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# The Marine Living Resources of the Southern Ocean

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*The author suggests that the abundance of marine life in Antarctica presents ample opportunity both for scientific study and for exploitation. The author provides a survey of the distinct ecological system of the Southern Ocean through his discussion of the main marine species—from the simple organisms involved in primary production to the large marine mammals which have been subject to exploitation in the past. His primary emphasis is on krill, the small, shrimp-like crustacean which serves as the pivotal link in the Antarctic food chain. The abundance of krill, its high nutritive value and its ease of harvesting are factors which the author perceives as according krill significant potential for exploitation. At the same time, he identifies economic and technical obstacles which must be overcome if commercial krill harvesting is to develop.*



## I. A GENERAL DESCRIPTION OF THE ECOSYSTEM OF THE SOUTHERN OCEAN

The waters surrounding the Antarctic continent, often called the Southern Ocean,[1] comprise a distinct and distinctive marine

* The views expressed herein are those of the author and do not necessarily represent the views of the Department of State or the United States government.

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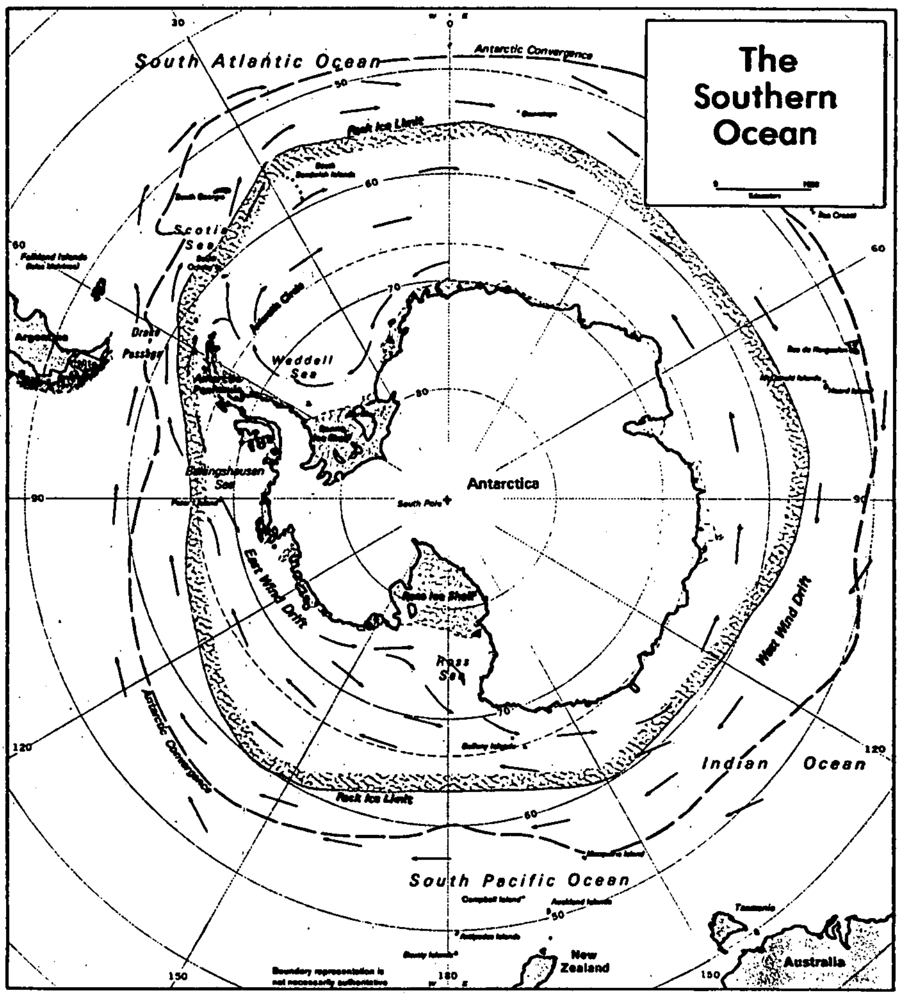
1. Currently, the term "Southern Ocean" does not have official recognition as a geographic appellation. The concept of the Southern Ocean, however, is well-established and provides a framework for examining Antarctic marine resources. *See generally* H.G.R. KING, THE ANTARCTIC (1972).

area. Although contiguous with the Atlantic, Pacific and Indian Oceans to the north, the Southern Ocean can be defined both in physical and ecological terms as being a separate region and not merely as being the southernly extension of the three northern oceans.




The Antarctic Convergence is generally considered to be the northern boundary of the Southern Ocean.[2] At the Convergence, there is both a significant change in the temperature and salinity of the surface waters and a related change in the composition and structure of the surface fauna. The Convergence generally lies between latitude 50° and 60° S. Sometimes referred to as the Ant-

2. THE FISH RESOURCES OF THE OCEAN 162 (J. Gulland ed. 1971) [hereinafter cited as FISH RESOURCES].

arctic Polar Frontal Zone, it is a complex transitional zone lying between the cold, low-salinity surface waters of the Antarctic and the warmer, higher-salinity surface waters of the subantarctic.[3]

The Southern Ocean is a deep oceanic system, four to five thousand meters (13,120 to 16,400 feet) in depth over most of its extent with only limited areas of shallow water.[4] The Antarctic continental shelf is generally narrow and is markedly depressed by the weight of the ice covering the continent, and the islands and submarine ridges also possess only limited adjacent shallow areas. The Scotia Arc, which extends from the Antarctic Peninsula through the South Sandwich Islands to South Georgia, rises steeply from the deep ocean floor, though there are shallow areas of some significance off both South Georgia and Kerguelen Island.

The waters surrounding Antarctica evidence a strong pattern of circulation. At the surface there is a layer of cold, low-salinity water. This surface mass, which moves in an easterly direction, is driven by the prevailing westerly winds (the West Wind Drift), except for a counter westward drift (the East Wind Drift) in areas immediately adjacent to the continent. At the Antarctic Convergence, this cold surface water sinks below warmer mixed water flowing in from the north, thus causing the change in fauna which marks the northern boundary of the Southern Ocean. At intermediate depths beneath this surface layer is an influx of relatively warm, high-salinity water from the north. This layer begins to rise at the periphery of the Southern Ocean as the Antarctic Circumpolar Water. Finally, there is a deep layer of cold, heavy-bottom water which flows northward from the Antarctic continent and is a source of deep ocean water for all of the other major oceans except the Arctic. Upwelling occurs in areas close to the continent and in a low-pressure belt at about latitude 65° S.[5]

Extensive areas of the Southern Ocean are subject to coverage by pack ice formed by freezing sea water. The pack ice covers approximately 13 million square kilometers (8.073 million square miles) of the Antarctic seas during the summer months and almost double that to approximately 25.5 million square kilometers (15.835 million square miles) during the winter months.[6] Some areas adjacent to, and part of, the Antarctic continent are permanent ice

3. TETRA TECH, INC., FINAL REPORT—THE ANTARCTIC KRILL RESOURCE: PROSPECTS FOR COMMERCIAL EXPLOITATION 12-15 (1978).

4. FISH RESOURCES, *supra* note 2, at 162.

5. *See* El-Sayed, *Biology of the Southern Ocean,* 18 OCEANUS 40, 41 (1975).

6. U.S. DEP'T OF STATE, FINAL ENVIRONMENTAL IMPACT STATEMENT FOR A POSSIBLE REGIME FOR CONSERVATION OF ANTARCTIC MARINE LIVING RESOURCES 22 (1978) [hereinafter cited as FINAL ENVIRONMENTAL IMPACT STATEMENT]; El-Sayed, *supra* note 5, at 41.

shelves formed by glaciation. The pack ice, in particular, provides an important habitat for seals and penguins.

Physical characteristics of the Southern Ocean combine with meteorological, climatic and solar regimes of the area to create an environment which supports distinct ecological systems. The Antarctic marine environment, like the northern high-latitude environments, is characterized by low species diversity and high individual species populations when contrasted with the low and mid-latitude areas.

Conditions in certain areas of the Southern Ocean are conducive to high levels of primary production during the summer months. The general circulation and upwelling processes provide a continuous source of nutrients which, when combined with the almost continuous summer sunlight, create an excellent environment for plant photosynthesis. In fact, almost all primary production takes place in the summer months. During winter, the sunlight for photosynthesis is vastly reduced and approximately one-half of the area south of the Convergence is covered by ice.[7] Therefore, the average productivity for the area as a whole is thought to approximate that of the other oceanic regions.[8]

Primary production in the Southern Ocean—the phytoplankton—is predominately composed of diatoms and other simple organisms dependent upon silica, in which the Southern Ocean is particularly rich. These phytoplankton are at the lowest trophic level and support a large standing crop of zooplankton. It has been estimated that one-half of the zooplankton biomass consists of the euphausiids known as Antarctic krill, a red shrimp-like crustacean which as an adult attains a length of fifty to seventy millimeters (two to three inches). The remainder of the zooplankton community is believed to be made up of smaller species, predominantly copepods.[9] Krill, which form the pivotal link in the Antarctic food chains, primarily feed directly on phytoplankton and, in turn, provide the primary food supply for a number of the species of marine mammals and birds of the Southern Ocean as well as the indirect supply for others.[10]

The baleen whale and the crabeater seal are major consumers

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7. FISH RESOURCES, *supra* note 2, at 162.

8. *Compare* FINAL ENVIRONMENTAL IMPACT STATEMENT, *supra* note 6, at 24 (total productivity is similar to that of other oceans) *with* FISH RESOURCES, *supra* note 2, at 163 (productivity of the Southern Ocean documented as 400% greater than that of the other oceans of the world). Earlier scientific investigation acquired a misleading picture of high productivity because they concentrated their investigations in the most productive areas.

9. FISH RESOURCES, *supra* note 2, at 162-67.

10. *See* FINAL ENVIRONMENTAL IMPACT STATEMENT, *supra* note 6, at 32.

of krill, while the Adelie penguin and various other species of birds also feed directly on the euphausiids. Marine mammals and birds which are indirectly dependent on krill include the leopard seal (which preys on crabeater seals and penguins), the skua (which preys on penguins and other birds) and the killer whale (which preys on seal as well as the larger whales).

Various species of fish also feed directly upon krill. The extent to which fish species preferentially select krill, as opposed to other zooplankton, is not known. Observations indicate that certain species cross the Convergence during the summer months to feed on krill and that other species found only south of the Convergence also include krill in their diet.[11] Though specific data are lacking, it is thought that squid consume very large amounts of the small crustacea.[12]

Species of larger crustacea are found in continental shelf and slope areas around a number of the subantarctic islands of the Southern Ocean area. Among these are rock lobsters, species of spiny lobsters (lithodids) and spider crabs.

There is a relatively rich benthic fauna on the narrow shelves of the Antarctic continent and its islands. The benthos, essentially part of a largely closed detrital food chain, is characterized by sessile and slow-growing organisms such as sponges, bryozoa, echinoderms, gorgonaceae and tunicates. It has been estimated that about sixty percent of the benthic fauna is not directly available as food for other organisms and none is considered to be available for human consumption.[13]

## II. THE MARINE SPECIES OF THE SOUTHERN OCEAN: RESOURCES FOR PAST AND POTENTIAL COMMERCIAL HARVESTING

The abundance of marine life in Antarctica presents ample opportunity both for scientific study and for potential exploitation. Despite the remoteness of the Southern Ocean, it has been the situs of commercial harvesting for two hundred years.

### A. *Whales*

On a seasonal basis, the Southern Ocean supports a larger stock of whales than any other ocean area of the world. It is frequented

11. *See id.* at 29; K. Green, Role of Krill in the Antarctic Marine Ecosystem 18 (Dec. 1977) (report to Department of State Office of External Research), *reprinted in* FINAL ENVIRONMENTAL IMPACT STATEMENT, *supra* note 6, app. C. at 1-34.

12. FINAL ENVIRONMENTAL IMPACT STATEMENT, *supra* note 6, at 28; K. Green, *supra* note 11, at 17-18.

13. FISH RESOURCES, *supra* note 2, at 165.

by the major species of the baleen whale: blue, humpback, Bryde's, sei, minke, fin and southern right whales. Sperm whales, the only species of large, toothed whales, are common in Antarctic waters, as are smaller cetaceans, including beaked and toothed whales, the pygmy right whale and the killer whale.

A number of whale stocks, including those found in the Southern Ocean, have been seriously depleted by inadequately regulated harvesting. Data developed on baleen whales stocks indicate the following estimates of original and existing stock populations:[14]

| Stock | Original (Thousands) | Present (Thousands) |
|---|---|---|
| Fin | 400 | 84 |
| Blue | 200 | 10 |
| Sei (including Bryde's) | 75 | 40.5 |
| Humpback | 100 | 3 |
| Minke | 200 | 200 |

It is estimated that there were about one million baleen whales in the Southern Ocean prior to the intensive whaling of the past century.[15] The Southern Ocean has been the scene of extremely heavy exploitation of whale stocks beginning in the late 1920's, and it was not until the early 1970's that International Whaling Commission (IWC) efforts to limit harvesting in that area began to bear fruit. The IWC, which includes all states that still engage in pelagic whaling, has developed measures (to be implemented by contracting governments) designed to protect and conserve whale stocks, including those in the Southern Ocean. Primary emphasis in managing whale stocks has been placed on the replenishment of seriously depleted stocks by means of controlled harvesting. Under IWC regulations, commercial whalers operating south of the Equator are forbidden to hunt for blue, fin, Bryde's, humpback, right and gray whales; the taking of sei, minke and sperm whales is subject to IWC

14. 1 GROUP OF SPECIALISTS ON LIVING RESOURCES OF THE SOUTHERN OCEAN, SCIENTIFIC COMM. ON ANTARCTIC RESEARCH AND SCIENTIFIC COMM. ON OCEANIC RESEARCH, BIOLOGICAL INVESTIGATIONS OF MARINE ANTARCTIC SYSTEMS AND STOCKS (BIOMASS) 24-25 (1977) [hereinafter cited as BIOMASS]. This data is a crude estimate representing the consensus among whale biologists. *See also*, TETRA TECH, INC., *supra* note 3, at 44; K. Green, *supra* note 11, at 10; Report of Group of Specialists on Living Resources of the Southern Ocean, Scientific Comm. on Antarctic Research and Scientific Comm. on Oceanic Research 11 (Aug. 23-24, 1976) (unpublished report from meeting at Woods Hole, Mass.) [hereinafter cited as Woods Hole Report].

15. El-Sayed, *supra* note 5, at 44.

quotas.[16] The 1977-78 combined quota for baleen whales for the entire Southern Hemisphere was 6,461 individuals.

### B. *Seals*

Another Antarctic mammal which has been over-exploited in the past is the seal. Six species of seal are to be found in the Southern Ocean. Four of these species, the crabeater, Weddell, leopard and Ross seals, are truly Antarctic in that their life cycles are tied to the pack ice which surrounds the Antarctic continent. Two of the species, the Southern elephant seal and the Southern fur seal, although concentrated in the Southern Ocean region, do not have life cycles with such strong association with the Antarctic pack ice. The crabeater seal is the most abundant, with a population estimated at up to thirty million individuals,[17] and it is thought to be the most important predator of krill, consuming an estimated 106 million metric tons (116.6 million short tons) a year.[18] Estimates place the Weddell seal population at between 200 and 500 thousand, the leopard seal population at 150 thousand and the Ross seal population at 50 to 100 thousand.[19]

Although seal blubber has been rendered for oil and the meat could be utilized as pet food, economic interest in Antarctic seals has centered upon their pelts. Over the last century, unregulated harvesting resulted in a serious depletion of the stock of fur seals, with estimates of one million seals having been taken. Fur seals are now reappearing in large numbers in their former habitats.[20] Although elephant seals were harvested when the fur seal population declined, the elephant seal population did not decline to a critical level because harvesting became unprofitable.

Presently, under the 1972 Convention for the Conservation of

16. FINAL ENVIRONMENTAL IMPACT STATEMENT, *supra* note 6, at 34. Although the IWC sets total catch limits based on scientific advice from the IWC Scientific Committee, the allocations to the particular countries are arranged outside the IWC. TETRA TECH, INC., *supra* note 3, at 123.

17. El-Sayed, *supra* note 5, at 44. *But cf.* BIOMASS, *supra* note 14, at 20-21 (table estimates 15 million seals); K. Green, *supra* note 11, at 19 (indicates that there are 15 to 30 million seals with some estimates as high as 30 to 70 million).

18. K. Green, *supra* note 11, at 21.

19. McWhinnie, *Potential Impact of Harvested Zooplankton on the South Circumpolar Ecosystem*, in B. PARKER, ENVIRONMENTAL IMPACT IN ANTARCTICA 295, 303 (1978); *cf.* BIOMASS, *supra* note 14, at 20 (population estimates of Weddell seal at 730,000; leopard seal at 220,000; and Ross seal at 220,000); El-Sayed, *supra* note 5, at 45 (estimates leopard seal at 200,000 to 300,000 and Ross seal at 100,000).

20. The relatively increased abundance of krill due to the reduction in whale stocks may have aided the recent expansion of the seal stock. I. EVERSON, THE LIVING RESOURCES OF THE SOUTHERN OCEAN (UNDP/FAO Southern Ocean Fisheries Survey Programme GLO/SO/77/1 1977).

Antarctic Seals,[21] effective March 11, 1978, all pelagic sealing would be banned; the killing or capturing of Southern fur seals, Southern elephant seals and Ross seals would be prohibited; and the annual killing or capture of crabeater seals would be fixed at 175 thousand individuals, leopard seals at 12 thousand, and Weddell seals at 5 thousand. Stocks of Southern fur and elephant seals might support regular harvesting if conservation measures succeed in restoring them to their former levels.

### C. *Birds*

The Antarctic continent and surrounding islands support a sizeable avifauna, which is an integral part of the ecology of the Southern Ocean. Unlike the whale and the seal populations, the bird population has generally not suffered from overexploitation in the past. The total population of all birds in the area of the Southern Ocean is thought to be approximately 188 million individuals.[22] This population consumes an estimated thirty-nine million tons of food annually, about half of which is consumed in the subantarctic region.[23] Thus, as consumers of krill, the bird population is about equal in importance to large whales and about half as important as seals.[24]

It is estimated that some thirty species of sea birds frequent Antarctic waters, approximately half of which nest on the Antarctic continent itself. Among these are the Antarctic South Polar skua, a relative of the gull; eleven species of petrel, including the snow petrel, whose range is completely limited to the Antarctic area; and the fulmars, whose range is mostly limited to the Antarctic area. In addition, six species of albatross, three species of tern—the cormorants, the cape pigeon and the sheathbill—are found in the Southern Ocean.[25] Seven species of penguins comprise about eighty-seven percent of the bird stock in Antarctica.[26] Two of the species, the Adelie and the Emperor penguins, breed on the continent itself and are exclusively Antarctic in distribution, while three other species,

21. Convention for the Conservation of Antarctic Seals, *done* June 1, 1972, T.I.A.S. No. 8826, *reprinted in* 11 INT'L L. MATERIALS 251 (1972).

22. BIOMASS, *supra* note 14, at 27. *But see* TETRA TECH, INC., *supra*, note 3, at 42 (estimates 200 million individuals); Woods Hole Report, *supra* note 14, at 12 (also estimates the total bird biomass to be nearly 200 million).

23. BIOMASS, *supra* note 14, at 27 (65% of the bird stock is distributed in the subantarctic region).

24. *See* text accompanying note 18 *supra;* TETRA TECH, INC. *supra* note 3, at 42.

25. BIOMASS, *supra* note 14, at 25-27.

26. *Id.* at 25. Penguins comprise 90% of the total Antarctic biomass and 83% of the subantarctic biomass.

the chin-strap, the Macaroni and the Gentoo penguins, are also to be found further north but tend to concentrate within the area of the Southern Ocean.

In the past, penguins have been exploited on a limited basis for commercial oil, and several bird species have been used as a food source by expeditions.[27] At present, however, the marine birds of the Southern Ocean are not considered a target for exploitation; rather, their importance is seen as consumers of krill, in which they rival the whale. It is estimated that penguins alone consume over fourteen million metric tons of krill a year.[28]

## D. *Fish*

In addition to the species of mammals and birds, approximately one hundred species of fish have been recorded in the Southern Ocean.[29] Data in this area, however, are insufficient and often do not distinguish between those reports referring to the Southern Ocean alone and those which also encompass subantarctic waters to the north.[30] The primary species found in the Southern Ocean fall into three families: the nototheniidae (cod-like species), the chaenichtyidae (the "ice fish") and the myctophidae (the mid-waters lantern fish which appear to be concentrated just south of the Convergence). In addition, several species of demersal fish native to more northern waters migrate seasonally across the Convergence to feed on krill and other zooplankton. In the area of the South Shetland and South Orkney Islands, for instance, southern blue whiting or southern poutassou *(Micromesistius australis)* and Patagonian hake *(Merluccius hubbsi)* have been observed in significant numbers during the summer months.[31] Both the blue whiting and Patagonion hake could offer harvesting potential during their summer migrations across the Convergence.

Fish species which might support significant fisheries are the nototheniids, sometimes collectively called "Antarctic cod," which are found in the waters above the continental shelves of Antarctica. Extensive fishing for nototheniids, particularly by the Soviet Union, developed in the 1960's. The annual catch has been estimated to have reached 200 to 300 thousand metric tons (220 to 330 thousand short tons).[32] There is evidence, however, that catches of nototheniids

27. FINAL ENVIRONMENTAL IMPACT STATEMENT, *supra* note 6, at 36.
28. K. Green, *supra* note 11, at 21.
29. TETRA TECH, INC., *supra* note 3, at 41. Of the 100 species of fish only about 12 species have been considered to have potential for commercial harvesting.
30. FISH RESOURCES, *supra* note 2, at 166.
31. *Id.*
32. *Id.* at 166.

iids have dropped off drastically since the early 1970's, which is an indication of overexploitation.[33]

### E. *Cephalopods*

A number of species of cephalopods have been found in the Southern Ocean. In particular, squid are thought to be present in large quantity, although there are no reliable estimates of squid abundance. It has been estimated, however, that squid consume as much as 100 million metric tons (110 million short tons) of krill a year, as opposed to the 64 million metric tons (71.5 million short tons) consumed by other fish species.[34] In turn, squid constitute a significant portion of the diets of sperm whales, seals, penguins, pelagic birds and fish. Although research which would permit meaningful estimates has not been carried out, the potential for commercial harvesting of squid is thought to be significant.[35]

### F. *Krill: The Pivotal Link*

The existence of large amounts of krill in the Southern Ocean and its importance in the Antarctic food chain has been known for many years.[36] Technically, the term krill applies collectively to the euphausiids, small, shrimp-like organisms with a global distribution. Although eleven species of euphausiids are found in the Southern Ocean, *Euphausia superba* constitutes by far the preponderant share of the biomass of Antarctic krill.[37] Because of its high nutritive value, this species is considered to be a potential primary food source for humans.[38] Interest in possible commercial exploitation of *Euphausia superba* has been developing since the mid-1960's, stimulated by recognition of its potential for human consumption, as well as the instinct of *Euphausia superba* for forming dense, poten-

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33. FINAL ENVIRONMENTAL IMPACT STATEMENT, *supra* note 6, at 35.

34. K. Green, *supra* note 11, at 18. This large consumption of krill makes squid comparable to the crabeater seal as a krill predator.

35. Further study is required to substantiate this belief. Although there are currently no commercial cephalopod fisheries in the Southern Ocean, there are squid fisheries in the waters of New Zealand and South America. *See* BIOMASS, *supra* note 14, at 28, 37.

36. *See* notes 10-12 and accompanying text *supra*. The Consultant to the U.N. Southern Ocean Fisheries Survey Programme stated that "[t]he immense size of the resource has been confirmed, at least to the extent that the sustainable yield will exceed by orders of magnitude the likely demand for many years to come." G. GRANTHAM, THE UTILIZATION OF KRILL 2 (UNDP/FAO Southern Ocean Fisheries Survey Programme GLO/SO/77/1 1977); *see* BIOMASS, *supra* note 14, at 13.

37. Next in importance to *Euphausia superba* are the species *Euphausia crystallorophias, Thysanoessa macrura* and *Euphausia Vallentini.*

38. BIOMASS, *supra* note 14, at 14; G. GRANTHAM, *supra* note 35, at 5; *see* McWhinnie, *supra* note 19, at 311-12.

tially harvestable swarms in surface waters during the summer. As a result of the predominance and importance of *Euphausia superba*, the term Antarctic krill has come to refer to this species alone.

### 1. LIFE HISTORY

The spawning habits, development and life span of *Euphausia superba* are not fully understood and further research is needed to elucidate its life cycle.[39] Estimates of the life span of these euphausiids range from two and one-half years to four years. Spawning takes place in February and there is some evidence that the adults, at least the males, die soon afterward. The eggs hatch the following summer and larval development occupies the first summer. At that time, *Euphausia superba* attain an average length of thirty millimeters (1.181 inches) and an average weight of 800 milligrams (.2824 ounces). They become sexually mature during either their second or third summer. Adults have an average length of approximately fifty millimeters (1.9685 inches) and an average weight of 1,200 milligrams (.4236 ounces).[40]

The specific areas in which spawning takes place have not been positively identified. Some observers believe that spawning is a relatively shallow water phenomenon in continental shelf or slope waters such as the Bransfield Strait and the western part of the Weddell Drift. Others have argued that spawning of *Euphausia superba* occurs in deeper oceanic waters, such as in the vicinity of the South Orkneys.[41] It is not known whether there is one or several breeding populations of *Euphausia superba*. Whatever the answer to this important question, the life stages of *Euphausia superba* must be integrated with the pattern of Antarctic currents to ensure the replenishment of the species throughout its observed geographical range.

### 2. DISTRIBUTION

During the summer, *Euphausia superba* are found in dense patches of a single age-class, which facilitates feeding by predators. These swarms occur mainly in the upper water layers to a depth of approximately 250 meters (820 feet). More than ninety percent of the population is found within 100 meters (328 feet) of the surface, the bulk often forming swarms at or near the surface itself.

39. McWhinnie, *supra* note 19, at 307. Each study that has been undertaken to determine the development of krill at different growth stages and climatic conditions has recorded a wide variance in individual sizes.

40. *See generally* TETRA TECH, INC., *supra* note 3, at 56-61.

41. *Id.* at 50-51.

*Euphausia superba* exhibit diurnal vertical migrations, with daytime concentrations generally to be found between ten and forty meters (32.8 to 130 feet) and nighttime concentrations to be found from the surface down to ten meters (32.8 feet).[42]

Behavioral variation, such as the diurnal vertical migration, is one factor thought to be responsible for the separate distribution of swarms of single age-class *Euphausia superba*. During the summer, the young tend to concentrate in southern areas, such as those south of the Scotia Sea. Adults, however, tend to concentrate in the north, in the Weddell Sea or the West Wind Drift. Segregation of the young and the adults apparently results from the differences in the depth of their vertical migration. These distinctions, in turn, separate the two groups into different horizontal water masses moving at varying rates. Since young *Euphausia superba* perform deeper migrations, they are carried further south from their spawning grounds. Mature crustaceans, whose vertical migrations are less pronounced, tend to be found further to the north.[43]

The distribution of *Euphausia superba* is circumpolar; krill are to be found throughout the Southern Ocean, between the Antarctic Convergence and the continent. However, because of the habits of the species and variation in the physical environment, there are distinct distributional patterns for krill in the Antarctic waters. Preliminary assessment indicates that the areas of gyres (cyclonic surface currents) are likely to contain the largest concentrations of krill. Such areas are found in the East Wind Zone, Weddell Sea, Ross Sea, Amundsen Sea, Bellingshausen Sea, north and east of South Georgia Island, the Scotia Sea north of the Orkney Islands, around the South Shetland Islands and west of the South Sandwich Islands.[44]

## III. Economic Considerations in the Harvesting of Krill

### A. *Estimates of Resource Potential*

Although there is sufficient information to indicate that *Euphausia superba* constitutes a major potential resource, serious obstacles hinder the development of reliable estimates of the standing stock and potential annual yield of Antarctic krill.[45] Systematic

42. *Id.* at 35-41.
43. *Id.* at 37-41.
44. *Id.* at 32.
45. *Id.* at 73-74. The growing interest in krill stems from the need to increase the world's food supply, particularly high-protein items, in light of world population growth. Although the Soviet Union and Japan have devoted the most research to the harvestry of krill, other countries encouraged by earlier results and impelled by the two hundred mile fishing zones

monitoring on a year-round basis is difficult, largely due to the harsh environmental conditions. Extrapolations from existing net tow data are subject to gross error because of the patchy distribution of the resource.[46]

Existing estimates have either been based upon hypotheses regarding overall annual production and food chain efficiency in the Southern Ocean or upon the indirect method of calculating the amount of krill from estimates of original whale consumption which are now available due to whale stock depletion.[47] Potential yield estimates, based upon overall annual production and a thirty percent availability for harvesting, range from over 1,000 million metric tons (1,100 million short tons) down to 30 to 54 million metric tons (33 million to 59.4 million short tons). Indirect estimates based upon the decline of whale stocks indicate that an annual krill yield ranging from 100 million to 250 million metric tons (110 million to 275 million short tons) is to be expected.[48] It should be noted that most of these estimates exceed the present total annual world catch of marine living resources (slightly over 65 million metric tons in 1972).[49] Readily exploitable concentrations of krill appear to be limited, however, to certain areas of the Southern Ocean, and it is possible that only a small part of the total krill production of the Antarctic can be harvested.[50] Nevertheless, it is believed that the harvestable yield of krill could still be several tens of million tons.[51]

### B. *Harvesting Techniques*

Harvesting is facilitated by the behavior of *Euphausia superba*, which, like shrimp in general, do not demonstrate any strong escape reaction to fishing gear, but rather are carried passively into the net by water flow. *Euphausia superba* can be located either visually on the sea surface, by acoustical means (sonar) in the upper water column, or by remote sensing from aircraft or satellite. Four major types of catch gear have been used in the exploratory harvesting of krill: the surface side trawl and frame net, stern (mid-water) trawls,

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instituted by many states, have deployed fleets to begin experimental fishing for krill in the Antarctic waters.

46. K. Green, *supra* note 11, at 15.

47. Woods Hole Report, *supra* note 14, at 15; *see* K. Green, *supra* note 11, at 25 (arguing that man's harvesting of krill is *not* similar to whale consumption and would disrupt the Antarctic ecosystem).

48. *See* FISH RESOURCES, *supra* note 2, at 164; TETRA TECH, INC., *supra* note 3, at 45. *But see* El-Sayed, *supra* note 5, at 47 (asserting little evidence for such a surplus).

49. El-Sayed, *supra* note 5, at 47.

50. *See* TETRA TECH. INC., *supra* note 3, at 74.

51. *See Id.* at 121; K. Green, *supra* note 11, at 25-26.

twin trawls and purse seiners.[52] The most promising results have been obtained with the use of mid-water trawls. Recent research by the Federal Republic of Germany, for instance, has yielded very high catch rates with such gear (an average of eight to twelve tons per hour).[53]

Exploratory harvesting of krill began in the 1960's, with Japan and the Soviet Union taking the lead. More recently, Poland and the Federal Republic of Germany have initiated significant fisheries research activities in the Southern Ocean. In addition, vessels from Chile, Spain, Norway, the German Democratic Republic and Taiwan have reportedly conducted investigations into krill harvesting.[54]

The 1976 Woods Hole Conference on Living Resources of the Southern Ocean, convened under the auspices of the Scientific Committee on Antarctic Research, examined the results of field investigations into the practicability of krill harvesting, particularly those obtained by the 1975-76 Polish and German expeditions.[55] The conference report concluded that:

> The technological difficulties of locating and catching krill have been overcome to the extent that krill could be caught in large quantities (perhaps several hundred tons per day) and at moderate cost (probably under $50 per ton) *provided* that the fishing operations did not have to be interrupted to handle and process the catch.[56]

Although there are no reliable data on total catches of krill, exploratory harvesting intensified during the mid-1970's and estimates of the maximum amount taken in any recent year range from 40 to 200 thousand metric tons.[57]

### C. *Processing and Marketing*

The high nutritive value of krill is demonstrated by a summary of its dry weight composition: 65.1% protein, 14.2% crude fat and 13.9% ash.[58] The protein found in *Euphausia superba* contains many important amino acids. A potentially significant source of vitamins A, B and D, krill is also rich in calcium, iron, magnesium and phosphorus. These crustaceans have been described as being similar in appearance, taste and texture to small lower-latitude shrimp.

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52. *See* TETRA TECH, INC., *supra* note 3, at 77-80.
53. *Id.* at 86.
54. *Id.* at 73-74.
55. Woods Hole Report, *supra* note 14, at 4.
56. *Id.* at 21.
57. *See* TETRA TECH, INC., *supra* note 3, at 73.
58. G. GRANTHAM, *supra* note 35, at 3; TETRA TECH, INC., *supra* note 3, at 103.

Once landed, *Euphausia superba* deteriorates very rapidly due to highly active enzymes in their organs. Therefore, it has to be quickly processed into a stable end or intermediate product. Rapid, on-board processing requires the use of advanced techniques, and the necessary technology is still in the developmental stage.

Assuming the requisite technology, the possible range of products from *Euphausia superba* would include: frozen whole krill, frozen whole tail meats, breaded krill sticks, coagulated krill pastes (for direct use or as a food enhancer), krill mince (for use in soups, pie fillings and salads), krill protein concentrates or other protein and vitamin supplements. In addition to such products for human consumption, krill could be processed for animal feed or chitin. Large-scale market acceptance of krill products has not been established, although tentative acceptance of some such products has been demonstrated in Japan.[59]

### D. *Operational Conditions*

Although existing techniques for harvesting living resources other than krill could probably be adapted without much difficulty to the Antarctic, the Southern Ocean imposes a number of operational challenges to the exploitation of *all* potential stocks. The Southern Ocean is an inhospitable environment. Weather conditions during most of the year are extreme; sea conditions can be among the most violent encountered anywhere, and ice covers the Antarctic waters during the long winter. These conditions, which affect living resources as well as would-be exploiters, could effectively limit the fishing season to the summer months.

There are a number of operational constraints derived from the sheer remoteness of the Southern Ocean. Its remoteness from potential markets for living resources is a factor of considerable economic significance. Transportation costs alone would be very high for potential catches and the logistics of fishery activities would be affected by its distance from other ports.[60] The ports of southern Argentina and Chile or of the islands of the Scotia Arc might offer suitable supply and logistical bases for a ground fishery, particularly since such a fishery is likely to be located in the vicinity of the

59. TETRA TECH, INC., *supra* note 3, at 107.

60. *Id.* at 93. Both construction and operating costs would be higher for Antarctic fishing vessels than for those operating elsewhere. Navigation through ice demands strengthened hulls and specialized steering equipment. Since few repair facilities would be available, extra equipment and personnel would be required. In addition, higher wages would be needed to induce crew members to endure the long expeditions and extreme environment. Furthermore, the fuel costs for transportation to the home ports of vessels not based in the Antarctic waters year-round might be prohibitive in comparison to the profits from possible catches.

Scotia Sea. A krill or squid fishery might also be located in this area, although the habits of these species may require considerably extended ranges for fishing vessels. Australia, New Zealand and South African ports might also have potential as support bases.

The operating constraints imposed by the Southern Ocean imply high initial capital costs and/or opportunity costs for the pursuit of commercial fishery operations in this region and will have a major impact on how and when exploitation of living resources in Antartica might take place. At the same time, the preliminary estimates of the resource potential of the Southern Ocean, primarily krill, are extremely large and particularly intriguing in the context of accelerated world demand for protein. In addition, major distant-water fishing states are seeking new fishing grounds as a result of the two hundred mile coastal state jurisdiction over fisheries. Interest in exploitation of living resources in the Southern Ocean is likely to become more intense and more specific with considerable rapidity.