The International

Antarctic Pack Ice Seals (APIS) Program

Multi-disciplinary Research into the Ecology and

Behavior of Antarctic Pack Ice Seals

Summary Update

by

The Expert Group on Seals (EGS)

Scientific Committee on Antarctic Research (SCAR)

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APIS
ANTARCTIC PACK ICE SEALS
An international research program coordinated by the SCAR Group of Specialists on Seals

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Summary Update

Background

The Antarctic Pack Ice Seals (APIS) Program was developed and executed by members of the SCAR[1] Group of Specialists on Seals and their National programs to consider the functional significance of upper trophic level predators in the Antarctic pack ice zone and to investigate the seals' interactions with their biological and physical environments. Recognizing the high cost and logistic difficulties in undertaking research in the pack ice on a circumpolar scale, scientists from the United States, Australia, Germany, South Africa, Norway, and the United Kingdom collaborated to implement a multi-disciplinary science program that would be far greater than the sum of its parts (Figure 1).

The pack ice region surrounding Antarctica contains at least 50% of the world's population of seals, comprising about 80% of the world's total pinniped biomass (Laws, 1984). As a group, these seals are among the dominant top predators in Southern Ocean ecosystems, and the fluctuations in their abundance, growth patterns, life histories, and behavior (e.g., Bengtson and Laws 1985, Testa *et al.* 1991, Boveng 1993) provide a potential source of information about environmental variability integrated over a wide range of spatial and temporal scales. Variations in top predator distribution, abundance, behavior, and physiology can provide valuable insights into locations of oceanographic features and areas of high secondary production.

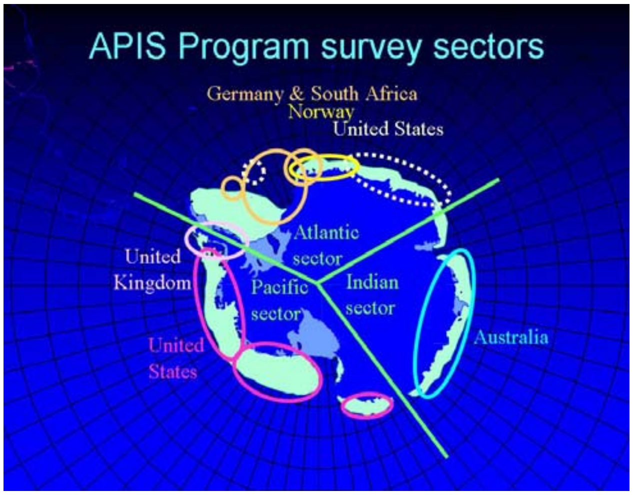

Figure 1. Plan for National participation in the international Antarctic Pack Ice Seal (APIS) program

[1] Scientific Committee on Antarctic Research.

One of the hypotheses by the international APIS Program is that there are measurable physical and biological features in the Southern Ocean that result in areas of high biological activity by upper trophic level predators. Environmental features such as the margin of the continental shelf, the physical characteristics of the sea ice, ocean fronts, and icebergs, are thought to produce conditions that lead to high biomass sites within the pack ice region. These sites may provide protection from predators, concentrated prey resources, access to water for foraging activity, and preferred sites for animals to give birth or molt. Moreover, such sites appear to be preferentially chosen depending upon species' sex, age, physiological condition, and general health characteristics. Preliminary data indicate a strong coupling between biological characteristics of the upper trophic level species and the physical features of the pack ice environment (e.g., Ainley and Jacobs 1981). However, there have only been rare opportunities to make simultaneous measurements assessing in detail the processes leading to high densities of upper trophic level species associated with such features.

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National APIS program summaries and published products derived from research efforts conducted during the International Antarctic Pack Ice Seals (APIS) program

I. United States APIS Program

Scientists from the United States took a multi-disciplinary approach when developing their contribution to the international APIS Program. A group of seventeen principal investigators from twelve agencies and institutions were funded by the National Science Foundation's Office of Polar Programs to undertake the APIS 2000 cruise, which focused on the pack ice zone of the Ross Sea. The total group of 31 scientists that participated in the APIS 2000 cruise had expertise in seal abundance and distribution, seal health and nutrition, seal population genetics and immunogenetics, seabird ecology, fish and squid ecology, zooplankton and krill ecology and physiology, sea ice dynamics, and physical oceanography. The following questions formed the foundation upon which the APIS 2000 investigators formulated hypotheses within their respective disciplines:

Within the sea ice zone in the eastern Ross/western Amundsen Seas in summer --

1. How is the distribution of upper trophic predators and their prey influenced by oceanic fronts and ecological features associated with bathymetry and sea ice?

2. Do biological features (e.g., prey composition and availability), have a stronger, direct influence on the distribution of upper trophic predators than do physical features (e.g., ice thickness, topography, floe size)?

3. Do upper trophic predators located in zones where their densities are relatively high exhibit behavioral and physiological characteristics that are different than those of predators in low density areas?

Research Summary

The APIS 2000 cruise, aboard the R.V.I.B *N.B. Palmer*, began upon departure from Lyttleton, NZ, on 20 December, and ended on 10 February upon arrival at McMurdo Station, Antarctica (Figure 2). The R.V.I.B. *N.B. Palmer* was an outstanding platform for conducting the APIS Program's multi-disciplinary research. The helicopter detail aboard provided an outstanding supplemental too for surveys and other project logistics whenever weather allowed. On a typical day, it was not unusual for our simultaneous science activities to include two helicopters aloft flying seal surveys, two or three zodiac boats supporting local seal work, divers, and sea ice sampling, and a CTD cast or HTI acoustic survey being conducted from the ship. Net tows were conducted in the evening when the seals went in the water to feed. During the 45 science days of the cruise there were 647 separate science events, ship track sampling of approximately 800 km along the Ross Sea polynya marginal ice zone, nearly 1000 km along the coastal fast ice, 2 "short" transects across the ice-covered shelf slope zone, four "long" transects from the coast to the northern marginal ice zone (each about 600 km long), and 175 hours of helicopter flights (which yielded well over 18,000 km of aerial survey transects for seals).

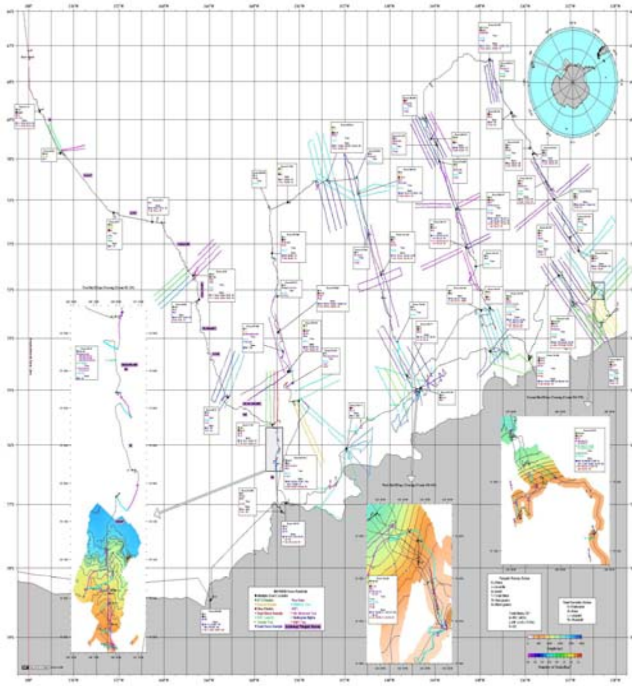

Figure 2. U.S. APIS 1999/2000 cruise track.

Seals:

Thirty satellite-linked transmitters (PTTs) were attached to the four pack ice seal specis.: twenty-two on crabeater seals, four on Ross seals, three on Weddell seals, and two on leopard seals. These were distributed proportionally to the relative abundance of each seal that were predicted before the cruise.

Aerial surveys included substantial coverage of all the major ecological sampling zones that we were targeting: continental shelf, shelf slope, interior pack ice, and northern marginal ice zone. Between the two helicopters we surveyed 18,576 km of pack ice habitat by air, and observed 11,414 seals (4,817 crabeater, 2,852 Weddell, 79 Ross, 33 leopard, and 3,633 unidentified seals) and 11,066 emperor penguins With this thorough coverage we observed an apparent latitudinal gradient in crabeater seal density along our four north-south transect lines. Density was highest in the vicinity of the shelf and slope (0.75 crabeater seals per square kilometer) and it decreased exponentially as we proceeded north over deeper water (0.22 and 0.24 seals per square kilometer in the mid-pack and northern ice edge, respectively). There was a slight increase in crabeater seal density at the northern ice edge; this higher density only extended 10-20 km into the pack from the consolidated ice edge, and may have resulted from the recent on-ice winds which consolidated the receding ice in the marginal sea ice zone. These preliminary results support our hypotheses that physical fronts associated with the continental shelf and shelf slope are important ecological factors influencing the distribution of crabeater seals. Analyses of those counts will be enhanced by a superb set of sea ice data obtained from the belly-mounted digital video cameras used on all flights.

Complete morphological body measurements were obtained for 157 seals. Biological samples to evaluate seal condition and nutrition were obtained from 154 of those seals for blood analysis (53 Weddell, 58 crabeaters, 40 Ross and 3 leopard seals) and animals for detailed morphometric measurements. More than 1,000 samples were shipped back to the U.S. for analysis, in addition to the analyses conducted on board the Palmer. Our preliminary data indicate that only about 10% of the seals had fed within 6 hours of capture, but only 1 of the 40 Ross seals met this criterion. These observations are congruent with the hypothesis that Ross seals occur the outer pack ice when molting, a time where most seals feed les often. Accordingly, our measurements of body fat levels are similar to values seen in other species of seals during the molting period and are on the lean side. Our ability to predict seal mass from length and girth measurements was quite strong, with a better than 0.99 correlation between predicted and actual. The nutritional and body morphometric data may be combined with analysis of lipid composition of potential or known prey to construct a model of predator-prey relationships. They may also be combined with seal distribution data and trawling data for prey to better model how nutritional status relates to seal distribution in the pack ice of the Ross Sea.

Biomedical samples were collected from over 130 seals. The most complete data set was for crabeater seals. Complete veterinary medical exams were done on 7-10 crabeater seals in each of the zones sampled on the cruise (pack ice transects, the northern ice edge, and the southern polynya, coastal area). Eighty-five microbiological cultures were made on over 70 animals, including *Salmonella* screens, gastrointestinal tract flora examinations, and skin and wound cultures.

Skin samples from 432 seals (181 crabeater seals, 202 Weddell seals, 42 Ross seals, and 7 leopard seals) were collected for molecular genetics studies, including basic population genetics and immunogenetics.

Very few leopard seals were encountered whereas Ross seals were found to be more common than expected. Crabeater seals are typically thought to prefer pack ice habitats while Weddell seals prefer fast ice habitats. This was the generally observed during the cruise though large numbers of subadult crabeater seals and newly weaned pups were seen in fast ice areas. These groupings were similar to those observed in the late 1970s during surveys along the Antarctic Peninsula in spring. This suggests that the pattern may be characteristic of young animals through more of the year than previously thought. Older crabeater seals and fewer pups were found in the interior pack ice zone. Despite the relative absence of leopard seals, the scarring on crabeater seals from leopard seal attacks was relatively high. This suggests that the leopard seal-Weddell seal encounters had occurred outside of the Ross Sea with the young crabeater seals then moving away to either look for denser food supplies or to simply escape leopard seal attacks.

In contrast, larger than expected numbers of Weddell seals were found in the interior pack ice zone, especially subadults and non-breeding adults. The greatest number occurred on large floes several km across. Moreover, the seals were generally hauled out near the middle of those large floes, similar to typical fast ice habitat structure. Ross seals were also relatively abundant in the Ross Sea. Most were hauled out alone on large floes and were molting.

The synergistic observations from other biological community sampling indicated that the benthic community of the shelf region along the coast had a high biomass of fish and invertebrates. Although the pathways are not clear, it seems likely this high biomass and possibly the particular assemblage of species there may be partly responsible for the observed patterns of distribution of adult and subadult Weddell and crabeater.

Seabirds:

Emperor penguins were encountered throughout the pack ice and also particularly in the fast ice near Mt. Siple on the Marie Byrd Land coast where they were molting. We now know what the preferred food is for those that choose to feed offshore in the pack before and after the molt, and what the diet is for those that feed and molt over the shelf.

Fish, squid, and zooplankton:

Nineteen 4 m^2 MOCNESS tows , 22 9 m^2 Tucker trawls, 5 15 m mid-water trawl samples, and 6 15 m bottom tows were obtained during the course of the APIS cruise, encompassing ice edge, deep pack ice, and shelf-slope environments. Mid-water fauna were sampled in two basic depth strata: 0-500 m and 500 to 1000 m. Bottom tows were executed on the shelf only, in depths ranging from 250 to 500 m.

The upper 500 m of the water column was nearly devoid of fishes, except over the shelf. The typical inhabitants of the midwater, the lanternfishes, were restricted to depths below 500 m and were even sparse there. When present, euphausiids dominated in the upper 200 m. The major predators caught in midwater tows were large jellies (e.g., Periphylla and Stygiomedusa). The findings suggest that the mesopelagic Ross Sea is exceptionally depauperate in biomass and diversity. In contrast, the benthic communty on the continental shelf was strikingly rich in fish and invertebrates. Ten minute tows recovered hundreds of kilos of invertebrate biomass, and greater than twenty five species of fishes. It appears that most of the marine life in the Ross Sea shelf lives on the sea floor.

Acoustic targets were most prevalent on the shelf in the coastal polynya, where dense layers and swarms were detected. Net tows suggested that those layers consisted mostly of the euphausiids, *Euphausia crystallorophias* and *E. superba*, and a juvenile fish, *Pleuragramma antarcticum*. Layers of euphausiids and juvenile *Pleuragramma* also were detected at a few stations along the ice edge of the Ross Sea Polynya north of the shelf slope. Swarms were less frequent at stations in the interior and at the northern edge of the pack ice. In all regions, acoustic targets occurred primarily in the upper 100 m of the water column.

Nearly 60 SCUBA dives and 49 net tows were made in a variety of coastal and offshore habitats. The pattern was similar for all four of the long ship transects. Adult and one year old *Euphausia superba* were caught at the northern edge of the APIS area and *Euphausia crystallorophias* at the southern edge. The water column in the middle area of transect 4 was dominated by copepods and krill biomass was at a low for the transect. Diving observations correlated well with the net catches with the exception that the underside of the pack ice seems the province of one year old and not adult *Euphausia superba*. Gravid adult *Euphausia superba* dominated the net catches of krill along the northern ice edge, making this one of the richest areas surveyed in terms of energy available to seals.

Hydrography and sea ice:

CTD casts were made throughout the study area about every 60 nm. Open water stations were also sampled north and south of the ice edges on the ends of the transects. Regular near surface sampling was done by the divers using a SeaCat CTD and sampling of water under the ice for isotopes during most of the daily dives. An additional seven ice cores were obtained on the last two transects at the once daily stops and gives a roughly regular grid of sea ice cores across the study area. On the stop at Bartlett Inlet near Cape Colbeck, small chunks of green iceberg were observed, and three of those were sampled.

The sea ice environmental characterization program was carried out during the APIS cruise from 25 Dec 1999 through to 15 Feb 2000 in the Eastern Ross Sea, Antarctica. Unique relationships between sea ice and the ecological system were found at several different trophic levels. At the primary level, the ice cores indicated extensive formation of ice algal communities. These were dominated by the snow-ice communities formed by the flooding of the top surface because of the substantial snow load on most types of the older ice. This type of interaction has also been seen in the other region of year-round pack ice, so, because of its ice coverage, the eastern Ross Sea accounts for nearly half the summer ice algal production in Antarctica. Antarctic krill (*E. superba)* were observed at high densities under ice that was determined to be first-year medium thick floes found primarily in the marginal ice zone, the boundary region between the pack ice and open ocean. Other work in the Weddell Sea has also shown high densities of krill under pack ice floes, so the Ross Sea pack ice also has similar relationships of krill and pack ice to that observed elsewhere. Unique to the Ross Sea are vast multiyear ice floes (>20km diameter) that are apparently attached to the shore for some period in their lifetime before breaking loose and floating freely. These floes provide a unique habitat for seals and penguins (apex predators) to forage and to haul out while molting in the late summer. More Ross seals were observed than during any previous surveys, apparently because they are drawn to the area in summer to molt on large stable first-year floes, farther north of the coast than the large multiyear floes. Both extensive fast ice along the coastline and drifting pack ice in the Shelf-Slope boundary zone provided haul-out areas for seals and penguins with access to food supplies in the coastal shelf region.

The following data sets were obtained in support of the sea ice portion of the program during this cruise:

--Ice Observations. A complete set of round-the-clock hourly ice observations, supplemented with photographic coverage, was made using the Antarctic Sea Ice Processes and Climate (ASPeCt) protocols. These observations characterize the local ice cover observed on an hourly basis and provide a statistical record of ice conditions along the ship's track of ice concentration, ice thickness, snow depths, floe sizes, ice types, deformation and open water characteristics. These records have been digitized and sent to the ASPeCt data archive for inclusion in the circumpolar Antarctic sea ice data archive from ship observations.

--Aerial imagery. Data were collected from the helicopters, in conjunction with seal and penguin observations, in support of the sea ice program. Over 10,000 miles of down-looking digital video were collected from low altitude, giving a relatively high-resolution record of sea ice conditions obtained from the swath of imagery. Techniques were developed to use the video record to extend the shipboard ice observations and resulted in a data set more than tripling the area of statistical ice observations. The eastern Ross Sea during this period is therefore the most extensively recorded area for quantitative ice conditions obtained in Antarctica. The data set on sea ice conditions were initially reduced under this project. Work on the quality control and analyses of the sea ice conditions from the video records are continuing under a complementary project on Antarctic sea ice thickness initiated after the APIS cruise.

--Surface measurements. Sea ice cores and ice thickness measurements were taken in nearly daily stops. The thirty-one cores provide substantive information on the detailed ice structure and biogeochemistry. The cores have been analyzed for structure, salinity, chl-a content, and oxygen isotopes. Proportions of the ice cover formed by flooding of the snow cover and by direct freezing were determined from these analyses, and allow biological-physical relationships to be determined at the ice microstructural level. We found that the proportion of snow ice formed varies from 10 to 30% of the structure observed, as found also in previous studies. The ice, though colored from high concentrations of biological material, was heavily weighted toward detrital matter, indicating a late summer deterioration of the plant community that occurred within the sea ice.

Sea ice cores have been taken on many projects dating back to the first of the modern era in Antarctica in 1977. A recent effort has been initiated to compile the core data into a data bank for analysis and comparison of the physical, chemical and biological data obtained through these sea ice cores. The core data bank is a project of ASPeCt (Antarctic Sea Ice Processes and Climate). Core data from our prior cruises in 1977, 1980, 1981, 1986, 1992, and 1994 have been provided for standardized input to the data bank. The 1999-2000 data from cores taken in APIS were compiled in the standard format and also provided to the data bank.

Iceberg feedbacks to sea ice formation conditions in the Ross Sea were studied using satellite data from 2001-2003. A radical change in fast ice formation in the western Ross Sea has occurred due to the lodging of the icebergs on north and eastern parts of Ross Island. The iceberg-sea ice interaction was also shown by other investigators to influence the penguin populations by their impacts on rookery access in the western Ross Sea area. As well, navigation into McMurdo station has been severely impacted by the presence of more extensive and older fast ice and summer-long drifting pack ice conditions. Work is continuing to determine the possible future impacts of the iceberg configuration.

A reanalysis of sea ice conditions using whaling records as a proxy for sea ice extent was conducted. We found that spring-summer ice extents are overestimated from ship records compared to satellite data and that whale species hunted in the previous era may also bias proxy records (towards greater apparent ice extents than seen on satellites). Contrary to a previous opinion, we conclude there is little direct evidence of a circumpolar decrease in ice extent in the 1960s as previously inferred from the whaling catch records.

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II. Australian Program

Research Summary

Participating Australian research groups

Australian contributors to the APIS program included researchers from the Australian Antarctic Division (AAD, chief scientists Colin Southwell and Harry Burton), the Australian Marine Mammal Research Centre (AMMRC, University of Sydney/Taronga Zoo, chief scientist Tracey Rogers), and the Antarctic Wildlife Research Unit (AWRU, University of Tasmania, chief scientist Mark Hindell).

Australian Antarctic Division

The primary contribution to APIS by the AAD was a major survey effort off east Antarctica between longitudes 60-150°E. Ship and aerial survey methods were developed and tested from 1994/95 to 1998/99 prior to the actual survey in 1999/00. During the survey, a ship and two aircraft covered over 9,000 km of survey transect throughout the pack-ice (Fig. 1), providing sighting data for crabeater, leopard and Ross seals from which abundance estimates could be developed. Sampling of the fast-ice was not sufficient to allow estimation of Weddell seal abundance across the region from this survey effort.

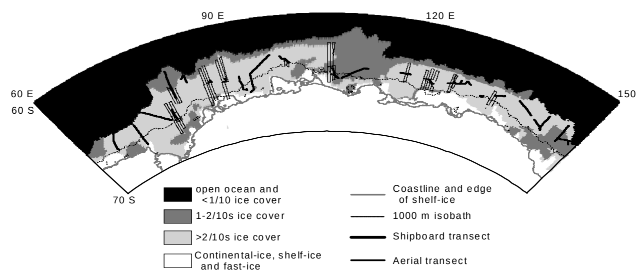

Figure 1. Australian program aerial and shipboard survey tracks, 1999/00.

A sedation protocol was developed for the crabeater seal and dive recorders were deployed on a sample of 25 crabeater seals to estimate the amount of time spent on the ice. There were limited opportunities to collect data on Ross seal haulout, and there were no opportunities to collect data on leopard seal haulout, during the AAD survey effort, making abundance estimation for these species difficult from AAD data only. Abundance estimation was enhanced by the contribution of Ross seal haulout data collected by Norwegian and US researchers, and by leopard seal haulout data collected by researchers from the AMMRC, to the analysis. Integration of sighting and haulout data was a complex analytical task and was undertaken by a coalition of analysts from the AAD, the National Marine Mammal Laboratory in the US, and statisticians at the University of St Andrews, as agreed at the 2001 meeting of the Expert Group on Seals. Data collected in the survey led to significant theoretical improvements in abundance estimation methods.

Estimates of the distribution and abundance of crabeater, Ross and leopard seals in the surveyed sector, and the methods used to obtain those estimates, are in a series of publications (see below).

In addition to survey work in the pack-ice, the AAD has undertaken aerial and ground surveys of Weddell seals in the Prydz Bay and Holme Bay regions, and studies of movement, diet, habitat use and population dynamics on the Weddell seal populations in Prydz Bay. Data on movement, habitat use and diet have been analyzed and published. Further data on distribution, abundance and marked animal resight data still require analysis. The seasonal movements and distribution and abundance of leopard seals in the sea-ice (Antarctic Zone) have also been investigated by matching the periodic fluctuations in annual numbers arriving at Macquarie Island with climate data. Analyses show that significant relationships exist between leopard seal numbers and the Antarctic Oscillation (AAO) also termed the Southern Annular Mode (SAM).

Australian Marine Mammal Research Centre

Work undertaken by the AMMRC focused on the biology and ecology of the leopard seal in the Prydz Bay region (movement, diving behavior, habitat use, diet, toxicology and disease), and on acoustic survey methods as an alternate or complement to traditional survey methods for pack-ice seals, as well as investigating some aspects of Weddell seal physiology. Fifteen leopard seals were satellite tagged with instruments. Most seals remained within 50 km of the tagging sites. The relatively sedentary movement of the leopard seals was unexpected particularly the movement of animals over winter, which although slightly offshore, did not reflect the usual northward winter migration described for the leopard seal. Leopard seal diet was assessed using scat and stable isotope analysis. The health status of leopard seals was assessed by an integrated study of body condition, hematology, serum biochemistry, serum proteins, and trace element and heavy metal analysis. Analysis of blood samples revealed significant differences in the value of several hematological, biochemical and serum proteins between leopard and Weddell seal populations. Gastrointestinal parasite burdens were present in the majority of the seals examined. Trace element and heavy metal analysis of several tissues revealed relatively low concentrations of the majority of these metals in the tissues, blood and fur. A sedation protocol, using a combination of Pethidine/Midazolam or Tiletamine/Zolazepam, was developed for the leopard seal. Trials of acoustic survey methods were undertaken in conjunction with the AAD ship survey effort during the spring of 1996 and 1997 and summer of 1997/98. During the visual surveys, sonobuoys with hydrophone were deployed at 18 m depth and the data transmitted by radio link back to the ship. While the acoustic data analysis has yet to be taken to the point of estimating absolute abundance, it is sufficient to show the value of acoustic surveying and how acoustic behaviour can affect the results.

Antarctic Wildlife Research Unit

The AWRU carried out surveys of crabeater seal distribution and abundance off George V Land, East Antarctica, during winter, and analysed diving and habitat use data obtained from dive recorders deployed on crabeater seals during the AAD survey effort. The AWRU also participated in two SO-GLOBEC cruises with the US Antarctic program. The study focused on winter foraging ecology and movements of crabeater seals on the Antarctic Peninsula. The AWRU has also studied the breeding biology and fine-scale foraging behavior of Weddell seals at McMurdo Sound, in collaboration with Antarctica New Zealand, and Otago University.

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III. South Africa APIS Program

Research Summary

To contribute to the envisaged APIS Program, the South African National Antarctic Program (SANAP) conducted an aerial survey in 1991/92 in the King Haakon VII Sea. However, as a result of ice damage to the rudder of the survey ship, the survey was restricted to the pack ice off the Princess Martha Coast (Bester *et al.* 1995). This latter survey, performed over the pack ice in close to the coast of Dronning Maud land, suggested that both crabeater and Ross seals were distributed evenly over the survey area and that ice cover in itself is a good predictor of seal densities, a notion that was later refuted when considering the entire width of the pack ice (Bester *et al.* 2002). The species composition of the seals was 94.4% crabeater, 3.4% Ross, 1.4% leopard and 0.8% Weddell seals. The density of seals nm^{-2} for the early season surveys (December) in the inner pack was 1.92 for crabeater, 0.0 for leopard, 0.026 for Weddell and 0.057 for Ross seals. The density for the late season surveys throughout the pack was 4.02 for crabeater, 0.10 for leopard, 0.029 for Weddell and 0.122 for Ross seals. These data supported the thesis that seal densities increase as the amount of pack ice diminishes with the advance of summer. Leopard seals were largely found near the retreating outer edge of the pack, and Weddell seals associated closely with the inshore fast ice, while both crabeater and Ross seals showed no statistically significant preference either for any part of the pack ice or for any particular geographical area covered during the surveys in the present study. The high densities (0.45-2.91 seals nm^{-2}) and percentage species contribution (9.7-32.4%) of Ross seals determined by shipboard censuses in the same area during the early 1970s could not be confirmed in the study, and it is likely that a real decrease in Ross seal numbers had taken place. The next survey in 1992/93 covered the width of the pack ice from the fast ice to the outer margin to compare the census results from pack ice close to the Dronning Maud Land (Bester *et al.* 1995) with those from the whole width of the pack ice in the Lasarev Sea and, secondly, to test whether Bester *et al.*'s (1995) hypothesis of an even distribution of seals on the pack ice held over the whole width of the pack ice.

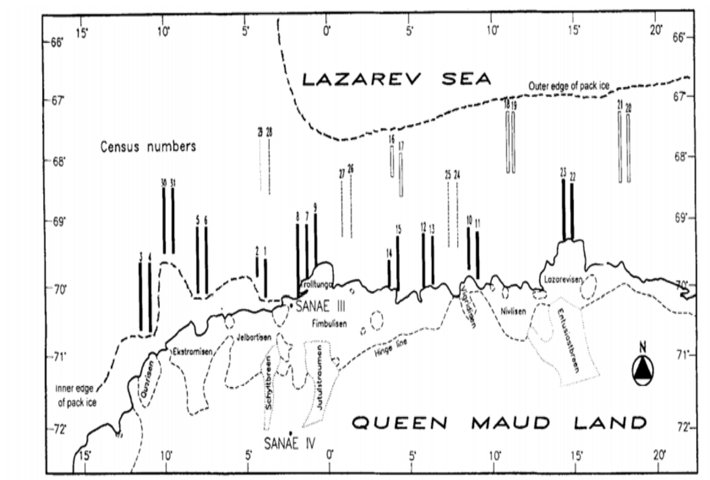

Fig. 1. Census area off Dronning Maud Land (Queen Maud Land), showing numbered aerial strip transects from which densities of the population of pack ice seals were estimated in 1992/93. Ascending numbers indicate the sequence in which the transects were flown. Line types indicate the spatial classification of transects: thick solid lines: inner zone, thick boxed lines: outer zone, broken lines: middle zone.

From December 15, 1992-January 4, 1993 aerial surveys of ice seals throughout the entire pack off Dronning Maud Land, Antarctica, were flown using Puma helicopters operating from the MV SA Agulhas (Fig. 1). The 31 transects of $^1/_2$ nm-width were flown at an elevation of 200 ft and a ground speed of 60 knots and covered 805.6 nm^2 of pack ice. The overall species composition of the seals was 97.8% crabeater seals, 1.67% Ross seals, 0.34% leopard seals and 0.15% Weddell seals. The density abundance of seals was 2.47 nm^{-2} for crabeater, 0.01 nm^{-2} for leopard, 0.004 nm^{-2} for Weddell seals, and 0.04 nm^{-2} for Ross seals. Leopard seals were again largely found near the outer edge of the pack, Ross seals were absent only in the outer pack, while Weddell seals were virtually absent in the pack ice. Present throughout, crabeater seals and Ross seals showed a statistically significant preference for the inner pack, the reasons for this being unclear.

In 1998, in collaboration with the German APIS program, the density, species composition, and possible change in the status of pack ice seals within the Weddell Sea were investigated during the 1997/1998 summer cruise of the RV 'Polarstern'. Comparisons were made with previous surveys in the Weddell Sea where it was assumed that all seals were counted in a narrow strip on either side of the ship or aircraft. A total of 15 aerial censuses were flown during the period the period 23 January – 7 March 1998 in the area bounded by 07^{0}08' and 45^{0}33' West longitude. The censused area in the eastern Weddell Sea was largely devoid of pack ice while a well circumscribed pack ice field remained in the western Weddell Sea. A total of 3636 (95.4%) crabeater seal, 21 (0.5%) Ross seals, 45 (1.2%) leopard seals and 111 (2.9%) Weddell seals were observed on the pack ice during a total of 1356.57 linear nautical miles (244.2 nm) of transect line censused. At a mean density of 21.16nm^{-2} over an area of 244.2 nm, it was the highest densities on record for crabeater seals with up to 411.7 nm^{-2} being found in small areas. The overall high densities of seals (30.18 nm^{-2}) recorded for the eastern Weddell Sea (27.46 nm^{-2}, 0.27 nm^{-2}, and 0.66 nm^{-2} for crabeater, leopard and Weddell seals respectively) was a consequence of the drastically reduced ice cover and the inverse relationship that exists between cover and seal densities. Ross seal densities (0.08 nm^{-2}) were the lowest on record for the area. It was suggested that seals largely remain within the confines of the pack ice despite seasonal and annual changes in its distribution. Indications were that in 1998 the El Niño had manifested itself in the Weddell Sea, markedly influencing the density and distribution of pack ice seals.

Publications through 2005

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IV. Norway APIS Program

Research Summary

Norwegian research activities focused on studies of physiology, distribution, dive behaviour and population abundance of crabeater, Ross, Weddell and leopard seals in the Weddell Sea and in the pack ice off the coast of Queen Maud Land during three expeditions; NARE (Norwegian Antarctic Research Expeditions) 1992/93,NARE 1996/97 and NARE 2000/01.

NARE 1992/93: In February 1993, 8 crabeater seals were tagged with satellite-linked dive recorders (SLDR), for studies of seasonal distribution and dive behaviour. The seals were followed by satellite for up to 109 days and new information on their distribution, dive behaviour and haulout pattern were obtained. Seven crabeater seals were killed for studies of digestibility of their major prey item, the Antarctic krill.

NARE 1996/97: In the first half of February 1997, ten crabeater seals were tagged with SLDR's in order to study distribution, dive behaviour as well as ambient temperatures at various water depths as recorded by the transmitters. The latter was done in order to correlate water temperature with the distribution of krill, as indicated by the location of tagged crabeater seals. Two Ross seals, one leopard seal and one Weddell seal were also tagged with SLDR's as pilot studies of their distribution and dive behaviour. In January and February, 1997, a total of 14 hours of aerial surveys to count seals were flown in the pack ice of the Weddell Sea, in order to make contributions to the combined efforts of new, revised populations estimates of Antarctic pack ice seals (APIS). Five seals (including crabeater, Weddell and leopard seals) were killed for studies of digestive physiology in relation to diet and dive behaviour.

NARE 2000/01: In the first half of February 2001, as a follow up of pilot studies in 1997, 10 Ross seals and 2 leopard seals were tagged with SLDR's in the pack ice off Queen Maud Land, in order to provide new information on the seasonal distribution, dive behaviour and general biology of these species. A complete yearly cycle was covered for the Ross seals as 5 of the seals were followed until moulting in February 2002. For the purpose of bacteriological and virological studies of pack ice seals, a total of 51 seals (including Weddell seals, crabeater seals, Ross seals and Antarctic fur seals (at Bouvet island)) were captured for collection of blood and fecal samples.

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V. *United Kingdom APIS program*

Research Summary

Scientists from the British Antarctic Survey, Cambridge, conducted aerial surveys along the Antarctic Peninsula during the International APIS program usin fixed-wing aircraft operating from Rothera Base, and extending into the southwestern Weddell Sea and the southeastern Bellingshausen Sea. Survey results are being analyzed with counts and sea ice information from other sectors of the Antarctic as part of the APIS Program's circumpolar survey of pack ice seal abundance and distribution.

VI. Germany APIS Program

Research Summary

The multidisciplinary German APIS approach includes studies on crabeater seals, Weddell seals and southern elephant seals; the latter being included retrospectively based on novel findings about their extended migrations into deep pack ice. The incorporation of elephant seals into APIS was acknowledged at the APIS meeting held in Concepción, Chile, in 1998. German contributions to APIS extended studies on pack ice seal abundance and distribution towards investigations on their anatomy, biochemistry, ecology, parasitology, physiology, and toxicology.

The German APIS contribution was linked to the Antarctic research programs of South Africa, Argentina and New Zealand, and includes individual contributions from the respective national programs. It was agreed at the 1995 APIS Program planning meeting to initialise APIS with its first field season during the 1995/96 austral summer. German APIS contributions were terminated in austral summer 2000/01.

Field campaigns (Table 1) prioritising surveys on pack ice seal abundance and distribution were carried out during five EMAGE flight campaigns (see below) and during a ship based helicopter survey of RV POLARSTERN during the expedition ANT XV leg 3 in 1998. Deployments of satellite transmitters on crabeater seals (n = 15) and time-depth recorders on Weddell seals (n = 25) were carried out during the expedition ANT XV leg 3 at Drescher Inlet in 1998. Deployments of satellite transmitters on southern elephant seals were done during ANT Land 96/97 (n = 20) and ANT Land 99/00 (n = 14) at King George Island. The total effort of research activities comprised 5 data sets on aerial pack ice seal surveys, 52 data sets on crabeater seal migratory and diving behaviour, 15 data sets on Weddell seal diving behaviour, and 114 data sets on southern elephant seal migratory and diving behaviour. Most of the primary data related to publications are available in Open Access through the data library PANGAEA - Publishing Network for Geoscientific & Environmental Data (www.pangaea.de). Individual data sets are referenced by their DOI for direct access and citation.

Aerial video surveys of Antarctic pack ice seals

The geophysical East Antarctic Margin Aeromagnetic and Gravity Experiment (EMAGE) of the Alfred Wegener Institute for Polar and Marine Research provided the unique opportunity to conduct aerial surveys of pack ice seal abundance and distribution over the continental shelf and adjacent deep sea region of the eastern Weddell Sea. The seal surveys were carried out during five consecutive austral summer campaigns (1996/97 – 2000/01) using a digital video camera on board the fixed-wing Dornier DO228-101 aircraft "Polar 2" of the German national programme. The camera (Sony DCR-VX 1000 E, 1:1.6 zoom lens, f:5.9-59 mm) was fixed on a specially prepared mount inside the aircraft and pointed vertically through a double-glazed hole in the bottom; the back of the camera pointed in flight direction. As demanded for EMAGE, the target altitude of the aircraft was 500 ft (152 m) and the target speed 130 kts (240 km/h; ground speed 70 m/s). The majority of survey transects was flown in NW-SE direction almost perpendicular to the coastline. This ideally satisfied a survey design recommended for APIS censuses because seal density gradients (e.g. from low to high) should be expected perpendicular rather than parallel to the coastline. Spacing between the flight transects was approximately 10 km.

Table 1: Land-, ship-, and airborn missions in liaison with the German APIS program 1996-2000

Expedition period	**Region**	**Target species**	**Mission based on**			
			Land	Ship	Heli	Aircraft
EMAGE 00/01	Weddell Sea	Pack ice seals				X
EMAGE 99/00	Weddell Sea	Pack ice seals				X
ANT Land 02/00-05/00	King George Island, South Shetland Islands	S. elephant seal	X			
EMAGE 98/99	Weddell Sea	Pack ice seals				X
NZ K071 10/98-12/98	Hutton Cliffs, McMurdo Sound	Weddell seal	X			
ANT XV-3 01/98-03/98	Drescher Inlet / Eastern Weddell Sea	Pack ice seals	X	X	X	
EMAGE 97/98	Weddell Sea	Pack ice seals				X
EMAGE 96/97	Weddell Sea	Pack ice seals				X
ANT Land 09/96-03/97	King George Island, South Shetland Islands	Southern elephant seal	X			

Most surveys were undertaken between 10:00 and 18:00 UTC. Determination of census strip-widths (optimally 70 m; others: 30, 50, 80, 120 m) was derived from the results of dry-runs on land involving pointing the camera from predefined distances at reference objects and, moreover, from test flights at predefined altitudes over reference objects on the ice shelf near Neumayer Station. The aperture and focus of the camera were set manually to avoid permanent adjusting (by auto-iris) when flying through clouds or from dark water to ice-fields. The digital image stabilizer (super steady shot) of the camera compensated for potential aircraft vibrations. The quality of video images proved to be excellent for counting seals hauled out on pack ice, though there were uncertainties to distinguish between seal species. Based on the adjustment of data from the camera (time indicator) and flight log (UTC), the transect coordinates (lat/long) were determined for every seal detected on the video material. Physical features such as sea ice coverage (10^{th}), ice shelf/edge, fast ice, coastal polynya, pack ice and the northern sea ice margin were also determined from the footage.

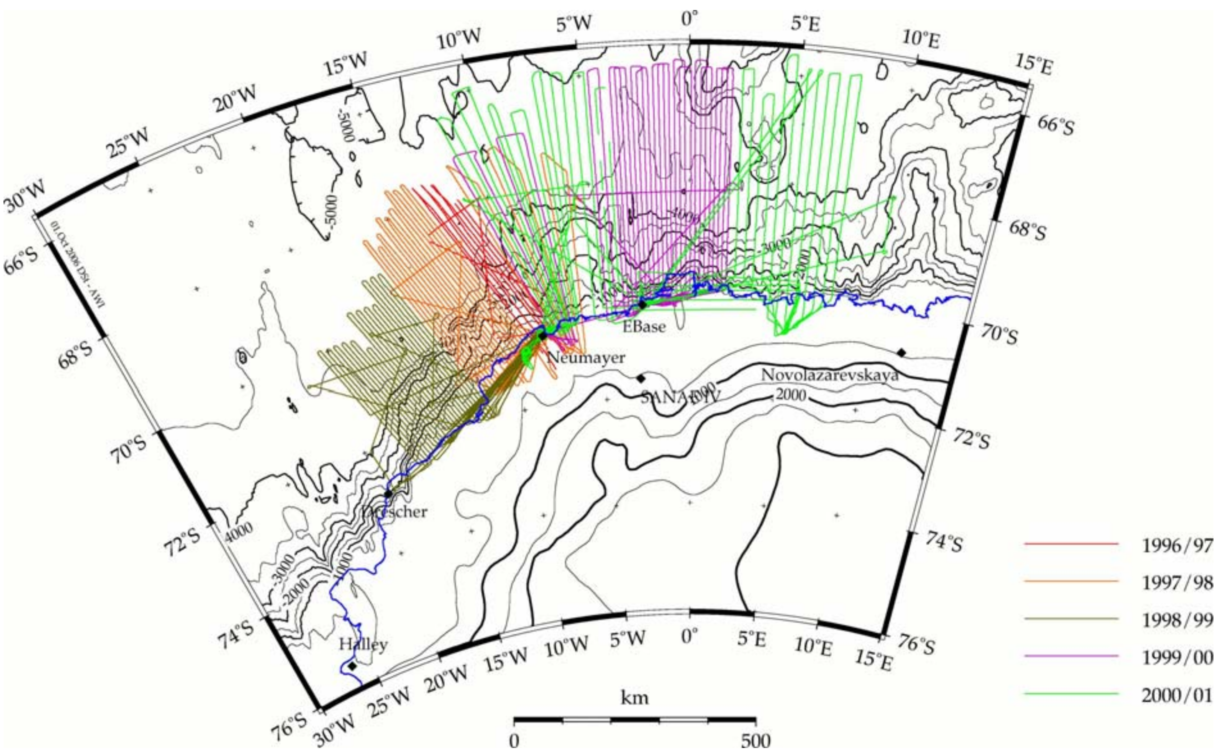

Figure 1: Survey boxes of the 5 EMAGE-APIS flight campaigns (1996/97 – 2000/01)

Season	Transect above sea ice [km]	Seals [n]
1969/97	2757	373
1997/98	2892	233
1998/99	1652	153 (+910 in inlets)
1999/00	1227	107
2000/01	4462	600
Total	13080	2376

Table 2: Basics for the 5 EMAGE-APIS survey boxes

The survey boxes of the five EMAGE flight campaigns covered an area of approximately 1000 x 450 km extending from 22°W to 8° E and 66° to 73° S (Figure 1). The total survey effort comprised more than 80,000 km of aerial transects of which 13,080 km were flown above sea ice (Table 2). Along these transects 2376 seals were counted of which 1466 animals hauled out on pack ice. The remaining 910 seals were observed on a few transect segments amounting to a length of only 32 km (8 min) flown parallel to the coastline above the fast ice of several inlets. This occurred during the 1998/99 campaign when the sea ice situation was very sparse. The distribution pattern of seals along the survey transects is shown in Figure 2.

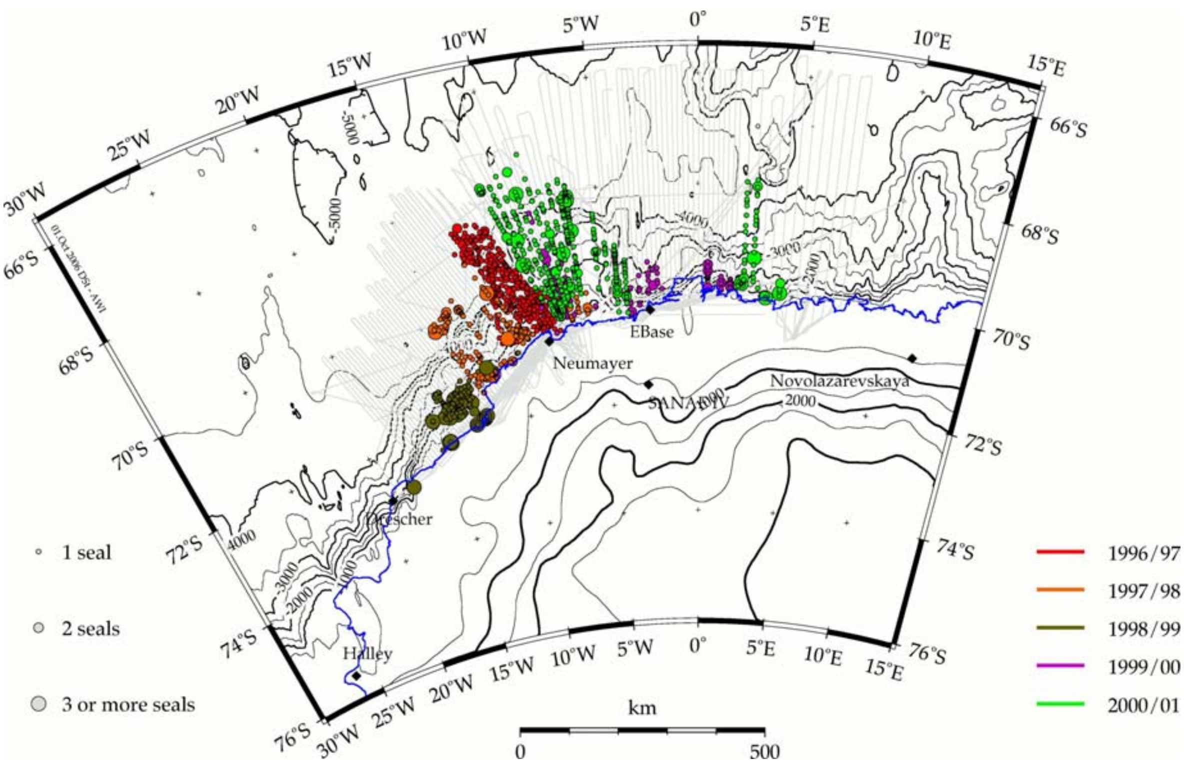

Figure 2: Distribution and abundance patterns of seals counted during the 5 EMAGE-APIS flight campaigns. The northernmost seal counts (coloured circles) of the 5 campaigns roughly correspond to the location of the northern sea ice margin during the respective study periods.

An extrapolation of the percentage contribution of each of the four species of pack ice seals will require liaison with results from APIS surveys conducted by other nations preferably by those who used helicopters. As agreed at the SCAR Group of Specialists on Seals meeting in Shanghai 2002, all relevant raw data of the present study were provided to the U.S. analytical task group in October 2003. The analytical group was asked by the owners of aerial and ship survey data to develop an analysis plan leading to the development of circumpolar estimates of population abundance for all species of Antarctic pack ice seals.

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