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Biology of the Antarctic Krill (Euphausia superba) and Fisheries Management Under the Convention on the Conservation of Antarctic Marine Living Resources

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Introduction

Activities in Antarctica have been governed by a few nations party to the Antarctic Treaty of 1959. The Antarctic Treaty arose through scientific interaction and cooperation among twelve nations active in Antarctica during the 1957-58 International Geophysical Year (IGY). Nations participating in the IGY (i.e., Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, United States, United Kingdom, Soviet Union) agreed to set aside the territorial claims issue, cooperated in establishing and supporting scientific stations, promoted the free exchange of scientific information and personnel, and supported joint scientific activities. The IGY set a precedent for cooperation and restraint. Its success led to a formal meeting among the 12 nations in Washington, D.C. in 1959 which produced the text of the Antarctic Treaty. Prior to the IGY, seven states (U.K., New Zealand, Australia, France, Norway, Chile, Argentina) had made territorial claims to sectors of Antarctica. Five states (U.S., U.S.S.R., South Africa, Japan, Belgium) neither made claims nor recognized the validity of claims made by the other nations (Fleischmann 1979; Scully 1979; Auburn 1982; Bilder 1982; Westermeyer 1982; Kimball 1983; Quigg 1983). Since its inception, four nations — Poland in 1977, West Germany in 1981, Brazil in 1983, and India in 1983 — have acceded to the Treaty and acquired Consultative Party status (Joyner 1983b). The Consultative parties set policy for activities in the Antarctic.

Nations active in Antarctica during the IGY recognized the uniqueness of the environment, and were primarily concerned with its preservation. The objectives of the Antarctic Treaty were to conserve the Antarctic ecosystem and to maintain the extant state of cooperation among nations. Westermeyer (1982: 306) states "[t]he Antarctic Treaty is . . . significant both for the provisions that have been included and for those that have been omitted. The basis for the present instability of the treaty lies in the fact the the difficult issues were shelved, not resolved." The Antarctic Treaty does not address the question of resource ownership, management or exploitation (Mitchell 1977; Tinker 1979; Joyner 1981, 1982, 1983a; Westermeyer 1982; Barnes 1982; Frank 1983; Kimball 1983; Fogleman 1983/84).

The living resources of Antarctica, especially krill (Euphausia superba) (Figure 1), represent a new and previously unexploited source of protein for the international community. Several nations have expressed interest in harvesting Antarctic living resources. However, there are two potential problems associated with the harvesting of krill: (1) krill are an essential food item for other Antarctic species (whales, seals, finfish, birds, squid), and a large-scale krill fishery could adversely affect both the biological and physical elements of the Antarctic ecosystem; and (2) uncertainty exists with regard to ownership of resources (Green 1977; Burton 1979; May 1979; May et al. 1979; Mitchell 1980; Beddington and May 1982; Westermeyer 1982; Quigg 1983; Fogleman 1983/84).

Interest in the development of a commercial fishery for Antarctic krill, the lack of a legal regime to govern and promote rational exploitation of Antarctic living resources, and a desire to avoid future conflict between claimants and non-claimants regarding the control of an Antarctic marine fishery, as well as the desire to set a precedent for management and exploitation of non-living resources were incentives for the negotiation of the Convention on the Conservation of

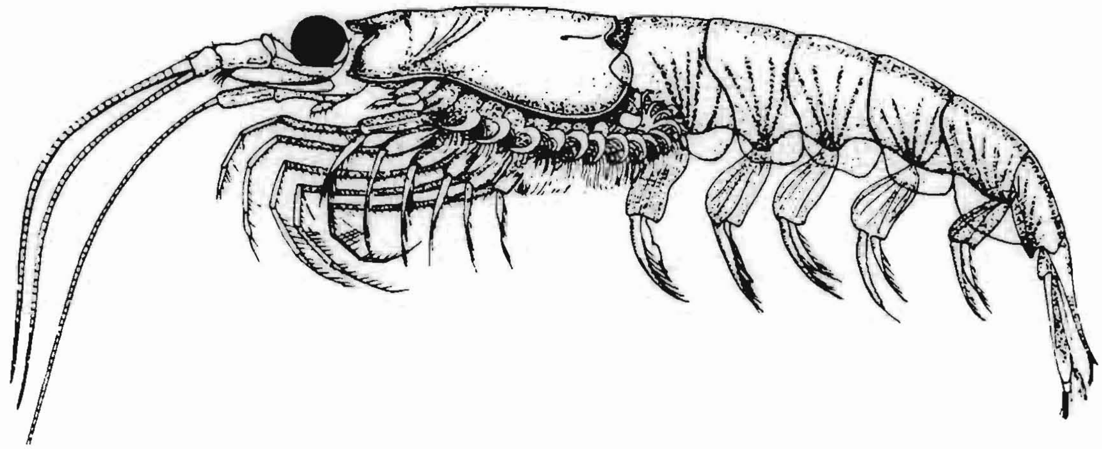

Figure 1. Euphausia superba (5 cm) - the krill of commercial interest in Antarctic waters (Everson 1977).

Antarctic Marine Living Resources (CCAMLR). Furthermore, the Antarctic Treaty Consultative parties wished to maintain and solidify their control and enhance their collective legitimacy in the Antarctic region. Concomitantly, the Treaty group wished to avoid the potential threat of interference from the rest of the international community (Barnes 1982).

The objectives of this paper are:

1. to define the Antarctic species of potential commercial interest;

2. to discuss the biology of Antarctic krill, *Euphausia superba*;

3. to evaluate the impact of a commercial krill fishery on the Antarctic ecosystem;

4. to evaluate and analyze the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR); and,

5. to determine whether the Convention can obtain the goal of ecosystem management -- allowing for "rational utilization" while protecting krill-dependent species in Antarctica.

Antarctic Marine Living Resources: The Potential Fishery

A number of harvestable species occur in the Southern Ocean, including whales, seals, fishes, crustaceans (krill), and cephalopods (squid) (Table 1). Although whales and seals have been commercially harvested in the past, krill, fish and squid are potentially important and currently underexploited food resources (Mitchell 1977; Everson 1977, 1978; El-Sayed and McWhinnie 1979; Westermeyer 1982; Fogleman 1983/84; O'Sullivan 1983; Knox 1983, 1984; Hamner 1984).

Seals

Sealing was the first commerical enterprise in the Southern Ocean. Southern fur and elephant seals were harvested as early as the 1770's. Fur seals were subject to uncontrolled harvesting and almost total

Zooplankton		
	Krill	*Euphausia superba*
		E. crystallorophias
		E. triacantha
		E. frigida
		Thysanoessa macrura
		T. vicina
Fish		
	Antarctic cod	*Notothenia rossii*
		N. gibberifrons
		N. coriiceps
		N. magellanica
		N. neglecta
	Antarctic tooth fish	*Dissostichus mawsoni*
	Patagonian tooth fish	*D. eleginoides*
	southern blue whiting or southern poutassou	*Micromesistius australis*
	Antarctic silverfish	*Pleuragramma antarcticum*
	icefish	*Channichthys rhinoceratus*
		Chaenocephalus aceratus
		Champsocephalus gunnari
		Pseudochaenichthys georgianus

Table 1. Common and scientific names of some species occurring South of the Antarctic Convergence (DOS 1978).

Squid	
giant squid	*Mesonychoteuthis hamiltoni*
other squid	*Moroteuthis ingens*
	Conatus fabricii
	Pareledone sp.
Birds	
Adelie penguin	*Pygoscelis adeliae*
Seals	
crabeater seal	*Lobodon carcinophagus*
leopard seal	*Hydrurga leptonyx*
Ross seal	*Omatophoca rossi*
Weddell seal	*Leptonychotes weddelli*
elephant seal	*Mirounga leonina*
fur seal	*Arctocephalus gazella*
Whales	
fin whale	*Balaenoptera physalus*
blue whale	*B. musculus*
sei whale	*B. borealis*
minke whale	*B. acutorostrata*
humpback whale	*Megaptera novaeangliae*
southern right whale	*Eubalaena australis*
sperm whale	*Physeter catodon*
killer whale	*Orcinus orca*

Table 1 (continued) (DOS 1978)

extermination. With the decline of the fur seal, hunters switched to the harvesting of elephant seals. However, the elephant seal industry was uneconomic, and exploitation was curtailed before stocks were reduced to critically low levels. A sealing industry has not existed in the Southern Ocean since 1964, except for Soviet exploratory harvesting of 100 crabeater seals in the early '70's. The Convention for the Conservation of Antarctic Seals (CCAS) was promulgated by the 12 Antarctic Treaty nations in 1972, and came into force in 1978 (Hammond 1980; Couratier 1983; O'Sullivan 1983; Quigg 1983; Zegers 1983).

There are six predominant seal species in Antarctica: Southern elephant, Crabeater, Ross, Leopard, Weddell and Southern fur Seals (Tables 2 and 3). The CCAS (Annex) established regulations and quotas for exploitation of crabeater, leopard and Weddell seals (175,000, 12,000, and 5,000, respectively), and prohibits the harvest of fur, elephant and Ross seals. The Soviet Union has recently expressed interest in establishing a sealing operation within the Antarctic (Everson 1977; Green 1977; O'Sullivan 1983; Quigg 1983; CCAS 1978; Knox 1983, 1984).

Whales

The Southern Ocean has been the world's major whaling grounds. The species of greatest commercial interest included the blue, fin, sei, minke, humpback and sperm whales (Table 4). Argentina, Japan, Panama, Norway, South Africa, the United Kingdom, the Netherlands and the Soviet Union have harvested whales in large quanitites since the early 1900s. The processing and harvesting capacity of the whaling industry increased substantially from the 1920's onward. The blue

Locality	Stock Size	Reliability
South Georgia	350 000	good
South Orkney Is.	1 000	poor
South Sandwich Is.	5 000	poor
Bouvetøya	1 000	poor
South Shetland Is.	3 000	poor
Isles Kerguelen	Unknown, if present probably few .	
Heard/McDonald	3 000	?

Table 2. Estimated stock sizes for Antarctic Fur Seals (Everson 1977).

Species		Stock Size (x 10^3)	Reference
Elephant Seal	*Mirounga leonina*	600 ± 100	Laws 1960, 1973; ACMRR
Crabeater Seal	*Lobodon carcinophagus*	15 000	Gilbert and Erickson 1977
Ross Seal	*Ommatophoca rossi*	(220)	Gilbert and Erickson 1977
Leopard Seal	*Hydrurga leptonyx*	(500)	ACMRR
Weddell Seal	*Leptonychotes weddelli*	(750)	ACMRR

Table 3. Species and stock sizes of Antarctic Phocid species (Everson 1977).

Species	Original Stock size (x 10^3)	MSY (x 10^3)	Present Stock size (x 10^3)	Authority
Blue	150	3-4	5-10	Chapman 1974
Fin	400	8	80	IWC 1976
Sei	(160)	4	89	IWC 1976
Minke	140	?	122	IWC 1976
Humpback	90-100	2-4	1.7-2.8	Chapman 1974
Sperm (O)	225	7	112	IWC 1976

Table 4. Stock assessments for Southern Hemisphere whales (Everson 1977).

whale (the largest species) was the first species harvested. As the population size of the blue whale decreased, whalers began to harvest fin, right, humpback, minke, sei and sperm whales. The International Whaling Commission (IWC) was established in 1946 to regulate the whaling industry. However, a drastic decline in whale stocks occurred despite the efforts of the IWC. Currently, only a few Japanese and Soviet whaling vessels operate in the Southern Ocean. The Japanese primarily harvest killer and minke whales for human consumption; while the Soviets preferentially harvest sperm whales for oil and minke whales for stockfeed meal, fertilizer, and medicines. The blue, humpback, fin, sei and right whales are protected species. The stock sizes of these species appear to be slowly increasing. However, investigators doubt that the stocks will ever reach their pre-whaling numbers. Krill are the predominant prey of baleen whales; while the toothed species consume large quantities of squid and fish (which are direct consumers of krill) (Table 5) (Everson 1977; Green 1977; Couratier 1983; O'Sullivan 1983; Knox 1983, 1984).

Fish

Only about 100 kinds of fish have been found south of the Antarctic Convergence. Nototheniiformes, a division comprising five families, form the dominant group in Antarctica. Two families, the Nototheniidae and Channichthyidae, contain the species of potential commercial importance due to the size and weight of individuals, and their abundance (Table 6). Antarctic cod, Antarctic toothfish, Patagonian toothfish, Antarctic herring, some ray species, and pelagic Southern blue whiting are known to occur in fishable concentrations

('000 metric tons)

Whale species	Consumption by initial whale stocks of Krill	Fish	Squid	Consumption by present whale stocks of Krill	Fish	Squid
Blue	71 700	1 478	740	3 400	70	35
Fin	81 500	1 680	840	16 400	339	169
Sei	5 700	116	58	2 900	60	30
Humpback	11 000	227	113	300	7	3
Minke	19 800	409	204	19 800	409	204
Sperm	-	500	10 200		244	4 632
Total	189 700	4 410	12 155	42 800	1 129	5 073

Table 5. Estimates of annual food consumption by whales in the Southern Ocean (Everson 1977).

Group	Species	Common Name
Rajidae	Raja georgiana R. murrayi R. eatonii	
Gadidae	Micromesistius australis	Southern Blue Whiting or Southern Poutassou
Merluciidae	Merluccius hubbsii	Patagonian Hake
Nototheniidae	Notothenia gibberifrons N. coriiceps N. neglecta N. rossii rossii N. rossii marmorata N. magellanica Dissotichus mawsoni D. eleginoides Pleuragramma antarcticum	 Marbled Notothenia Antarctic Tooth Fish Patagonian Tooth Fish
Channichthyidae	Champsocephalus gunnari Channichthys rhinoceratus Pseudochaenichthys georgianus Chaenocephalus sp. Chionodraco sp.	

Table 6. Fish species of potential commerical importance in the Southern Ocean (Everson 1977).

(Everson 1977, 1978; Barnes 1982; Boczek 1983; O'Sullivan 1983; Knox 1983, 1984).

The U.S.S.R. has commercially harvested Antarctic fish since 1967, and during the peak season of 1975-76 landed approximately 300,000 tons of fish (primarily Antarctic cod and herring, Southern blue whiting and Patagonian hake). The Soviets harvested 10,000 tons from the Kerguelen Island region during the 1981-82 season. Japan, the Federal Republic of Germany and Poland have launced exploratory fishing expeditions. The West Germans have been most successful with some fish catches exceeding those of the Soviet vessels. Fishing has been concentrated in the Atlantic sector of the Southern Ocean and off Kerguelen Island for shelf species. The fish are used primarily for human consumption, but some are reduced to fish meal. The fish stocks are probably fully utilised; some catches of most species have declined indicating possible over-exploitation (Everson 1978; Barnes 1982; Westermeyer 1982; Boczek 1983; O'Sullivan 1983).

Cephalopods

Squid are a critical group in the Antarctic ecosystem, constituting a large portion of the diet of sperm whales, seals, penguins and some fish species (Tables 7 and 8). There is a paucity of information on Antarctic cephalopods. Currently, there is not a cephalopod fishery in waters South of the Antarctic Convergence. However, investigators believe that squid species occur in fishable concentrations (Table 9). Squid fisheries exist in areas adjacent to the Southern Ocean (off Australia, New Zealand and South America) (Table 10) (Everson 1977; Green 1977; O'Sullivan 1983; Knox 1983, 1984).

Family	Stomach contents of		Nets
	Sperm Whale	Weddell Seal	
Onychoteuthidae	54%	32%	
Cranchidae	23%		25%
Histioteuthidae	11%		
Octopoda		35%	
Bathyteuthidae			42%
Brachioteuthidae			13%

Table 7. Important Cephalopod families (Everson 1977).

Consumer	Estimated Annual Consumption (t x 10^3)		Reference
Birds	5 900 - 7 900	7 000	Croxall (Unpubl. MS)
Seals		5 550	Laws 1977
Whales			Laws 1977
Baleen	441		
Sperm	4 632		
		5 073	
Total		17 623	

Table 8. Estimated present day consumption of Cephalopods in the Antarctic Zone (Everson 1977).

	Distribution (S. Hemisphere)	Vert. Range (m)	Size Mantle length/ weight (cm/kg)	Diet of Sperm Whales	Current Fishery	Notes	Reference
ONYCHOTEUTHIDAE							
Onychoteuthis banksii	Sub-Antarctic	0-150 (800)	30/1	X	X		1, 7
Moroteuthis ingens	Antarctic	0-400	100/25	X			1, 7
Moroteuthis robsoni	S. Atlantic	0-500	47/	X			1
THYSANOTEUTHIDAE							
Thysanoteuthis rhombus	S. Atlantic		60/				1
OMMASTREPHIDAE							
Nototodarus sloani sloani	New Zealand	0-500	40/1.5		X	See Section	1, 8
Nototodarus gouldi	Southern Australia	0-500	40/1.5		X	Small fishery. Preyed on by bluefin tuna	1, 3, 4
Todarodes sagittatus	S. Atlantic, S. Ind. S. Africa	0-800	50/3	X	X	Fished for bait	1, 5
Todarodes filippovae	Sub-Antarctic		40/1.5				
Illex argentinus	Patagonian Shelf	0-500	40/1.5		X		2
Martialia hyadesi	S. Pac. Convergence		40/1.5				2
Symplectoteuthis Oualaniensis	S. Ind. S. Pac. S. Afr.	0-1000	30/1		X		1
Dosidicus gigas	S. Pac. Chile	0-1000	150/25	X	X		1, 2, 6
Ommastrephes pteropus	S. Atl. S. Afr.	0-1000	40/2				1
Ommastrephes bartrami	S. Pac. Chile	0-1000	30/1.5				1
HISTIOTEUTHIDAE							
Histioteuthis bonelli	Sub-Antarctic	100-800		X			1
ARCHITEUTHIDAE							
Architeuthis sp.	Atl. Pac. Ind.		500/1000	X			1, 7
GONATIDAE							
Gonatus fabricii	Antarctic		20/1	X			1
(antarcticus)	Sub-Antarctic		20/1	X			1
LOLIGINIDAE							
Loligo sp.	Sub-Antarctic Patagonian Shelf S. Atl.	0-200			X		2
OCTOPODIDAE							
Pareledone sp.	Antarctic Sub-Antarctic					Demersal Shelf Area	

References:

1. Clarke 1966
2. Voss 1973
3. Anon 1964
4. Allen 1945
5. Nesis 1964
6. Nesis 1970
7. Listed by Castellanos (1964) as being of economic importance although no data available to suggest that commercial concentrations exist (Voss 1973)
8. Saito 1976

Table 9. Cephalopod species which may be present in the Southern Ocean in fishable concentrations (Everson 1977).

(metric tons)

	Statistical Area	1970	1971	1972	1973	1974	1975
Cuttlefish	47	100	0	(100)	0	(7)	16
	51	(7 100)	(9 100)	(13 800)	(11 800F)	5 359	3 665
	57	(100)	(100)	(100)	(300)	(580)	(476)
Squids (Loligo Sp.)	41	(700)	(500)	(500)	(600F)	(600F)	(540F)
	47	300	200	300	600	1 318	839
	57	(900)	(900)	(800)	(900)	(1 500)	(1 301)
	87	(300)	(400)	(700)	(300)	(92)	(466)
Illex	41	1 300	1 800	1 800	4 100	5 000	4 600
Nototodarus	57						232
	81				13 400	19 620	6 682
Other Squids	47	1 300	1 000	1 100	1 000	3 464	3 991
	51	0	0	500	700	800	242
	81	0	0	100	1 700	47	1 005
	87	(500)	(500)	0	0	—	—
Octopus	41	(200)	(100)	(100)	(100F)	(100F)	(100F)
	51					608	606
	57	0	100	100	0	(8)	(8)
	87	0	0	0	(100)	(19)	(13)
TOTALS		12 800	14 700	20 000	35 700	39 122	24 782

Table 10. Reported catches and landings of squid, cuttlefish and octopus from areas adjacent to the Southern Ocean. Figures in parenthesis refer to catches probably made well north of the Antarctic (Everson 1977).

Krill

The krill species of commercial interest in Antarctica is _Euphausia superba_. _E. superba_ is commercially attractive because of its nutritional value, shoaling characteristics, abundance (constituting between 10 and 50% of the zooplankton biomass), high protein content, and the ease with which it can be harvested. Krill tend to congregate in swarms of a single age class. These swarms average 40 x 60 meters in size. Estimates of the standing stocks of krill vary widely (Tables 11 and 12) and range from 125 million metric tons to 6 billion metric tons (Hamner, 1984). The standing stock of "unutilized" krill is purported to exceed the combined world harvest of all other marine species (the estimated total world catch for 1980 was 72 million tons) (Figure 2) (Everson 1977; El-Sayed and McWhinnie 1979; Alverson 1980; Holdgate 1983; O'Sullivan 1983; Knox 1984; Hamner 1984).

Incentives for the development of a commercial krill fishery include: (1) most of the conventionally harvested species are either fully exploited or over-exploited, (2) there has been an increase both in human population growth and in demand for animal protein, and (3) the encroachment of coastal state jurisdiction with the establishment of 200-mile Exclusive Economic Zones (EEZs) has negatively impacted the fishing industries of nations with distant water fishing fleets (U.S.S.R, Japan), and these nations must look elsewhere for marine species. The demand for greater supplies of food fish will require the utilization of unconventional species (krill, mesopelagic fish) (El-Sayed and McWhinnie 1979; Robinson 1980; COFI 1983a, 1983b; Couratier 1983; Powell 1983).

Biomass (million metric tons)	Source
44.5–521	Marr (1962)
750	Gulland (1970)
5000 –7500	Moiseev (1970)
953 –1350	Makarov and Shevtsov (1972)
800	Lubimova et al. (1973)
125 –200	Everson (1977)

Table 11. Estimates of krill biomass (Knox 1984).

Production (million metric tons)	Source
110	Foxton (1956)
50–500	Gulland (1970)
153	Mackintosh (1970)
1500–2250	Moiseev (1970)
25–50	Lubimova et al. (1973)

Table 12. Estimates of krill annual production (Knox 1984).

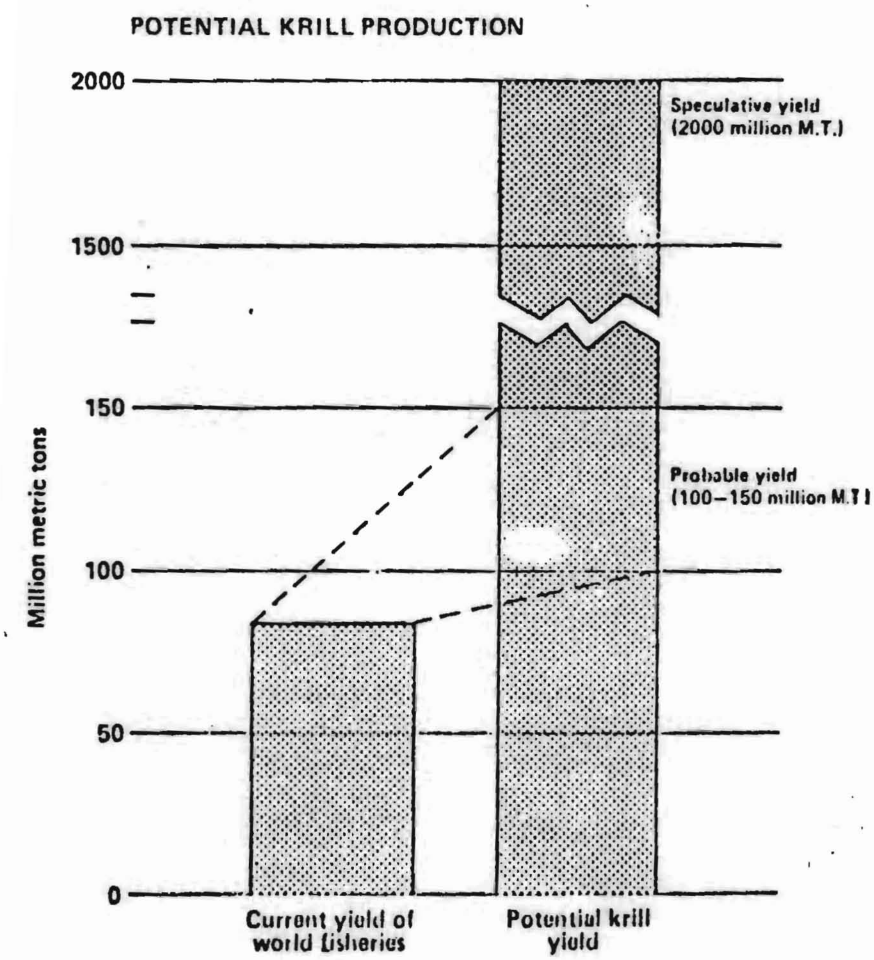

Figure 2. Comparison of potential krill production with the current yeild of world fisheries (Alverson 1980).

Exploratory harvesting of krill began in the 1960s with the U.S.S.R. (Figure 3). Japan entered the krill industry shortly thereafter. Chile, Argentina, Poland, F.R.G., G.D.R., Taiwan, Korea, and Spain have expressed interest in the development of a commercial krill industry. Krill products have been marketed experimentally in Japan, the U.S.S.R., Chile, West Germany, Poland, Norway, and Australia. Products include whole krill boiled and frozen, or canned, krill sticks, coagulated paste used in other products, krill mince, and krill protein concentrate. However, there are several problems associated with the harvest of krill including: (1) krill are a critical component of the Antarctic food web, and are directly or indirectly consumed by all Antarctic species, (2) consumer acceptance of krill and krill products has not been overwhelming, (3) krill decompose rapidly after harvesting, (4) their small size creates problems in designing appropriate processing techniques, and (5) the short fishing season (about 5 months), hazardous navigation conditions, remoteness of the area and high cost of fuel preclude establishment of a cost-effective industry. Despite the costs, fishing fleets harvested about 500,000 metric tons of krill during the 1981-82 summer season (Grantham 1977; Bakus et al. 1978; El-Sayed and McWhinnie 1979; Alverson 1980; Boczek 1983; O'Sullivan 1983; Fogleman 1983/84; Hamner 1984; Knox 1984).

Biology of *Euphausia superba*

Krill are euphausid crustaceans constituting 85 species worldwide. There are six commonly occurring species in the Southern Ocean (Figure 4): *Euphausia superba*, *E. crystallorophias*, *E. vallentini*, *Thysanoessa macrura*, *E. frigida*, and *E. triacantha*. Krill have a circumpolar

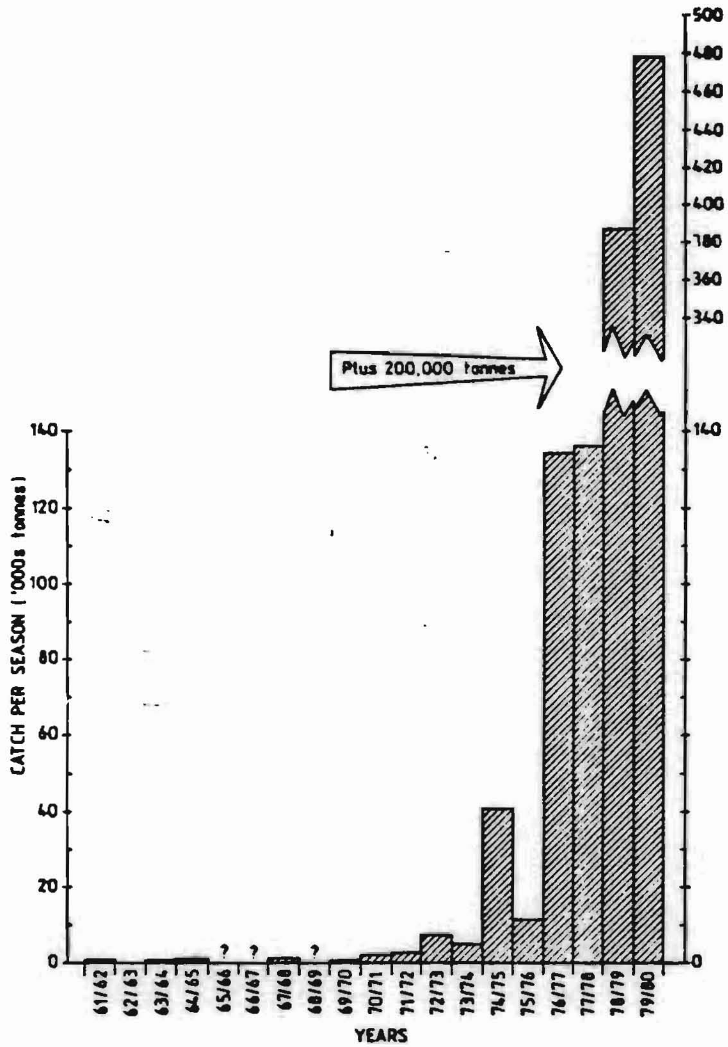

Figure 3. Total krill catches in the Southern Ocean (Knox 1984).

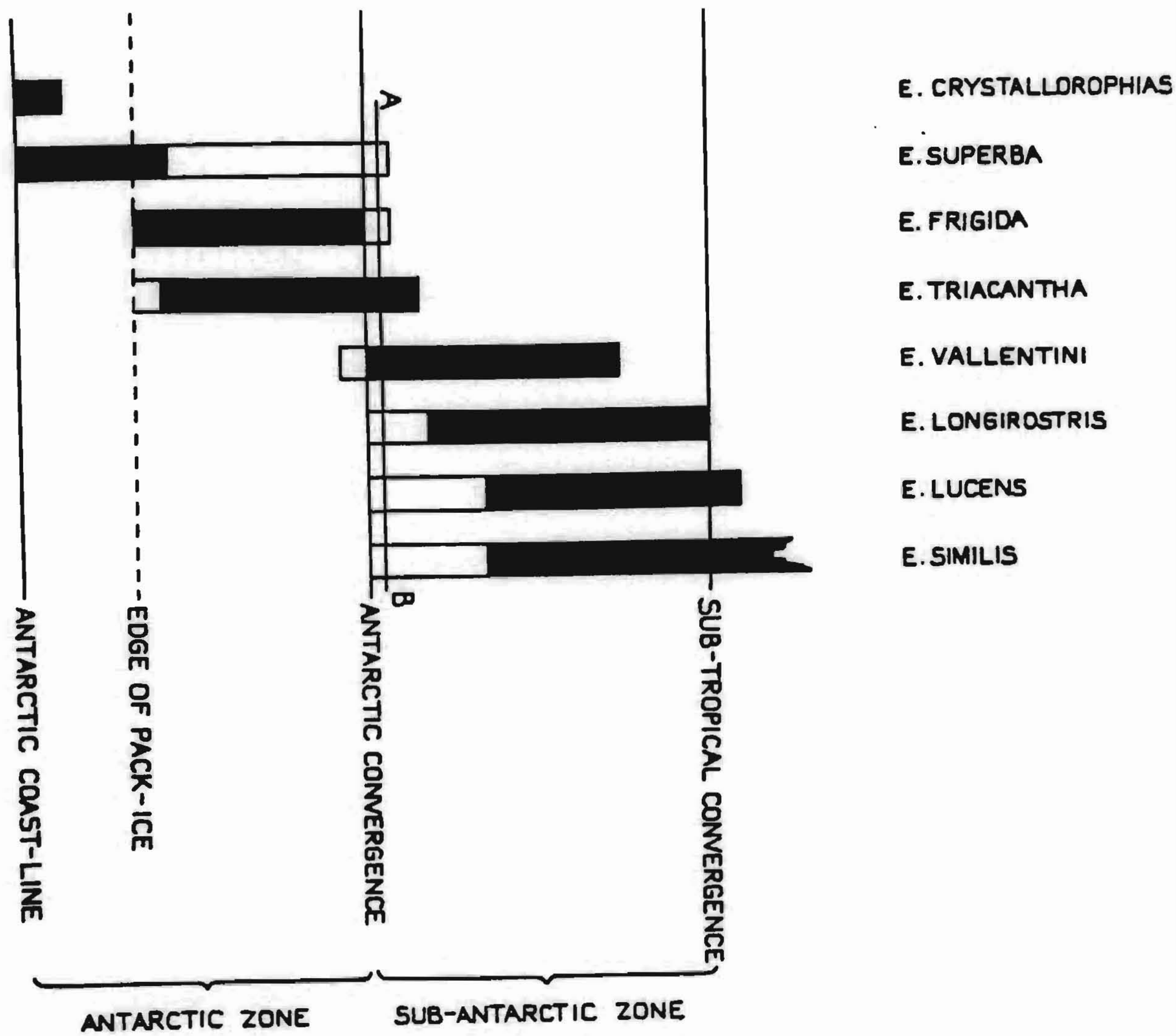

Figure 4. Distribution of Euphausia species in the surface waters of the Antarctic and sub-Antarctic zones. The blacked in portion of each column shows the normal range of that species, the entire column the possible range (Everson 1977).

distribution but are most abundant in the Weddell Sea, the East Wind Drift, the Weddell Drift, the Scotia Sea, and off South Georgia (Figure 5). Euphausids occur both under ice and in open waters. The largest and most abundant species is *E. superba*. *E. superba* is the Antarctic species of commercial fisheries interest (henceforth krill refers to *E. superba*). *E. superba* congregate in dense swarms in the upper 100 meters of the water column, and are restricted to waters south of the Antarctic Convergence. *E. superba* exhibits extremely patchy distribution, and the density of swarms varies highly. Very little is known of the biology, ecology, and behavior of Antarctic krill. Effective fisheries management schemes depend on recruit-death models which require information on reproduction and development of target species (Everson 1977; Bakus et al. 1978; Department of State 1978; El-Sayed and McWhinnie 1979; Ettershank 1983; Fogleman 1983/84; Sissenwine 1984).

The following discussion is a review of the literature on the biology of krill, and is restricted to discussion of *E. superba* both because of its potential for commercial exploitation and its importance in the Antarctic ecosystem.

Spawning and Development

E. superba spawns in the surface layers and eggs develop through sequential larval stages: Nauplius (2 stages), Metanauplius, Calyptopes (3 stages), and Furcilia (6 stages). According to the developmental ascent hypothesis (Figure 6), eggs sink to 500-2000 m or more; early larval stages (nauplii, metanauplii) occur at these depths. Subsequent larval stages ascend and occur at shallower depths (less than 200 m) (Ikeda 1984). George (1980) found that krill larvae are

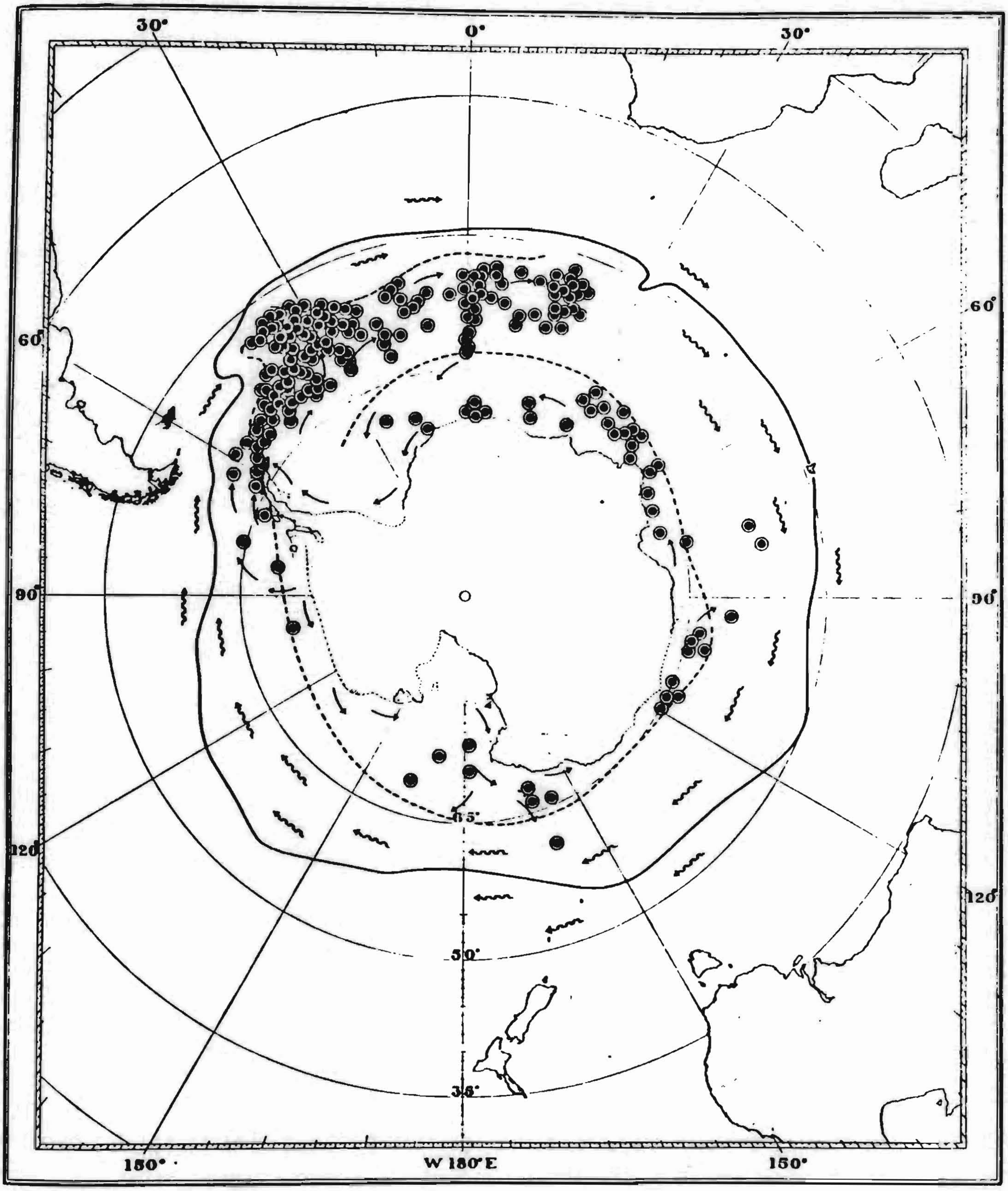

Figure 5. Principal concentrations of Antarctic krill (DOS 1978).

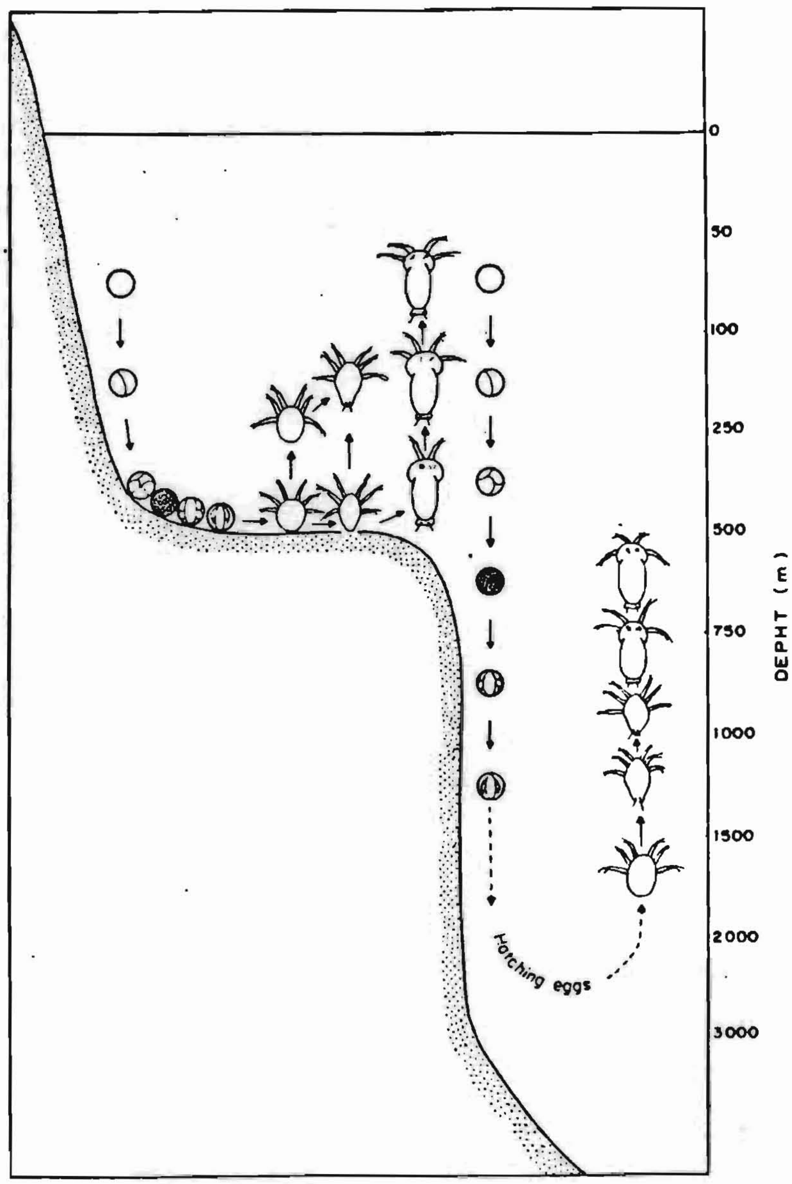

Figure 6. Vertical distribution and migration of the early development stages of krill on the shelf (left), and in deep water (right) (Everson 1977).

more tolerant of high pressure than post-larval stages (juveniles, adults). Investigators believe that depth (probably pressure) is necessary for development (Everson 1977; Ikeda 1984). However, results from laboratory experiments on the development of eggs and nauplii of E. superba led Marshall and Hirche (1984) to conclude that high hydrostatic pressure is not necessary for spawning or normal development of eggs. The ecology of krill larvae is not fully understood (Everson 1977; Ikeda 1984).

Ikeda (1984) determined developmental time and nutritional requirements of krill larvae raised from eggs in the laboratory. Nauplius I and Metanauplius stages appeared at 8 and 20 days, respectively, after egg release. Total development time from egg to the final larval stage was 127 days. Calyptopes I is the first feeding stage; subsequent growth of larvae depend on food abundance and temperature. The results of starvation experiments indicated that food availability is an important factor determining the successful development of larvae from Calyptopes I to the final larval and adult stages.

Ross and Quetin (1983) determined the spawning frequency of E. superba in the laboratory. Previous investigators proposed that krill spawn only once or twice during the spawning season (Everson 1977; El-Sayed and McWhinnie 1979; Denys and McWhinnie 1982), and estimated fecundity to be between 2,000 and 3,000 eggs per spawning. Ross and Quetin (1983) observed multiple spawning behavior (9-10 times per season) with an average of 2,500 eggs produced per spawning per female. The investigators estimated egg production at 22,000 eggs $female^{-1}$ $season^{-1}$, which is twice that of estimates made by other investigators. The results further indicate that oogenesis is relatively short (weeks not months), and E. superba (like the anchovy) continuously produces eggs over the spawning season. In conclusion, females have higher fecundities then previously estimated. These results have important implications for the management of a krill fishery (Ross and Quetin 1983) since information about survivorship and fecundity within a population are critical to effective fisheries management (Beddington and May 1982).

Ettershank (1983) investigated age structure and cyclical annual size change in E. superba. Krill do not carry overwintering stores of fat (Ikeda and Dixon 1982). Krill revert to an immature form as a part of their overwintering strategy, and regress in size after spawning. The results negate the traditional method of studying age structure of krill populations through length-frequency histograms. The assumption that large krill are older is therefore not necessarily correct (Ettershank 1983; Ikeda and Dixon 1982).

Feeding and Anti-predator Behavior

Krill are omnivores, consuming a wide variety of food types. However, phytoplankton is the predominant food item in their diet (Bakus et al. 1978; Hamner et al. 1983). Krill form high density swarms and use rheotactic cues supplied by the wake of preceding animals to maintain schools. Swarming may be a strategy associated with food acquisition and predator defense (Antezana et al. 1982; Hamner et al. 1983).

Morris et al. (1983) determined the nature of the interaction between feeding activity, swarming behavior and vertical migration. Field sampling of a krill patch over the South Georgia continental shelf indicated a diurnal rhythm of swarming behavior, vertical migration and gut fullness. Laboratory data revealed that krill feed throughout a 24-hour period, with peak activity at night. Furthermore, filtration rate is inversely proportional to krill density.

Morris and Ricketts (1984) studied a krill patch near South Georgia, sampling at 4 depths (0-3, 10-50, 70-100, and 100-150 meters), 6 times a day for 6 consecutive days. Field experiments provided data on the interactions among feeding, swarming and vertical migration of krill and allowed the contruction of a simple feeding model for krill. The results indicate a correlation between time of day and stomach fullness, but not between time of day and gut fullness. Stomachs were fuller during and immediately after darkness, reflecting an increase in the level of filtration activity. Depth did not affect stomach, hepatopancreas or gut fullness. These results challenge previous assumptions which suggest a strong linkage between feeding behavior and vertical migration.

A number of behavioral defenses have evolved in prey species to deter predators. Gregarious behavior appears to be an effective anti-predator strategy. Gregarious behavior is "a form of cover-seeking in which each animal tries to reduce its chance of being caught by a predator" (Hamilton 1971: 295), and appears to prevail in habitats that lack suitable shelter. The literature suggests that anti-predator defense and enhancement of other important activities, i.e., foraging, reproduction, and mate attraction are important advantages of group living (Zahavi 1970; Lazarus 1972; Alexander 1974; Wilson 1975; Morse 1977; Bertram 1978; Rubenstein 1978; Wittenberger 1981; Antezana et al. 1982; Hamner et al. 1983). Crustaceans often form aggregations which function in predator defense (Baal 1953; Carlisle 1957; Stevcic 1971;

Powell and Nickerson 1965; Bertness 1981) through a "selfish herd" strategy (Hamilton 1971: 295). Carlisle (1957) listed predator protection during molting as the primary advantage of aggegrations in spider crabs. Maja squinodo aggregate in heaps when in shallow water, due to increased vulnerability to predators; in deep water the heaps disperse. The structure of aggregations reflects its anti-predator function: subordinate crabs occur within heaps, while dominant crabs (with larger claws) are on the surface or away from heaps (Stevcic 1971).

Predators affect the activity patterns and reproductive and life history strategies of crustaceans. Results of field and laboratory investigations led Stein and Magnuson (1976) to conclude that the predatory fish Micropterus dolomieui affected the distribution and behavior of the crayfish, Orconectes propinquus. The behavioral change in juvenile and female Orconectes, because of higher vulnerability, was more pronounced than the response of large, adult males. In the presence of Micropterus, there was a decrease in foraging time and active behavior (walking, feeding) and an increase in defensive behavior (burrowing, chelae display). Furthermore, crayfish selected the substrate that provided the most protection from the predator.

In tropical hermit crabs, Calcinus obscurus and Clibanarius albidigitus, two behavioral responses — the escape response and formation of aggregations -- occur in anti-predator defense. The more effective escape response in Calcinus reflects the differential survival of this species compared to Clibanarius. Furthermore, experiments indicated fewer successful predation attempts on grouped, compared to solitary Clibanarius (Bertness 1981).

The anti-predator strategy of the lobster, Homarus americanus changes during development. In larval and early juvenile stages, Homarus relies on an escape response (the tail flip); as adults aggressive defense occurs more frequently. Changes in anti-predator behavior probably reflect varying physiological constraints during different stages of the life cycle (Lang et al. 1977).

Strong (1973) observed variability in the duration of amplexus for three populations of the amphipod Hyalella azteca. Amplexus increases the apparent size and decreases rate of movement in amphipods making individuals more susceptible to predators. Amplexus in populations under high predation pressure was much shorter than in populations experiencing little or no predation.

Predator identity determines the morphology, behavior, and life history strategies of the phantom midges Chaoborus flavicans and C. obscuripes. C. flavicans occurs in habitats rich in visual (fish) predators. As a result, C. flavicans exhibits diel migration patterns (Stenson 1981). Zaret and Suffern (1976) proposed that vertical migration in zooplankton was an adaptation to visual predators. C. flavicans migrates towards the sediment during the day, is morphologically lightly pigmented and emerges later in the year. C. obscuripes is exposed to non-visual (benthic) predators. Diel migrations do not occur in this species and individuals are darkly pigmented (compared to C. flavicans). Emergence occurs earlier in the year due to foraging requirements. Through selective feeding fish predators enhance prey availability for C. flavicans resulting in emergence later in the year (Stenson 1981).

Morris et al. (1983) and Antezana et al. (1982) suggest that swarming in krill may have an anti-predator function. Like juvenile lobsters, krill exhibit tail flipping behavior in response to disturbance (Hamner et al. 1983). Hamner et al. (1983) observed synchronous molting in a school of *E. superba* when disturbed by divers. The abandoned molts gave the visual impression that the school was still present. Presumably, the molts serve as decoys for visual predators. This behavior is unique since crustaceans are believed to molt only in response to hormonal cues.

The Antarctic Ecosystem, Exploitation of Krill and Fisheries Management

Krill occupy a critical position in the Antarctic marine food web (Figure 7). Estimates of annual krill consumption by higher trophic levels include: baleen whales — 42.8 million metric tons; crabeater seals -- 106 million metric tons; Leopard, Ross and Fur seals (indirect consumption through predation on fish and squid) -- 4 million metric tons; penguins and winged birds -- 39 million metric tons; fish and squid -- 100-200 million metric tons (Tables 13 and 14) (El-Sayed and McWhinnie 1979: 17). The total consumption of krill by natural predators equals or exceeds the minimum estimate for standing stocks of krill (Green 1977; Laws 1977; Burton 1979; El-Sayed and McWhinnie 1979; May et al. 1979; Beddington and May 1982; Joyner 1981, 1982, 1983a).

Justification for exploitation of Antarctic krill is based on the premise that there is currently a krill "surplus." The "surplus" is derived from the difference between the amount of krill consumed annually by the original whale stocks and that consumed by extant stocks (Tables 15 and 16). Several investigators suggest that the "surplus" has become available to other consumers. Evidence for this hypothesis is the increased growth rates, earlier age at maturity, and higher pregnancy rates for baleen whale species; earlier age at

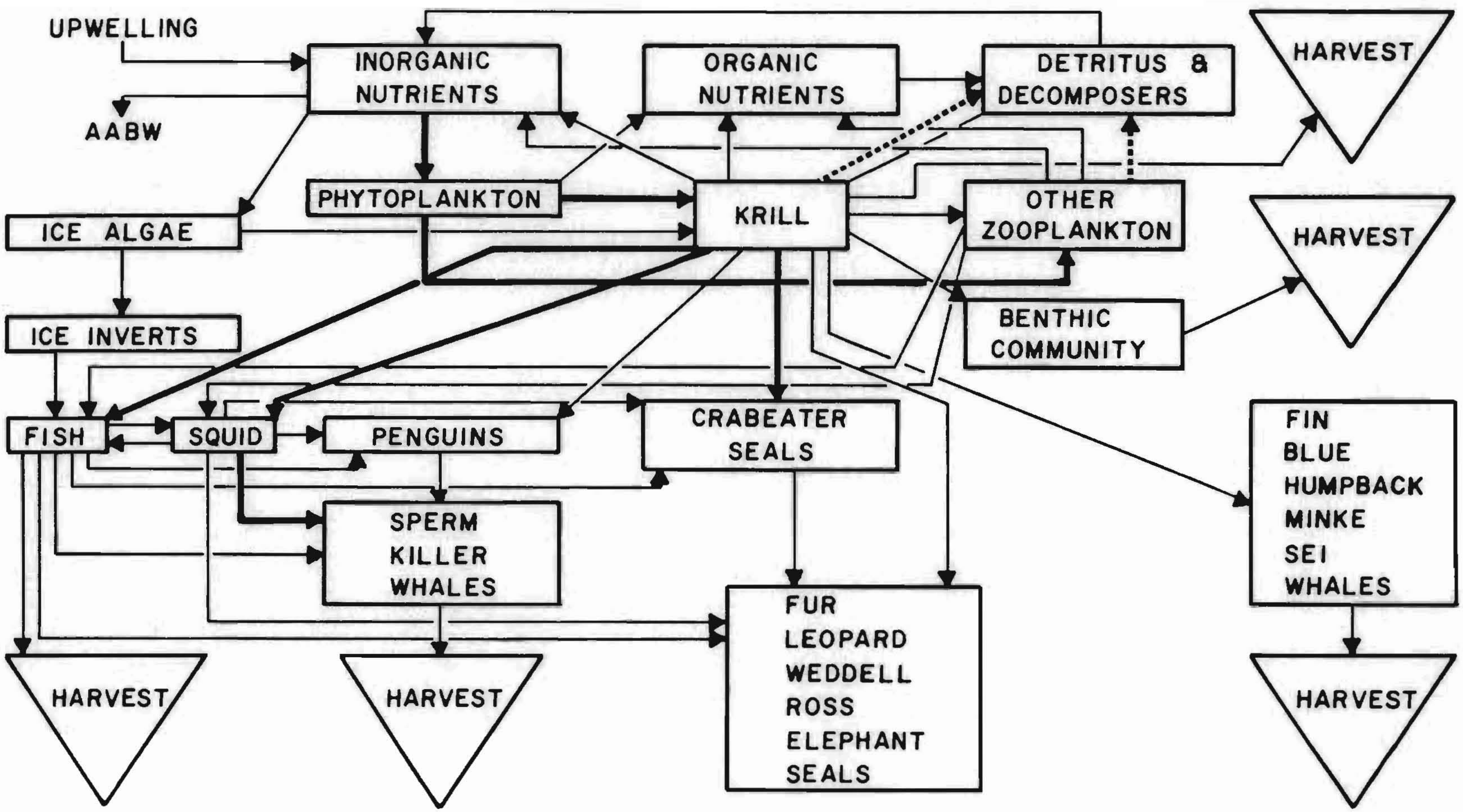

Figure 7. Food web relationships in the Antarctic marine ecosystem (DOS 1978).

TO \ FROM	Ice Algae	Ice Invert.	Phyto-plankton	Krill	Other Zoopl.	Fish	Squid	Birds
Ice Algae								
Ice Inverts.	90							
Phyto-plankton								
Krill	75		2500					
Other Zoopl.	75	4	2000					
Fish		10		64	11		6	
Squid				100	34	2		
Penguins				14.4		1.8	1.8	
Crabeater Seals				106		3	2	
Other Seals				3.1	1	7	4.7	0.5
Baleen Whales				42.8				
Toothed Whales						0.5	4.6	0.3

Table 13. Annual total consumption. Units 10^6 metric tons net weight (Green 1977).

STOCK	ESTIMATED AVERAGE POPULATION SIZE	X BODY WEIGHT EATEN/YR	ANNUAL FOOD CONSUMPTION		
			TOTAL	KRILL	OTHER
Phytoplankton Production	6080 (16 $gC/m^2/yr$: Holm-Hansen, et al 1975) 9500 (25 $gC/m^2/yr$: Green 1975) 15200 (40 $gC/m^2/yr$: Currie 1964) assumes area 34×10^6 km^2 and 1 gC : 10 g wet weight				
Krill	200 - 600 (Woods Hole conference) 225 (75 dry wt.: Gulland 1970) 183 (P·B 1.8:1: Allen 1971, and 330 as P estimate, chart) 930-1350 (Makarov and Shevkov, 1972) calculations used 250 ave. and 600 max				
Other zoopl	same as krill (Gulland 1970)				
Fish	14 (Green 1977, based on predation estimates)	6.5 Everson 1970	91	64	27
Squid	12.4 (Green 1977, based on predation estimates)	11 Hurley 1976	136	100	36
Birds	0.27 (Prevost, in press)	67	18	14.4	3.6
Crabeater	3 (Laws 1977) 4-6 (Siniff and Hofman, pers. com.) calculations use 5.5	23.45 Oritsland 1977	111	106	5
Other seals	Ross 0.38 (Laws 1977) fur 0.015 (Laws 1977) elephant 0.3 (Laws 1977) Weddell 0.25 (Hofman, p.c.) leopard 0.2 (Hofman, p.c.) total 0.8	23.45	18.7	3.1	15.6
Baleen whales	blue 0.8 (Laws 1977) fin 4 " humpback 0.08 " sei 0.7 " minke 1.4 "	4.2 (Lockyer 1976) 14.6	3.5 16.9 0.3 3.0 20.4	3.4 16.4 0.3 2.9 19.8	0.1 0.5 0 0.1 0.6
Toothed whales	sperm 1.16 (Laws 1977) killer 0.05 (rough guess)	4.2 25	4.9 1.25	0 0	4.9 1.25

Table 14. Stock and krill consumption estimates. Units 10^6 metric tons wet weight (Green 1977).

Author	Krill eaten by initial whale stock Ton x 10^6	Krill eaten by present whale stock Ton x 10^6	Potential "Surplus" Ton x 10^6
Marr (1962)	38	-	-
Studentskiy (1967)	-	270	-
Kasahara (1967)		24 - 36 (Fin Whale)	
Zenkovich (1970)	150	-	-
Mackintosh (1970)	120 - 170	(10)****	100 - 150
Hempel (1970)	45 - 60	-	-
Gulland (1970)	>50	-	-
Nemoto (1970)*	77	-	-
Doi (1973)**	200	-	-
Lyubimova *et al.* (1973)	(800 - 5000)***	-	-
Ohmura	250	(40)****	100 - 200
Laws (1977)	-	-	153
Laws (in press)	190	43	147

Table 15. Estimates of annual consumption of krill by whales (Everson 1977).

	Estimated consumption of krill prior to whaling million ton/year	Estimated consumption now million ton/year
Whales	190	43
Seals	(?)	64
Birds	(?)	15 - 20
Squid	(?)	(100 ?)
Fish	(?)	(?)
TOTAL	> 190	> 200

Table 16. Estimated consumption of krill by major predators (Everson 1977).

maturity for crabeater seals; and significant population increases in fur seal stocks and penguin populations. The average age at sexual maturity has decreased from 4 to 2.5 years in crabeater seals. The best-documented increases in population size occur in areas of greatest overlap between whales and other species in the past (Everson 1977; May 1979; Beddington and May 1982; Holdgate 1983). In conclusion, the concept of a krill "surplus" available for commerical exploitation is negated by the "likelihood" that the Southern Ocean is moving towards a "new equilibrium." The "surplus" is contributing both to an increased standing crop of krill and increased population growth among higher trophic levels (i.e., baleen whales, seals, penguins, sea birds, fishes, squid) (May et al. 1979; Beddington and May 1982: 66).

The Antarctic marine ecosystem is unique in that one species, E. superba, sustains a wide variety of predators, either through direct or indirect consumption (whales, seals, penguins, birds, squid, and fishes) (Holdgate 1983). Traditional simplistic single-species models of fisheries management are unsuitable for application to multispecies situations. The guiding principle in single-species models is maximum sustainable yield (MSY). Furthermore, environmental and biological parameters are treated as constants, and harvesting and management strategies assume exact knowledge of a fishery system (i.e., population size, catch, fishing effort, recruitment) (Beddington and May 1977; Bengston 1978; May et al. 1979; May 1980; Sissenwine 1984). May et al. (1979: 268-372) present three models for harvesting of interacting populations which illustrate the problems associated with managing a system by managing the individual yield of species without regard to species interactions. In the Antarctic ecosystem, the maximum sustainable yield of krill corresponds with the extinction of whales and other krill predators, while the MSY of whales is achieved by not fishing for krill (May et al. 1979; Beddington and May 1980).

In conclusion, krill is a critical component of the Antarctic food web. Currently, too little is known about the life history parameters of krill to justify extensive commercial harvesting. Exploitation will displace some predators, especially the chief krill consumers, and could adversely impact the recovery of endangered whale species. Man as a harvester cannot exactly replace whales as a predator in the Antarctic food web. The evidence suggests that the Antarctic ecosystem has already adjusted partially to the reduced whale population. Potential impacts associated with an extensive krill harvest include: (1) a shift in community structure, (2) adverse effects on target as well as dependent and related species, (3) increased competition for food among krill predators, and (4) indirect impacts arising from increased ship traffic in Antarctica (pollution, disruption of spawning grounds, habitat destruction) (Green 1977; Bengston 1978).

CCAMLR: Objectives, Provisions, and Problems

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was signed by fifteen states (G.D.R., F.R.G., Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, Poland, South Africa, U.S.S.R, U.S.A.) in May, 1980. Observers from the European Communities, the FAO, the Intergovernmental Oceanographic Commission, the International Union for the Conservation of Nature and Natural Resources, the IWC, the Scientific Committee on Antarctic Research and the Scientific Committee on Ocean Research also attended. The CCAMLR entered into force on 7 April 1982, with the requisite eighth ratification (Hammond 1980; Auburn 1982; NSF 1982; Joyner 1983a, 1983b; Quigg 1983; Fogleman 1983/84).

Accelerated interest among nations to harvest krill, establishment of 200-mile EEZs and the exclusion of distant water fleets from traditional fishing grounds, the absence of international law pertaining to Antarctic living resources, fear of interference from nations and organizations outside the Antarctic Treaty framework, a desire to unequivocally establish authority in the Southern Ocean area by Treaty Consultative Parties, the need to pacify and reconcile differences between claimants and non-claimants, and the fact that the major portion of the resources occurs within 200 miles of islands in the most disputed sectors of Antarctica, were incentives for negotiation of the CCAMLR (Auburn 1982; Barnes 1982).

The objective of the Convention is to manage the harvesting of Antarctic marine living resources. Articles I and II are the foundation of the attempt for renewable resource conservation (Hammond 1980; Joyner 1983b). The area of applicability under the Convention is defined in Article I, and incorporates a much larger area than that under the auspices of the Antarctic Treaty. Antarctic marine living resources are defined as all populations found south of the Antarctic Convergence. Signatories recognized the interdependence of all components of the ecosystem. Article I (3) states "[t]he Antarctic marine ecosystem means the complex of relationships of Antarctic marine living resources wih each other and with their environment" (Hammond 1980; CCAMLR 1982).

Article II contains the key conservation provision. Article II (1-2) defines the objective of the Convention as the conservation of

Antarctic marine living resources where conservation includes rational use. Furthermore, Article II (3a-c) states:

> 3. Any harvesting and associated activities in the area to which this Convention applies shall be construed in accordance with the provisions of this Convention and with the following principles of conservation:
>
> (a) prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment;
>
> (b) maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in sub-paragraph (a) above;
>
> (c) prevention of changes or minimization of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources.

The Antarctic Treaty and the CCAMLR are closely linked. An objective was to solidify the Consultative Parties' control over decision making in Antarctica and the adjacent coastal zone, and to legitimize their self-imposed status as protectors and managers of the Antarctic region (Barnes 1982). Article III binds CCAMLR Contracting Parties, regardless of their relationship to the Antarctic Treaty, to Articles I and V of the Antarctic Treaty (CCAMLR 1982). Article I of the Antarctic Treaty establishes that "Antarctica shall be used for peaceful purposes only" and prohibits ". . . any measure of a military nature . . ." Article V prohibits nuclear testing and radioactive waste disposal in Antarctica. Article IV of the CCAMLR binds all contracting parties to Articles IV and VI of the Antarctic Treaty. Article IV of the Antarctic Treaty (and the CCAMLR) deals with the sovereignty problem. States do not compromise previous territorial claims to Antarctica by signing the Treaty. Furthermore, Article IV prohibits new claims and does not require states to recognize existing claims (Ant. Treaty 1959; CCAMLR 1982). Article IV freezes the existing nations from asserting their pre-existing legal positions with regard to claims of territorial sovereignty (Bilder 1982). Article VI delimits the area of Antarctica applicable under the Antarctic Treaty, but does not define the area of high seas (Ant. Treaty 1959; Westermeyer 1982). Article V (1) requires all contracting parties to ". . . acknowledge the special obligations and responsibilities of the Antarctic Treaty Consultative Parties for the protection and preservation of the environment of the Antarctic Treaty area." Futhermore, all Parties ". . . will observe . . . the Agreed Measures for the Conservation of Antarctic Fauna and Flora and such other measures as have been recommended by the Antarctic Treaty Consultative Parties in fulfillment of their responsibility for the protection of the Antarctic environment . . ." (Article V (2)) (CCAMLR 1982).

The Convention creates a special body, the Commission for the conservation of Antarctic marine living resources (Article VII), whose function is ". . . to give effect to the objective and principles set out in Article II . . ." (Article IX (1)). A Scientific Committee is established (Article XIV) which "shall provide a forum for consultation and cooperation concerning the collection, study and exchange of information with respect to the marine living resources . . ." of

Antarctica (Article IV (1)). Furthermore, the CCAMLR establishes a Secretariat.

Although quite an accomplishment, the Convention suffers from both procedural and substantive flaws. First, the Convention is burdened with a double-vetoe system. Article IX provides an objection procedure regarding conservation measures allowing any Party 90 days to notify the Commission that a conservation measure is unacceptable; upon notification, the Party is not bound by that measure. Article XII requires concensus voting on "matters of substance," and "the question of whether a matter is one of substance shall be treated as a matter of substance" (CCAMLR 1982; Barnes 1982; Boczek 1983; Frank 1983; Joyner 1983b).

Second, Article XXIV requires establishment of an observation and inspection system. However, observers and inspectors are subject only to the jurisdiction of their respective nations, and do not work directly for the Commission (CCAMLR 1982; Barnes 1982; Boscek 1983).

Third, the CCAMLR, like the Antarctic Treaty, fails to address the sovereignty issue. Fourth, there is a pronounced orientation towards exploitation of resources rather than protection and preservation of the marine environment. Fifth, national catch and effort restrictions are not established. Absence of a national quota system could result in over-capitalization in the fishery. Sixth, the scope of authority granted the Scientific Committee is limited thus precluding sound decision making regarding harvesting levels. Finally, the system for dispute resolution is unsound. Article XXV requires the peaceful settlement of disputes through ". . . negotiation, inquiry, mediation, conciliation, arbitration, judicial settlement, or other peaceful means . . .", if unresolved Article XXV (2) recommends referral to the

ICJ. However, conciliation or arbitration are not compulsory (Barnes 1982; Boczek 1983; Joyner 1983b; Frank 1983).

Discussion

Until recently, international law pertaining to the conservation, management and exploitation of Antarctic marine living resources did not exist. Prior to ratification of the CCAMLR, the only international agreements relating to Antarctic living resources were the Convention for the Conservation of Antarctic Seals and Agreed Measures for the Conservation of Antarctic Fauna and Flora (Hammond 1980).

Accelerated interest in exploitation of Antarctic living resources provided the impetus for negotiation of the CCAMLR. First, the present world fishery situation precludes further exploitation of traditionally harvested species since most are either fully exploited or over-exploited. The rate of growth of the world-wide fish catch has declined precipitously over the past decade. Concurrently, the forces influencing demand -- population and income -- have grown. The greatest growth in demand for protein will be in developing countries, where the rate of population growth is highest. Supplies of food fish may be increased through exploitation of unconventional species (krill, mesopelagic fish), utilization of pelagic species for human consumption rather than as material for fish meals, and through aquaculture (Gulland 1977; Robinson 1980; COFI 1983a, 1983b).

Second, the recent trend towards the establishment of 200-mile EEZs, with coastal state control over a variety of activities including fishing by foreign nations, and the exclusion of nations from these zones has and will force distant water fishing fleets to explore for and exploit less conventional species. Third, the heightened demand for protein both in less developed and developed countries, and for seafood of good quality at a reasonable price forecasts the need to enter new fisheries (Gulland 1977; El-Sayed and McWhinnie 1979; Robinson 1980; COFI 1983a, 1983b).

In 1980, the total world catch was estimated at 72 million tons, reflecting a considerable decline in rates of growth in world catches (from approximately 6% per annum to approximately 1%). Furthermore, projections for the year 2000 estimate a world population of 6 billion people who (at 1980 levels of consumption) will require an additional 19 million tons of fish (COFI, 1983b: 2). Therefore, Antarctic finfish and krill are of considerable commercial interest. Poland, East Germany, and the Soviet Union harvested nearly 300,000 tons of finfish in 1977. The Antarctic cod was extensively harvested by the Soviet Union in the early '70s, possibly beyond its sustainable yield. Some investigators speculate that krill could be "one of the world's largest untapped living resources" (Barnes 1982: 241). Standing stocks of krill are estimated between 125 million and 6 billion metric tons (Hamner 1984: 642). Exploratory harvesting for krill began with the Soviets and Japanese, and in recent years, a large number of nations have expressed interest in harvesting krill (Bakus et al. 1978; Joyner 1981; Barnes 1982; Hamner 1984; Knox 1984).

Fishing nations justify the harvesting of krill through the notion that there exists a krill "surplus," resulting from the severe depletion of traditional krill predators (i.e., baleen whales). Commercial harvesting of whales has significantly altered the Antarctic marine ecosystem. However, the data suggest that the stocks of other Antarctic species (birds and seals) and extant whale species have adjusted to the krill "surplus." Extensive harvest of *E. superba*, given their central role in the Antarctic ecosystem, is likely to negatively impact both the recovery of endangered whale species and survivorship of co-occuring seal, bird, fish and squid species. Dayton (1972; cited in Bengston 1978: 107) defines "foundation species" as low-trophic level species which are major contributers to community structure. These species are critical to the preservation of the community. Studies on the interrelationships of species in an ecosystem indicate that competition and predation are important factors in shaping community structure. Predators are known to impact prey populations, typically depressing population size. Predation also promotes co-existence among highly competitive species (Connell 1961a, 1961b, 1970; Paine 1966, 1971; Krebs 1978; Roughgarden 1979; Schoener 1982).

In recognition of these ecological principles, as well as incentives discussed earlier, the Antarctic Treaty Parties negotiated the text of the Convention on the Conservation of Antarctic Marine Living Resources. The key element in the Convention is the ecosystem approach, rather than reliance on traditional single-species fisheries models. Most fisheries agreements have focused on harvested species, establishing quotas to maximize the annual sustainable yield. Single-species deterministic models describing the interactions between fish and harvesters are based on equations that treat environmental and biological parameters as constants, and therefore ignore an important feature of fishery systems - uncertainty (Beddington and May 1977; May et al. 1978; May et al. 1979; May 1980; Sissenwine 1984). Sissenwine (1984: 21) states "The central problem facing fishery scientists and fishery managers is to understand and deal with recruitment variability." The multispecies approach reduces the problem of uncertainty (Sissenwine 1984).

The Convention parties adopted the maximum net productivity (MNP, Article 3(a)) criterion. MNP is defined as the point where birth minus death is maximized, and where the population grows at its fastest rate. MNP is calculated with reference to the initial unexploited population size (Barnes 1982).

In conclusion, although an admirable and innovative beginning, the CCAMLR is riddled with ambiguity and uncertainty. First, an ecosystem approach to management requires knowledge of the biology of target, associated and dependent species. Ecological relationships with the biotic and abiotic environment are not well documented for E. superba. An integral component of effective fisheries management is comprehension of the biology and ecology of the target species, including data on distribution, abundance, behavior and interactions with other species. Second, the Convention is faulty with regard to the double-vetoe system, its failure to establish national catch and effort restrictions, the limited authority granted the Scientific Committee, and the system for dispute resolution. The ideal of long-term conservation may be superseded by the goal of short-term exploitation. Third, the viability of the Convention is threatened by the potentially volatile claims dispute. Finally, it is unlikely that the international community will continue to accept the self-delegated special status of the Antarctic Treaty group (Barnes 1982; Boczek 1983; Joyner 1983b; Frank 1983). Currently less developed countries demand a New International Economic Order to increase their roles in world decision-making processes and to assure a more equitable distribution of world wealth. LDCs favor a sovereign equality that recognizes their right to full participation in decisions that affect their welfare (Juda 1979). The Convention provides a framework for an international strategy based on rational exploitation and conservation. However, the ecosystem goal of fisheries management depends on accumulation of information describing the biology of target and dependent species, and their interactions. Furthermore, the efficacy of the Convention may be enhanced only through continued international cooperation, communication and compromise.

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