the ambient field can often have a number of sources, some targets and some interferers and since there are complicated propagation effects, the design of trackers is difficult. Most involve some form of Kalman filtering and some have integral propagation models.

Advanced beamforming

Most passive sonars are based upon a plane wave model for the ambient field components. Plane wave beamforming is robust, has several computational advantages, and is well understood. However, in many sonars this model is not adequate because the arrays are so long that wavefront curvature becomes an issue or the arrays are used vertical where acoustic propagation introduces multipaths. Advanced beamforming concepts can address these issues.

Wavefront curative becomes important when the target is in the near field of the array (usually given by the Fresnel number $2L^2/\lambda$) which is a consequence of either very long arrays or high frequencies. A quadratic approximation to the curvature is often used and the array is actually designed to focus it at specific range (rather than at infinite range which is the case for plane waves). When focused at short ranges, long-range targets are attenuated. This introduces the focal range as another parameter for displaying the sonar output.

At long ranges and low frequencies or in shallow water acoustic signals have complex multipath or multimode propagation which leads to coherent interference along a vertical array or a very long horizontal array. The appropriate array processing is to determine the full field Green's function for the signal and match the beamforming to it, a technique known as matched field processing (MFP). MFP requires knowledge of the sound speed profile along the propagation path, so its performance depends upon the accuracy of environmental data. It is a computationally intensive process, but has the powerful advantage of being able to resolve both target depth and range, as well as azimuth. MFP is an active subject of passive sonar research.

See also

Acoustic Scattering by Marine Organisms. Acoustics, Deep Ocean. Acoustics, Shallow Water.

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SOUTHERN OCEAN FISHERIES

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History

The history of harvesting living resources in the Southern Ocean goes back two centuries. Soon after South Georgia was discovered by Captain Cook, hunters arrived in search of fur seals (*Arctocephalus gazella*). Between 1801 and 1822, over 1 200 000 skins were taken there before the sealers moved on to the South Shetlands. The extent of the carnage was such as to bring the species close to extinction by the 1870s. In the early twentieth century elephant seals (*Mirounga leonina*) were harvested at South Georgia because their blubber provided higher-grade oil than that from whales. A strong management regime was instituted in 1952, which allowed the population to recover from earlier overexploitation. Elephant seals were also harvested at Macquarie Island, although there was less of a link to the whaling industry.

Whaling has been the largest fishing operation in the Southern Ocean. Initially this was shore-based but, with the introduction of floating factories in 1925, catching vessels could search much of the

Southern Ocean. Overcapitalization of the industry and, in the early years, a lack of robust population models to provide management advice, meant that the industry declined. Research at that time, particularly by Discovery Investigations, provided much valuable information not only on whales but also on their food, krill.

With the decline in shore-based whaling, fishing fleets from Japan and the former Soviet Union turned their attention to harvesting fish and krill. Scientists expressed several concerns over this development: First that there was no international fishery regime in place for the region; second that an unregulated fishery on krill could lead to overexploitation as had happened with the whales; and third that significant fishing of krill might adversely affect the recovery of baleen whales.

Member states of the Antarctic Treaty, an agreement that arose directly from scientific collaboration during the International Geophysical Year, agreed that a management regime needed to be established for Southern Ocean resources. The first step was the Convention for the Conservation of Antarctic Seals, which came into force in 1972 even though there was at that time no harvesting of seals or any intention voiced to that end. Scientific advice underpinning this agreement come from the Scientific Committee for Antarctic Research (SCAR). The establishment of the BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks) program in 1976, again through support from SCAR, in collaboration with the Scientific Committee for Oceanic Research (SCOR), International Association of Biological Oceanography (IABO) and Advisory Committee on Marine Resources Research (ACMRR), led naturally to the Convention for the Conservation of Antarctic Marine Living Resources, negotiated in 1980 coming into force in 1982.

Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)

The overriding concern leading to the establishment of CCAMLR was that overexploitation of krill might adversely affect dependent species. This is encapsulated in Article II as a series of general principles of conservation that in summary form set out in paragraph 3 state that any harvesting shall be conducted in such a way as to

(a) prevent the decrease in the size of the harvested population to levels below those which ensure its stable recruitment;
(b) maintain the ecological relationships between harvested, dependent, and related populations; and
(c) prevent changes or minimize the risk of changes in the marine ecosystem that are not reversible over two or three decades.

Subparagraph (a) is essentially a statement of the traditional single-species approach to fisheries management and setting an upper limit to the total catch that can be taken for any individual species. This maximal level – which, it should be noted, is a limit and not a target – must then be reduced to take account of the dependent species as required by subparagraph (b). Finally, there is the requirement in subparagraph (c) that any ecological changes should be reversible within a finite and limited period.

These three components of Article II encapsulate what has come to be known as the ecosystem approach to management of marine living resources. CCAMLR was the first international fisheries commission to make this a central plank of its management regime, and even though the approach has received wide approval it is only now, twenty years later, that it is beginning to be considered for implementation in other forums.

The Antarctic Treaty covers the land and ice-shelves south of 60°S with an agreement that all territorial claims within that region are 'frozen.' Essentially this means that anything other than sovereignty can be discussed. At the time of the negotiation of CCAMLR it was known that the distribution of Antarctic krill and some finfish stocks extended some way north of the Treaty zone. Accordingly, the CCAMLR region was designated to cover the area south of the Antarctic Convergence (now called the Antarctic Polar Frontal Zone, APFZ). This area is designated by lines joining parallels of latitude and meridians of longitude, that are set out in Article I paragraph 5, which approximate the Antarctic Convergence. For the most part the fit is good, but for political reasons some small parts were excluded. Within the region between the Convergence and latitude 60°S lie several Sub-Antarctic islands for which sovereignty is claimed by member states of CCAMLR. Prior to the conclusion of negotiation of the CCAMLR Convention, France had declared a 200 mile exclusive economic zone (EEZ) around Kerguelen and Crozet and obtained agreement that, through what has become to be known as 'The Chairman's Statement' of 19 May 1980, within the zone France would take note of CCAMLR advice but would be free to implement its own policy. Subsequently, other claimant states of Sub-Antarctic islands have implemented a similar policy to France.

Krill

Although originally applied to 'fish fry,' the term krill is now taken to refer to euphausiids, of which six species occur in the Southern Ocean. Of these the only one that is targeted commercially is the Antarctic krill, *Euphausia superba*. Antarctic krill are small shrimplike crustacea that grow to a maximum length of 65 mm. They are widely distributed in the Southern Ocean south of the APFZ. On the continental shelf they are replaced by their smaller congener *E. crystallorophias*. Concentrations are normally found close to islands and the continental shelf break and have in the past been considered as constituting separate populations or management units. Although they are carried around the continent on the Antarctic Circumpolar Current (ACC), the extent of mixing between groups of krill from different regions is not clear.

The sheer size of the Southern Ocean, allied to the fact that much of it is covered in sea ice, means that it has never been possible to estimate the standing stock over the whole region. Synoptic surveys have been undertaken over part of the region in the Atlantic and Indian Ocean sectors. The most recent in the Atlantic sector, CCAMLR Area 48 (see **Figure 1**), gave an estimated standing stock of 44 Mt, while a survey in the Indian Ocean sector in 1996 gave estimated values of 3.04 Mt between 80° and 115°E and 1.79 Mt between 115° and 150°E.

In common with many zooplankters, krill undergo diurnal vertical migration within the top 200 m, although the pattern is not consistent with time or locality. They are often found at the surface at night, although daytime surface concentrations are not infrequent. They frequently occur in swarms with a density of several thousand individuals per cubic meter and it is these swarms that are targeted by commercial fishers.

Antarctic krill are filter feeders dependent primarily on phytoplankton. Arising from this, in the early season 'green' krill, with large amounts of chlorophyll in the hepatopancreas, predominate. These green krill are associated with a 'grassy' flavour to products manufactured for human consumption. Later in the season, colorless 'white' krill predominate.

Estimates of production have been based on consumption of krill by dependent species and, even allowing for considerable uncertainty over the conversion factors, indicate that production is over 100 Mt a year.

Commercial fishing began in the 1960s and had reached 1000 t a year by 1970. Initially these catches were reported to FAO in the category 'Unspecified Marine Crustacea' and, although they are generally thought to refer to krill, the figures do not match those subsequently reported to CCAMLR as krill. By the late 1970s the total reported catch had risen to over 300 000 t, giving cause for concern that a very rapid and large-scale expansion of the fishery might be imminent. The main fishing nations at that time were the former Soviet Union, Japan, and Poland. With the collapse of the former Soviet Union, the total reported catch is now dominated by Japan, which has continued to take around 60 000–70 000 t per year. Apart from Japan and Poland, small catches have been reported in recent years by Bulgaria, Chile, Korea, Russia, Ukraine, and the United Kingdom (see **Table 1**).

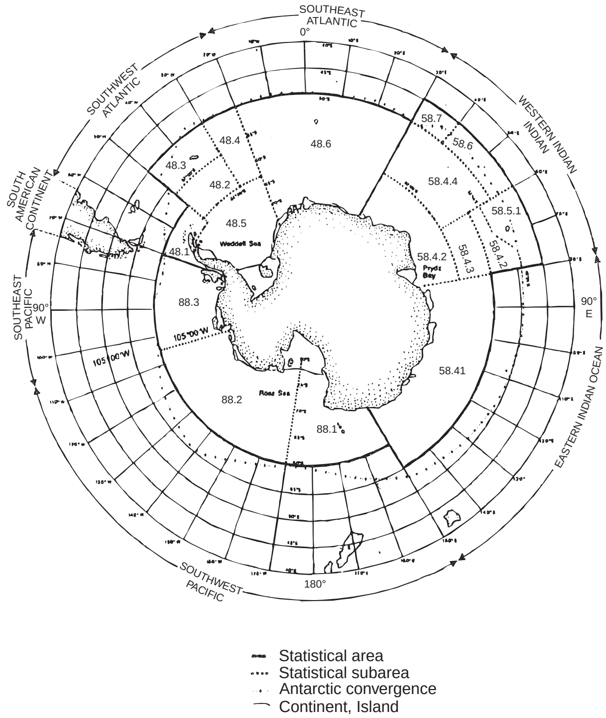

Figure 1 CCAMLR Statistical Areas, subareas, and divisions.

In the early years of the fishery, catches were reported from the Indian and Atlantic Ocean sectors with relatively small amounts coming from the Pacific sector. During the 1990s the pattern has changed such that virtually all catches are taken from the Atlantic sector. In the summer months this is predominantly the Antarctic Peninsula (Subarea 48.1) and South Orkneys (Subarea 48.2); and in the winter, because the more southerly grounds are closed owing to sea ice, around South Georgia (Subarea 48.3).

In the early years a variety of fishing methods were attempted. Early attempts at developing surface trawls, with a codend pump, towed alongside the fishing vessel failed because of the cumbersome

Table 1 Annual reported catches (tonnes) of Antarctic krill by nation

Year	*Japan*	*Poland*	*USSR*	*Russia*	*Ukraine*	*Argentina*	*Bulgaria*[a]	*Chile*	*E. Germany*	*Korea*	*Spain*	*Latvia*[a]	*Panama*[a]	*UK*
1970														
1971														
1972														
1973	59													
1974	646		19 139											
1975	2 677		41 352											
1976	4 750		609					276						
1977	12 802	6 966	71 656					92						
1978	25 219		106 991				94		8					
1979	36 961		295 508				46		102	511				
1980	36 275	226	440 516					0	0	0				
1981	27 698	0	420 434					0	0	0				
1982	35 116	0	491 656					0	0	1 429				
1983	42 282	360	180 290					3 752	0	1 959				
1984	49 531	0	74 381					1 649	0	5 314				
1985	38 274	0	150 538					2 598	0	0				
1986	61 074	2 065	379 270					3 264	0	0				
1987	78 360	1 726	290 401					4 063	0	1 527	379			
1988	73 112	5 215	284 873					5 938	0	1 525				
1989	78 928	6 997	301 498					5 329	0	1 779				
1990	62 187	1 275	302 376					4 501	396	4 040				
1991	67 582	9 571	275 495					3 679		1 211				
1992	74 325	8 607		151 725	61 719			6 066		519				
1993	59 272	15 911		4 249	6 083			3 261		0				
1994	62 322	7 915		965	8 852			3 834		0		71		
1995	60 303	9 384			48 886			0		0			141	
1996	60 546	20 610			20 056			0		0			495	
1997	58 798	19 156			4 246			0		0			0	308
1998	63 233	15 312			0			0		1 618			0	634
1999	71 318	18 554			5 694	6 524		0		1 228			0	

[a]Not a member state of CCAMLR when the catches were made.

nature of the gear and the relative infrequency of daytime surface swarms. Likewise, purse seines have proved impractical. Currently, midwater trawls with a mouth area of 500–700 m^2 and a fine mesh throughout are used. Krill swarms are detected using directional sonar and the fishing depth of the net is adjusted by reference to a netsounder. When regions of high concentration have been found, the vessels continue to fish on them without spending a great deal of time in searching farther afield. Haul duration is generally controlled to ensure a maximum catch of 7–10 t. This is because with large catches the krill tend to became crushed in the cod end and product quality suffers.

Over several seasons Japanese fleets have changed their fishing patterns, delaying the commencement of fishing until late in the austral summer and continuing through to the winter so as to avoid catching 'green' krill; products made from green krill have a lower market value than white krill. There is also a preference for larger krill, which, owing to diurnal vertical migration, tend to be deeper by day than small krill, a factor reflected in the fishing depth.

Much effort has been expended in developing krill products for direct human consumption, but much of the current catch has been used for domestic animal feed and, particularly in recent years, for aquaculture feed. The Japanese fishery produces four types of product: fresh frozen (46% of catch), boiled frozen (10% of catch), peeled krill meat (10% of catch), and meal (34% of catch). These are used for aquaculture and aquarium feed (43% of catch), for sport fishing bait (45% of catch), and for human consumption (12% of catch). There are plans for further products such as freeze-dried krill and krill hydrolysates, although currently these are only at an early developmental stage.

In the 1970s high contents of fluoride were reported from krill. This was found to be localized to the exoskeleton, where it can reach 3500 μg F per g dry mass, although concentrations in the muscle appear to be less than 100 μg F per g dry mass. Providing the krill are peeled soon after capture or the whole krill are frozen at a temperature lower than $-30°C$, the fluoride concentration in the muscle remains low.

Finfish

Fisheries for finfish developed very quickly. In 1969 and 1970 around 500 000 t of fish were taken from the South Georgia, and in 1971 and 1972 a further 300 000 t were taken from Kerguelen. Although the catches were initially reported to FAO as 'Unspecified Demersal Percomorphs' it is widely assumed that the dominant species in the catches was *Notothenia rossii*. Smaller catches in following years were reported from South Shetland and South Orkney Islands. These catch rates were unsustainable and the species remains at a low stock level. Other species that were taken at this time included grey rockcod, *Lepidonotothen (Notothenia) squamifrons*, and mackerel icefish, *Champsocephalus gunnari*. During the 1980s and coincident with the start of CCAMLR, catches of other species were reported including *Chaenocephalus aceratus, Chaenodraco wilsoni, Channichthys rhinoceratus, Chionodraco rastrospinosus Pseudochaenichthys georgianus*, *Dissostichus eleginoides, Gobionotothen (Notothenia) gibberifrons* and *Patagonotothen guntheri*. There was also a fishery for Myctophidae, principally *Electrona carlsbergi*, which reached a peak of 78 000 t in 1991 but ceased two years later coincident with the collapse of the former Soviet Union. In recent years the only target species have been mackerel icefish and Patagonian toothfish.

Mackerel Icefish

The mackerel icefish is a Channichthyid; these 'white blooded fish' are the only group of vertebrates that do not have erythrocytes or any effective blood pigment. They occur on the shelf in waters rarely more than 500 m deep. Spawning is thought to occur in fiords and bays during April and May and the eggs, > 3 mm diameter, hatch in the spring coincident with the spring primary production bloom and new generations of copepods in the plankton. The fish become sexually mature at around 3 years of age when they are 25 cm in total length. Their diet is predominantly krill, although they will take a variety of other species, particularly when krill are scarce.

At Kerguelen it has been possible to follow growth through several years by analysis of length distributions. Of particular interest is a three year cycle in the population. It is not clear whether this is a natural phenomenon or one induced by fishing pressure. At South Georgia there have been similar fluctuations in stock size, although in that case they have been attributed to enhanced predation pressure by fur seals at times of krill scarcity.

Initially bottom trawls were used in the fishery but these were banned by CCAMLR in the early 1990s to reduce damage to the benthic environment. The use of midwater trawls, as well as having a much reduced impact on benthic biota, is also accompanied by reduced by-catches. Currently there are limited trawl fisheries at Kerguelen and South Georgia. The fish are generally headed and gutted and then frozen; they fetch a price similar to that of

Table 2 Toothfish catches (tonnes) by area[a]

Subarea/Division	Estimated total catch	Reported catch 1996/97	Estimated unreported catch from catch/effort data	Unreported catch as % of the estimated total catch
South Georgia (48.3)	2389	2389	Probably low	Probably low
Prince Edward Is. (58.7)	14286	2386	11900	83.3
Crozet Is. (58.6)	19233	333	18900	98.2
Kerguelen (58.5.1)	6681	4681	2000	29.9
Heard Is. (58.5.2)	8037–12837	837	7200–12000	89.6–93.4
All subareas	48856–53656	10856	38000–42800	77.8–79.8

[a]Reported in relation to unreported catch of toothfish during the 1996/97 season. The unreported catch is estimated from market landings, numbers of vessels seen, and observed catch rates. (Anon, 1997.)

medium-small to medium sized cod. The fillets contain slightly more fat than average whitefish.

At Kerguelen the management regime has been operated exclusively through the French authorities. Around South Georgia a Total Allowable Catch (TAC) has been set based on production estimates using trawl survey results. The most recent TACs have been based on the lower 95% confidence limit from the surveys.

Toothfish

There are two species of the genus *Dissostichus*, which are broadly separated geographically. *D. mawsoni* is present in the high Antarctic close to the continent, whereas *D. eleginoides* is present around sub-Antarctic islands and extends outside of the Antarctic zone to Patagonia and the west coast of South America. Toothfish are the largest Nototheniid fish in the Southern Ocean, growing to a maximum length of over 2 m and mass of around 100 kg. They are relatively slow-growing reaching sexual maturity at around 90–100 cm. Spawning is thought to occur in the latter part of the winter.

At Kerguelen a trawl fishery has become established in various parts of the shelf, with trawlers mainly from France and Russia. The management regime is implemented by French authorities.

In the early years at South Georgia, toothfish appeared as a by-catch in the trawl fishery, sometimes to the extent of a tonne of fish in a haul. Toward the end of the 1980s, long-liners from the former Soviet Union began fishing at the shelf slope around South Georgia and obtained good catch rates. With the increasing fishing effort being applied, concern was expressed at the sustainability of the resource. Owing to the high value of the catch, other nations have joined the fishery; these include Argentina, Bulgaria, Chile, Korea, Ukraine, and the United Kingdom. Two types of long-line system are used: Mustad Autoliner and the Spanish system with a ground line and parallel fishing line. The lines are baited with squid, horse mackerel or sprats and fished on the bottom for around 12 h in water around 1000 m deep.

It is possible that the by-catch of rays and grenadiers may be significant, although at present data are scarce. Of much greater concern is the incidental mortality caused to seabirds that attack the baits as the lines are shot. Very low recruitment of albatrosses to the breeding populations at South Georgia has been directly attributed to mortality caused by long-line fishing, not only for toothfish within the Southern Ocean but also due to tuna long-lining over much of the Southern Hemisphere. It has been demonstrated that restricting the setting of lines to the hours of darkness together with weighting the lines is adequate to eliminate this mortality, if applied diligently.

Toothfish fetch a high price on international markets and this has been a major cause of illegal and unregulated fishing within the Southern Ocean. This reached a peak in 1997 when over 90% of catches in some areas were thought to have been taken outside of CCAMLR regulations. To combat this activity, CCAMLR has introduced a catch documentation scheme whereby only fish that have been taken in compliance with CCAMLR Conservation Measures can be issued with a valid certificate. This measure is having a positive effect as currently certificated catches attract a price of around $10 000 per tonne whereas uncertificated catches fetch only around $3000 per tonne (see **Table 2**).

Crabs

There are two species of crab in the waters around South Georgia, *Paralomis spinosissima* and *P. formosa*. In the early 1990s there was an exploratory study to fish them. In view of the lack of knowledge of either species, CCAMLR imposed a rigorous fishing plan for the study. Following fishing in the area during 1993, when 299 t were caught, and 1996, when 497 t were caught, the fishing company decided that these catches were uneconomic and did not pursue the matter. Subsequently there have been expressions of interest by other companies, but no further fishing activity.

Squid

For many years it has been known that squid figure in the diets of many predators in the Southern Ocean. Regurgitated stomach content samples from albatrosses and petrels indicated that in many cases these squid were quite fresh, leading to the conclusion that they had been taken from adjacent waters. Exploratory ventures in 1989 and 1996 by Korean squid jiggers found small concentrations of *Martialia hyadesi* close to the APFZ in summer and on the South Georgia shelf in winter. World market prices of squid have meant that further ventures are likely to be only marginally profitable. However, advances in processing whereby the second tunic can be easily removed may change this situation in the near future.

Southern Ocean Management Regime

The sections of Article II of the CCAMLR Convention provide a clear framework for the management regime. In the first instance, harvested species need to be managed such that their long-term sustainability is not threatened by commercial activities. This requirement can be met through the application of traditional fisheries models and others developed within CCAMLR such as the Krill Yield Model (KYM) and Generalized Yield Model, the underlying principles of which are set out below.

1. To aim to keep the krill biomass at a level higher than would be the case for single-species harvesting considerations.
2. Given that krill dynamics have a stochastic component, to focus on the lowest biomass that might occur over a future period, rather than on the average biomass at the end of that period, as might be the case in a single species context.
3. To ensure that any reduction of food to predators that might arise out of krill harvesting is not such that land-breeding predators with restricted foraging ranges are disproportionately affected compared to predators in pelagic habitats.
4. To examine what levels of krill escapement are sufficient to meet the reasonable requirements of predators.

The KYM has the general formula [1], where Y = yield, B_0 = median unexploited biomass, and γ = proportionality coefficient.

$$Y = \gamma B_0 \quad [1]$$

Currently two values of γ are calculated. The first, γ_1, is chosen such that the probability of the spawning biomass dropping below 20% of its pre-exploitation median level over a 20-year harvesting period is 10%, and the second γ_2 is chosen so that the median krill escapement over a 20-year period is 75%. The lower of γ_1 and γ_2 is selected for the calculation of krill yield. These principles are applied so as to account for sustained consistency in catch with time while at the same time taking account of uncertainties in the estimators. This implies a conservative approach to the application of fishery models in pursuit of the precautionary principle; this approach is followed in the advice that comes forward from the Scientific Committee and is implemented by the Commission. Within this overall framework, due regard has to be taken of the requirements of dependent species – the ecosystem approach.

Early in the history of CCAMLR it became apparent that a wide range of interpretations can be put on the definition of an 'ecosystem approach.' At one extreme is an endeavor to understand all interactions in the food web in order to formulate management advice. Such an approach is favored by idealists on the one hand and those who did not wish to see any form of control on the other. It is impracticable because no advice would emerge in a timely manner. Recognizing this, CCAMLR has set up an Ecosystem Monitoring Program (CEMP) whereby certain features of a small suite of dependent species are monitored. Currently the CEMP species are Adelie, chinstrap, gentoo, and macaroni penguins; black-browed albatross; fur seal and crabeater seal. Key parameters associated with the ecology of each of these species are monitored according to a series of agreed CEMP protocols. The aim of the program is to determine how the dependent species perform in response to krill availability and how this is affected by fishing activities. CEMP parameters integrate krill availability over different time and space scales, varying from months and hundreds of kilometers in the case of the total mass of individual penguins on arrival at a colony at the start of breeding, to days and tens of kilometers in the case of foraging trip duration while feeding chicks. These provide indicators of overlap with commercial fishing. The other components monitored relate to the vital rates of dependent species – changes in population size, mortality, and recruitment – and progress is currently in hand to integrate these into the overall management process.

Recent papers have linked variations in krill distribution and standing stock to climate change and El Ñino–Southern Oscillations through their effects on the ACC and sea ice regime. The CCAMLR management scheme implicitly takes account of such long-term environmental change because its regime can be adjusted to compensate as the monitored species and variables change with time.

See also

Crustacean Fisheries. Current Systems in the Southern Ocean. International Organizations. Krill. Marine Mammals, History of Exploitation.

Further Reading

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SPERM WHALES AND BEAKED WHALES

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Introduction

Sperm whales and beaked whales are among the largest and most enigmatic of the odontocetes (toothed whales). These species tend to live far offshore in regions of deep water, and perform long, deep dives in search of their squid prey. This has generally made the study of these animals much more difficult than that of more accessible, near-shore cetacean species. In addition, the pygmy and dwarf sperm whales, and many species of beaked whale, have superficially similar external morphology, and so are often difficult to identify to species level in the wild. The study of many of these species has therefore been based primarily on examination of stranded and beachcast animals. As a result, we currently know little about many of these relatively large mammals. For example, one species of beaked whale, Longman's beaked whale, has been identified only from two skulls in Australia and Somalia. Another putative species, *Mesoplodon* species 'A' has only ever been observed at sea, and knowledge of its morphological characteristics remains far from complete. New species of beaked whales are still being discovered. For example, the pygmy beaked whale and Bahamonde's beaked whale were only identified in the last decade from specimens collected in Peru and Chile, respectively. Likewise, the dwarf and pygmy sperm whale were only recognized as separate species in the 1960s.

The sperm and beaked whale species about which we know most are the sperm whale, the northern bottlenose whale and Baird's beaked whale. Much of the information about these species has come from scientific research programs conducted in conjunction with historic whaling operations. Longer-term, nonlethal studies of wild populations only began in the early 1980s. These focused initially on sperm whales, and today include research on populations of northern bottlenose whales and dense-beaked whales. Such studies help provide important behavioral information about these species which was previously not available from studies of dead animals.

Taxonomy and Phylogeny

There are three superfamilies within the odontocetes: the Physeteroidea (sperm whales), the Ziphioidea (beaked whales), and the Delphinoidea (river dolphins, oceanic dolphins, porpoises, and monodontids). The superfamily Physeteroidea encompasses two families: the Physeteridae which contains the sperm whale, and the Kogiidae which contains the pygmy sperm whale and the dwarf