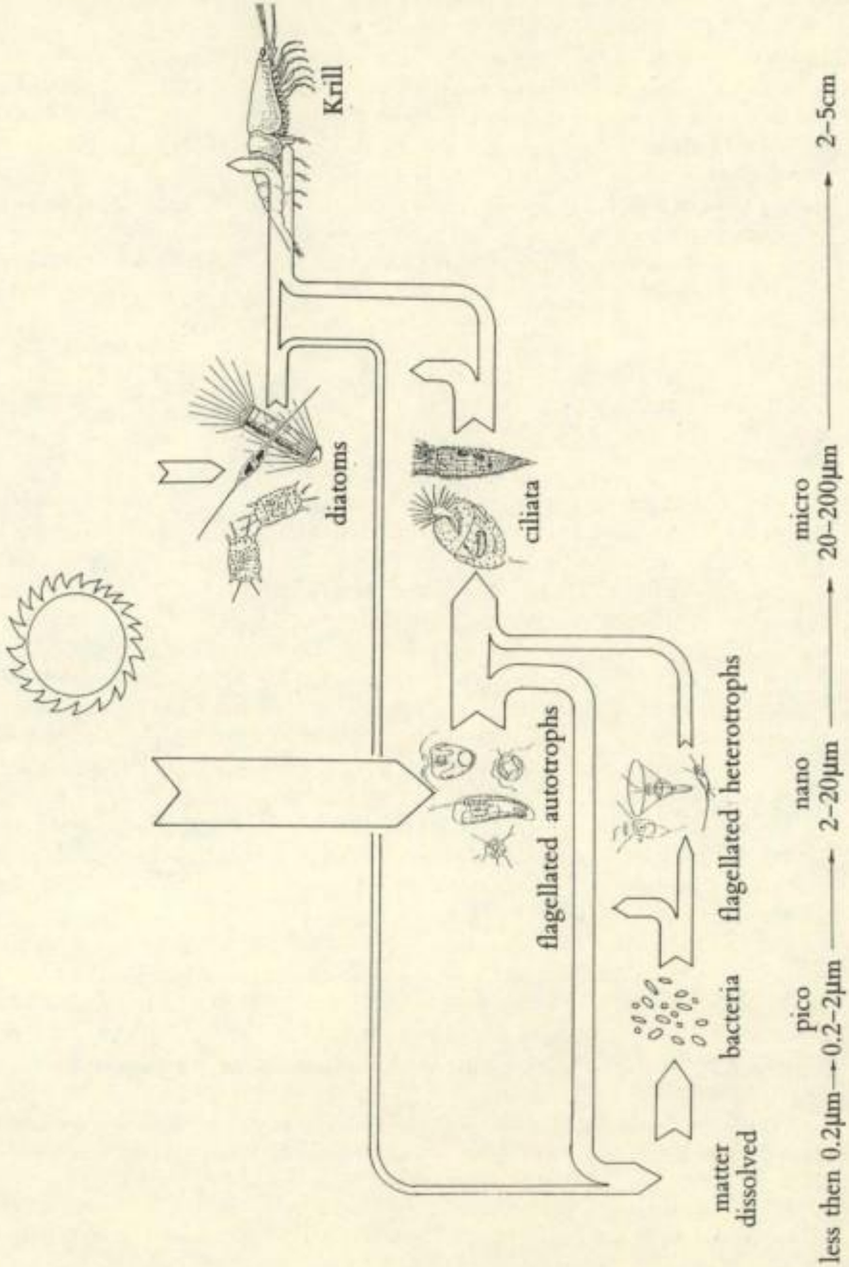

Figure 7.8 The Antarctic Food Chain

The first levels of the food chain in the Antarctic marine ecosystem are characterized by the presence, next to large diatoms directly consumed by krill, of an important microbial loop consisting of organisms which are too small to be directly consumed.

The essential resources of food for krill are therefore produced in the form of a *pulse* which is extremely limited in time and in area.

Moreover, not all of this production, which is so short lived and localized, is available for feeding. Krill, by taking the largest algae by preference, encourage the development of nanoplanktonic algae of a size between 2 and 20 µm which to a large extent escape the feeding process. Typically, the nanophytoplankton takes over immediately after the first passage of the krill. Thereafter, a complex food chain develops, in which the bacteria, using dissolved organic materials produced by the algae or liberated otherwise, and protozoans, filtering the nano- and bacteria plankton, constitute additional intermediaries between the algae and the krill (Figure 7.8), further diminishing the potentially available food resources for the higher trophic levels.

IN THE UPPER LEVELS OF THE FOOD CHAIN, ORGANISMS ADOPT A K-STRATEGY

The limited character, being episodic and variable in space, of the feeding resources offered by the lower levels of the Antarctic food chain constitutes an extremely severe constraint for the life of higher organisms in the Antarctic ocean. All these organisms have developed, in a completely convergent manner, a certain number of adaptations which can be seen as responses to this fundamental constraint. All of them, as we have seen, are relatively large compared to the organisms occupying a corresponding trophic position in temperature or tropical ecosystems. They are capable of rapid movements over long distances. They have the capacity for storing large reserves of food and for mobilizing them to meet their energy needs during prolonged periods of starvation. Their basal metabolism is weak and their reproduction rate extremely low. They have considerable longevity.

All these characteristics, shared by all the upper organisms of the polar regions, correspond typically to a K-strategy in the exploitation of resources in their environment. In ecology one can distinguish between two ways of exploiting the resources of the environment.

r-Strategy favours speed of growth to the detriment of the development of elaborate structures. This is the strategy of colonizing organisms and, in a general manner, of all organisms which dominate in the early stages of ecological succession and are characterized by a rapid rate of renewal.

K-strategy on the other hand, favours the development of complex structures, offering protection against predators or permitting a more profound and complete exploitation of environmental resources. This is the strategy adopted by organisms having a pluri-annual development which dominates in the mature stages of ecological systems. K-strategy is characterized by a low rate of renewal.

In order to exploit the thin and fugitive resources offered by the bottom of the Antarctic food chain on a permanent basis, only a K-strategy is considered appropriate.

THE ANTARCTIC ECOSYSTEM IN THE FACE OF EXPLOITATION AND POLLUTION

A SYSTEM DOMINATED BY K STRATEGIES CANNOT SUPPORT LARGE DEDUCTIONS

The dominance of K strategies in the upper levels of the Antarctic food chain explains both the apparent richness and the extreme fagility of the ecosystem. The build-up of the biomass of higher organisms of a large size, constituted to a large extent by reserves, is considerable, but the rate of renewal of this biomass is, on the other hand, very limited. Thus, if in the temperate or tropical marine environment ten to twenty generations of zooplankton occur annually, the longevity of krill is at least seven years.

The richness of the Antarctic ecosystem is only in appearance. Richness should be seen as a dynamic notion, linked to the speed of renewal, to income; by contrast with abundance, a static notion, linked to standing stock, to capital.

The richest environments, that is to say those most susceptible to the largest deductions, are those environments dominated by the r- strategy, capable of providing a surplus of exportable production rapidly. By contrast, the lengthy period for the renewal of the higher organisms of the Antarctic renders them extremely vulnerable to deductions which rapidly affect the stock, sometimes in an irreversible manner.

THE ANTARCTIC ECOSYSTEM CAN BE EXTREMELY SENSITIVE TO LOCAL DISTURBANCES

The fragility of the Antarctic ecosystem in the face of deductions is accompanied by a particular sensitivity with regard to accidental disturbances, even those which are local. The brevity of the biological production period, during which the essential resources used during the whole year are produced, renders the ecosystem specially vulnerable to any pollution which might occur at this critical moment. Even if it is only of anecdotal importance compared to the size of the problems facing the whole of the Antarctic continent, an example is illustrative of the extreme vulnerability of animal populations at the moment of their reproduction period. The sinking of the Bahia Paraiso in January 1989 provoked the first oil spill in the Antarctic ocean. Evaluating the impact of this accident has not yet been completed. Observations have nevertheless been published showing the total failure to reproduce amongst the populations of Antarctic skuas in the region affected by the hydrocarbon pollution.[9] This failure did not occur as a direct result of the oil, but rather by increased predation on young chicks less well protected by their parents as a result of the long periods of cleaning which these animals had to undergo in order to recover from the oil spill.

[9] Z. A. Eppley, M. A. Rabega, "Indirect effect of an oil spill: reproductive failure in a population of South Polar skuas following the 'Bahia Paraiso' oil spill in Antarctica", *Mar. Ecol. Prog. Ser.* (1990) 67: 1–6.

Elsewhere, the very specific metabolism of higher Antarctic organisms, which accumulate fatty reserves to support them at a later date, renders them very sensitive to intoxication by heavy metals and pesticides. Note, for example, that despite levels of pollution in the form of PCB and mercury which are infinitely smaller in this environment, the degree of contamination of Antarctic organisms is similar to that observed in the North Sea.[10]

CONCLUSIONS

Paradoxically, despite the rigour of its climate, during the nineteenth and early twentieth centuries the Antarctic ocean seemed to be an area of hunting and fishing of extraordinary richness. Nevertheless, the repeated failure of commercial exploitation demonstrates its vulnerability. The study of the functioning of the Antarctic marine ecosystem now explains this paradox of apparent richness and great fragility: it is a result of the K-strategy adopted by the higher organisms to exploit resources which are limited in time and area.

The Antarctic ocean offers to mankind feeding resources which it is no doubt legitimate to wish to exploit. But the exploitation of the environment by man can also adopt either an r-strategy or a K-strategy.

The r-strategy has prevailed in the past: to be the first to exploit the resource, to take the best part of the ready stock as quickly as possible, even if it means exhausting its capacity to renew itself.

Is it not high time to develop the principles of a K-strategy to exploit the resources of this region? To put in place structures and control mechanisms which would allow a form of exploitation which respects the fundamental ecological mechanisms thereby ensuring its permanence? It is in this spirit that the Convention on the Conservation of Antarctic Marine Living Resources was developed in 1982 with the aim of developing a "rational utilization" of the living marine resources, in a spirit of protection of the ecosystem. Even if the achievements of the 1982 Convention are to be welcomed, we must nevertheless recognize two types of constraint which seriously limit its efficacy. The first is political: the Commission has no constraining power (unanimity of member states is required for all decisions) nor control powers (the statistics on catches and fishing efforts are provided by the states themselves). The second is scientific: the inevitable delay between the observation of reductions of stocks of certain species and the measures designed to remedy them, considerably limit the efficacy of these measures in the absence of predictive models based on the knowledge of the dymanics of the Antarctic ecosystem.

The pursuit of scientific research in this domain must therefore be seen as an essential part of the K-strategy for the exploitation of resources: we are still far from being able to predict the effects of human disturbances, be they local or global, on the functioning of the ecosystem. Only a better understanding of the laws regulating this functioning will allow us to fix the limits within which the biological resources of the Antarctic effectively merit the title of "renewable resources".

[10] C. Joiris, W. Overloop, "PCB's organochlorine pesticides and mercury in the lower trophic levels of the Indian sector of the Antarctic marine ecosystem", in S. Caschetto (ed.), *Belgian Scientific Research Programme on Antarctica* Vol. 1: *Plankton Ecology* (Prime Minister Services Science Policy Office, 1989), pp. 1–29.