National Science Foundation
Division of Polar Programs
Arlington, Virginia

DRAFT ENVIRONMENTAL DOCUMENT CONCURRENCE

Activity:
Perform Marine Geophysical Survey, Collect Bathymetric Measurements, and Conduct Sediment Coring by the RVIB Nathaniel B. Palmer in the Ross Sea
[PGAN1402.IEE]

I have read the attached document and concur with the findings and recommendation. I concur that the proposed activity can commence.

Proposals Covered: Timing and Duration Of The LGM and Post-LGM Grounding Events in Whales Deep Paleo Ice Stream, Eastern Ross Sea Middle Continental Shelf, Bart **1246357**;

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Dr. Polly Penhale Date
Senior Advisor, Environment

National Science Foundation
Division of Polar Programs
Arlington, Virginia

DRAFT ENVIRONMENTAL DOCUMENT AND FINDING OF NO SIGNIFICANT AND NOT MORE THAN MINOR OR TRANSITORY ENVIRONMENTAL IMPACT

Perform Marine Geophysical Survey, Collect Bathymetric Measurements, and Conduct Sediment Coring by the RVIB Nathaniel B. Palmer in the Ross Sea
NSF Tracking Number **[PGAN14XX.IEE]**

FINDING

The National Science Foundation (NSF) has prepared an Initial Environmental Evaluation (IEE)/Environmental Assessment (EA) to conduct marine-based studies in the Ross Sea. Three Alternatives were evaluated:

Alternative A: Perform Geophysical Survey, Collect Bathymetric Measurements, and Conduct Sediment Coring in the Ross Sea beginning in January 2015 with an Incidental Harassment Authorization

Alternative B: Perform Geophysical Survey, Collect Bathymetric Measurements, and Conduct Sediment Coring in the Ross Sea at an alternate time with an Incidental Harassment Authorization

Alternative C: No Action and no Incidental Harassment Authorization

Based on the analyses in the environmental document (IEE/EA), I believe that implementation of Alternative (A) is the preferred alternative and is not a major federal action that would have a significant effect on the human environment, within the meaning of the National Environmental Policy Act (NEPA) of 1969, whose standards are expressly incorporated in section 2403a of the Antarctic Conservation Act of 1978, as amended, as specified therein. The proposed action involves marine-based activities onboard the R/V Nathaniel B. Palmer occurring in January through March 2015 and includes the use of a low-energy acoustic source for seismic surveying over a 1,750 km track, operation of transducer-based instruments (e.g., Acoustic Doppler Current Profiler [ADCP], sonar), and collection of sediment core samples from the seafloor. Likewise, the action is also not one that would have more than a minor or transitory effect on the Antarctic environment, within the meaning of the Antarctic Conservation Act of 1978, as amended, and the Protocol on Environmental Protection to the Antarctic Treaty (1991). Therefore, a comprehensive environmental evaluation would not be prepared.

The time frame for Alternative A was chosen because this is the time of year with the most favorable conditions. A second alternative (Alternative B) was considered. This alternative would defer project initiation to late March or April 2015. In general, potentially affected species would be slightly less common in the area as they would have started migrations to northern latitudes. The detailed elements of the proposed action for Alternative B would be

identical to Alternative A. Environmental conditions (e.g., increasing darkness, increased ice coverage, increased ice thickness) would make implementation of Alternative B more difficult. These conditions potentially could result in some or many of the science activities not being accomplished. The resulting impacts from Alternative B likely would be similar to those described in this environmental document. Because of the potential risks of not meeting science objectives, further analysis of Alternative B beyond the details described herein is not warranted.

I recommend this activity proceed based on the implementation of Alternative A. This alternative provides for the use of field studies to collect data that would evaluate the timing and duration of two grounding events to the outer and middle shelf of the Whales Deep Basin (WDB), a West Antarctic Ice Sheet (WAIS) paleo ice stream trough in eastern Ross Sea. The research activities are consistent with the NSF efforts to promote scientific investigations while protecting the Antarctic environment.

Recommending Official **Date**	**Recommending Official** **Date**
Scott Borg	Li Ling Hamady
Antarctic Sciences Section Head	Environmental Policy Specialist

DRAFT INITIAL ENVIRONMENTAL EVALUATION

National Science Foundation
Division of Polar Programs
Arlington, Virginia

Perform Marine Geophysical Survey, Collect Bathymetric Measurements, and Conduct Sediment Coring by the RVIB Nathaniel B. Palmer in the Ross Sea [PGAN1401.IEE]

1.0 PURPOSE AND NEED

Overview

In support of the United States Antarctic Program (USAP), the National Science Foundation (NSF) proposes to perform marine-based studies, including evaluation of the timing and duration of two grounding events (i.e., advances of grounded ice) to the outer and middle shelf of the Whales Deep Basin (WDB), a West Antarctic Ice Sheet (WAIS) paleo ice stream trough in eastern Ross Sea, as shown in Figure 1. The studies will involve a seismic survey, acquiring core samples from the seafloor, and performing radiocarbon dating of benthic foraminifera to meet a number of research goals. The area proposed for study is shown in Figure 2.

The proposed research activities are designed to meet a number of research goals and would include: 1) conducting a seismic survey along a 1,750-km track (Figure 2) using a two generator-injector (GI) airgun array (with a 'hot spare') as a low-energy seismic source and a hydrophone streamer, 2) conducting multibeam swath bathymetry (Figure 2), 3) acquiring bottom imaging using underwater camera systems, and 4) collecting approximately 32 core samples from the seafloor using various methods and equipment.

Grounding events in the WDB are represented by seismically resolvable Grounding Zone Wedges (GZWs). During the proposed activities in the Ross Sea, researchers will acquire additional seismic data and multibeam bathymetry and imaging to precisely define the depositional and erosional limits of the outer and middle shelf GZWs. The proposed collection of benthic samples and resulting analyses will test the hypothesis and counter hypothesis regarding the WAIS retreat as it relates to the WDB paleo ice stream through: 1) radiocarbon dating in situ benthic foraminifera isolated from diamict deposited on the GZW foreset; 2) ramped pyrolysis of acid insoluble organic (AIO) isolated from diatom ooze overlying GZW diamict; 3) calculating the duration of the two grounding events; and 4) extracting pore-water from the GZW diamict to determine salinity and $\delta^{18}O$ values to test a numerical model prediction regarding the WAIS retreat.

The proposed sediment coring activities include the following:

- Box coring at 3 locations;
- Gravity coring at 3 locations;
- Jumbo piston coring at 4 locations;
- Kasten coring at 11 locations; and
- Standard piston coring at 11 locations.

Figure 1. Ross Sea Study Area

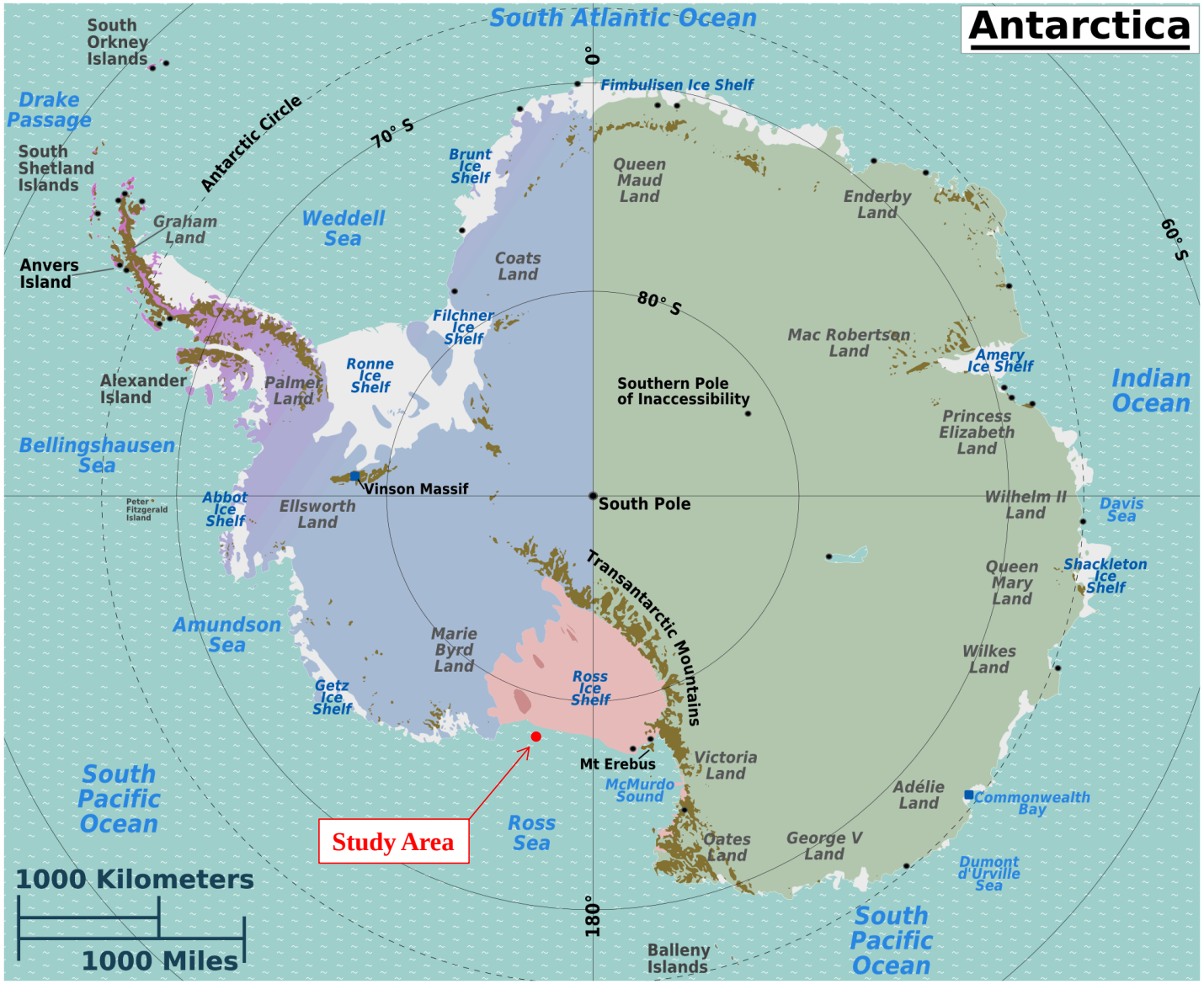
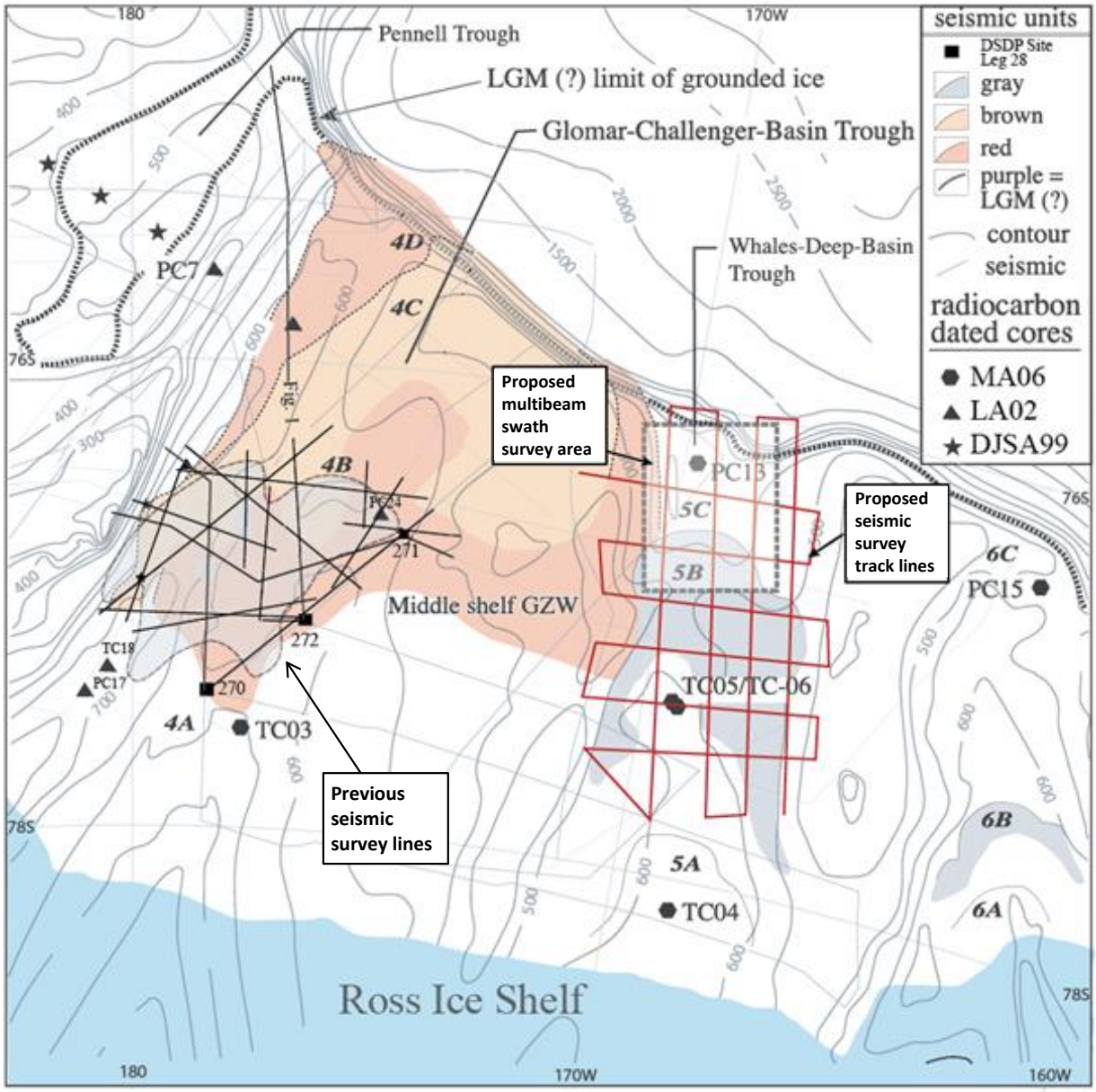


Figure 2. Ross Sea Proposed Cruise Track



The locations of the coring activities will be determined by data collected during the seismic survey. From the sediment cores, the in situ foraminifera and ramped pyrolysis radiocarbon data will be used to conduct a detailed comparison of AIO versus foraminifera radiocarbon dates. The grounding-event duration data generated will provide a test of the two radiocarbon dating strategies.

The Committee for Conservation of Antarctic Marine Living Resources (CCAMLR) has adopted conservation measures (22-06, 22-07, and 22-09) to protect vulnerable marine ecosystems (VME), which include seamounts, hydrothermal vents, cold water corals and sponge fields. The conservation measure 22-07 includes mitigation and reporting requirements if VME are encountered. The science team would follow these requirements if VMEs are encountered while sampling the sea bottom.

Programmatic Environmental Analysis

The NSF prepared a Programmatic Environmental Impact Statement (EIS)/Overseas Environmental Impact Statement (OEIS) (hereafter called PEIS) for Marine Seismic Research funded by the National Science Foundation (NSF) or Conducted by the U.S. Geological Survey in compliance with the National Environmental Policy Act (NEPA); the Council on Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of NEPA; NSF procedures for implementing NEPA and CEQ regulations (45 CFR 640); and Executive Order (EO) 12114, Environmental Effects Abroad of Major Federal Actions. A Record of Decision (ROD) followed the publication of the Final PEIS in June 2012 and concluded the NEPA process.

The PEIS examined the potential impacts that may result from geophysical exploration and scientific research using seismic surveys that are funded by NSF or conducted by the USGS. Due to the potential for NSF-funded marine seismic cruises to occur across the world's oceans, it was necessary to narrow the focus of the impact analysis presented in the Final PEIS to a number of representative or exemplary analysis areas. In this regard, 13 exemplary (representative) analysis areas were proposed for analysis within the Final PEIS, including 5 areas which were subject to detailed analysis [Detailed Analysis Areas (DAAs)] and 8 subject to qualitative analysis [Qualitative Analysis Areas (QAAs)]. One of the QAAs was designated the Sub-Antarctic (located east of New Zealand at 42° S, 145° W) and is particularly relevant to the proposed action described in this IEE with respect to biota that may be present in the Ross Sea during the austral summer.

The PEIS set up a framework for streamlining the preparation of subsequent environmental documents where needed for individual cruises. Thus, while NSF-funded marine seismic research was reviewed in the PEIS, the analysis of site-specific impacts from future cruises such as the proposed action in the Ross Sea would be supplemented with additional analysis. Tiering this environmental document off of the PEIS increases its utility and meaning to the public, without duplicating previous paperwork and environmental analyses. Finally, the PEIS enabled the identification of an appropriate and prudent set of standard mitigation measures to be integrated into this and future NSF-funded cruises:

- Development of mitigating measures during the design and planning of research activities;
- Visual monitoring for marine mammals and turtles;
- Proposed safety radii or mitigation zone (MZ) (standard 328-ft (100-m) MZ for all research efforts with low-energy acoustic sources in water depths >100 m); and
- Mitigating measures to be implemented during operations, including: ramp-ups, shutdowns, and avoidance.

Functionally, this IEE/EA would use the environmental setting and impact assessment data presented in the PEIS for the Sub-Antarctic QAA as a basis for the evaluation and supplemented with available site-specific data for the subject region of the Ross Sea. Historical sightings data from previous cruises in the proposed study area would be used to augment the Sub-Antarctic QAA data and provide semi-quantitative estimates of species population density.

In addition, a significant portion of the environmental analysis for the effects to marine mammals was based on the PEIS and recently tiered environmental documents, including the Environmental Analysis of a Marine Geophysical Survey by the R/V Marcus G. Langseth on the mid-Atlantic Ridge, April–May 2013 prepared by LGL Ltd., environmental research associates on behalf of Lamont-Doherty Earth Observatory and the National Science Foundation Revised 4 April 2013 (LGL Report TA8220-1).

2.0 PROPOSED ACTION

The proposed marine action would occur in selected regions of the Ross Sea (located north of the Ross Ice Shelf) and focus on the WDB trough (encompassing the region between 76°S and 78°S, and between 165°W and 170°W) as shown on Figure 2. Figure 2 also illustrates the general bathymetry of the study area and the previously collected data with respect to seismic units and dated cores.

Under Alternative A, the research would begin approximately on 24 January 2015 and span 27 days for the proposed research activities, ending approximately on 26 February 2015. The research team would join the USAP research vessel RVIB Nathaniel B. Palmer (NBP) at McMurdo Station, where the vessel would be completing other science and operational activities. At the end of this proposed research voyage in the Ross Sea, the NBP resume other operational activities, and transit to and arrive at Hobart, Australia approximately on 20 March 2015.

The timeframe for Alternative A was chosen because a vessel was available for use, there are generally favorable weather conditions, and the Ross Sea region is generally clear and ice-free during the January-February time period due to a large polynya that routinely forms in front of the Ross Ice Shelf.

A second alternative (Alternative B) was considered. This alternative would defer project initiation to late March or April 2015. In general, potentially affected species would be slightly less common in the area as they would have started migrations to northern latitudes. The detailed elements of the proposed action for Alternative B would be identical to Alternative A.

Environmental conditions (e.g., increasing darkness, increased ice coverage, increased ice thickness) would make implementation of Alternative B more difficult. These conditions potentially could result in some or many of the science activities not being accomplished. The resulting impacts from Alternative B likely would be similar to those described in this environmental document. Because of the potential risks of not meeting science objectives, further analysis of Alternative B beyond the details described herein is not warranted.

Vessel Specifications

The USAP research vessel RVIB Nathaniel B. Palmer (NBP) would be used to conduct the proposed research activities. The NBP has a length of 93.9 m, a beam of 18.3 m, and a design draft of 6.8 m. It is equipped with four Caterpillar Model 3608 diesel engines (each rated at 3300 brake horsepower [BHP] @ 900 rpm) and a water jet azimuthing bow thruster. Electrical power is provided by four Caterpillar 3512, 1050-kW diesel generators. The maximum speed of the NBP is 14.5 knots and the average speed is 10.1 knots. The cruising speed would be approximately 5 knots (vary between 4 and 6 knots) when the GI guns are operating. The NPB operating range is 27,780 km (approximately 70 to 75 days).

The NBP also would serve as the platform from which vessel-based protected species observers (PSOs) will watch for marine mammals before and during airgun operations. Other details of the NBP include the following:

Owner:	Edison Chouest Offshore, Inc.
Operator:	Edison Chouest Offshore, Inc.
Chartered:	NSF
Flag:	United States of America
Date Built:	1992
Gross Tonnage:	6,174 GT
GI Airgun Compressor:	Borsig-LMF Seismic Air Compressors, 1,200 cfm at 2000 psi
Accommodation Capacity:	22 crew plus 37 scientists

Specific details of the activities to be performed under Alternatives A or B are described below.

2.1 Seismic Survey

The proposed seismic survey would be performed in the Ross Sea along tracklines totaling approximately 1,750 km and in water between 100 and 1,000 m deep (Figure 2). The trackline distance includes equipment testing, start-up, line changes, repeat coverage of areas as needed, and equipment recovery. The proposed seismic research activities would bisect approximately 25,500 square kilometers (km^2) in the Ross Sea region (see Figure 2). Seismic surveys would be conducted during the day and during and after twilight for up to 100 hours of continuous operation.

The seismic survey would be conducted within an area of approximately 3,882 km^2. This estimate is based on the maximum number of kilometers for the seismic survey (1,750 km) multiplied by the area ensonified around the planned seismic lines (1.109 km x 2). The

ensonified area is based on the predicted RMS radii (m) presented in modeling data (Attachment A) assuming 100% use of 2 x 105 in^3 GI airguns in water depths between 100 to 1,000 m which was calculated to be 1,109 m (1.109 km).

The seismic survey would involve the use of a low-energy acoustic source consisting of a two GI airgun array and either one or two 100-m solid-state hydrophone streamers towed behind the vessel. A third gun would serve as a "hot spare" to be used as a backup in the event that one of the two firing guns malfunctions. Detailed specifications, including dominant frequency and source output, for the airguns can be found in Attachment A. The airguns would be deployed in an array at a depth of approximately 3 to 4 m below the surface, spaced approximately 3 m apart and between 15 and 40 m astern. Each airgun would be configured to a displacement volume of 1,720 cubic centimeters (cm^3)(105 cubic inches) for both the generator and injector, and are considered a low-energy acoustic source as defined in the PEIS. The guns would fire the compressed air volume in unison in a harmonic mode and at an approximate firing pressure of 2,000 pounds per square inch (psi). In harmonic mode, the injector volume is designed to destructively interfere with the reverberations of the generator (source component). Firing the guns in harmonic mode maximizes resolution in the data and minimizes any excess noise in the water column or data caused by the reverberations (or bubble pulses).

Weather conditions permitting, it is anticipated that the seismic surveying **would not exceed 1,750 km in length and 200 hours of operation for the entire cruise** as summarized in Table 1.

Table 1. Proposed Seismic Survey Activities in the Ross Sea

Survey Length (km)	Cumulative Duration [1] (hours)	Airgun Array Total Volume	Frequency Between Seismic Shots	Streamer Length
1,750	≤ 200	2 x 105 in^3 (2 x 1,720 cm^3)	5-10 seconds	100 m

Note: [1] Seismic operations are planned for no more than 100 continuous hours at a time.

During the seismic survey, the vessel would attempt to maintain a constant cruise speed of approximately 5 knots (9 km/hr). There would be between 360 and 720 shots per hour and the relative linear distance between shots would be between 15 and 30 m. The airguns would operate continuously for no more than 100 hours at a time based on operational constraints. The cumulative duration of airgun operation will not exceed 200 hrs which would include equipment testing, ramp-up, line changes, and repeat coverage.

Weather and sea conditions would be closely monitored including conditions that could limit visibility. Heavy pack ice conditions are not anticipated to be encountered during the cruise; however, if icebreaking is required during the cruise, it is expected to occur on a limited basis, and is described in Section 2.4. If situations are encountered which pose a risk to the equipment, impede data collection, or require the vessel to stop forward progress, the seismic survey equipment would be shut down and retrieved until conditions improve. In general, the airguns and streamer could be retrieved in less than 30 minutes.

Based on modeling data, the outputs from a pair of 105/105 in^3 GI airguns such as those being used in the proposed action are considered a low-energy acoustic source in the PEIS for marine seismic research (NSF, 2011). A low-energy source was defined in the PEIS as an acoustic source whose received level at 328 ft. (100 m) is less than 180 decibels re 1 microPascal (dB re 1µPa). The PEIS also established for these low-energy sources, a standard MZ of 100 m for all low-energy sources in water depths >100 m. This 100 m standard MZ would be used during the proposed activity.

The PEIS did not define a standard Full Mitigation Zone (FMZ) for low-energy acoustic sources, therefore L-DEO model results are proposed to be used during the proposed action for the region in which NMFS estimates behavioral disturbance (≥160 dB re 1 µPa [rms]) might occur (Level B Harassment). The FMZ is dependent on the array used and the water depth (see Table 2) and would be used accordingly to identify and report an event that could be interpreted as behavioral disturbance of marine mammals.

Table 2. Proposed MZ and FMZ for the Seismic Survey

Source and volume	Water depth	Predicted RMS radius (m) based on modeling and empirical measurements			Proposed MZ and FMZ based on modeling/empirical measurements and the PEIS	
		190 dB	180 dB	160 dB	MZ (190/180 dB)	FMZ (160 dB)
2 x 105 in^3 GI guns	100-1000 m	36	111	1109	100/100	1109

Monitoring and mitigation measures for the low-energy seismic survey would include:

- Pre-planning of the cruise to identify the smallest airgun array that could be used and still meet the geophysical scientific objectives.
- Employing three Protected Species Observers (PSOs) consistent with NMFS requirements, including a marine mammal expert familiar with species in the Southern Ocean to serve as the lead PSO.
- Establishing the MZ and FMZ.
- Minimum of one observer maintaining a visual watch for marine mammals during all airgun operations.
- Two observers maintaining a visual watch for marine mammals from 30 minutes before the start of ramp-ups through the duration of the ramp-ups (and when possible at other times) during the day. One observer would then be on station during daytime operations.
- Shut-downs when marine mammals are detected in or about to enter the designated MZ. Following a shut-down, airgun activity would not resume until the PSO has visually observed the marine mammal(s) exiting the mitigation zone and concluded that it is not likely to return or has not been seen within the mitigation zone for 15 minutes for species with shorter dive durations (small odontocetes) or 30 minutes for species with longer dive durations (mysticetes and large odontocetes). Although power-down procedures are often standard operating practice for seismic surveys, they are not proposed to be used during this planned seismic survey because powering-down from two airguns to one

airgun would make only a small difference in the mitigation zone(s) - but probably not enough to allow continued one-airgun operations if a marine mammal came within the mitigation zone for two airguns.

To implement these measures, PSOs would monitor for the visual presence of cetaceans and pinnipeds prior to and during daytime seismic survey operations. Monitoring procedures and resources are described in detail in Section 13. During seismic operations, three PSOs would be based aboard the NBP. The PSOs would be approved by NMFS and the lead PSO would be experienced with species in the Southern Ocean. The other PSOs would receive additional specialized training from the PSO to ensure that they can identify Southern Ocean species. During the majority of seismic operations, one PSO would monitor for marine mammals around the seismic vessel.

Seismic operations would be conducted during the day and during and after twilight for up to 100 continuous hours during the survey. The PSOs would be on duty in 4-hour shifts; however during off-hours, the resting PSO may be called for consultation should a second opinion be needed. Other crew would also be instructed to assist in detecting marine mammals and implementing mitigation requirements (if practical). Before the start of the seismic survey, the crew would be given additional instruction regarding how to do so. PSOs will have direct radio contact with the bridge and chief scientist during the seismic surveys. The vessel operator, science support personnel, and the science party must comply immediately with the observer's call to shut down any/all the airguns.

For at least 30 minutes prior to the seismic survey, two PSOs would scan the surface looking for animals within the MZ from the ship. If no animals are in or approaching the 100-m MZ, the airguns would be ramped up (gradually increasing the output sound level by first using one GI gun and then adding the second) to provide time for undetected animals to vacate the area.

A "ramp-up" procedure would be used when starting up at the beginning of seismic operations or any time after the entire array has been shut down for more than 15 minutes, which means starting with a single GI airgun and adding a second GI airgun after five minutes. During ramp-up, the two PSOs shall monitor the mitigation zone, and if marine mammals are sighted, a shutdown shall be implemented as though the full array (both GI airguns) were operational. Therefore, initiation of ramp-up procedures from shutdown requires that the two PSOs be able to view the full mitigation zone.

During ramp-up, the time between airgun shots would be five minutes. The observations would continue during the seismic survey and if a marine mammal is sighted within the FMZ, the crew would be notified of a possible shut-down if the animal approaches the inner MZ. Observations within the FMZ would also include searching for pinnipeds that may be present on the surface of the sea ice (i.e., hauled out) and that could potentially dive into the water as the vessel approaches. The ship may use evasive maneuvers (altering vessel course and speed) to avoid intercepting the path of an approaching marine mammal if the maneuver can be implemented safely and without damaging the deployed equipment. If speed or course alteration is not safe or practicable, or if after alteration the marine mammal still appears likely to enter the mitigation zone, further mitigation measures, such as a shutdown, shall be taken.

Seismic survey activities would only be initiated during periods of optimum visibility when marine mammal observers could see the MZ without compromise by adverse weather or diminishing ambient light levels. During periods of reduced visibility, seismic survey activities would cease if observers cannot delineate the MZ.

The airguns would be shut down if a marine mammal is detected within, approaches, or enters the relevant mitigation zone (reference Table 2). A shutdown means all operating airguns are shutdown (i.e., turned off). Following a shutdown, airgun operations would not resume until the PSO(s) have visually observed the marine mammal(s) exiting the mitigation zone and is not likely to return, or has not been seen within the mitigation zone for 15 minutes for species with shorter dive durations (small odontocetes) or 30 minutes for species with longer dive durations (mysticetes and large odontocetes, including sperm, killer, and beaked whales).

The seismic surveys may continue into night and low-light hours if such segment(s) of the survey is initiated when the entire relevant mitigation zones are visible and can be effectively monitored. No initiation of airgun array operations will occur from a shutdown position at night or during low-light hours (such as in dense fog or heavy rain) when the entire relevant mitigation zone cannot be effectively monitored by the PSO(s) on duty. To the maximum extent practicable, seismic operations (i.e., shooting airguns) will be scheduled during daylight hours. Note that there would be 24-hour or near 24-hour daylight (civil twilight) in the study area between 24 January and 26 February (http://www.timeanddate.com/sun/antarctica/mcmurdo?month=2&year=2015). Therefore, the entire relevant mitigation zones would be visible and would be effectively monitored.

2.2 Bathymetric Measurements and Imaging Surveys

Complementing the seismic survey, detailed swath bathymetry measurements focused on a specific study area within the Ross Sea would be made using hull-mounted sonar systems during seismic survey operations. The proposed bathymetry research would bisect approximately 8,300 square kilometers (km^2) in the Ross Sea region (see Figure 2).

In addition, other transducer-based instruments onboard the vessel would be used continuously during the cruise for operational and navigational purposes. During operations, when the vessel is not towing seismic equipment, its average speed would be 10.1 knots (18.8 km/hr). Operating characteristics for the instruments to be used are described below.

Single Beam Echo Sounder (Knudsen 3260) – The hull-mounted CHIRP sonar would be operated continuously during all phases of the cruise. This instrument is operated at 12 kHz for bottom-tracking purposes or at 3.5 kHz in the sub-bottom profiling mode. The sonar emits energy in a 30° beam from the bottom of the ship.

Single Beam Echo Sounder (Bathy 2000) – The hull-mounted sonar characteristics of the Bathy 2000 are similar to the Knudsen 3260. Only one hull-mounted echo sounder can be operated at a

time and the specific model to be used is expected to be selected by the scientific researchers. The Bathy 2000 was the preferred instrument for many previous surveys on the RVIB Palmer.

Multibeam Sonar (Simrad EM120) – The hull-mounted multibeam sonar would be operated continuously during the cruise. This instrument operates at a frequency of 12 kHz and has an estimated maximum source energy level of 242 dB re 1μPa (rms) and emits a very narrow (< 2°) beam fore to aft and 150° in cross-track. The multibeam system emits a series of nine consecutive 15 millisecond (ms) pulses.

Acoustic Doppler Current Profiler (ADCP) (Teledyne RDI VM-150) –The hull-mounted ADCP would be operated continuously throughout the cruise. The ADCP operates at a frequency of 150 kHz with an estimated acoustic output level at the source of 223.6 dB re 1μPa (rms). Sound energy from the ADCP is emitted as a 30^0 conically-shaped beam.

Acoustic Doppler Current Profiler (ADCP) (Ocean Surveyor OS-38) – The characteristics of this backup hull-mounted ADCP unit are similar to the Teledyne VM-150. It would be continuously operated.

Acoustic Locator (Pinger) – A pinger would be deployed with certain instruments (e.g., camera) and equipment (e.g., corers) so these devices can be located in the event they become detached from their lines. A pinger typically operates at a frequency of 12 kHz, generates a 5 ms pulse per second, and has an acoustical output of 162 dB re 1μPa (rms). A maximum total of 32 coring samples would be obtained using these devices and ranging from 1.5 to 3 hours per sample and it is estimated that the pinger would operate a total of 96 hours.

Passive Instruments – During coring activities in the Ross Sea, underwater imagery will be obtained through deployment of a benthos bottom camera and towed benthic camera system. In addition, approximately 50 expendable bathythermographs (XBTs) would also be released over the course of the cruise to obtain temperature data necessary to calculate sound velocity profiles used by the multibeam sonar.

2.3 Core Sampling

The primary sampling goals involve the acquisition of sediment cores for analysis. The coring locations will be determined using data generated by the seismic survey. It is anticipated that cores will be advanced at a total of 32 coring locations using a variety of methods and several different types of equipment designed to meet research specific objectives. The proposed coring activities are summarized in Table 3.

The small-diameter coring devices would collect sediment from the seafloor at 32 sample locations. At each sampling location up to 176 cm^2 of seafloor would be disturbed by deployment of the coring devices, yielding a cumulative total of approximately 1 m^2 disturbance during the project.

Table 3. Proposed Coring Activities in the Ross Sea

Sampling Device	Core Diameter (cm)	Core Length (m)	No. of Cores
Box core (rectangular profile)	10	0.5	3
Gravity core	7.5	3	3
Jumbo piston core	12.7	12	4
Kasten core	15	6	11
Standard piston core	8.9	9	11

2.4 Icebreaking

If icebreaking is required during the course of the research activities in the Antarctica region, it is expected to occur on a limited basis. The research activities and associated contingencies are designed to avoid areas of heavy sea ice condition, and the Ross Sea region is typically clear during the January-February time period due to a large polynya that routinely forms in front of the Ross Ice Shelf.

Researchers will work to minimize time spent breaking ice. The proposed science operations are more difficult to conduct in icy conditions because the ice noise degrades the quality of the geophysical and Acoustic Doppler Current Profiler (ADCP) data. Also, time spent breaking ice takes away from time supporting research. Logistically, if the vessel were in heavy ice conditions, researchers would not tow the air gun and streamer, as this would likely damage equipment and generate noise interference. It is possible that the seismic survey can be performed in low ice conditions if the RVIB NBP could generate an open path behind the vessel.

Because the RVIB NBP is not rated to break multiyear ice routinely, operations generally avoid transiting through older ice (i.e., 2 years or older, thicker than 1 m). If sea ice is encountered during the cruise, it is anticipated the NBP will proceed primarily through one year sea ice, and possibly some new, very thin ice, and would follow leads wherever possible. Satellite imagery from the Ross Sea region (http://www.iup.physik.uni-bremen.de:8084/ssmis/) documents that sea ice is at its minimum extent during the month of February.

Based on estimated transit to the seismic and bathymetric survey and conditions expected, it is estimated that the RVIB NBP will actively break ice up to a distance of 500 km. Based on a ship's speed of 5 knots under moderate ice conditions, this distance represents approximately 54 hours of icebreaking operation. It is noted that typical transit through areas of primarily open water and containing brash ice or pancake ice are not considered icebreaking for the purposes of this assessment.

3.0 AFFECTED ENVIRONMENT

The description of the affected environment in the PEIS, Chapter 3, focuses only on those resources potentially subject to impacts. Accordingly, the discussion of the affected environment (and associated analyses) has focused mainly on those related to marine biological resources, as the proposed short-term activities have the potential to impact marine biological resources within

the project area. These resources are identified in Section 3.0, whereas the potential impacts to these resources are discussed in Section 4.0. Initial review and analysis of the proposed project actions determined that the following resource areas did not require further analysis in this IEE/EA:

- *Transportation* — Only the NPB would be used during the marine seismic survey. Therefore, projected increases in vessel traffic attributable to implementation of the proposed activities would constitute only a negligible portion of the total existing vessel traffic in the analysis area;
- *Air Quality/Greenhouse Gases* — Project vessel emissions would result from the proposed activities, however these short-term emissions would not result in any exceedance of Federal Clean Air standards. Emissions would be expected to have a negligible impact on the air quality within the survey area;
- *Land Use* — All activities are proposed to occur in the marine environment. Therefore, no changes to current land uses or activities within the project area would result from the proposed actions;
- *Safety and Hazardous Materials and Management* — No hazardous materials would be generated or used during proposed activities. All project-related wastes would be disposed of in accordance with Federal and international requirements including the Protocol on Environmental Protection to the Antarctic Treaty;
- *Geological Resources (Topography, Geology and Soil)* — The proposed actions would result in only short-term displacement of soil and seafloor sediments through coring in the seafloor. Proposed activities would not adversely affect geologic resources, as only minor impacts would occur;
- *Water Resources* — No discharges to the marine environment are proposed within the project area that would adversely affect marine water quality.
- *Socioeconomic and Environmental Justice* — Due to the extremely remote location of the proposed activities, no environmental justice or socioeconomic impacts (including commercial fishing or tourism activities) would be anticipated as result of the proposed activities;
- *Visual Resources* — No visual resources would be anticipated to be negatively impacted as a result of the location of the proposed activities; and
- *Cultural Resources* — There are no known cultural resources in the proposed project area. Therefore, no impacts to cultural resources would be anticipated.

The proposed marine action would occur in selected regions of the Ross Sea (located north of the Ross Ice Shelf) and focus on the WDB trough (encompassing the region between 76°S and 78°S, and between 165°W and 170°W) as shown on Figure 2. Figure 2 also illustrates the general bathymetry of the study area and the previously collected data with respect to seismic units and dated cores.

The description of the environment of the Ross Sea and region is presented below and derived primarily from the *State of the Ross Sea Region - Marine Environment Ross Sea Region. A State*

of the Environment Report for the Ross Sea Region of Antarctica (New Zealand Antarctic Institute, 2001) included as Attachment B.

3.1 Physical Conditions

The Ross Sea lies to the north of Earth's largest ice shelf, the Ross Ice Shelf (RIS), which covers an area of 520,000 km^2, with an average thickness of 370 m. The Ross Sea stretches between Cape Adare to the west and Cape Colbeck to the east. The outer portion of the RIS floats on seawater that is modified during its transit beneath the shelf, and that mixes and exchanges with waters to the north over the continental shelf. The continental shelf north of the RIS covers an area of 466,000 km^2, with an average depth of ~ 530 m, and the shelf break occurs at ~ 700 m depth. However, of importance to the biota, small portions of the Ross Sea are shallower than 200 m. Numerous troughs running roughly in a north-south direction, carved by ice streams during past glacial periods, traverse the shelf. These troughs, and the intervening banks, influence regional circulation, sedimentation, and biogeochemical and biological processes. Unlike other Antarctic continental shelves, the northwest portion of the Ross Sea shelf was not glaciated during the previous glacial maxima, which is an important characteristic with regard to the composition of regional biota.

The Ross Sea is the most southerly oceanic water body in the world, extending to about 78°S, where it meets the Ross Ice Shelf. Sea water circulates freely under the shelf. The presence of a 1,000 km wide and deep continental shelf contrasts to most other areas of the Antarctic coastline, where the shelf is either narrow or absent. Strongly localized but large-scale glacial action in the past has given rise to a very irregular topography with the sea floor typically covered with glacial sediments of silt, sand, gravel and scattered erratic boulders. A conspicuous feature of the Ross Sea is a relatively narrow ridge, a vast terminal moraine, running northwest from Cape Colbeck to the Pennell Bank. This ridge was formed by a grounded ice sheet from a former period of glaciation.

Sea ice extends during the austral winter to cover up to 85 percent of the Ross Sea. There is considerable year-to-year variation in the extent of this ice, largely due to climatic variation. Large polynyas (areas of combined open water and thin ice surrounded by sea and/or land and ice) are a feature of the Ross Sea and play an important role in many natural processes, including heat transfer from ocean to atmosphere and phytoplankton production.

Three main oceanic frontal zones occur within the Ross Sea region; the Antarctic Convergence, Antarctic Divergence and Antarctic Slope Front (Fig. 2). Frontal zones separate water masses of different temperature and salinity and exhibit marked biological and physical changes. The interchange of these water masses, especially at the Antarctic Divergence, provides the minerals and nutrients fundamental to marine biological production.

3.2 Acoustic Environment

The PEIS describes ambient noise conditions common throughout the world's oceans, including noise generated by wind and waves, precipitation, geological sources, sea ice, and biological

sources. The PEIS further described the factors that affect sound propagation in the marine environment, such as geology, bottom topography, temperature, and salinity.

Background underwater acoustic sources in Antarctic waters include the movement and grinding of ice floes, grounding of icebergs, wind, waves, precipitation, and earthquakes (SCAR, 2004). Earthquakes have occurred in the Ross Sea.

3.3 Biota

The Ross Sea polynya contains the most productive and spatially extensive phytoplankton bloom in the entire Southern Ocean and in mid-winter covers an area of 27,000 km^2. The Ross Sea is characterized by high levels of phytoplankton primary production in the spring and summer. The production of zooplankton (secondary producers) is similar to that found in other comparable areas of the Southern Ocean, although the distribution of euphausiids (krill) does differ.

The Ross Sea is biologically active and diverse with productive phytoplankton, zooplankton, including krill populations, whales returning to feed from breeding areas in the north, as well as seal colonies, fish, and flying seabirds. The seafloor in the Ross Sea is also known to contain diverse benthic communities. Endangered Species Act (ESA) listed species are identified in section 3.3.7 and listed in Table 11.

As described in Section 2, this IEE/EA would use the environmental setting and impact assessment data presented in the PEIS for the Sub-Antarctic QAA as a basis for the evaluation of the proposed action. The following presents descriptions of the biological communities that may be present in the study area. A cross-reference of species names used in this document to their common names appears in Attachment C.

3.3.1 Marine Invertebrates

Various species of decapods and 35 squid, 10 octopus, and 4 cuttlefish species are listed in the PEIS as occurring in the sub-Antarctic area (Table 4). The cephalopods (squid and octopi) comprise an important part of the diet of a number of predator species, including penguins and other sea birds, seals and whales. It is noted that some of the species listed in the PEIS are not expected to occur in the proposed study area.

Table 4. Potential Occurrence of Decapod Crustaceans and Cephalopod Mollusks Identified in the PEIS Sub-Antarctic Area

Group	Potential Occurrence
Decapods	
Lobsters	B F E a
Crabs	B F E a
Shrimps	B F c
Cephalopods	
Octopuses	B F c

Table 4. Potential Occurrence of Decapod Crustaceans and Cephalopod Mollusks Identified in the PEIS Sub-Antarctic Area

Group	Potential Occurrence
Squids	B F E M a
Cuttlefishes	B F c
Nautiluses	-

Notes: B = breeds within the area; **E** = economically important fishery within the area; **F** = feeds within the area; M = migrates through the area but unlikely to breed there. **a** = Abundant: the species group is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more; **c** = common: the species group is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s; **-** = species group does not occur there. Table reproduced from the PEIS
Source: NSF 2011

3.3.2 Fish

Higher group fish species that potentially occur within the sub-Antarctic area as cited in the PEIS are listed in Table 5. There are no ESA-, International Union for Conservation of Nature (IUCN-), or Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES-) listed fish species identified for this analysis area.

Table 5. Potential Occurrence of Higher Fish Groups Identified in the PEIS Sub-Antarctic Area

Higher Fish Group	Potential Occurrence (Jan-Feb)
Hagfishes & Lampreys	-
Sharks, Skates, Rays, & Chimeras	B F M
Sturgeons	-
Herring-likes	-
Salmon, Smelts, etc.	-
Cod-likes	B E F M
Pipefishes & Seahorses	-
Scorpionfishes	B F M
Perch-likes	B E F M
Tuna & Billfishes	B F M
Flatfishes	B E F M
Coelacanths	-

Notes: B = breeds within the area; **E** = economically important fishery within the area; **F** = feeds within the area; **M** = migrates through the area. Table reproduced from the PEIS.
Source: NSF 2011.

The fish fauna of the Ross Sea is composed of 95 species from 16 families and is dominated by notothenioids (a perchlike group; 64% of species), with the remainder being mostly liparids (snailfishes) and zoarcids. The notothenioid group comprises six families including Antarctic cods (Nototheniidae), plunderfishes (Artedidraconidae), spiny plunderfishes (Harpagiferidae), thornfish (Bovichtidae), dragonfishes (Bathydraconidae) and icefishes (Channichthyidae).

Notothenioids become progressively more dominant in the southernmost regions of the Ross Sea (DeWitt 1970, in Attachment B). Although the notothenioids make up only 55 percent of all fish species recorded from the Antarctic continental shelf, they comprise around 70 percent of species in the Ross Sea (Eastman and Eakin 1998, in Attachment B).

There is little information available on the density, population dynamics and biomass of the fish in the Ross Sea, apart from those dwelling within the inshore waters of McMurdo Sound and Terra Nova Bay, and from research associated with exploratory fishing.

In Terra Nova Bay and the western Ross Sea, the ichthyoplankton (fish larvae) community is dominated by nototheniids (98.3 percent of all larvae) (Granada et al. 2000 in Attachment B). Silverfish was the dominant species sampled in spring-summer cruises, ranging from 98.6 percent in 1987/88 to 99.8 percent in 1995/96.

Some benthic species such as *Trematomus bernacchii* and *T. centronotus* are common in shallow ice-disturbed zones, as well as their larger predators like the dragonfishes. *T. hansoni, T. loennbergi and T. lepidorhinus* are more common in deeper water below 30 m. *Pagothenia borchgrevinki* is commonly found under annual ice. The pelagic Antarctic silverfish is common offshore at all depths down to 900 m. One of its predators, the Antarctic toothfish, is regularly caught at depths of 300 to 500 m. Icefishes (Channichthyidae) are rarely seen in McMurdo Sound but are commonly caught at Terra Nova Bay to the north. Snailfishes (Liparidae) and eelpouts (Zoarcidae) are the only non-notothenioids regularly caught in the waters of McMurdo Sound and then only at depths of around 500 m.

Species diversity of the larval fish community of the western Ross Sea has been found to be similar to that recorded elsewhere in Antarctica with a greater abundance near shore (Vacchi et al. 1999, 2000, in Attachment B). Faunistic composition and species diversity of the fishes in Terra Nova Bay do not differ substantially from other coastal fish communities inhabiting sites in East Antarctica.

Based on CCAMLR reports, fisheries in the Ross Sea region reported catches of 3,799 metric tonnes during the 2013 reporting period, comprising primarily (94 percent) of toothfish (Dissostichus), with the remainder of the catch being from Channichthyidae, Macrourus, Antimora, and Rajidae.

3.3.3 Sea Turtles

Five species of sea turtles have been observed in the sub-Antarctic (Table 6) and are considered uncommon to common. No sea turtle nesting occurs in the region. Occurrences of the species' within the proposed study area is not expected.

Table 6. Potential Occurrence of Sea Turtles Identified in the PEIS Sub-Antarctic Area

Species	Potential Occurrence (winter)
Green Turtle	cM
Hawksbill	cM
Loggerhead	u? M
Olive ridley	cMF
Kemp's ridley	-
Leatherback	u? MF
Flatback	-

Notes: F = known to feed within the area, **M** = known to migrate through the area; **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few 10s, **u** = uncommon: the species is expected to be encountered at most a few times a year assuming many visits to the area; - = species does not occur; **?** = uncertain. Table reproduced from the PEIS.
Source: NSF 2011.

3.3.4 Seabirds

Seabirds are considered species that nest on land but spend all or a considerable portion of their lives in marine environments and surface- or plunge-dive below the water surface in search of prey. Six seabird families may potentially occur within the sub-Antarctic area and are listed in Table 7.

Table 7. Potential Occurrence of Seabirds Identified in the PEIS Sub-Antarctic Area

Group	Potential Occurrence (Jan-Feb)
Albatrosses	FM a
Petrels/Shearwaters	FM a
Diving-petrels	F a
Gannets/Boobies	FM u
Gulls	M r
Terns/Noddies	FM c

Notes: F = known to feed within the area; **M** = known to migrate or disperse through the area; **a**= abundant: the species is expected to be encountered during a single visit to the area and the number of individuals encountered during an average visit may be as many as hundreds or more, **c** = common: the species is expected to be encountered once or more during 2-3 visits to the area and the number of individuals encountered during an average visit is unlikely to be more than a few10s, **u** = uncommon: the species is expected to be encountered at most a few times a year assuming many visits to the area, **r** = rare: the species is not expected to be encountered more than once in several years. Table reproduced from the PEIS.
Source: NSF 2011.

The bird population of the Ross Sea region has been estimated by Ainley (1985) to total about 10 million birds, which in December to early January translates to an average density of 16 birds per km^2 and a biomass of 44 kg per km^2. This population is dominated in numbers by the Antarctic petrel, with an estimated 5 million birds, followed by the emperor penguin, and the Adélie penguin. Eleven species of sea bird breed in the Ross Sea region. Six of these species (two penguins, three petrels and a skua) breed south of the Balleny Islands and Scott Island. All of the species breeding in the region are found elsewhere in Antarctica, and without Scott Island and the Balleny Islands, the avian biodiversity of the Ross Sea region is relatively low. A number of other, mainly Sub-Antarctic, sea birds are known to forage south of the Antarctic Convergence, although they do not breed in the region.

Three distinct communities or assemblages of bird species are recognizable in the Ross Sea region (Table 8). The most distinct community is associated with the pack ice and waters dominated by pack ice. The second community is linked to the cold waters north of the pack ice, especially where icebergs occur. With the exception of the Antarctic petrel, members of this second community are apparently less restricted to their habitat than the members of the pack ice community are to theirs. The third community is more diverse, consisting of Sub-Antarctic species that move across the Polar Frontal Zone. Members of these sea bird communities are not evenly distributed within their favored oceanographic habitats. During the breeding season the density of birds of most major high latitude species is much greater near their respective breeding areas. Vast areas of seemingly suitable foraging habitat are often left vacant during the breeding season (Ainley et al. 1984, in Attachment B).

Table 8. Sea Bird Assemblages of the Ross Sea Region

Sea Bird Community	Chief Species	Other Species
Pack ice and waters dominated by pack ice	Emperor penguin	Wilson's storm petrel
	Adélie penguin	Southern giant petrel
	Antarctic petrel	Southern fulmar (*Fulmaris glacialoides*)
	Snow petrel	
	South polar skua	
Cold waters north of pack ice, iceberg zone	Southern fulmar	Light-mantled sooty albatross
	Wilson's storm petrel	Southern giant petrel
	Antarctic petrel	Pintado petrel
	Mottled petrel	Snow petrel
Sub-Antarctic species that move across the Polar Frontal Zone	Black-browed albatross	Antarctic prion
	Light-mantled sooty albatross	Wandering albatross
	Southern giant petrel	White-headed petrel
	Pintado petrel	Royal albatross (*Diomedea epomophora*)
	Mottled petrel	Grey-headed albatross (*Thalassarche chrysostoma*)
	Antarctic prion	White-chinned petrel (*Halobaena caerulea*)
	Sotty shearwater	Blue petrel (*Halobaena caerulea*)
	Black-billed storm petrel	Diving petrel (*Pelecanoides spp.*)
	Southern skua	King penguin (*Aptenodytes patagonica*)

Source: Ainley et al. 1984, in New Zealand Antarctic Institute, 2001.

3.3.5 Penguins

Emperor, Adélie, and chinstrap penguins breed in the Ross Sea region. Chinstraps breed in small numbers on the Balleny Islands, the only location where they breed on that side of the Antarctic continent. Adélie penguins breed at 35 rookeries in the Ross Sea region, with a total of about 1 million breeding pairs representing over a third of the total Antarctic breeding population (Woehler 1993, in Attachment B).

Emperor penguins breed in seven colonies in the Ross Sea region, making up 30 percent of the world emperor penguin population (Kooyman 1993, Woehler 1993, in Attachment B). The birds are dependent on open water or polynyas that allow breeding birds access to foraging areas as early as possible in spring (Kooyman 1993, in Attachment B). Emperors are also dependent on coastal annual fast ice that does not break out until after the chicks of the year have fledged, in late December.

The two biggest Emperor penguin colonies in Antarctica are located at Coulman Island and Cape Washington. Six colonies lie off the Victoria Land coast and one off Marie Byrd Land (Kooyman 1994, in Attachment B). The colony at Cape Crozier has about 1,000 pairs and is the

most southerly of all emperor penguin colonies. Cape Roget is the most northerly Ross Sea colony but is still further south than much of the rest of the Antarctic coastline where other emperor colonies occur. Aerial photography in 1983 and air and ground counts in 1990 indicate that the population is generally increasing (Kooyman and Mullins 1990, Kooyman 1993, in Attachment B). Cape Washington fledged 24,000 chicks in 1990, an increase of 4,000 over 1986 counts, and Coulman Island fledged 28,000 in 1990, an increase from 22,000 in 1983. However, the population at Franklin Island has decreased by more than half from the 5,000 counted in 1983.

Although the proposed seismic survey would be conducted more than 100 km from the nearest land mass, the research activities are within a penguin's maximum foraging range of 550 km from one of these colonies. The proposed survey would take place within the austral summer breeding period for these species (October-March).

3.3.6 Marine Mammals

The Ross Sea is a feeding ground for a variety of marine mammals, including cetaceans (whales), both baleen (mysticetes) and toothed whales (odontocetes) and pinnipeds (seals). The most dominant cetacean are minke whales (Balaenoptera acutirostrata) while Crabeater seals (Lobodon carcinophagus) are the most numerous seal species followed by Weddell seals (Leptochynotes weddellii).

Population data and marine mammal sightings data and density data specific to the Ross Sea and South Pacific region were reviewed and compiled to characterize marine mammals expected to be present during the research activities. The listing of the data sources, observational characteristics associated with sightings data, species observed within the data sets, correction factors, and population density estimates by data source for cetacean and pinniped species that would be present in the proposed study area are summarized in Attachment D. Historical sightings data and estimated densities from previous cruises and other research specific to the Ross Sea were reviewed and compiled to provide a more accurate representation of the species that may be encountered in the Ross Sea during the proposed action and provide quantitative estimates of species population density. Based on this review, Table 9 identifies the species expected to be present in the Ross Sea during the seismic survey. The species observed and observational characteristics associated with sightings data and the estimated densities are presented in Attachment D.

Table 9. Projected Number of Cetacean and Pinnipeds Expected to be Encountered During the Proposed Seismic Survey

Common Name	Areal Density (No. /km^2)	Estimated Number of animals [Note 1]
Mysticetes		
Blue whale	0.0065132	25

Table 9. Projected Number of Cetacean and Pinnipeds Expected to be Encountered During the Proposed Seismic Survey

Common Name	Areal Density (No. /km^2)	Estimated Number of animals [Note 1]
Fin whale	0.0306570	119
Humpback whale	0.0321169	125
Minke whale	0.0845595	328
Sei whale	0.0046340	18
Odontocetes		
Arnoux's beaked whale	0.0134420	52
Hourglass dolphin	0.0189782	74
Killer whale	0.0208872	81
Layard's beaked whale	0.0044919	17
Long-finned pilot whale	0.0399777	155
Southern bottlenose whale	0.0117912	46
Sperm whale	0.0098821	38
Pinnipeds		
Crabeater seal	0.6800000	2,640
Elephant seal	0.0001300	1
Leopard seal	0.0266700	104
Ross seal	0.0166700	65
Weddell seal	0.1066700	414

Note: Calculated take is estimated density multiplied by the 3,882 km^2 area ensonified to 160 dB (rms) around the planned seismic tracklines (1,109 m x 2 x 1,750 km).

3.3.7 Endangered Species

Marine organisms inhabiting the Southern Ocean are included in the IUCN Red List, a comprehensive inventory of the global status of plant and animal species. The Red List uses established criteria to evaluate the extinction risk of thousands of species and subspecies. No fish or benthic invertebrates in the Southern Ocean are considered endangered in the IUCN Red List. Table 10 identifies the status of penguin and marine mammal species in the Southern Ocean. Three marine mammal species are identified as endangered by IUCN: blue, fin, and sei whales.

Table 10. IUCN Red List and CITES Species – Southern Ocean

Common Name(s)	Red List Category	CITES
Emperor penguin	NT ver 3.1 (2012)	
King penguin	LC ver 3.1 (2012)	
Antarctic fur seal, Kerguelen fur seal	LC ver 3.1 (2008)	App II
Antarctic minke whale	DD ver 3.1 (2008)	App I
Sei whale	EN A1d ver 3.1 (2008)	

Table 10. IUCN Red List and CITES Species – Southern Ocean

Common Name(s)	Red List Category	CITES
Blue whale, sibbald's rorqual, sulphur-bottom whale	EN A1d ver 3.1 (2008)	App I
Common rorqual, fin whale, fin-backed whale, finback, finner, herring whale, razorback	EN A1d ver 3.1 (2008)	App I
Arnoux's beaked whale	DD ver 3.1 (2008)	App I
Cuvier's beaked whale	LC ver 3.1 (2008)	
Pygmy right whale	DD ver 3.1 (2008)	
Commerson's dolphin	DD ver 3.1 (2008)	
Southern right whale	LC ver 3.1 (2008)	App I
Long-finned pilot whale	DD ver 3.1 (2008)	
Leopard seal	LC ver 3.1 (2008)	
Flatheaded bottlenose whale, southern bottlenose whale	LC ver 3.1 (2008)	
Hourglass dolphin	LC ver 3.1 (2008)	App I
Weddell seal	LC ver 3.1 (2008)	
Southern right whale dolphin	DD ver 3.1 (2008)	App I
Crabeater seal	LC ver 3.1 (2008)	
Humpback whale	LC ver 3.1 (2008)	App I
Gray's beaked whale, southern beaked whale	DD ver 3.1 (2008)	
Layard's beaked whale, strap-toothed whale	DD ver 3.1 (2008)	
Southern elephant seal	LC ver 3.1 (2008)	App II
Ross seal	LC ver 3.1 (2008)	
Killer whale, orca	DD ver 3.1 (2008)	App I
Spectacled porpoise	DD ver 3.1 (2008)	
Sperm whale	VU A1d ver 3.1 (2008)	
Adelie penguin	NT ver 3.1 (2012)	
Chinstrap penguin	LC ver 3.1 (2012)	
Gentoo penguin	NT ver 3.1 (2012)	

Notes: IUCN Red List Categories: EX - Extinct, **EW** - Extinct in the Wild, **CR** - Critically Endangered, **EN** - Endangered, **VU** - Vulnerable, **LR/cd** - Lower Risk/conservation dependent, **NT** - Near Threatened (includes **LR/nt** - Lower Risk/near threatened), **DD** - Data Deficient, **LC** - Least Concern (includes LR/lc - Lower Risk, least concern); **CITES** = Convention on International Trade in Endangered Species of Wild Fauna and Flora (www.cites.org); **APP** – Appendix I or II.

CITES is an international agreement between governments, whose purpose is to ensure that international trade in specimens of wild animals and plants does not threaten their survival. Roughly 5,000 species of animals and 29,000 species of plants are protected by CITES against over-exploitation through international trade. They are listed in the three CITES Appendices, with data compiled and provided by the UNEP World Conservation Monitoring Centre. Table 10 also indicates those species that are included in one of the CITES Appendices.

The National Marine Fisheries Service (NMFS) is responsible for listing marine species under the Endangered Species Act (ESA) and implementing conservation and recovery efforts under the Protected Resource Program. The ESA listings include species inhabiting the Southern Ocean around Antarctica. The seismic survey, as a proposed Federal action funded by NSF, has the potential to affect these species. Table 11 identifies the ESA-listed species that may be present during the proposed action, including within the study area and transit to and from the study area.

Table 11. Status of ESA-listed Species Found in the Southern Ocean

Species	Year Listed	Status	Critical Habitat	Recovery Plan
Cetaceans				
Blue whale	1970	E	n/a	final
Fin whale	1970	E	n/a	final
Humpback whale	1970	E	n/a	final
Sei whale	1970	E	n/a	final
Sperm whale	1970	E	n/a	final
Pinnipeds				
None identified in the study area				
Sea Turtles				
None identified in the study area				

NOTES: E = endangered; **F**= foreign species that occur entirely outside of U.S. territory; Critical habitat and recovery plans are not required for foreign species; critical habitat is also not required for species listed prior to the 1978 ESA amendments that added critical habitat provisions. NSF consulted the published FWS listing of foreign species and noted that no species are on the list.
http://ecos.fws.gov/tess_public/SpeciesReport.do?lead=10&listingType=L
Source: NOAA Fisheries, March 2014
The request for 'take' under the Endangered Species Act is located in Table 13

3.4 Protected Area Status

The Ross Sea region is not currently designated a marine protected area.

4.0 ENVIRONMENTAL ANALYSIS

This section of the IEE/EA identifies the potential environmental effects resulting from the proposed activities in Alternatives A. Potential environmental effects resulting from Alternative B would likely be similar to Alternative A since fewer animals would be in the area. The direct effects of the proposed actions include interactions with the environment such as physical changes or entities imposed on or released to the environment. The proposed actions involve the use of an acoustic source for seismic surveying, operation of transducer-based instruments (e.g., ADCP, sonar), and collection of sediment samples from the seafloor. These activities would

result in the release of acoustical energy to the underwater environment and physical disturbance of the seafloor.

The PEIS defined the preferred alternative as the use of low-energy acoustic sources with generic mitigation measures and sets up a framework for the preparation of subsequent environmental documents. Thus, the analysis of site-specific impacts from the proposed action and relevant mitigating measures is presented in this IEE/EA and is described below.

4.1 Acoustic Outputs

During the seismic and bathymetric surveys, multiple acoustic sources would be operating simultaneously and emitting sound energy to the marine environment. Acoustical energy released by the airguns would attenuate with distance from the source. Transducer-based instruments release pulsed and highly directional acoustic energy that is significantly less intense outside the focus of the beams. Although sounds emitted underwater from multiple sources are additive, the logarithm scale which characterizes sound energy causes the most intense sound source to be dominant while less intense sources contribute little to the overall sound energy received by a receptor.

The acoustic outputs from the airguns and the transducer-based instruments emit sufficient energy to be detected by many marine organisms, including marine mammals, a considerable distance from the source. If exposed to high sound levels, potential adverse effects to marine organisms may include behavioral disturbance, masking of natural sounds, injury and, under extreme conditions to marine mammals, temporary or permanent hearing impairment.

A description of potential impacts to each type of biological community that may result from acoustic outputs during seismic studies is presented below.

4.1.1 Marine Invertebrates

There are currently no quantitative data indicating the effects of the proposed action would adversely affect a population of marine invertebrates. Extrapolation from several studies suggests that a small number of some species or developmental stages of individual invertebrates could theoretically sustain injurious effects if they are within several meters of an operating source; however, the number of invertebrates potentially disturbed in this way would not be expected to exceed the number disturbed under natural conditions.

4.1.2 Fish

Fish in proximity to the proposed activities may potentially be affected by acoustical outputs. Generally, physiological damage or mortality in fish would only be realized if an organism was extremely close to one of the acoustic sources.

Based on the available information, fish populations expected in the survey area would include a number of families, including Nototheniiformes. The potential impacts of scientific research using seismic surveys on marine fish populations in Antarctica are not predicted to be significant

(NSF, 2011). Potential impacts as a result of exposure to airgun acoustic releases primarily include short-term behavioral or possibly physiological impacts to small numbers of individuals. The small number of individual fish that could potentially experience injurious or mortal impacts when within a few meters of a high-energy acoustic source is considered insignificant on a population scale.

Short-term behavioral effects such as localized displacement or disturbance of individual fish are the most likely effects expected. It is unlikely that fish individuals would remain sufficiently near an acoustic source to be exposed to a harmful noise level. Avoidance reactions are to be considered reversible and the organisms are expected to return to the area after the vessel departs. Overall, effects on fish are expected to be minor and transitory.

4.1.3 Sea Turtles

Because sea turtles are not expected to be present in the study area, no impacts to any of their populations are expected. However, they may be observed during the transit to and from Hobart, Australia.

4.1.4 Seabirds

There are no scientific data indicating or suggesting that seabirds are adversely affected by seismic airguns or other sound sources used during typical seismic surveys. Moreover, thousands of hours of observational data by observers during numerous seismic surveys throughout the world suggest that seabirds do not remain in the water near airgun acoustic sources where they would be at potential risk of injury. Therefore, acoustic impacts of airguns on seabirds would be limited to temporary displacement of individuals (avoidance response), and no significant impacts are expected at the population level for all seabird species.

4.1.5 Penguins

There is very little information available to suggest that the underwater sounds at the intensity level expected during the proposed seismic and bathymetric surveys would have an adverse impact on penguins. It is likely that the vessel could encounter penguins during the seismic survey since this area lies within the 550-km foraging range that penguins travel from established colonies (SCAR, 2002). If encountered, it is likely that penguins would be diving and foraging for food. Similar to impacts on seabirds, there would be no significant impacts to individual penguins or their populations expected from the proposed seismic surveys (NSF, 2011). Impacts to penguins, if any, would be limited to avoidance responses and would not likely result in exposure to harmful sound levels. Overall, the impact to penguins from acoustic outputs is considered to be minor and transitory.

4.1.6 Marine Mammals

Current NMSF Guidelines

If exposed to high sound levels, potential adverse effects to marine mammal species may include behavioral disturbance, masking of natural sounds, physiological stress and, under extreme

conditions, temporary or permanent hearing impairment resulting in injury or mortality. Under the U.S. Marine Mammal Protection Act (MMPA), a "take" is defined as any action to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal. The term "harassment" was further defined in the 1994 amendments to the MMPA as any act of pursuit, torment, or annoyance, at two distinct levels:

- Level A Harassment – potential to injure a marine mammal or marine mammal stock in the wild.

- Level B Harassment – potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavior patterns including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering.

Based on current NMFS guidelines, the threshold for received pulse levels that may result in injury or hearing impairment to marine mammals (i.e., Level A Harassment) is defined as ≥ 180 dB re 1 μPa (rms) for cetaceans and ≥ 190 dB re 1 μPa (rms) for pinnipeds. The threshold sound level that is expected to cause marine mammals to display avoidance reactions (behavioral disturbance, i.e., Level B harassment) is defined by NMFS as ≥ 160 dB re 1 μPa (rms). The NMFS guidelines were incorporated into the mitigating measures in the PEIS to prevent marine organism exposure to sound levels that may potentially result in physiological damage or hearing impairment (i.e., Level A harassment).

Pending NMFS Guideline Revisions

As presented in the Supplemental Draft Environmental Impact Statement for the Effects of Oil and Gas Activities in the Arctic Ocean (NMFS, 2013), NMFS is currently in the process of revising and updating acoustic thresholds to incorporate newer science and utilize improved methods. NMFS is proposing to modify the criteria using more recent data, which suggest that: 1) hearing impairment effects to phocids differ from otariids, because of their inner ear anatomy, and; 2) that cetaceans are more likely to incur temporary threshold shift (TTS) and subsequent Permanent hearing impairment (PTS) within the frequency ranges of their best hearing sensitivity. NMFS is using a phased approach to conduct these updates. The thresholds currently being revised include: 1) the injury (Level A Harassment) thresholds to be applied to all sound sources and; 2) the behavioral (Level B Harassment) thresholds to be applied only to seismic activities and seismic-like sound sources (e.g., primarily mobile and impulsive sources). NMFS will provide a full description of the derivation of the revised acoustic thresholds once the internal review is complete and NMFS' revised acoustic thresholds are released for public comment through a separate process. Depending on the timing and implementation of revisions to the acoustic thresholds, changes to the distances from sound sources within which impacts are quantified would be revised for the proposed action.

NMFS' preliminarily plans include exploring the use of dose-response or risk function-like curves to characterize the relationship between received sound level and behavioral responses. Additionally, it has become increasingly evident that the context in which marine mammals are exposed to sound (e.g., the behavioral state of the animal, whether a sound source is approaching and how fast, etc.) can affect both how an animal initially responds to a sound and the ultimate impacts of the sound exposure on that individual. NMFS is also exploring additional methods of

augmenting the use of a dose-response-like curve to address contextual factors beyond received level (such as distance from the sound or behavioral state of the animal), as well as the more chronic effects of sound sources operated over longer periods of time.

NMFS has conducted preliminary evaluation, and suspects that the distances from the source within which animals would be potentially exposed to injurious levels would primarily fall within the distances to the current 180-dB SPL rms threshold for cetaceans. However, for phocids, the distances within which received levels may exceed the new thresholds could be somewhat larger than the distances to the current 190-dB threshold. Depending on the timing and implementation of revisions to the acoustic thresholds, changes to the distances from sound sources within which impacts are quantified would be revised for the proposed action.

Effects of the Proposed Action

No adverse effects to the marine mammals such as physiological damage or hearing impairment are expected to occur during the proposed action due to the implementation of monitoring and mitigation measures consistent with NMFS guidelines and the PEIS. During seismic and bathymetric surveying, effects on marine mammals are expected to be limited to short-term behavioral disturbance reactions exhibited by animals avoiding or being temporary displaced by acoustical sources, such as the airgun array and narrowly focused transducer beams on the moving vessel (Level B Harassment). The acoustic outputs from the airguns and transducer-based equipment are not expected to mask underwater sounds used by marine mammals due to the short duration of the acoustic pulses even though some frequencies used may overlap with those used by certain cetaceans (SCAR, 2002).

The PEIS analysis determined that with implementation of the proposed monitoring and mitigation measures, impacts to cetaceans are expected to be limited to behavioral disturbance and localized avoidance in the area near the active airguns. This is expected to have negligible short- and long-term impacts on individual odontocetes, their habitats, and regional populations.

The PEIS found in Sections 3.6.4.3 and 3.7.4.3 that operation of Multibeam Echosounders (MBES) and Sub-bottom Profilers (SBPs) is not likely to impact mysticetes or odontocetes because the intermittent and narrow, downward-directed nature of these acoustic sources would result in no more than one or two brief ping exposures of any individual animal, given the movement and speed of the vessel. Similarly, the intermittent nature of ADCPs and other pingers would, at most, result in short-term, localized behavioral changes.

A report on the effects of marine acoustics in the Southern Ocean by the Scientific Committee on Antarctic Research (SCAR) concluded that airgun seismic surveys and transducer-based equipment are not considered a threat to marine mammal populations (SCAR, 2006). The SCAR report also documented that while acoustic outputs from transducer-based sources may create temporary behavioral changes and displace a small number of animals, their use is not considered a risk. Therefore, the effects of the proposed activities to marine mammals that may be encountered in the study area are expected to be minor and transitory. Overall, the disturbances that may result from the study activities are considered reversible and the animals are expected to return to the area after the vessel departs.

Coring activities would be highly localized and short-term in duration, and would not be expected to significantly interfere with marine mammal behavior. The PEIS identified potential direct effects to include temporary localized disturbance or displacement from associated sounds and/or physical movement/actions of the operations. Additionally, the potential indirect effects to mysticetes were identified to consist of very localized and transitory/short-term disturbance of bottom habitat and associated prey in shallow-water areas as a result of coring.

It is important to note that non-icebreaking vessels, as well as natural sounds, such as those arising from sea ice motion and whale flukes hitting the ocean surface, also present similar sound impacts. Underwater noise from various vessels, including tug boats, oceanographic research vessels, and fisheries research vessels in open water, as well as icebreakers traversing sea ice, often exceed 120 dB, the existing threshold for Level B harassment set by NMFS (2005).

Further details pertaining to potential effects from acoustic sources on different classes of marine mammals including cetaceans and pinnipeds are described below. Table 12 provides an estimate of the density and number of marine mammals that may be encountered during the 1,750-km seismic survey, based on sightings data (Attachment D).

Table 12. Projected Number of Cetacean and Pinniped Takes in the Proposed Study Area

Common Name	Areal Density (No. /km^2)	Estimated Level B Harassment/Take During Seismic Operations (No. of animals) Note 1	Estimated Level B Harassment/ Take During Ice Breaking Operations (No. of animals) Note 2	Estimated Total Level B Harassment/ Take
Mysticetes				
Blue whale	0.0065132	25	140	165
Fin whale	0.0306570	119	660	779
Humpback whale	0.0321169	125	692	816
Minke whale	0.0845595	328	1,821	2,149
Sei whale	0.0046340	18	100	118
Odontocetes				
Arnoux's beaked whale	0.0134420	52	290	342
Hourglass dolphin	0.0189782	74	409	483
Killer whale	0.0208872	81	450	531
Layard's beaked whale	0.0044919	17	97	114
Long-finned pilot whale	0.0399777	155	861	1,016
Southern bottlenose whale	0.0117912	46	254	300
Sperm whale	0.0098821	38	213	251
Pinnipeds				
Crabeater seal	0.6800000	2,640	14,647	17,287
Elephant seal	0.0001300	1	3	4
Leopard seal	0.0266700	104	574	678
Ross seal	0.0166700	65	359	424
Weddell seal	0.1066700	414	2,298	2,712

Note:
[1] Calculated seismic survey take is estimated density multiplied by the 3,882 kmarea ensonified to 160 dB (rms) around the planned seismic lines (1,109 m x 2 x 1,750 km).

[2] Calculated ice breaking take is estimated density multiplied by the area ensonified to 120 dB (rms) around the potential icebreaking tracklines (21.54 km x 500 km).

Cetaceans

Mysticetes

Because mysticetes feed at high latitudes in summer, several species are expected to be in the area during the seismic survey, including blue, sei, minke, and humpback whales. As summarized for the Sub-Antarctic region in the PEIS and separately corroborated by actual sightings data, some mysticetes are expected to be in the study area during the proposed action. Table 12 includes an estimate of the density and number of mysticetes that may be encountered during the 1,750-km seismic survey.

Auditory impairment or other non-auditory physical effects would be limited to exposures within short distances from the acoustic sources and unlikely, since mysticetes typically avoid seismic vessels (Richardson et al. 1995). Level B disturbances are not expected to result in long-term or significant consequences to disturbed individuals or their populations. No Level A effects (injury, mortality) are anticipated.

Operation of MBESs, SBPs, and pingers is not likely to impact mysticetes. The intermittent and narrow downward-directed nature of the MBES and SBP acoustic sources would result in no more than one or two brief ping exposures to an individual mysticete given the movement and speed of the vessel and organism; such brief exposure to this sound is not expected to cause injury or PTS based on results of limited studies of some odontocete species (PEIS Appendix E, NSF 2011).

Odontocetes

Odontocetes are highly mobile and often move seasonally, traveling to high latitudes for summer feeding. Table 12 includes an estimate of the density and number of mysticetes that may be encountered during the 1,750-km seismic survey.

The proposed airguns for the seismic survey have dominant frequency components of 2-188 Hz. This frequency range somewhat overlaps the lower part of the frequency range of odontocete calls and/or functional hearing (full range about 150 Hz to 180 kHz). Airguns also produce a small proportion of their sound at mid- and high frequencies, although at progressively lower levels with increasing frequency. These frequencies overlap most, if not all, frequencies produced by odontocetes. Odontocetes are presumably more sensitive to the mid- to high frequencies produced by the MBESs, SBPs, and pingers than to the dominant low frequencies produced by the airguns and vessel.

Odontocetes display variable reactions to seismic surveys, but can be generally tolerant and show some disruption of foraging; therefore, short-term Level B exposures may occur. Similar to mysticetes, potential injuries (Level A exposures) are not likely due to behavioral avoidance.

Pinnipeds

The six species of seals that may be present in the study area during the proposed action are expected to be mostly found near pack ice or coastal areas and not prevalent in open sea areas where the seismic survey would be conducted. Based on sightings data and population density estimates (see Attachment D), Table 12 includes an estimate of the density and number of pinnipeds that may be encountered during the 1,750-km seismic survey.

With implementation of the proposed monitoring and mitigation measures, impacts of proposed seismic surveys to pinnipeds are expected to be limited to behavioral disturbance and, in some cases, localized avoidance of the area near the active airguns.

These effects of the proposed action are expected to have negligible short- or long-term effects on individuals, habitats, and regional populations of pinnipeds. Because of prominent avoidance reactions, pinnipeds are not expected to be exposed to potentially harmful sound levels above 190 dB re 1 μPa (rms) during the seismic survey. If an individual pinniped experiences temporary hearing impairment, full recovery of hearing is anticipated once the organism is no longer exposed. No serious injury or mortality of pinnipeds is expected.

There are currently no data on the potential disturbance effects of echosounders or sub-bottom profilers on pinnipeds. Based on observed pinniped responses to underwater sounds and the narrowly focused nature of transducer produced acoustic releases, effects, if any, to pinnipeds are expected to be short-term or momentary startle responses of no lasting consequence to the organisms.

Request for Take under the Endangered Species Act

The applicant requests non-lethal 'take' of odontocetes and mysticetes protected under the Endangered Species Act that may be in the area where proposed activities may occur during the cruise. The estimated 'take' is listed in Table 13 and is based on the data provided in Table 12.

Table 13. Take Request for Species Protected Under the Endangered Species Act Encounters in the Study Area

Common Name	Expected Sightings during the 1,750-km Seismic Survey	Expected Sightings during Icebreaking Operations	Potential Take Expected in the Study Area
Blue whale	25	140	165
Fin whale	119	660	779
Humpback whale	125	692	816
Sei whale	18	100	118
Sperm whale	38	213	251

4.2 Physical Disturbances

Impacts resulting from coring activities would occur due to the inherent physical disturbance of the seafloor during sampling activities. In addition, there is a possibility that benthic organisms

may be displaced or killed, if present. Depending on the type of coring device used, it is anticipated that up to 176 cm^2 of seafloor may be disturbed at each of the 32 sampling locations, representing a total disturbance of approximately 0.6 m^2.

During the proposed sediment coring activities, it is anticipated that the resulting voids in the seafloor would quickly fill with sediment as the disturbed areas collapse and native material is redistributed by bottom currents. Impacts resulting from sediment coring activities are expected to be minor and transitory.

When the core samples are retrieved from the seafloor, material may fall from the sampling device causing a temporary turbidity plume in the water column. Impacts resulting from the dispersal of sediment in the water column and deposition on the seafloor would be localized and would not significantly alter water quality or adversely impact benthic organisms.

4.3 Planned Releases

During proposed surveying activities, expendable XBT sensors may be released to the sea each day and would not be retrieved. The 2-kg XBT probes measure water temperature as each unit sinks to the seafloor while transmitting data through a wireline to the ship. Approximately 50 XBT probes are expected to be released during the cruise in the Ross Sea region. No releases are planned during the transit to Hobart, Australia. The deposition of these devices on the seafloor would be extremely localized events that would yield less than minor impacts.

The number of expendable devices released would be documented and reported per the requirements of the *USAP Master Permit*.

4.4 Accidental Releases

Potential releases to the environment may include accidental spills or leaks of fuel or other hazardous materials (oil, glycol) and the unexpected loss of equipment. Since accidental releases are not planned, their frequency, magnitude, composition, and resulting environmental effects cannot be projected in advance.

Accidental spills of fuel, oil, or other substances from vessel operations are possible but very unlikely based on previous experience. Over 10 years of operation the NBP has only experienced five spills, all of which have involved hydraulic fluid, as documented in the *USAP Master Permit* Annual Report for the years when these events occurred. Each spill incident represented the release of a small quantity of liquid (≤ 12 liters). Should an accidental release occur during the proposed surveys, specific resources would be available to minimize the migration of the material, facilitate cleanup, and remediate affected media. Should a spill or loss of equipment occur, the event would be documented and reported consistent with the requirements of 45 CFR §671 and the *USAP Master Permit.*

4.5 Endangered Species

No adverse impacts to endangered species are expected to occur during the proposed action. Endangered or threatened marine mammal species would not be exposed to harmful sound levels during the seismic survey that would result in injury or hearing impairment (Level A Harassment). Additionally, mitigating measures would be taken during seismic survey activities to immediately shut down the airguns if marine mammals (including endangered species) are observed in, or entering, the MZ (that would result in a Level A exposure). In the event an endangered species enters the FMZ, it may experience short-term behavioral disturbance (Level B Harassment).

4.6 Cumulative Impacts

Cumulative impacts result when the effects of an action are added to or interact with other effects in a particular place and within a particular time. For example, the combined acoustic outputs from the seismic surveying activities along with the simultaneous use of transducer-based equipment (multibeam sonar, sub-bottom profiler, ADCP) could be more significant than any of these sources operating individually.

Background underwater acoustic sources in Antarctic waters include the movement and grinding of ice floes, grounding of icebergs, wind, waves, precipitation, and earthquakes (SCAR, 2004). Furthermore, earthquakes have occurred in the Ross Sea. The proposed studies represent short-term events and would not incrementally increase background noise levels in the Ross Sea.

Potential biological receptors (including marine mammals, invertebrates, and fish) are expected to detect sounds emitted from the ship during the proposed survey activities and exhibit avoidance reactions before being exposed to sounds from multiple sources. The infrequent performance of seismic surveys in the area reduces the risk that individual animals may be cumulatively exposed to potentially disruptive or harmful sound levels. Cumulative impacts to seabirds including penguins would be negligible.

As described in the PEIS (NSF, 2011), impacts to marine mammals from low-energy seismic source surveys are expected to be limited to localized and short-term behavioral changes and no impacts are anticipated at the regional population level. Thus, the proposed seismic survey would not cause chronic disruption of normal behavioral patterns or yield long-term displacement of marine mammals from preferred feeding or breeding areas. Furthermore, human-related activities in the Ross Sea are comparatively limited when considered in the context of the global scale, and the few, relatively short, localized research cruises by the USAP or other nations (see Attachment E) would not have more than a negligible cumulative effect on marine mammals at the individual or population level. Planned monitoring and mitigation measures, which include visual monitoring and the use of mitigation zones, would serve to reduce the level of impact and the likelihood of cumulative effects.

It is noted that icebreaking is conducted annually in McMurdo Sound in the McMurdo Station area to provide an open channel for resupply vessels. It is possible that a long-migrating animal or population exposed during the proposed cruise could be exposed to anthropogenic sounds

during migration to another location or region, including icebreaking in McMurdo Sound; seasonal migration patterns of some cetaceans and pinnipeds involve long distances. However, such exposures would be considered a series of short-term behavioral changes. There is no evidence that such short-term effects, whether considered alone or in succession, result in long-term adverse impacts to individuals or populations assuming important habitats or activities are not disturbed. Additionally, migrating marine mammals have been exposed to many anthropogenic underwater sound activities for decades in all ocean basins. Some of these populations continue to grow despite certain anthropogenic marine activities that have been shown to result in behavioral disturbances to some individuals. In summary, cumulative impacts to mysticetes, odontocetes, and pinnipeds are expected to be negligible and insignificant.

The collection of sediment materials in the Ross Sea would be limited to 32 cores using a variety of coring devices up to 15 cm in diameter. These types of coring devices typically recover intact sediments and would not severely disturb the bottom habitats. The cumulative effects of these sampling efforts are expected to be less than minor.

No cumulative impacts are expected to result from regular deployment of up to 50 XBTs during the proposed activities. These devices would be released at various locations and would either sink to the seafloor or eventually wash ashore, resulting in less than minor impact.

The Ross Sea region has been studied by several National Antarctic Programs including marine-based studies sponsored by the U.S. and New Zealand. Within the Ross Sea region, limited commercial fishing and tourism has also occurred in the past. If any of these types of vessels are encountered, it is unlikely that they would be adversely affected by the proposed action. Efforts will be made to identify such cruises and coordinate with them to reduce potential impacts.

4.7 Impact Assessment Summary

The potential environmental impacts associated with the proposed action in Alternative A to perform marine-based studies in the Ross Sea have been identified and evaluated in this IEE/EA. Table 14 summarizes the potential environmental impacts and their significance. The potential environmental impacts associated with the proposed action under Alternative B would be similar to those identified with Alternative A.

The findings of this assessment indicate that the outputs associated with the proposed research activities would have minor and transitory effects on the marine environment in the Ross Sea. The underwater release of acoustic energy from the two-airgun array, transducer-based equipment, and icebreaking activities has the potential to cause transient behavioral changes in sensitive marine receptors. While the acoustic sources are not expected to cause physiological damage to the biota, some organisms may experience short-term behavioral changes such as avoidance reactions. Short-term behavioral disturbances defined by NMFS as Level B Harassment of marine mammals are expected. These responses are likely to disappear either once the vessel leaves the area or the affected organism migrates outside the study area. Additionally, the short-term duration of the seismic survey and its relatively limited extent within the context of the Ross Sea would minimize the risk of causing significant adverse effects to a population of marine organisms inhabiting the region. Considering these factors, it is not

expected that marine organisms would be exposed to noise of sufficient intensity and duration to cause injury or permanent behavioral changes.

The No Action Alternative (Alternative C) would preclude the collection of the proposed seismic and bathymetric survey data and hinder the geophysical and physical oceanographic investigation of the Ross Sea. Data related to the nature of the Grounding events in the WDB would not be collected and would not be available to the science community. Loss of these data would be significant.

Table 14. Summary of Potential Impacts from Geophysical Studies in the Ross Sea

Activity	Output	Environmental Impacts[1]					
		Affected Environment	Duration	Extent	Intensity	Probability	Environmental Rating
Conduct Seismic Survey	Acoustic Releases (2-airgun array)	Cetaceans, Penguins, Pinnipeds, Fish	Short-term (≤ 200 hours)	3,882 km^2	Low (reversible)	Likely [2]	2
		Benthos				Unlikely	0
Conduct Bathymetric Surveys	Acoustic Releases (single-beam echo sounder, multibeam sonar, ADCP)	Cetaceans, Penguins, Pinnipeds, Fish	Short-term (≤ 27 days)	8,300 km^2	Low (reversible)	Possible	1
		Benthos				Unlikely	0
Perform Icebreaking	Acoustic Releases	Cetaceans, Penguins, Pinnipeds, Fish	Short-term (≤ 54 hours)	500 km	Low (reversible)	Possible	1
		Benthos				Unlikely	0
Collect Sediment Core Samples	Physical Disturbances	Seafloor (soft substrates)	Short-term	Localized ≤ 32 locations (0.6 m^2 total)	Moderate	Certain	2
		Benthos				Likely	1
	Acoustic Releases (pinger)	Cetaceans, Penguins, Pinnipeds, Fish	Short-term	Localized ≤ 32 locations	Low (reversible)	Unlikely	0
Deploy XBTs	Material Releases	Ross Sea	Long-term	~50	Low	Unlikely	0
Operate the NBP in Study Area	Operational Outputs (acoustic, air emissions, wastewater, mechanical)	Ross Sea	Short-term (≤ 30 days)	Localized	Low	Unlikely	0
	Accidental Releases/Spills	Ross Sea	Long-term	Localized	Low-Moderate	Highly Unlikely	0

Table 14 Notes:

[1] The potential environmental impacts associated with the proposed action under Alternative B would be similar to those identified with Alternative A.

[2] Total length of survey; up to 200 hours of operation; individual receptors are not likely to be exposed over the entire survey.

Environmental Rating:

+ = environmental improvement
0 = no substantial effect or highly unlikely
1 = minor, short-term effect
2 = minor effect that continues for a limited period of time after the activity is completed
3 = minor, localized long-term effect
4 = environmental effects may be substantial or long-term

5.0 COORDINATION WITH OTHER AGENCIES

This document will be used as supporting documentation for an IHA application submitted by NSF to NMFS, under the U.S. MMPA, for "taking by harassment" (disturbance) of small numbers of marine mammals during this proposed seismic survey. Potential impacts to endangered species and critical habitat have also been assessed in the document; therefore, it will be used to support the ESA Section 7 consultation process with NMFS and USFWS.

NSF will coordinate the planned marine mammal monitoring program associated with the seismic survey with any parties that express interest in this survey activity. NSF has coordinated, and will continue to coordinate, with other applicable Federal agencies as required, and will comply with their requirements.

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Attachment A
Seismic Source Acoustic Modeling Data
prepared by Lamont-Doherty Earth Observatory

Elements for the "Airgun Description" section.

The R/V *Nathaniel B. Palmer* would tow a pair of 105-in^3 Sercel GI airguns and would acquire data at a cruising speed of ~ 5 knots. Seismic pulses would be emitted at intervals of 5 seconds or longer. Data would be recorded on a 100-m long, 24-channel streamer. Acquisition is planned along a series of predetermined lines in waters 100 to 1000 m in depth.

The two GI guns would be towed on a string at 3 m spacing from each other, at a tow depth of 3-4 m. The source would include a hot spare in case one of the elements breaks down. The source would be towed between 15 and 40 m astern.

As the survey line progresses, the towed hydrophone array (streamer) receives the reflected signals and transfers the data to the on-board acquisition system. Given the relatively short streamer length behind the vessel, the turning rate of the vessel while the gear is deployed is much higher than the limit of five degrees per minute for a seismic vessel towing a streamer of more typical length (>>l km). Thus, the maneuverability of the vessel is not limited much during operations.

The GI guns would be used in harmonic mode, that is, the volume of the injector chamber (I) of each GI gun is equal to that of its generator chamber (G): G=I=105 in^3 (1721 cm^3) for each GI gun. The generator chamber is the one responsible for introducing the sound pulse into the ocean. The injector chamber injects air into the previously-generated bubble to maintain its shape and thus prevent further oscillations, and does not introduce more acoustic energy into the water. The Nucleus modeling software used at Lamont-Doherty Earth Observatory of Columbia University (L-DEO) does not include GI guns as part of its airgun library, however signatures and mitigation models have been obtained for two 105-in^3 G guns that are close approximations. A tow depth of 4 m is assumed and would result in the largest radii.

The source output (downward) associated with this 210 in^3 total generator volume would be 234.1 dB re 1 μPa·m for 0-pk and 239.8 dB re 1 μPa·m for pk-pk. These numbers were determined using the aforementioned G-gun approximation to the GI gun and using signatures filtered with DFS V out-256 Hz 72 dB/octave. The dominant frequency range would be 20-150 Hz for a pair of GI guns towed at 4 m depth.

The nominal downward-directed source levels indicated above do not represent actual sound levels that can be measured at any location in the water. Rather, they represent the level that would be found 1 m from a hypothetical point source emitting the same total amount of sound as is emitted by the combined GI airguns. The actual received level at any location in the water near the GI airguns would not exceed the source level of the strongest individual source, that is, 228.3 dB pk or 234.0 dB pk-pk. Actual levels experienced by any organism more than 1 m from either GI gun would be significantly lower.

A further consideration is that the rms (root mean square) received levels that are used as impact criteria for marine mammals are not directly comparable to the peak (0–pk) or peak to peak (pk–pk) values normally used to characterize source levels of airgun arrays. The measurement units used to describe airgun sources, peak or peak-to-peak decibels, are always higher than the rms decibels referred to in biological literature. A measured received level of 160 dB re 1 μPa rms in the far field would typically correspond to ~170 dB re 1 μPa pk, and to ~176–178 dB re 1 μPa pk-pk, as measured for the same pulse received at the same location (Greene 1997; McCauley et al. 1998, 2000). The precise

difference between rms and peak or peak- to-peak values depends on the frequency content and duration of the pulse, among other factors. However, the rms level is always lower than the peak or peak-to-peak level for an airgun-type source.

Proposed Exclusion Zones

Received sound levels have been modeled by Lamont-Doherty Earth Observatory of Columbia University (L-DEO) for a number of airgun configurations, including two 105-in^3 G guns, in relation to distance and direction from the airguns (Fig. 2). The model does not allow for bottom interactions, and is most directly applicable to deep water. Because the model results are for G guns, which have more energy than GI guns of the same size, those distances overestimate (by ~10%) the distances for GI airguns; no adjustment is made to correct for this.

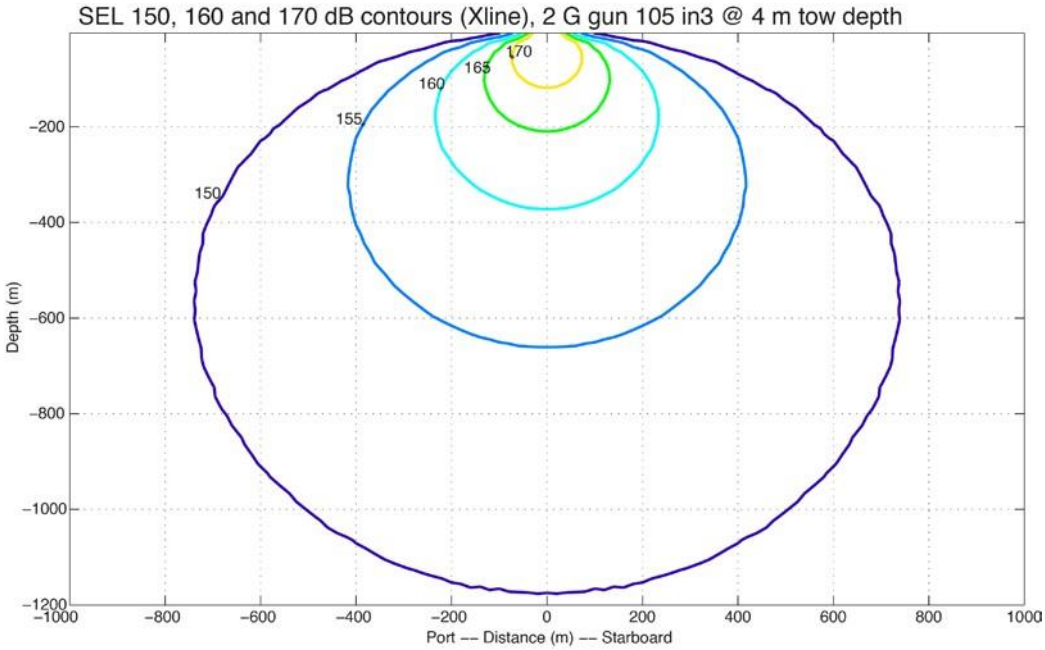
Empirical measurements concerning the 180- and 160-dB re 1 μPa (rms) distances ("radii" around the source) have been acquired for various airgun arrays during acoustic verification studies conducted by L-DEO in the northern Gulf of Mexico in 2003 (6-, 10-, 12-, and 20-airgun arrays, and 2 GI airguns; Tolstoy et al. 2004 [Referenced in PEIS Appendix H]) and 2007–2008 (18- and 36-airgun arrays; Tolstoy et al. 2009; PEIS Appendix H [Diebold et al. 2010]). For the 2 x 105-in^3 GI gun source, measurements were obtained only in shallow water. When compared to measurements acquired in deep water (>1000 m), mitigation radii provided by the L-DEO model are found to be conservative. The acoustic verification surveys also showed that distances to given received levels vary with water depth - these are larger in shallow water, while intermediate/slope environments show characteristics intermediate between those of shallow-water and those of deep-water environments - and documented the influence of a sloping seafloor.

The only empirical measurements obtained for intermediate water depths (100–1000 m) during either survey were for the 36-aigun array in 2007–2008 (PEIS Appendix H [Diebold et al. 2010]). Following results obtained at this site (PEIS Appendix H [Diebold et al., 2010]; their Fig. 16) and earlier practice, a correction factor of 1.5, irrespective of distance to the array, is used to derive intermediate-water radii from modeled deep-water radii. Estimates of the maximum distances from the GI guns where sound levels of 160, 180 and 190 dB re 1 μPa (rms) are predicted to be received in intermediate (100–1000 m) water are shown in Table 1: distances of 739 m, 74 m and 24 m, respectively, are obtained from L-DEO model results in deep water (Fig. 2), which after multiplication by the correction factor of 1.5 become 1109 m, 111 m, and 36 m in intermediate water depth environments.

The PEIS defined a low-energy source as any towed acoustic source whose received level is ≤180 dB at 100 m, including any single or any two GI airguns and a single pair of clustered airguns with individual volumes of ≤250 in^3. In § 2.4.2 of the PEIS, Alternative B (the Preferred Alternative) conservatively applied a 100-m exclusion zone (EZ) for all low-energy acoustic sources in water depths >100 m. Consistent with the PEIS, that approach is used here for the pair of 105-in^3 GI airguns. A fixed full mitigation zone (FMZ), or 160 dB "Safety Zone" was not defined in the PEIS for the same suite of low-energy sources, therefore, L-DEO model results for the 105-in^3 G airguns are used here to determine the 160 dB radius.

The 180-dB re 1 μPa_{rms} distance is the safety criterion as specified by NMFS (2000) for cetaceans and 190-dB re 1 μPa_{rms} for pinnipeds. The 180-dB distance would also be used as the EZ for sea turtles, as required by NMFS in other seismic projects (e.g., Smultea et al. 2004; Holst et al. 2005a,b; Holst and Beland 2008; Holst and Smultea 2008; Hauser et al. 2008). If marine mammals or sea turtles are detected within or about to enter the appropriate EZ, the airguns would be shut down immediately.

Southall et al. (2007) made detailed recommendations for new science-based noise exposure criteria. NSF would be prepared to revise its procedures for estimating numbers of mammals should NMFS implement new acoustic criteria guidelines. However, currently the procedures are based on best practices noted by Pierson et al. (1998), Weir and Dolman (2007), Nowacek et al (2013), and Wright (2014).



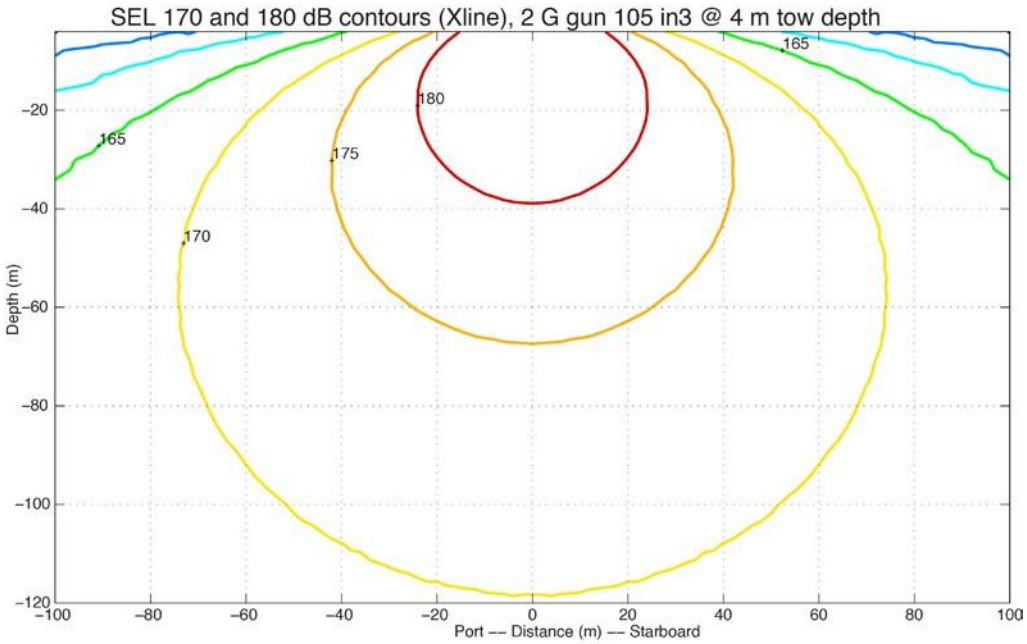


Figure 2. Deep-water model results showing received sound levels from two 105-in^3 G guns at 4 m tow depth, similar to the two 105-in^3 GI airguns that would be used during the *R/V Palmer* survey in the Ross Sea in January 2015. The distance to the 150 dB SEL contour (proxy for 160 dB RMS) is 739 m, the distance to the 170 dB SEL contour (proxy for 180 dB RMS) is 74 m, and the distance to the 180 dB SEL contour (proxy for 190 dB RMS) is 24 m. Model results provided by L-DEO.

Table 1. Predicted distances to which sound levels of 190, 180 and 160 dB re 1 µPa (rms) might be received from two 105-in^3 G guns, similar to the two 105-in^3 GI guns that would be used during the *R/V Palmer* survey in the Ross Sea in January 2015. Distances are based on model results provided by L-DEO (presented in Fig. 2). The Exclusion Zones (EZs) and Full Mitigation Zone (FMZs) proposed for this survey are provided below and are based on model results and standard EZs established in the PEIS for low energy sources.

Source and volume	Water depth	Predicted RMS radii (m) based on modelling			Proposed EZ and FMZ based on modelling and PEIS	
2 x 105 in^3 GI guns 4 m tow depth		190 dB	180 dB	160 dB	EZ (190/180 dB)	FMZ
	100-1000 m	36	111	1109	100/100	1109

Attachment B

State of the Ross Sea Region - Marine Environment
excerpt from *Ross Sea Region 2001: A State of the Environment Report for the Ross Sea Region of Antarctica.* New Zealand Antarctic Institute.

5

State of the Ross Sea Region **Marine Environment**

David Given

The Ross Ice Shelf marks the southern navigable boundary of the Ross Sea although sea water continues to circulate under the ice shelf.

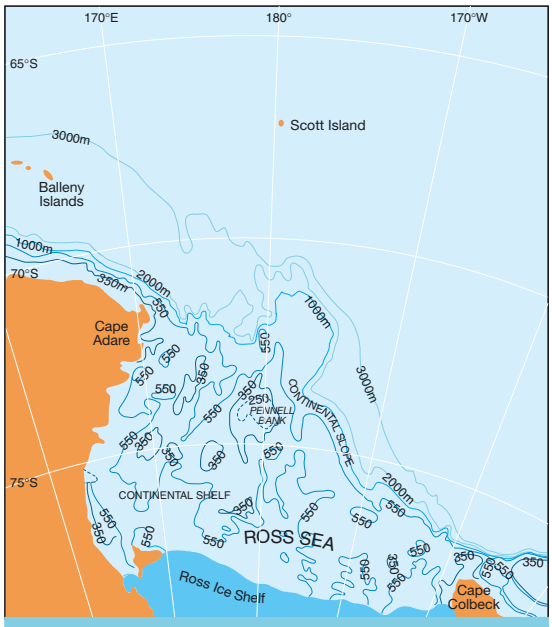


Figure 1: Bathymetry of the Ross Sea region. Key features of the sea floor are the extent of the continental shelf and the depth at which the shelf break occurs, a depth much greater than continental shelves elsewhere in the world. Source: Kennet (1968), Russo et al. (1999).

KEY FEATURES

The Southern Ocean surrounds Antarctica, has a profound influence on the continent and plays a major role in many important global processes. The composition of the major oceans of the world is influenced by the Southern Ocean (only part of which is in the Ross Sea region), and the exchange of the world's warmer oceans with the cold water of this ocean is crucial to maintaining the global heat balance.

In the Ross Sea region, the Pacific sector of the Southern Ocean extends into a large embayment, the Ross Sea, which stretches between Cape Adare in the west and Cape Colbeck in the east (Fig. 1). The Ross Sea is a vast, nearly 1,000 km wide shelf sea and is the most southerly oceanic water body in the world, extending to about 78°S, where it meets the Ross Ice Shelf. Sea water then continues to circulate freely under the shelf.

The presence of a wide and deep continental shelf contrasts to most other areas of the Antarctic coastline, where the shelf is either narrow or absent. Strongly localised but large-scale glacial action in the past has given rise to a very irregular topography with the sea floor typically covered with glacial sediments of silt, sand, gravel and scattered erratic boulders. A conspicuous feature of the Ross Sea is a relatively narrow ridge, a vast terminal moraine, running northwest from Cape Colbeck to the Pennell Bank. This ridge was formed by a grounded ice sheet from a former period of glaciation.

Key features of the marine environment of the Ross Sea region are summarised in Box 1.

Box 1 Key Features of the Ross Sea Region Marine Environment

- Three frontal zones (the Antarctic Convergence, Antarctic Divergence and Antarctic Slope Front) separate water masses of different temperature and salinity and exhibit marked biological and physical changes.
- A number of major water masses can be distinguished below the surface, characterised by their particular temperature and salinity relationships. These masses play a major role in Southern Ocean and global oceanic circulation.
- To the north is the cold Antarctic Circumpolar Current which circles Antarctica and is the largest ocean current system on Earth.
- During winter, the sea ice extends to cover up to 85 percent of the Ross Sea with considerable year-to-year variation in the extent of this ice, largely due to climatic variation.
- Large polynyas (areas of combined open water and thin ice surrounded by sea and/or land and ice) are a feature of the Ross Sea and play an important role in many natural processes, including heat transfer from ocean to atmosphere and phytoplankton production.
- The Ross Sea polynya contains the most productive and spatially extensive phytoplankton bloom in the entire Southern Ocean and in mid winter covers an area of 27,000 km^2.
- The Ross Sea is characterised by high levels of phytoplankton primary production in the spring and summer.
- The production of zooplankton (secondary producers) is similar to that found in other comparable areas of the Southern Ocean, although the distribution of euphausiids (small shrimp-like organisms called krill) does differ.
- A cold and dark but also extremely stable benthic (sea floor) environment exists where many animals grow slowly, are long-lived and sometimes attain giant size.
- The biodiversity of benthic communities is extremely high with species diversity in nearly all major groups of marine invertebrates considerably higher than in the Arctic.
- Squid, fish, birds, seals and cetaceans (whales and dolphins) constitute the higher order predators as in other parts of the Southern Ocean.
- There is little information available on the density, population dynamics and biomass of the fish in the Ross Sea, apart from those dwelling within the inshore waters of McMurdo Sound and Terra Nova Bay, and from research associated with exploratory fishing.
- Eleven bird species breed in the region with the avifauna dominated in numbers by the Antarctic petrel (*Thalassoica antarctica*) and in biomass by emperor penguins (*Aptenodytes forsteri*).
- Crabeater seals (*Lobodon carcinophagus*) are the most numerous seal species followed by Weddell seals, (*Leptochynotes weddellii*).
- Minke whales (*Balaenoptera acutirostrata*) dominate the cetacean population and the killer whale (*Orcinus orca*) is commonly seen in McMurdo Sound.

STATE OF KNOWLEDGE

Data Sources

Although considerable data exist for the Southern Ocean around Antarctica, comparatively little information has been collected in the marine environment of the Ross Sea region. Publications on various aspects of the Southern Ocean, including information on ocean systems, marine living resources, physical oceanography, environmental data, and bio-physical relationships are detailed in Knox (1994). Knox also provides a comprehensive summary of the biology of the Southern Ocean as well as the issues surrounding resource exploitation and management. Recent publications on the oceanography (Spezie and Manzella 1999) and ecology (Faranda et al. 2000a) of the Ross Sea have also appeared. Selected recent publications specific to the Ross Sea are detailed in Table 1 and more detailed summaries of published material by subject are provided throughout this chapter.

Subject	References
Oceanography	De Master et al. 1992, Spezie and Mazella 1999
Polynyas	Smith and Gordon 1997, Bromwich et al. 1998
Phytoplankton	Arrigo and McClain 1994, Di Tullio and Smith 1996, Smith et al. 1996
Benthic organisms	Dell 1990, Battershill 1992, Cormaci et al. 1992, Gambi 1994, McClintok and Baker 1998
Fish	Eastman and Eakin 1998, Eastman and Hubold 1999, Vacchi et al. 1999
Birds	Kooyman 1994, Taylor et al. 1990, Ainley et al. 1998, Cherel and Kooyman 1998, Olmastroni et al. 1998, Wilson et al. 1998, Wilson et al. 2001
Seals	Testa 1994, Stewart et al. 1998

Table 1: Selected recent references specific to aspects of the Ross Sea region marine environment.

Bathymetry

The extent of the continental shelf and the depth at which the shelf break (the point at which the continental shelf emerges from the deep sea bottom) occurs dominates the bathymetry of the Ross Sea. The shelf break lies at about 800 m, a depth much greater than continental shelves elsewhere in the world (Fig. 1). Around New Zealand, for example, the shelf break generally occurs at about 250 m. Beyond the Ross Sea shelf break, depths of over 2,000 m are encountered. The topography of the continental shelf itself is locally modified by canyons and banks (shallow areas), including a ridge between 350 and 550 m deep and 180 m wide that runs northwest from Cape Colbeck to the Pennell Bank. From this shallow rise, the sea floor climbs gradually inland so that the rise forms a rim to a basin-like depression to the south and southwest.

The shelf is typically covered with glacial sediments of silt, sand, gravel and scattered erratic boulders (Kennett 1968). Due to their glacial origin, the sediments are generally poorly sorted and range from gravely to sandy, especially on the Pennell Bank and along the coast. Muddy sediments, with a relatively small proportion of sand, cover most of the shelf and continental slope. The sediments on the continental shelf also accumulate massive amounts of organic matter as a consequence of high levels of diatom production (Ledford-Hoffman et al. 1986). The largely single-celled diatom algae are the principle component of phytoplankton. The diatomaceous ooze that these organisms produce consists of resistant siliceous cell walls called frustules. This secretion accounts for the high levels of silica in the Ross Sea – levels higher than in any of the world's oceans. Near Ross Island, the sediments contain varying amounts of material of volcanic origin, reflecting the geological history of this part of the Ross Sea region.

Physical Oceanography

Frontal Zones and Circulation

Three main oceanic frontal zones occur within the Ross Sea region; the Antarctic Convergence, Antarctic Divergence and Antarctic Slope Front (Fig. 2). Frontal zones separate water masses of different temperature and salinity and exhibit marked biological and physical changes. The interchange of these water masses, especially at the Antarctic Divergence, provides the minerals and nutrients fundamental to marine biological production.

The Antarctic Convergence (Polar Frontal Zone) lies between about 55ºS and 60ºS and separates subantarctic water to the north from Antarctic water to the south. This is a zone of variable width, characterised by steep gradients in sea surface temperatures and abrupt changes in phytoplankton composition and abundance, zooplankton distribution, pelagic bird species, and weather conditions. The Antarctic Convergence lies within the Antarctic Circumpolar Current or West Wind Drift – a broad zone of surface water that flows from west to east, driven by westerly winds. The Antarctic Convergence is a complex system where wave-like disturbances frequently close on themselves to form rings and eddies with a lifetime that varies from days to years (Foster 1984).

South of about 65ºS, where the winds from the east and southeast blow off the ice sheet, the Antarctic Coastal Current, or East Wind Drift, flows in the opposite direction – from east to west. The boundary between the East Wind Drift and the West

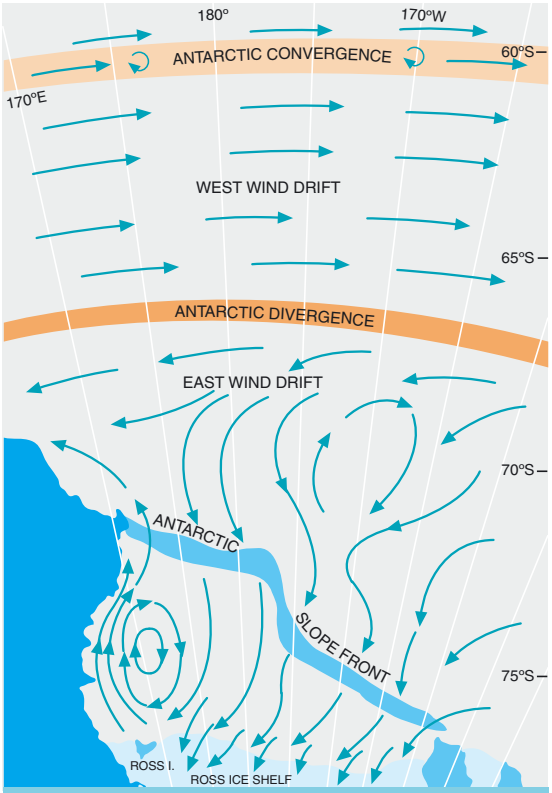


Figure 2: Oceanic fronts and surface water circulation in the Ross Sea region. Three main fronts occur; the Antarctic Convergence (Polar Frontal Zone), the Antarctic Divergence and the Antarctic Slope Front, sited over the continental shelf break.

Kim Westerskov, AntNZ Pictorial Collection

Several oceanic frontal zones occur in the seas of the Ross Sea region. These zones separate water masses of differing temperature and salinity and are marked by distinct biological changes.

Wind Drift forms the second frontal zone, the Antarctic Divergence, where deeper water that is rich in nutrients upwells to the surface, resulting in enhanced phytoplankton production.

A third frontal zone, the Antarctic Slope Front, lies over the edge of the continental shelf in the southern Ross Sea (Ainley and Jacobs 1981, Jacobs 1991) and is centred 10 – 45 km seaward of the shelf break, placing it just south of the 1,000 m depth contour. This topographically controlled front is marked by strong subsurface gradients in ocean currents and temperature, and by along-shore currents that are stronger than those occurring in most surface waters of the adjacent continental shelf. The slope front lies at the northern margin of the massive phytoplankton bloom that occurs over the Ross Sea continental shelf in summer.

Warm deep waters approach the continental slope of the Ross Sea from the northwest in the west and from the east-northeast in the east. These waters are seasonally cooled and warmed, salinised by the formation of sea ice, and freshened by water from melting ice. Ice and water is then moved west and north by surface circulation, which is mainly due to the extensive cyclonic gyre on the western side of the Ross Sea (Fig. 2). Surface waters move to the southeast along the eastern periphery of this cyclonic system. As the southeast flowing water approaches the Ross Ice Shelf, the current is deflected to the west, with part joining the cyclonic circulation and part passing beneath the shelf. Along the Victoria Land coast, a northward flowing coastal current forms a well defined and comparatively narrow stream (Tressler and Ommundsen 1962). Some of this water returns to the cyclonic circulation, while the rest turns to the west round Cape Adare and eventually joins the Antarctic Coastal Current.

Subsurface circulation is formed by two different anticyclonic gyres at each end of the Ross Sea, which are connected by a U-shaped cyclonic feature in the vicinity of the Ross Ice Shelf (Locarnini 1994).

Water masses

In the Ross Sea region, several distinct water masses can be distinguished, which are generally defined by the particular relationships between temperature and salinity (Fig. 3) (Jacobs and Comiso 1989, Carmack 1992, Jacobs and Giulivi 1999). Three water masses can be distinguished in the deeper oceanic waters of the Ross Sea region and five over the continental shelf and slope (Gouretski 1999).

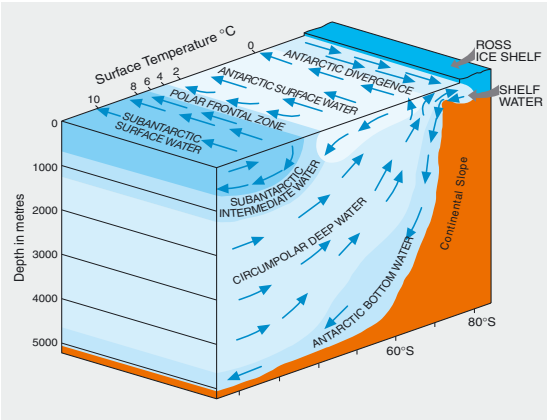


Figure 3: Water masses and flows of the Ross Sea region in average summer conditions. Source: Knox (1994).

Antarctic Surface Water, Circumpolar Deep Water and Antarctic Bottom Water occupy the oceanic parts of the region. Of these, Circumpolar Deep Water constitutes the greatest volume of water in the Southern Ocean and is characterised by high nutrient levels, generated from phytoplankton as it sinks through the water column. Antarctic Bottom Water occupies the deepest region of the water column and plays a major role in the global ocean circulation system. To form bottom water, the temperature must drop to below 0ºC and salinities must increase enough to initiate sinking. These conditions exist during winter sea ice formation, when salt is rejected making the already cold, dense water heavier. This water then sinks into basins in the continental shelf and spills over the continental slope in heavy "tongues" that move towards the equator, with some water even entering the northern hemisphere. The primary source of Antarctic Bottom Water is in the western Weddell Sea, and production in the Ross Sea is probably an order of magnitude less.

Antarctic Surface Water, High Salinity Shelf Water, Low Salinity Shelf Water, Ice Shelf Water, and modified Circumpolar Deep Water can be identified over the continental shelf and slope of the Ross Sea, although in contrast to other water masses, those on the continental shelf are highly variable. Antarctic Surface Water is found throughout the Ross Sea during the summer, with surface temperatures generally higher in the south where the pack ice opens up earlier in the summer and a wide range of salinities occur. Below this layer, dense shelf waters occur. High Salinity Shelf Water is the densest water found in the Southern Ocean and the high salinities are explained by the intensive process of ice formation in polynyas along the coast (Jacobs et al. 1985). Low Salinity Shelf Water is found in the eastern Ross Sea and is marked by slightly warmer sea surface freezing temperatures and lower salinities. Ice Shelf Water exhibits temperatures below the sea surface freezing point, an indication of interaction with the Ross Ice Shelf at depth. This water is concentrated in the west of the Ross Sea where it emerges from under the ice shelf (Jacobs and Giuvili 1999). Modified Circumpolar Deep Water represents deep oceanic waters that have penetrated the continental shelf. This water is warmer and occupies depths between 200 and 300 m.

Sea Ice

Sea ice is an important component of Antarctic ocean processes. The annual growth and melting of sea ice represents one of the greatest seasonal surface changes on Earth. At its maximum in winter, Antarctic sea ice covers an area of 19 million km^2 – greater than the land area of the continent (Fig. 4). At the end of summer in February, Antarctic sea ice covers approximately 4 million km^2. This annual pulse of winter extension and summer retraction to the continent of sea ice is the main driving force of the vertical circulation of Southern Ocean waters. Sea ice influences a number of global processes and has a profound effect on global climate through its effect on the exchange of heat between the atmosphere and the ocean (Box 2).

Sea ice influences ocean ecosystems by enhancing phytoplankton activity so that the levels of production in the ocean are strongly linked to the advance and retreat of sea ice, as well as to areas of strong mixing of water masses at the frontal zones. Sea ice also provides a surface for prolific ice algae growth and associated communities of microorganisms and provides habitat for higher animals such as penguins and seals.

"The annual growth and melting of sea ice represents one of the greatest seasonal surface changes on Earth."

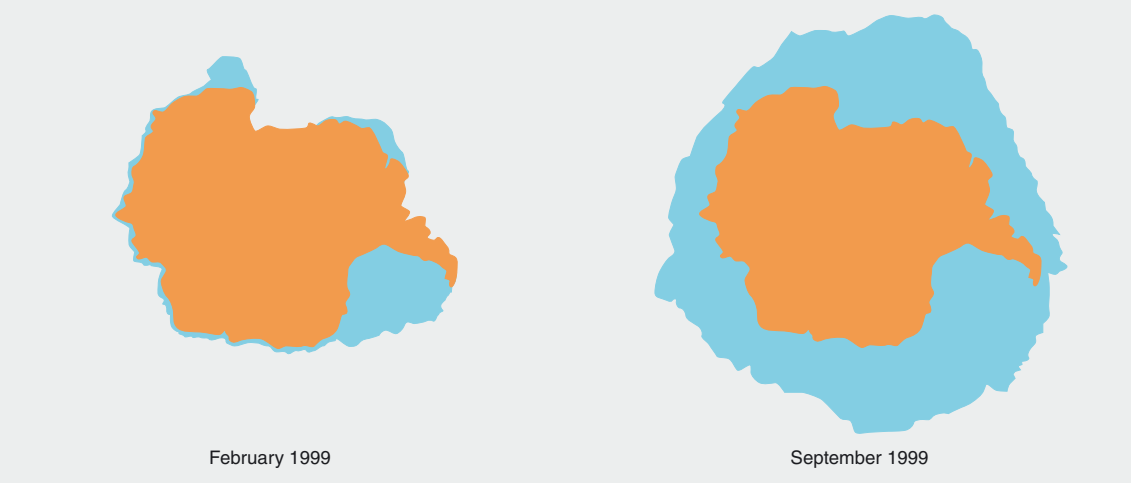


Figure 4: Approximate extent of Antarctic sea ice in summer (February) and winter (September). This change in sea ice extent represents one of the greatest seasonal surface changes on Earth. Sources: National Snow and Ice Data Center, University of Colorado, Boulder, CO, USA and United States Geological Survey Global Change Research Programme.

Box 2 The Role of Antarctic Oceans in the Global Climate System

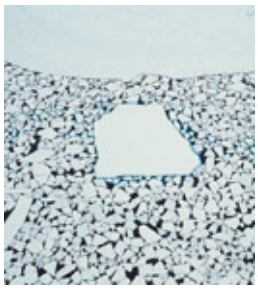
Global climate is most directly affected by processes in the oceans around Antarctica through the formation of sea ice. Sea ice increases the amount of solar radiation reflected at the ocean surface compared to open water. Consequently, changes in the distribution and extent of sea ice can change the amount of heat entering the atmosphere, which in turn affects climate. Sea ice also shields the ocean from wind and the wind's influence on ocean circulation.

Antarctic oceans are important to global climate in other ways too. The exchange of heat and chemicals between the atmosphere and the ocean is an important part of the global climate system. In some regions, air/sea interactions produce water that is denser than its surroundings, and this water sinks into the oceans. Water of differing properties will rise at other locations, depending on ocean circulation. This complex system of water mass renewal plays a major role in controlling climate change because the processes and rates of these phenomena determine the storage and transport of chemicals (that include greenhouse gases, such as carbon dioxide), and heat by the ocean.

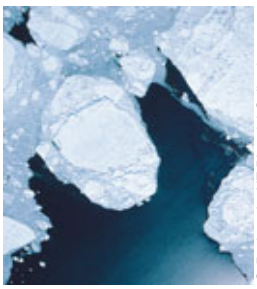
Antarctic Bottom Water, cold saline water formed around Antarctica as a result of the sea surface freezing, is a major component of this ocean circulation system. This water circulates from Antarctica into the northern hemisphere in periods of decades or longer. A small change in the wind or temperature at the surface of the Southern Ocean may alter the rate of production of Antarctic Bottom Water which in turn may change the deep water circulation of the oceans, thereby altering the climate in a more significant way.

Understanding sea ice and ocean circulation processes and the way they respond to changing conditions at the ocean surface is crucial to our wider understanding of global climate change.

Emma Waterhouse



C. Rudge, AntNZ Pictorial Collection



C. Rudge, AntNZ Pictorial Collection

Emma Waterhouse

Sea ice is an important and distinctive feature of the marine environment and also influences a number of global processes including climate. From left: Fast ice forms a continuous cover over the ocean, especially near the coast, the break up of fast ice, pack ice in the open ocean, and pancake ice, an early stage of sea ice formation.

Sea ice forms each autumn in Antarctica when the surface of the sea freezes as water temperatures reach -1.8ºC. Pack ice occurs in the open ocean, while near to shore, fast ice forms a continuous cover. This annual fast ice, which breaks up in the summer, varies in thickness from 2 – 2.5 m, although in some areas multi-year fast ice may reach thicknesses of 5 m.

From May to September, 86 percent of the Ross Sea shows ice coverage (Jacobs and Comiso 1989). This equates to over 4 million km^2 or one-fifth of the total extent of Antarctic winter sea ice. In the remainder of the year, varying levels of coverage and open water are experienced (Fig. 5). The continental shelf is largely ice-free throughout late summer (February), with a residual pack ice field northeast of the Ross Ice Shelf. In March, rapid autumn ice growth begins around the residual pack ice field and along the coastline, attaining high concentrations on the eastern shelf while the northwestern shelf remains ice-free. In winter, ice concentrations are generally less along the coastline and over the deeper oceanic areas of the region. Large polynyas and several smaller ones develop on the western continental shelf in December. By January, the pattern of ice melt opens the Ross Sea to the north, with ice usually remaining to the east. By February, the Ross Sea may be essentially ice-free away from the coasts and ice shelf.

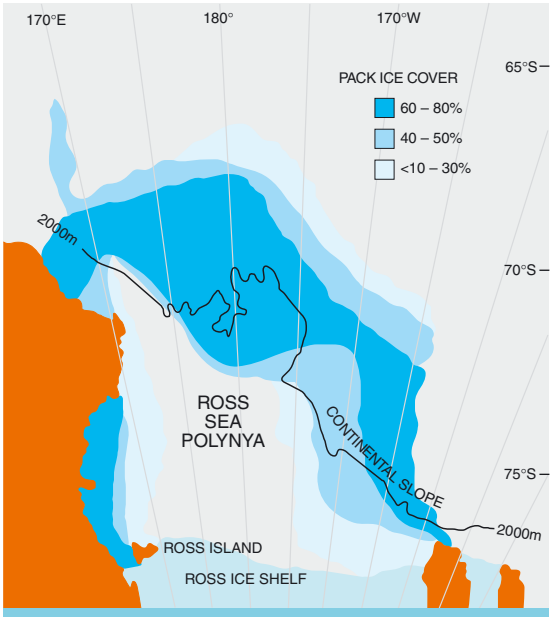


Figure 5: The distribution of pack ice in the Ross Sea region from late December to January. Features are the largely ice-free Ross Sea polynya and the dense concentration of pack ice over the continental slope and along the Victoria Land coast. Source: Ainley (1985).

Polynyas

Polynyas are areas of partially or totally ice-free ocean. They tend to occur where high winds rapidly disperse freshly formed ice, at times when air temperatures are well below the freezing point of sea water (Van Woert 1999). Polynyas play an important role in heat transfer from oceans to the atmosphere, ice production, the formation of dense shelf water, spring disintegration of sea ice, phytoplankton and zooplankton production, and the distribution of higher trophic animals such as cephalopods (squid and octopods), fish, birds, seals and cetaceans. Within polynyas, the oceanic heat loss may be 10 – 100 times above that of the ice covered surface.

The existence of open water in winter in the Ross Sea has been known since Robert Scott's early explorations. More recently, Zwally et al. (1985) and Bromwich et al. (1998) have reviewed the occurrence, extent, and variability of the Ross Sea polynya, which covers an area of about 27,000 km^2. This polynya owes its existence to a persistent cyclone near Roosevelt Island, which induces a sea level pressure distribution over the Ross Ice Shelf. This phenomenon results in an intensification and northward propagation of katabatic winds across the ice shelf and out to sea. The immediate effect of such katabatic surge events is the development of the Ross Sea polynya.

Other polynyas also occur in the Ross Sea and include small polynyas off Cape Royds, Ross Island, and a larger one in Terra Nova Bay (Kurtz and Bromwich 1985, Van Woert 1999). The Terra Nova Bay polynya is a stable feature, recurring annually and persisting throughout the winter, although it appears to vary in extent from less than a kilometre to 5,000 km^2 (Kurtz and Bromwich 1985, Van Woert 1999). Van Woert (1999) suggests that the extent of the polynya is due to both local and katabatic winds at Terra Nova Bay, as well as regional katabatic winds blowing off the Ross Ice Shelf. Fluctuations in air temperatures have also been noted as contributing to the size of this polynya.

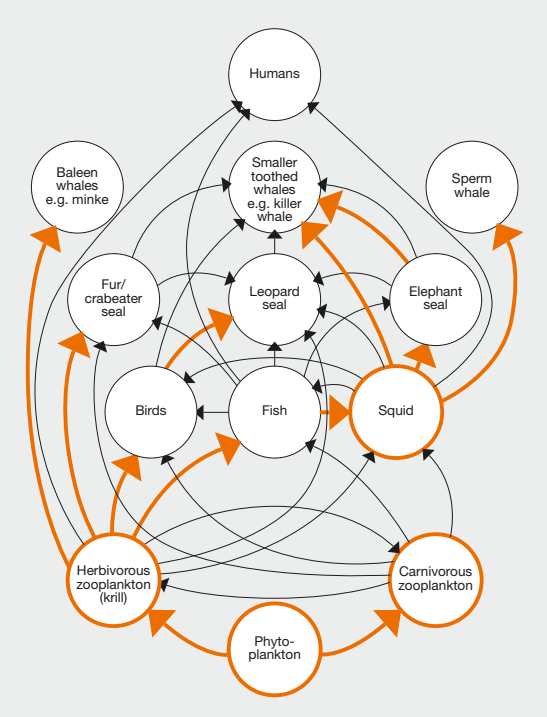


Figure 6: Main elements of the Antarctic marine food web. The orange lines represent the more important links in the food web. Sources: Knox (1990), Hansom and Gordon (1998).

Primary Production – the Phytoplankton

Recent research has confirmed that the Ross Sea is one of the most biologically productive regions of the Southern Ocean (Sullivan et al. 1993, Arrigo and McClain 1994, Walker et al. 1995, Carrada et al. 2000, Innamorati et al. 2000, Saggiomo et al. 2000) with estimated annual production four-fold higher than the average global ocean production (Saggiomo et al. 2000). Phytoplankton (floating microscopic marine plants) are the primary producers in the ocean, providing the basis for the marine food web (Fig. 6). These tiny organisms, through photosynthesis, fix inaccessible forms of inorganic carbon using energy from the sun. This process plays a key role in the exchange of gases, in particular carbon dioxide, between the ocean and the atmosphere.

> “The Ross Sea polynya is the site of the most productive and spatially extensive phytoplankton bloom in the entire Southern Ocean.”

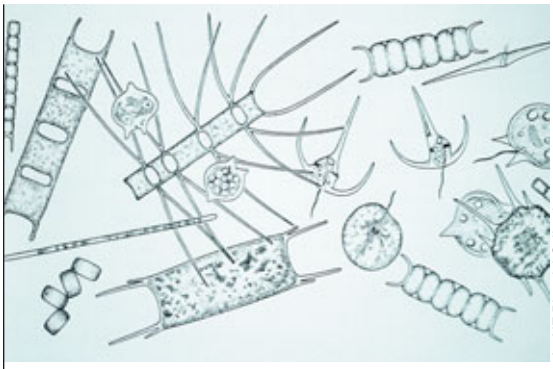
Within the Ross Sea, three subsystems of primary production can be distinguished. These correspond to the pack ice covered areas, the marginal ice zone, and the Ross Sea polynya (Carrada et al. 2000, Saggiomo et al. 2000). The Ross Sea polynya is the site of the most productive and spatially extensive phytoplankton bloom in the entire Southern Ocean (Sullivan et al. 1993, Carrada et al. 2000, Innamorati et al. 2000, Saggiomo et al. 2000). High chlorophyll concentrations (greater than 20 µg l^{-1}) have been detected using satellite sensors (Comiso et al. 1993), and in situ observations have occasionally

measured concentrations in excess of 10 µg l^{-1} (De Master et al. 1992). During cruises in January 1990, and February 1992, Walker et al. (1995) found that biomass and primary productivity were greatest in mid-January. Biomass concentrations in the north of the Ross Sea were on average only 23 – 37 percent of those in the south in 1990 and 38 – 83 percent in 1992. This difference is due to the southern Ross Sea becoming largely ice-free in December whereas the northern area does not become ice-free until mid-January.

As summer progresses, the aerial coverage of pack ice reduces due to melting and decay at the ice edge. As the ice decays and melts, it releases the sea ice microbial community into the water column. Relatively fresh water is also released into the water column, resulting in a surface layer that is vertically stable. A low salinity layer is formed above the high salinity water, with the two layers separated by a discontinuity layer at 10 – 50 m depth (a layer of rapid change in salinity) through which mixing is negligible. This layering ensures that the phytoplankton, which do not sink below the discontinuity layer, are maintained in a well-illuminated environment, and coupled with maximum solar radiation, conditions are established for the development of phytoplankton blooms (Smith and Nelson 1986).

Investigations of an ice edge phytoplankton bloom in the western Ross Sea off Victoria Land in January/February 1983 recorded extremely high chlorophyll concentrations in the bloom, which extended for some 200 km (Smith and Nelson 1985a, 1985b, Nelson and Smith 1986). Concentrations of biogenic silica were the highest reported to that date from the world's oceans, averaging about three times higher than concentrations reported from upwelling regions off the coast of northwest Africa. These ice edge phytoplankton blooms are significant in the overall primary productivity of the Ross Sea, with the high productivity largely due to the diatom *Fragilaropsis* cf. *curta* (Carrada et al. 2000, Innamorati et al. 2000, Saggiomo et al. 2000).

An important component of the annual primary production is the microalgae that grow in association with the sea ice (Horner et al. 1992, Legendre et al. 1992). The sea ice provides a growth substratum and refugium for a complex microbial community consisting primarily of microalgae, bacterium, protozoa and small metazoa. In McMurdo Sound, the microalgal standing crop in the interstitial assemblage that develops in the bottom 25 cm of the ice column has been measured at between 121 – 131 mg chl a m^{-2} (Palmisano and Sullivan 1983). The sea ice microalgal community makes a substantial contribution to the overall primary production of the Ross Sea and also provides a food source for the cryopelagic community, which comprises the ice associated fish, *Pagothenia borchgrevinki*, larval fishes, amphipods, copepods, and adult and larval euphausiids. In winter, the microalgae provide food for larval and adult krill.


AntNZ Pictorial Collection

Marine diatoms.

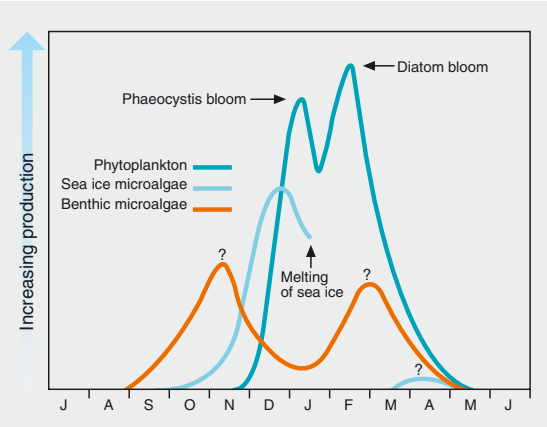


Figure 7: The seasonal cycle of microalgal production in McMurdo Sound. Little research has been done on benthic microalgae and on autumn production of sea ice microalgae. Source: Knox (1990).

Microalgal production follows a predictable annual pattern in the Ross Sea (Fig. 7). Diatoms dominate early in the season (mid-November to mid-December), followed by a bloom of the colonial alga, *Phaeocystis pouchetii*, from mid-December to early January and a subsequent diatom bloom in late January/February. *Phaeocystis* blooms are a common feature in the Ross Sea (El Sayed et al. 1983, Palmisano et al. 1986, Stoekner et al. 1995). The sea ice microalgal production commences in spring, reaching a peak in mid-December, and from mid-January the production is released into the water column with the ice melt. There may be a further, smaller sea ice microalgal production in the autumn after the sea ice has reformed. The production curve for the benthic microalgae that occur on shallow sediments is somewhat speculative as little research has been conducted. A spring peak of production occurs in early November before the growth of the sea ice microalgae reduces the light available to the benthic microalgae (Knox 1990). A second peak is thought to occur after the breakout and melting of the sea ice.

Zooplankton float, drift or swim in the ocean and graze mainly on phytoplankton so that their reproduction coincides with the seasonal pulse of phytoplankton production (Knox 1994). Zooplankton include protozoa, the larval and juvenile stages of copepods, herbivorous adult copepods (especially *Calanus propinquus* and *C. acutus*), krill and the mollusc *Limacina helicina*. Omnivorous zooplankton are present below 50 m depths and are dominated by the copepod *Metridia gerlachei*, amphipods and ostracods. Copepods (*Euchaeta antarctica*), mollusca (*Clione* sp.), chaetognaths (arrow worms), and the larvae of the pelagic fish *Pleuragramma antarcticum* dominate the carnivorous zooplankton. Below 500 m, the omnivorous mysid *Antarctomysis ohlini* is the only dominant species. Salps (free-swimming tunicates) are essentially restricted to the waters north of the Antarctic Divergence.

Ross Sea zooplankton and community structure are similar to those found in other comparable areas of the Southern Ocean such as the Weddell Sea and Prydz Bay and are characterised by a complete absence of benthic larvae (Hecq et al. 2000), low biodiversity (few species), and diurnal and seasonal migrations (Mackintosh 1973). Large size is also a feature of many species of zooplankton, typified by krill (Box 3) and copepods, as is their slow growth and long life cycles.

Copepods and the pteropod *L. helicina* (a pelagic mollusc) dominate the zooplankton in outer McMurdo Sound following the breakout of the ice (Hopkins 1987). Other important species are the ice krill (larval stages), large radiolarians, and the pelagic polychaete, *Pelagobia longicirrata*. The dominant macro-plankton and micro-nekton (actively swimming) species found include ice krill (post larval stages), amphipods, a mysid shrimp, chaetognaths, the pteropod *Clione antarctica*, siphonophores, and larval and postlarval stages of the fish *P. antarcticum*.

A comparison of the zooplankton community in outer McMurdo Sound with that of Croker Passage on the Antarctic Peninsula (Hopkins 1985a, 1985b) has revealed that while the two areas have many species in common, the biomass composition is different. Croker Passage is a high biomass area dominated by krill, with a zooplankton-euphausiid-fish combined biomass of 58 g dry weight m^{-2} (Hopkins 1985a). McMurdo Sound has much lower standing stocks, with a total zooplankton-euphausiid-fish biomass of only 3.5 g dry weight m^{-2} (Hopkins 1987). Furthermore, the ratios of these biomass components differ radically and reflect the abundance and overwhelming dominance of krill in the vicinity of the Antarctic Peninsula and the lesser abundance of ice krill in McMurdo Sound. Salps are also a major biomass component in Croker Passage but are absent from McMurdo Sound. Fish biomass is comparable in the two ecosystems, but while *P. antarcticum* and the myctophid, *Electrona antarctica*, share dominance in Croker Passage, myctophids are absent from McMurdo Sound. Myctophids are however abundant in the outer Ross Sea.

Box 3 Distribution and Biomass of Krill in the Ross Sea

The shrimp-like krill (*Euphausia superba*) are widespread and abundant in the Southern Ocean and an important part of the Antarctic marine food web. Other species of euphausiids are also important, including, for the Ross Sea, the smaller ice krill (*E. crystallorophias*). Until comparatively recently, the krill populations of the Ross Sea have received very little attention. Early studies of their distribution concluded that the major concentrations in the Ross Sea occurred north of 70ºS and that krill were rare in the inner Ross Sea where ice krill dominated (Marr 1962, Mackintosh 1973). These conclusions were later confirmed by Lubimova et al. (1984) and Shimadzu (1984), although Maslennikov (1980) identified concentrations of krill along the northern Victoria Land coast.

In recent years, Italian scientific expeditions have carried out surveys of the distribution and biomass of krill in the inner Ross Sea (CCAMLR 1998, Azzali and Kalinowski 2000, Azzali et al. 2000, Faranda et al. 2000b). The results of these surveys indicated that dense concentrations of krill are present in regions of the Ross Sea that previously had been considered to be krill deficient. The biomass of krill in the Ross Sea has been estimated at around 3 million metric tonnes and during the late spring, is concentrated over the continental shelf. However, by the beginning of summer, the main part of the biomass occurs on the continental slope (between 71 and 73ºS).

When the sea is almost fully covered by ice, or when the ice edge is moving northwards, populations of krill are restricted in narrow ice-free areas, where very dense aggregations are formed. Around these areas, density peaks of krill-consumer populations have been found, including minke whales, crabeater seals and Adélie penguins. Krill makes up the main part of the zooplankton biomass on the continental slope and the central part of the continental shelf. However, south of 75°S and westwards (from longitude 171°E) this relationship progressively changes in favour of smaller plankton and the ice krill.

M. MacFarlane, AntNZ Pictorial Collection

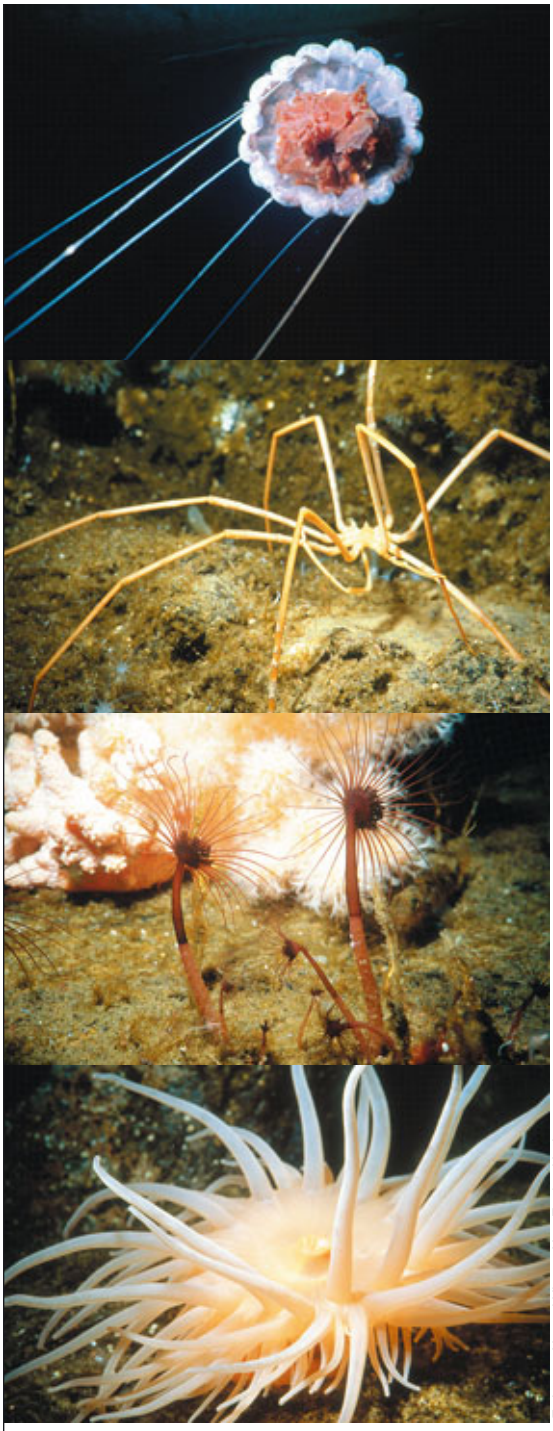
Krill are an important part of the marine food web of the Southern Ocean.

Biodiversity

Rich and diverse communities of plants and animals, many of which are unique to Antarctica, live on the bottom of the sea floor in the region. These benthic habitats are among the most spectacular to be found anywhere in the world. They too are little studied but generally appear similar to those existing in other regions of the Antarctic. Studies have tended to concentrate on the shores of McMurdo Sound and in Terra Nova Bay. More recently, biodiversity data was collected in the vicinity of some northern Victoria Land sites, including Cape Hallett and the Possession and Balleny islands (Mitchell 2001).

Virtually all studies that have looked at subtidal ecosystems in Antarctica have remarked on the extremely high diversity and level of endemism. With perhaps the only exceptions being decapod crustaceans (shrimps, crabs and crayfish) and cirripedes (barnacles), the species diversity in nearly all major groups of Antarctic marine invertebrates is at least 50 – 100 percent higher than in the Arctic and is comparable with temperate or even tropical environments (Dearborn 1968, White 1984, Arntz et al. 1997). Levels of endemism in the major groups of Antarctica's marine benthic fauna range from 50 – 95 percent of all species present, indicating a long period of isolation and independent evolution.

One unusual feature of such specialisation is that a few groups account for much of the diversity (they have a high degree of dominance). It is typical that a few families or genera within each animal group have undergone adaptive radiation to produce numerous species, all filling specialised ecological niches, whereas other closely related groups have not. Moreover, because many of the dominant invertebrates reproduce without pelagic larval stages, different regions of Antarctica tend to have a high proportion of endemic species (Arnaud 1977, White 1977, Picken 1980). Dell (1990) found that of the 193 species of shelled molluscs recorded from the Ross Sea, 13 percent or 25 species were thought to be endemic, although this may simply reflect a lack of more widely distributed sample data, particularly for the very small species.



E. Jowett, Natural History New Zealand Ltd.

The invertebrate fauna of the Ross Sea region is diverse and exhibits a high level of endemism, with many species as yet undescribed. From top: Jellyfish, sea spider and anemones.

> "Virtually all studies that have looked at subtidal ecosystems in Antarctica have remarked on the extremely high diversity and level of endemism."

Kim Westerskov, AntNZ Pictorial Collection

Platelet ice forms on the underside of sea ice and, when it ammalgamates on the sea floor, can trap sediment and animals.

Hard Bottoms (rock and consolidated sediments)
Hard bottoms account for only a small fraction of the total area of the Ross Sea and are presumed to be exclusively coastal, although deep offshore reefs (Anderson 1991) and seamounts (elevations in the ocean floor) do occur. Patterns of biological zonation on these shores are markedly different from those observed in more temperate regions and are primarily determined by depth and the physical disturbance associated with annual formation of sea and anchor ice (Dayton et al. 1970).

The shallowest hard-bottomed zone extends to around 15 m from the surface and is heavily impacted by sea ice and the formation of platelet and anchor ice. Anchor ice is formed by amalgamations on the sea bed of the platelet ice that forms beneath sea ice, and can smother or enclose and trap sediment and benthic animals. It is most abundant in winter and close to large ice masses such as the Ross Ice Shelf, but theoretically cannot form at depths greater than 50 – 75 m (Littlepage 1965). Once the ice mass attains sufficient size, its buoyancy can rip it from the substrate and carry all that it contains to the surface, although it is probably more common for it to simply melt away as the water warms. Battershill (1989) found that up to 70 percent of the sea floor at Cape Armitage (Hut Point Peninsula, Ross Island) was unoccupied at depths of 22 – 25 m and attributed this to anchor ice disturbance. Ice scours on rocky substrate create bare space for recolonisation by plants and animals, and on soft sediments, regularly disturbed areas are devoid of large sessile organisms and are primarily inhabited by infaunal species, such as tube-dwelling worms and amphipods, and mobile opportunists like urchins and starfish. Older scours become colonized by sedentary infauna, such as the burrowing anemone, *Edwardsia meridionalis*. During summer, these shallows become carpeted with a dense mat of ephemeral microscopic plants, including filamentous blue-green algae and benthic diatoms.

In stark contrast, undisturbed rock faces and consolidated sediments in deeper water harbour a dense tube-mat community of more sedentary organisms, including large polychaete worms, crustaceans, and suspension-feeding bivalve molluscs. Anchor ice can occasionally extend to 30 m from the surface, a depth that abruptly marks the lower limit of the next faunal zone. Since sediments between 15 and 30 m depth are only rarely disturbed, faster growing sessile animals are dominant such as soft corals (*Alcyonium paessleri*), hydroids (*Tubularia ralphiii, Corymorpha parvula* and *Ophiodes arboreus*), large sea anemones (*Urticinopsis antarctica* and *Isotealia antarctica*), and the fast growing bush sponge *Homaxinella balfourensis*. Also abundant is the fan worm *Potamilla antarctica* and the large tunicate *Cnemidocarpa verrucosa*. A small, but numerically dominant species that is particularly suited to this habitat is the soft coral *Clavularia frankliniana*. These species colonise this region in the absence of competition for space from the slower growing sponges that dominate in deeper water. Such competition for space is a feature of shallow rocky marine habitats worldwide and is characterised by the production of chemical defence mechanisms to prevent overgrowth by neighbouring organisms.

A rich and diverse community of slow-growing sessile organisms, predominantly sponges, dominates on hard bottoms at depths greater than 30 m. This is the so-called sponge garden zone. The sea floor may be totally covered by many different species with some individuals over a metre tall. These species in turn provide a three-dimensional living substrate for a multitude of other organisms which are elevated in the water column, where increased current flow brings greater food availability, especially for particle feeding organisms such as crinoids (feather stars), ophioroids (brittle stars) and holothurians (sea cucumbers). This community may extend to considerable depths on suitable substrate. Even in these deeper waters, the passage of drifting icebergs can cut swathes through the long-lived and stable sessile (fixed and stationary) communities, which are so slow growing that even such infrequent disturbance can have a significant effect. Iceberg scours have been found at depths of up to 700 m and may play an important role in structuring successional processes in the deep-water sponge communities (Gutt 2000).

Soft Sediments

Soft sediments dominate the sea floor of the Ross Sea region. Barrett et al. (1983) sampled the sea bed throughout Granite Harbour and McMurdo Sound, mostly at depths greater than 300 m and, with few exceptions, found muddy sand with relatively sparse macrofauna. In shallower soft sediment areas of McMurdo Sound, total biomass is generally lower than in those areas with hard substrates dominated by sponge communities, although the sponge spicule mat, and its associated abundant macrofauna, sometimes occurs on consolidated soft sediment as well as rock. However, infaunal abundance in soft sediments may be extremely high, particularly in the east of McMurdo Sound where densities of up to 155,000 individuals per square metre have been recorded (Dayton and Oliver 1977). By stark contrast, densities are at least an order of magnitude lower at sites in western McMurdo Sound. This decline has been attributed to oligotrophic conditions caused by nutrient impoverished water flowing north from under the Ross Ice Shelf. There are other interesting differences between the western and eastern shores of McMurdo Sound. Some areas in the west support high densities of the scallop *Adamussium colbecki* (Stockton 1984), which is virtually absent from the east side, as well as a great diversity of brittle stars and the interesting pencil urchin *Ctenocidaris perrieri*.

The large burrowing bivalve mollusc (*Laternula elliptica*) dominates the biomass, although huge numbers of much smaller infaunal species also occur, such as polychaetes, amphipods, isopods, ostracods, cumaceans, tanaids, gastropods and smaller bivalves. Coelenterates, such as the soft coral *Clavularia frankliniana* and the burrowing anemone *Edwardsia meridionalis*, are the dominant sessile macrofauna, and mobile scavengers and predators such as fish, starfish, sea urchins, nemertean worms, large anemones, and pycnogonid sea spiders are still relatively abundant.

Some sessile animals, such as the soft coral *Gersemia antarctica*, are adapted to detrital feeding (Slattery et al. 1997), which is unique among soft corals. This feature is possibly an adaptation to complement planktonic suspension feeding that becomes restricted by the highly seasonal productivity of Antarctic waters and the relatively oligotrophic conditions that prevail in the west of McMurdo Sound. In many respects, both the physical conditions and the soft sediment benthos in southern reaches of western McMurdo Sound resemble that of the deep sea but occur at safe diving depths, making this a potentially important experimental model for deep-sea ecosystems (Dayton and Oliver 1977).

“The sea floor may be totally covered by many different [sponge] species with some individuals over a metre tall.”

Seaweeds are an important component of shallow-water marine communities in Antarctica, but they show a gradual decline with increasing latitude. One factor in this decline is the greater degree of seasonality that is found closer to the South Pole, with the occurrence of the polar night at latitudes greater than 66ºS. The annual formation of sea ice also limits light penetration for much of the year, and seaweeds are affected by the same abrasive scouring by ice that limits the colonisation of shallow water by sessile animals. In southernmost latitudes, where sea ice lasts longer in summer and forms earlier in autumn than further north, large benthic marine algae (seaweeds) have difficulty surviving, and the community is primarily animal, except where summer blooms of benthic microflora occur in shallow water. More northern latitudes do support abundant seaweed growth. The red algae *Phyllophora antarctica* and *Iridaea cordata* are common at Cape Evans on Ross Island (Miller and Pearse 1991), at Granite Harbour on the western side of McMurdo Sound, and dominate shallow hard bottoms (2 – 30 m deep) at the more northern Terra Nova Bay, where encrusting coralline algae also become common (Cormaci et al. 1992, Gambi et al. 1994). It is generally believed that brown macroalgae, common in other Antarctic and subantarctic zones, are absent from the Ross Sea (Cormaci et al. 1992). However, some anecdotal reports of drift algae at Cape Hallett imply that such flora may be present in the more northern reaches.

Under the Ross Ice Shelf

Relatively little is known about the biological environment below the Ross Ice Shelf. In the late 1970s, a major study to investigate life beneath the shelf 450 km from open sea, revealed some interesting observations (Clough and Hansen 1979). Results showed that although animals were present they were mostly sparsely distributed and possibly errant individuals that had strayed under the shelf. Mostly, mobile crustaceans were observed, including copepods, mysids, euphausiids, isopods and amphipods (Lipps et al. 1978, 1979). Remotely operated cameras also recorded the presence of fish. This community is probably supported by drift material that circulates under the ice shelf from productive open sea to the north (Bruchhausen et al. 1979). Measures of productivity below the Ross Ice Shelf returned extremely low values combined with an almost complete absence of any animals living either in or on the bottom sediments (Azam et al. 1979). More productive benthic communities may establish in coastal areas and at the margins of ice shelves, where ice is thinner and light can penetrate or where currents transport food under the ice.

Biomass and Productivity

The high biomass values for Antarctic benthic communities have recently been confirmed by statistical evaluation of data from several areas around the world (Brey and Gerdes 1997). At depths of 10 – 1000 m, community biomass is up to an order of magnitude higher than in comparable non-Antarctic regions. An example is the western side of Ross Island, which seems to represent something of a marine oasis even by Antarctic standards. Although generally similar in patterns of vertical zonation and community composition to other areas, the standing biomass here is higher than almost any other region so far studied in the Antarctic. This high biomass has been attributed to the presence of a southerly current along the western shore of Ross Island that carries water enriched by the annual summer bloom in plankton (Barry and Dayton 1988). Unfortunately this area has also been subjected to serious marine pollution from McMurdo Station, although the impacts seem to be quite localised.

In comparison to their high biomass, sessile Antarctic communities are characterised by low rates of productivity. Rather than being a specific adaptation to a unique environment, these low rates are probably just a consequence of low temperatures and irregular food supply (Brey and Clarke 1993). Many Antarctic benthic invertebrate species brood their young rather than producing planktonic larvae (Picken 1980), and sessile filter feeders, although generally slow growing and long-lived, show annual spurts in growth associated with the summer phytoplankton bloom (Clarke 1988). Many of the larger mobile invertebrates such as starfish, urchins and amphipods also rely on a discontinuous food supply and are opportunistic predators or necrophagous (carrion feeding) scavengers (Arnaud 1970).

Cephalopods

The Southern Ocean contains large stocks of cephalopods (squid and octopods), which form an important part of the diet of a number of species. Sea birds, seals and whales are estimated to consume 34 million metric tonnes of cephalopods per year (Clarke 1983). Little is known about the cephalopods of the Ross Sea, including the biomass, total annual production and, as with other areas around Antarctica, stock availability. Although there is very little current commercial exploitation of the cephalopod resources in the Southern Ocean, several extensive fisheries have been developed in the subantarctic waters, including for the squid *Notodarus sloani* off the New Zealand subantarctic islands.

Fish

Apart from studies carried out by United States and New Zealand scientists in McMurdo Sound, and by Italian scientists based at Terra Nova Bay, there is little comprehensive information available on the fish fauna of the Ross Sea region. Offshore collections have been sporadic, and despite a limited number of cruises throughout the 1960s, 1970s and more recently in the 1990s, no comprehensive summary of the fish fauna of the Ross Sea has been published. The results of two bottom-trawling cruises in 1996/97 and 1997/98 highlight our incomplete knowledge of the fishes of the Ross Sea (Eastman and Hubold 1999). Forty-seven species were collected representing eight families and included four new species, a new colour morph of a known species, and eight rare species. Four new locality records were also established for the Ross Sea as well as three records of the most southerly occurrences in the Southern Ocean and eleven new depth records. The developing fishery in the region (see *Fishing and Whaling*) is adding to our knowledge of the deep water fish fauna and their distribution. Several collections of specimens from the fishery are currently being studied and initial results indicate several new records for the region and some potentially new species.

Of the 174 species of fish recorded from the continental shelf of Antarctica, at least 80 occur in the Ross Sea south of the 1000 m isobar (Eastman and Hubold 1999), including 54 notothenioids and 26 non-notothenioid species (Table 2).

Rajidae
Bathyraja eatonii *
Bathyraja maccaini *
Bathyraja sp *
Raja georgiana

Bathylagidae
Bathylagus antarcticus

Paralepididae
Notolepis coastsi

Myctophidae
Electrona antarctica[1]
Gymnoscopelus
- *braueri*
- *nicholsi*

Krefftichtys anderssoni
Lampanyctus achirus
Protomyctophum bolini

Muraenolepididae
Muraenolepis microps *

Macrouridae
Macrourus whitsoni

Liparidae
Careproctus polarsterni
Edentoliparis terraenovae[2]
Paraliparis
- *andriashevi*
- *antarcticus* *
- *devriesi*
- *fuscolingua*
- *new sp. 1**
- *new sp. 2**

Zoarcidae
*Lycodichthys dearborni** *Ophthalmolycus*
- *amberensis* *
- *bothriocephalus* *

Pachycara brachycephalum *

Nototheniidae
Aethotaxis mitopteryx
Dissostichus mawsoni
Gvozdarus svetovidovi
Notothenia coriiceps[3]
Pagothenia
- *borchgreviniki*
- *brachysoma*

Paranotothenia dewitti[4]
Pleuragramma antarcticum *
Trematomus
- *bernacchii* *
- *eulepidotus* *
- *hansoni*
- *lepidorhinus* *
- *loennbergii* *
- *newnesi*
- *nicolai*
- *pennellii* *
- *scotti* *
- *tokarevi*

Artedidraconidae
Artedidraco
- *glareobarbatus* *
- *loennbergi* *
- *orianae* *
- *shackletoni* *
- *skottsbergi* *

Dolloidraco longedorsalis *
Histiodraco velifer *
Pogonophryne
- *albipinna*
- *barsukovi*
- *cerebropogon* *
- *dolichobranchiata*
- *lanceobarbata*
- *macropogon*
- *marmorata* *
- *mentella* *
- *permitini*
- *phyllopogon* *
- *scotti* *

Bathydraconidae
Akarotaxis nudiceps *
Bathydraco
- *macrolepis* *
- *marri* *
- *scotiae*

Cygnodraco mawsoni *
Gerlachea australis *
Gymnodraco acuticeps *
Prionodraco evansii *
Racovitzia glacialis *
Vomeridens infuscipinnis *

Channichthyidae
Chaenodraco wilsoni
Chionodraco
- *hamatus* *
- *myersi* *

Cryodraco antarcticus *
Dacodraco hunteri *
Neopagetopsis ionah *
Pagetopsis
- *macropterus* *
- *maculatus* *

Notes:
*indicates species captured during cruises 96-6 and 97-9 of the RV *Nathaniel B. Palmer*
[1] A single specimen collected 241 km offshore from Terra Nova Bay Station at about 74º55'S, 172º30'E. As this is well south of the shelf break, the specimen is likely a stray.
[2] Formally *Paraliparis terraenovae*
[3] A single specimen has been collected a Terra Nova Bay and this is probably the southern extent of its range in the Ross Sea.
[4] Species formerly included in *Notothenia magellanica*. Represented by one specimen (USNM 171 000) from surface waters of the eastern Ross Sea (Kainan Bay), 78º14'S, 161º55'W.

Table 2: Fish fauna of the Ross Sea. Species include those found living over the continental shelf and slope to a depth of 1,000 m. The northern limit is around Cape Adare. The arrangement is by evolutionary development for families and alphabetical for genera within families and for species within genera. Source: Eastman and Hubold (1999).

Iain MacDonald, AntNZ Pictorial Collection

Notothenioid fish of the Ross Sea. From left: *Trematomus bernacchii*, *Trematomus pennelli*, *Pagothenia borchgrevinki*, *Trematomus hansoni*.

L. Bercusson, AntNZ Pictorial Collection

Antarctic toothfish is one of the fish species caught and studied by scientists in McMurdo Sound.

The most specialised and numerically significant of the families of fishes recorded from Antarctica are those of the notothenioid group. The group comprises six families including Antarctic cods (Nototheniidae), plunderfishes (Artedidraconidae), spiny plunderfishes (Harpagiferidae), thornfish (Bovichtidae), dragonfishes (Bathydraconidae) and icefishes (Channichthyidae). The notothenioids have diversified from an ancestral stock of benthic species to occupy a vast array of differing ecological niches and include the cryopelagic (associated with the underside of sea ice) *Pagothenia borchgrevinki*, the extremely abundant Antarctic silverfish *P. antarcticum*, and the Antarctic toothfish *Dissostichus mawsoni* and Patagonian toothfish *D. eleginoides*. One of the specialisations of this group that has enabled them to survive in the cold but stable marine environment of the high Antarctic is the evolution of antifreeze proteins that prevent the formation of ice in their blood. Only the antifreeze-bearing notothenioids are able to endure the presence of large amounts of ice in the near-freezing surface waters close to the Antarctic continent (DeVries 1970). Other fish groups that lack antifreeze are confined to deep waters, or lower latitudes where ice is less common. For this reason, notothenioids become progressively more dominant in the southernmost regions of the Ross Sea (DeWitt 1970). Although the notothenioids make up only 55 percent of all fish species recorded from the Antarctic continental shelf, they comprise around 70 percent of species in both the Ross (Eastman and Eakin 1998) and Weddell seas (Hubold 1991).

Adaptive radiation has distributed these fishes among available ecological niches. Some benthic species such as *Trematomus bernacchii* and *T. centronotus* are common in the shallow ice-disturbed zones, as well as their larger predators like the dragonfishes. *T. hansoni, T. loennbergi* and *T. lepidorhinus* are more common in deeper water below 30 m. *Pagothenia borchgrevinki* is commonly found under annual ice. The pelagic Antarctic silverfish is common offshore at all depths down to 900 m. One of its predators, the Antarctic toothfish, that attains 1.75 m in length and can weigh over 80 kg, is regularly caught at depths of 300 to 500 m. The interesting white-blooded icefishes (Channichthyidae), which lack haemoglobin, are rarely seen in McMurdo Sound but are commonly caught at Terra Nova Bay to the north. Snailfishes (Liparidae) and eelpouts (Zoarcidae) are the only non-notothenioids regularly caught in the waters of McMurdo Sound and then only at depths of around 500 m.

Further recent studies supported by the Italian National Programme for Antarctic Research have looked at the larval and juvenile fishes of the Ross Sea and coastal fish communities at Terra Nova Bay (Vacchi et al. 1999, 2000). Species diversity of the larval fish community of the western Ross Sea has been found to be similar to that recorded elsewhere in Antarctica with a greater abundance near shore. Faunistic composition and species diversity of the fishes in Terra Nova Bay do not differ very much from other coastal fish communities inhabiting sites in East Antarctica, such as Lutzow-Holm Bay and the Vestfold Hills region.

The dominant pelagic species in the Ross Sea is the Antarctic silverfish which comprises up to 96 percent of fish biomass (DeWitt 1970). Studies carried out in Terra Nova Bay and the western Ross Sea (Granada et al. 2000) found that the ichthyoplankton (fish larvae) community was dominated by nototheniids (98.3 percent of all larvae). Silverfish was the dominant species sampled in spring-summer cruises, ranging from 98.6 percent in 1987/88 to 99.8 percent in 1995/96. Silverfish occurs in the diet of the Antarctic toothfish and is also a major food item in the diets of Weddell seals, killer whales, Adélie and emperor penguins, south polar skuas and Antarctic petrels. In common with other coastal high latitude systems, it occupies a key role in the pelagic ecosystem.

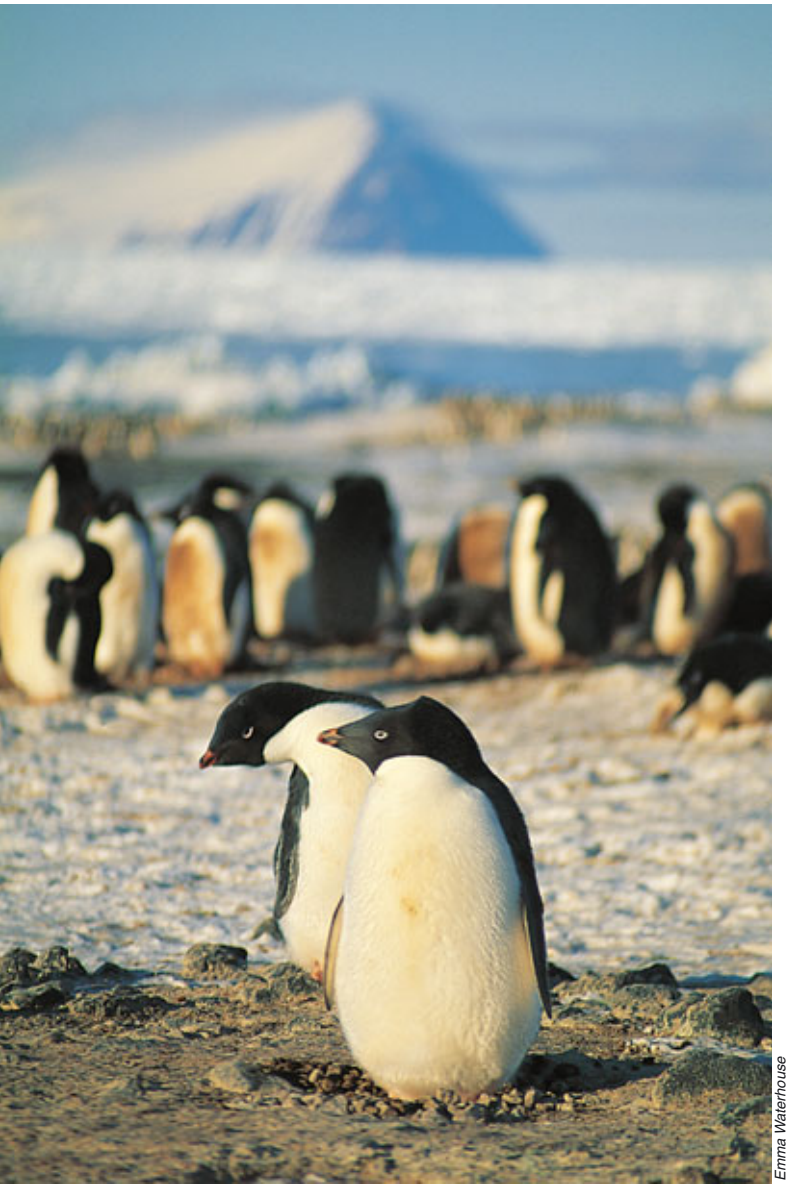
Sea Birds

Biodiversity and Biomass

Antarctic sea birds are an important part of the Southern Ocean ecosystem, consuming krill, other zooplankton and larval fishes. Sea birds depend on the ocean for their food but breed on land during the short Antarctic summer. On a local scale they may have a significant impact on prey species and at breeding sites strongly influence the terrestrial ecosystem. The Ross Sea region is very important in its representation of Antarctic birds, in particular emperor and Adélie penguins. Populations of these two birds in the Ross Sea region comprise about a third of the total world populations, and many of the breeding colonies are the southernmost occurrence for the species. Eleven species of sea bird breed in the Ross Sea region. However, only six of these species (two penguins, three petrels and a skua) breed south of the Balleny Islands and Scott Island (Table 3). All of the species breeding in the region are found elsewhere in Antarctica, and without Scott Island and the Balleny Islands, the avian biodiversity of the Ross Sea region is relatively low. Although not breeding in the region, a number of other, mainly subantarctic sea birds, are known to forage south of the Antarctic Convergence.

The bird population of the Ross Sea region has been estimated by Ainley (1985) to total about 10 million birds, which in December to early January translates to an average density of 16 birds per km^2 and a biomass of 44 kg per km^2. This population is dominated in numbers by the Antarctic petrel, with an estimated 5 million birds, followed by the emperor penguin, and the Adélie penguin.

> "The Ross Sea region is very important in its representation of Antarctic birds, in particular emperor and Adélie penguins."



Emma Waterhouse

Adélie penguins at the large rookery at Cape Bird, Ross Island.

Common Name	Latin Name
Penguins	
Emperor penguin	*Aptenodytes forsteri*
Adélie penguin	*Pygoscelis adeliae*
Chinstrap penguin[2]	*Pygoscelis antarctica*
Petrels	
Snow petrel	*Pagodroma nivea*
Antarctic petrel	*Thalassoica antarctica*
Wilson's storm petrel	*Oceanites oceanicus*
Pintado petrel[3]	*Daption capense*
Antarctic fulmar[3]	*Fulmaris glacialoides*
Antarctic prion[1]	*Pachyptila desolata*
Skuas	
South polar skua	*Stercorarius maccormicki*
Southern skua[2]	*Stercorarius lonnbergi*

Notes:
[1] Scott Island only
[2] Balleny Islands only
[3] Scott Island and Balleny Islands only

Table 3: Breeding birds of the Ross Sea region.

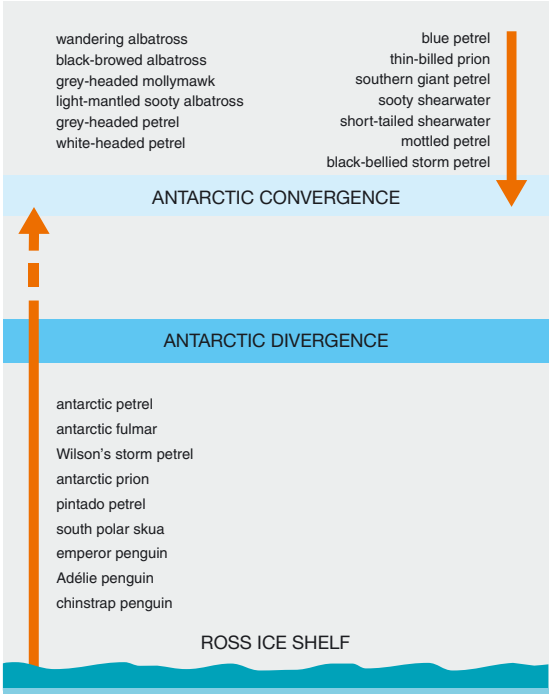


Figure 8: Feeding ranges of Ross Sea region birds. The Antarctic Convergence plays an important role in determining the distribution of birds and to some extent halts the southward movement of several subantarctic species.

Kim Westerskov, AntNZ Pictorial Collection

Alan Hemmings

Emma Waterhouse

Subantarctic seabirds that commonly move across the Polar Frontal Zone. From top: Black-browed albatross, southern giant petrel, light-mantled sooty albatross.

Sea Bird Assemblages

The distribution and abundance of sea birds in the Ross Sea region is influenced by oceanographic features such as the Antarctic Convergence (Polar Frontal Zone) and the Antarctic Divergence, the location of areas where food is abundant, the occurrence of sea ice, and the location of breeding sites (Ainley and Jacobs 1981, Ainley et al. 1984). Where the Polar Frontal Zone is sharply defined, it may halt the southward movement of some subantarctic birds, including the wandering albatross (*Diomedea exulans*), black-browed albatross (*D. melanophris*), grey-headed mollymawk (*D. chrysostoma*), light-mantled sooty albatross (*Phoebetria palpebrata*), thin-billed prion (*Pachyptila belcheri*), grey petrel (*Procellaria cinerea*), and white-headed petrel (*Pterodroma lessoni*) and restricts the northward movement of the open-water Antarctic birds (Harper et al. 1990) (Fig. 8).

However, Ainley et al. (1984) demonstrated that many subantarctic species do, to varying degrees, move south of the Polar Frontal Zone, including the black-browed albatross, light-mantled sooty albatross, southern giant petrel (*Macronectes giganteus*), pintado petrel, Antarctic prion, mottled petrel (*Pterodroma inexpecta*), sooty shearwater (*Puffinus griseus*), short-tailed shearwater (*P. tenuirostris*), black-bellied storm petrel (*Fregata tropica*) and southern skua. Among the most abundant of these species in the open-water and iceberg habitat north of the pack ice are sooty and short-tailed shearwaters. Ainley et al. (1984) recorded between 8 and 10 sooty and short-tailed shearwaters per square kilometre in this zone in December and January respectively. Short-tailed shearwaters also forage north of the pack ice in summer (Harper et al. 1990, Veit and Hunt 1991) and yet, along with the sooty shearwater and mottled petrel, breed far to the north.

Three distinct communities or assemblages of bird species are recognisable in the Ross Sea region (Table 4). The most distinct community is associated with the pack ice and waters dominated by pack ice. The second community is linked to the cold waters north of the pack ice, especially where icebergs occur. With the exception of the Antarctic petrel, members of this second community are apparently less restricted to their habitat than the members of the pack ice community are to theirs. The third community is more diverse, consisting of subantarctic species that move across the Polar Frontal Zone. Members of these sea bird communities are not evenly distributed within their favoured oceanographic habitats. During the breeding season the density of birds of most major high latitude species is much greater near their respective breeding areas. Vast areas of seemingly suitable foraging habitat are often left vacant during the breeding season (Ainley et al. 1984).

Sea bird community	Chief species	Other species
Pack ice and waters dominated by pack ice	Emperor penguin Adélie penguin Antarctic petrel Snow petrel South polar skua	Wilson's storm petrel Southern giant petrel Southern fulmar (*Fulmaris glacialoides*)
Cold waters north of pack ice, iceberg zone	Southern fulmar Wilson's storm petrel Antarctic petrel Mottled petrel	Light-mantled sooty albatross Southern giant petrel Pintado petrel Snow petrel Antarctic prion
Subantarctic species that move across the Polar Frontal Zone	Black-browed albatross Light-mantled sooty albatross Southern giant petrel Pintado petrel Mottled petrel Antarctic prion Sooty shearwater Black-bellied storm petrel Southern skua	Wandering albatross White-headed petrel Royal albatross (*Diomedea epomophora*) Grey-headed albatross (*Thalassarche chrysostoma*) White-chinned petrel (*Procellaria aequinoctialis*) Blue petrel (*Halobaena caerulea*) Diving petrel (*Pelecanoides spp*) King penguin (*Aptenodytes patagonica*)

Table 4: Sea bird assemblages of the Ross Sea region. Three distinct sea bird communities can be determined. Source: Ainley et al. (1984).

Figure 9: Known breeding localities of petrels in the Ross Sea region.

Alan Hemmings

Pintado petrel.

Petrels

Information on the numbers and distribution of petrels breeding in the Ross Sea region is very limited. Antarctic petrels are the most numerous species in the Ross Sea region and on the basis of at-sea surveys, Ainley et al. (1984) suspect that millions must breed somewhere in Marie Byrd Land. However, just one colony with an estimated 10,000 pairs has been found in this area (Broady et al. 1989). Small numbers also breed at the Balleny Islands and on Scott Island. There are no known breeding sites in Victoria Land, though one is believed to exist in Robertson Bay near Cape Adare.

Snow petrels are often observed throughout the Ross Sea region, and the larger subspecies *Pagodroma nivea major* is known to breed in considerable numbers at the Balleny Islands, with fewer on Scott Island (Jouventin and Viot 1985). In Victoria Land, the smaller subspecies (*P. nivea*) is thought to breed in the Morozumi Range and is known from at least eight other locations (Fig. 9). Snow petrel numbers are estimated at about 2 million, making it the second most abundant petrel species in the region.

Even less is known about Wilson's storm petrel breeding sites, although the species is thought to breed at the Balleny Islands (Robertson et al. 1980) and is confirmed on Scott Island and eight sites in Victoria Land, with an estimated total population of 400,000. This petrel is associated with open water and open leads in the pack ice (Ainley et al. 1984). Antarctic fulmar, pintado petrel and Antarctic prion are not known to breed in Victoria Land but do breed at the Balleny Islands and Scott Island. The Antarctic prion is only known to inhabit Scott Island (Harper et al. 1984).

Penguins

Three species of penguin breed in the Ross Sea region; the emperor, Adélie, and chinstrap penguins. This latter species only breeds on the Balleny Islands and only in small numbers (Robertson et al. 1980). The colony is also the only record of chinstraps breeding on this side of the Antarctic continent.

Emperor penguins are known to breed in seven colonies in the Ross Sea region, making up 30 percent of the world emperor penguin population (Kooyman 1993, Woehler 1993), including the two biggest colonies in Antarctica, at Coulman Island and Cape Washington. Six colonies lie off the Victoria Land coast and one off Marie Byrd Land (Kooyman 1994) (Fig. 10). The small colony at Cape Crozier, with about 1,000 pairs, is the most southerly of all emperor penguin colonies, and the most northerly Ross Sea colony, at Cape Roget, is still further south than much of the rest of the Antarctic coastline where other emperor colonies occur.

Common to all six Victoria Land colonies is the proximity (less than 6 km away) of open water or polynyas that probably persist through winter, allowing breeding birds access to foraging areas as early as possible in spring (Kooyman 1993). Emperor penguins everywhere are dependent on coastal annual fast ice that does not break out until after the chicks of the year have fledged, in late December. Populations flourish wherever there is an extensive area of fast ice, with open water nearby and some protection from the worst storms (Kooyman 1993).

Aerial photography from 1983, and air and ground counts in 1990, have been used to assess the number of chicks produced at the six Victoria Land emperor penguin colonies. Results indicate that, in general, the population is increasing (Kooyman and Mullins 1990, Kooyman 1993). For example, Cape Washington fledged 24,000 chicks in 1990, an increase of 4,000 on the previous 1986 census, and Coulman Island fledged 28,000 in 1990, an increase

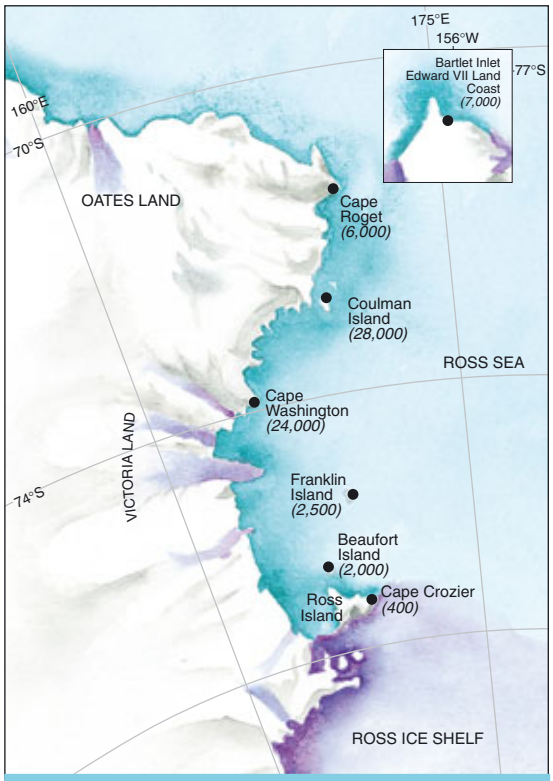


Figure 10: The location and size (number of fledgling chicks in 1990) of the seven emperor penguin colonies of the Ross Sea region.

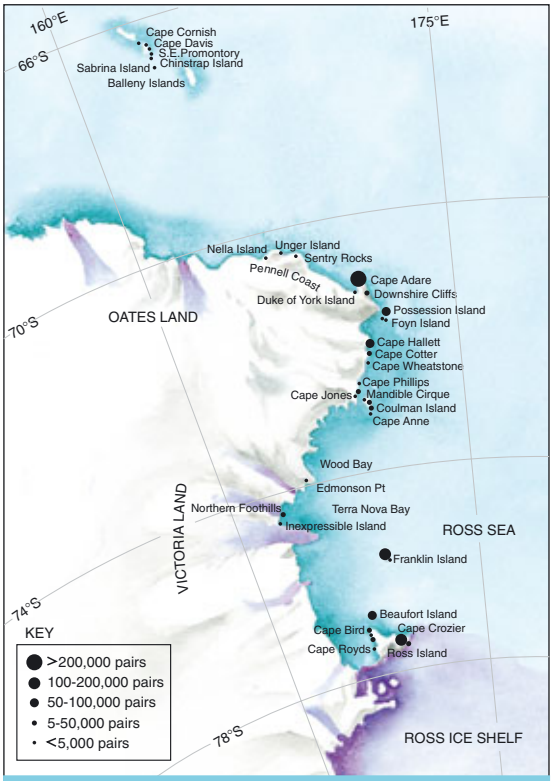


Figure 11: The location and size (number of pairs) of Adélie penguin rookeries in the Ross Sea region.

G. Wilson, AntNZ Pictorial Collection

The only breeding site for the chinstrap penguin in the Ross Sea region is on the Balleny Islands.

Y. Martin, Ant/NZ Pictorial Collection

Emperor penguin colony on fast ice at Cape Crozier.

> “…emperor penguins may be particularly vulnerable to longer-term climate change and subsequent alterations to their breeding areas.”

from 22,000 in 1983. However, the population at Franklin Island has decreased by more than half from the 5,000 counted in 1983. Kooyman noted that both the Beaufort and Franklin island colonies are vulnerable to early breakout of the very limited area of fast ice available for breeding.

In colonial sea bird populations, large environmentally induced changes in any of the conditions that are necessary for successful breeding can result in a year when few, if any, offspring are successfully produced. If the event is isolated, the population will easily recover. However, emperor penguins may be particularly vulnerable to longer-term climate change and subsequent alterations to their breeding areas. During the last century, there have been major fluctuations in the breeding population of emperor penguins at Cape Crozier for example, ranging from 0 – 1,400 chicks, primarily as a result of the instability of the sea ice on which the penguins breed (Harper et al. 1984, Kooyman and Mullins 1990).

Adélie penguins have been extensively studied in the Ross Sea region, and a good body of literature now exists, reviewed in Young (1981), and has been added to by numerous recent publications (Table 5). The results of these and other studies have significantly advanced our knowledge of Adélie penguins, and current Australian and Italian work at the Terra Nova Bay colonies is providing invaluable insights into this species’ ecology at a little studied part of the bird’s latitudinal range (Olmastroni et al. 1998).

Adélie penguins are now known to breed at 35 rookeries in the Ross Sea region, with a total of about 1 million breeding pairs (Fig. 11) representing over a third of the total Antarctic breeding population (Woehler 1993). The location of breeding sites is the result of several factors, including the persistence throughout most summers of wide belts of fast ice (thus denying access to much of the Pennell Coast and to the Victoria Land coast between Coulman Island and Wood Bay and south of Inexpressible

Subject	References
Distribution, abundance	Taylor et al. 1990, Taylor and Wilson 1982, 1985, 1990, Ainley et al. 1998
Demographics and population regulation	Ainley et al. 1983, Blackburn et al. 1991, Wilson et al. 2001
Chick creching	Davis 1982a
Timing of nest relief	Davis 1982b
Incubation routines and mate choice	Davis 1988
Survival of eggs and chicks	Davis and McCaffrey 1986
Foraging patterns	Davis and Miller 1990, Ainley et al. 1998
Foraging and krill stocks	Miller and Davis 1993
Winter foraging	Davis et al. 1996
Mate choice	Davis and Speirs 1990
Circadian rhythms and melatonin	Cockrem 1990, 1991
Sperm competition	Hunter et al. 1995
Colony age and DNA differentiation	Ritchie and Lambert 1998

Table 5: Aspects of Adélie penguin ecology and associated references.

Island), a lack of suitable terrain for nesting (ice-free ground safe from avalanches), as in the eastern Ross Sea and at the Balleny Islands, and the tendency for small colonies to form around large colonies (Ainley et al. 1995). Adélie penguin populations have fluctuated during the last century, and this may be related to the extent of winter sea ice (Box 4).

Skuas

Southern skua breeding is only thought to occur on the Balleny Islands but has not been confirmed (Young 1990). Much more is known about the distribution and numbers of breeding south polar skuas in the Ross Sea region, largely due to work summarised by Watson et al. (1971) and surveys by Ainley et al. (1986). These surveys increased the number of known breeding sites from 21 to 55 (Fig. 13), although the coastline north of 73ºS, from Cape Jones to Cape Adare was not surveyed, and up to 20 more skua breeding sites may exist there. Estimates of 15,000 skuas for the Ross Sea region during summer have been made. The skua colony at Cape Crozier is reputedly the largest in the world, and it is also the site of the best long-term demographic study of the skua ever conducted.

Ainley et al. (1986) reviewed the available counts of skua populations in the Ross Sea region and concluded that there had been an increase in skua numbers in southern McMurdo Sound and especially during the 1950s and early 1960s when human refuse at the McMurdo Station dump was readily obtainable. In contrast, skua numbers at Cape Hallett declined from 180 pairs in 1959/60 (Reid 1964) to 98 pairs in 1971/72 (Trillmich 1978) when the research station was closed. Although the decline has been attributed to human disturbance, only 84 pairs were counted in 1983, which suggests that other factors may have contributed to the decline (Ainley et al. 1986).

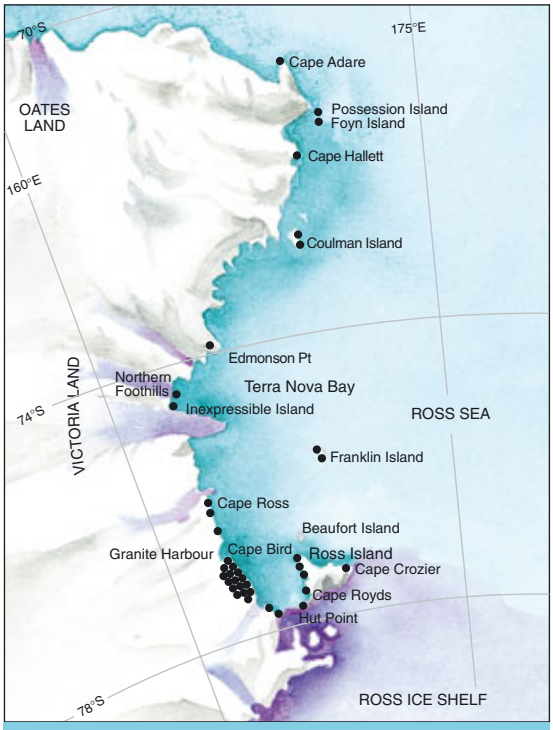


Figure 13: Distribution of breeding skuas in the Ross Sea region. Source: Ainley et al. (1986).

Box 4 Adélie Penguin Population Trends and Possible Causes

For colonies where data were available, Adélie penguin populations in the Ross Sea region declined throughout the 1960s. In 1968, population numbers reached a low point at both Cape Hallett in the northern Ross Sea and on Ross Island in the south. Thereafter, numbers rose steadily until the mid 1970s and then, after levelling off for a few years, increased dramatically after 1981 (Taylor et al. 1990). Increases from 1981 until 1987 were substantial and ranged from 40 – 80 percent. However, the fall in breeding populations in colonies in both these areas after 1987 was even more dramatic, and most gains were lost by 1990. Since then, numbers have begun to grow again, most obviously at Cape Royds (Fig. 12).

The data now conclusively show that the long-term and substantial fluctuations in the numbers of breeding pairs of Adélie penguins on Ross Island is in phase and similar in all Adélie penguin colonies throughout the Ross Sea region. The Cape Royds and Cape Hallett colonies, which have a history of human disturbance, experienced the same fluctuations in population numbers at the same time as the undisturbed colonies on Ross Island (Thomson 1977, Wilson et al. 1990). Late breakout of sea ice associated with Ross Island Adélie penguin colonies has been shown to have an immediate and detrimental effect on numbers of breeding pairs and their efficiency in terms of reproduction (Stonehouse 1967, Ainley and LeResche 1973, Spurr 1975).

Recent research has also shown that there is a highly significant negative relationship between maximum winter sea ice and numbers of breeding pairs counted at the colonies, with a 5 – 6 year lag. In the Ross Sea, unlike the Antarctic Peninsula region, winter sea ice is always present and extends north well beyond the shelf break where sea bird prey is abundant (Ainley and Jacobs 1981, Ainley et al. 1998). Adélie penguins over-wintering in the Ross Sea, in years when the maximum sea ice extends further north than normal, may be pushed so far beyond the productive water of the shelf break that they are in effect in a marine desert. Lack of food leads to starvation or increased predation, disproportionally affecting less experienced birds, hence the 5 year lag in the effect in the breeding population as 5 years is the average age of recruitment of birds into the breeding population (Wilson et al. 2001).

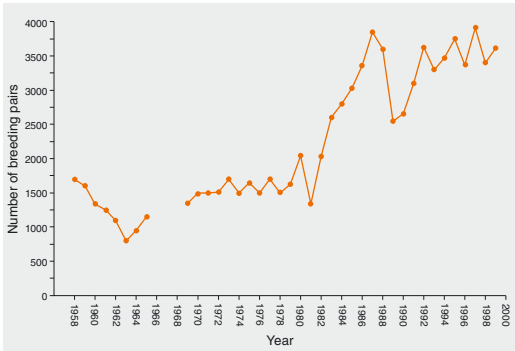


Figure 12: Changes in the population of Adélie penguins at Cape Royds, Ross Island. Source: Landcare Research Ltd, New Zealand.

The breeding biology of south polar skuas is well understood, as is their relationship to penguins (Young 1994). When skuas nest in association with Adélie penguins, they take advantage of the nutritional resources offered by the penguins, in the form of eggs, chicks and spilt regurgitated food. However, only 16 of the 55 skua breeding sites surveyed in the Ross Sea region are associated with Adélie penguin colonies, and those skua breeding sites are nearly all small, contributing only 20 percent of the total breeding pairs. The occurrence of many more skuas breeding at sites other than Adélie penguin colonies lends strong support to the argument that skuas do not depend on penguins for food, but that both species are nesting on the small amount of suitable ice- and snow-free environment available, nearest to abundant marine foraging areas (Ainley et al. 1986, Young 1994).

Kim Westerskov, AntNZ Pictorial Collection

South polar skua in flight.

Sea Bird Foraging and Diet

Most work on sea bird foraging and diet has been carried out during the chick provisioning season. Sea birds feed largely on fish, squid, plankton, crustacea and krill (Box 5) and employ different foraging methods to obtain their prey. Almost all albatrosses and petrels, for example, take prey from the surface through either dipping, plunging or surface diving, whereas penguins are characterised by pursuit diving. Most sea birds are also opportunistic scavengers.

A study conducted by Ainley et al. (1984) has helped to determine feeding habitat and prey capture techniques for the Ross Sea region. The authors also sampled breeding and non-breeding individuals of several key species in the sea bird communities that frequent various feeding localities. In general, in oceanic habitats just north of the shelf break, crustacea (mainly krill) and squid predominate numerically in the diet of most bird species. In the continental slope area, the importance of krill in the diet increases, and fish (mostly *P. antarcticum*) replace squid to some extent. In continental shelf waters, fish and crustacea (mostly ice krill) predominate, and squid appears to be of negligible importance.

Box 5 Seabird Diet and Antarctic Silverfish

The Antarctic silverfish, *Pleuragramma antarcticum*, is the dominant fish in the neritic waters (the portion of the sea floor that lies between the low water mark and the edge of the continental shelf) of both the Ross and Weddell seas and feeds on copepods and ice krill (*Euphausia crystallorophias*) (Gon and Heemstra 1990, Eastman 1993). Silverfish acts as a link between plankton and the higher order marine predators such as the birds, seals and whales in the shelf waters and is particularly important in the Ross Sea because of the extensive continental shelf (Ainley and DeMaster 1990). Studies of the diet of emperor penguins located outside the Ross Sea have shown that penguins nurturing chicks feed on fish, squid and crustaceans. Fish, mainly *P. antarcticum* is always an important component of the sea bird diet, but the dietary importance of cephalopods and crustaceans varies according to locality and the distance to deeper water beyond the continental shelf (reviewed in Cherel and Kooyman 1998).

With 30 percent of the world's population of emperor penguins breeding in the Ross Sea, it is surprising that until recently we knew very little about their diet there. Cherel and Kooyman's (1998) investigation of the diet of emperor penguins feeding chicks during spring at Cape Washington, Coulman Island and Cape Roget clearly shows the critical importance of *P. antarcticum* in the diet (approximately 80 percent by mass at Cape Washington and 90 percent by mass at Coulman Island and Cape Roget). Ross Sea Adélie penguins feed to some degree on the same community of prey as emperor penguins. Although *P. antarcticum* is always important in the diet, the proportion of ice krill in the Adélie penguin chick-provisioning diet is normally much greater than for emperor penguins (Ainley et al. 1998). Telemetry studies (Ward et al. 1986, Davis et al. 1988, Sadleir and Lay 1990), during the egg incubation phase, show that most Adélie penguins move northwards beyond the range of the tracking stations (around 40 km) for most of their time at sea, and birds sampled for diet during the same period, as they arrived at Cape Bird, mostly contained ice krill (Van Heezik 1988).

Silverfish is also of importance in the diet of several surface-feeding birds, including the south polar skua, snow petrel and Antarctic petrel (Ainley et al. 1984, Mund and Miller 1995), in the diet of several squid species (Lu and Williams 1994), and also in the diet of some fish, including *Dissostichus mawsoni* (Takahashi and Nemoto 1984, Eastman 1985).

Clearly the importance of *P. antarcticum* in the Ross Sea marine food web cannot be over emphasised.

Tim Higham, AntNZ Pictorial Collection

Until recently very little was known about the diet of emperor penguins in the Ross Sea. Research has now shown that the Antarctic silverfish is of critical importance in the emperor penguin's diet.

An important conclusion from Ainley's work (also see Ainley et al. 1992) is that on the basis of weight of prey rather than number, squid and fish are major dietary components for most Antarctic sea birds, and krill are relatively less important than has been generally thought. Furthermore, what little nutritional segregation exists among species has been accomplished through differences in feeding behaviour, prey size and feeding habitat. The study hypothesised that if food supply limits the population size of Antarctic sea birds at all, it is most likely to do so during winter. This is the period when prey availability to surface foragers (including Adélie penguins) is reduced by maximum pack ice cover, and prey abundance is minimal.

Seals

Seals are the most common marine mammals in the Ross Sea. Five species have been recorded, including the Weddell seal (*Leptochynotes weddellii*), crabeater seal (*Lobodon carcinophagus*), Ross seal (*Ommatophoca rossii*), leopard seal (*Hydrurga leptonyx*) and southern elephant seal (*Mirounga leonina*). The first three species can be considered to be exclusively Antarctic in distribution with only very occasional observations of stragglers north of the Antarctic Circle. The distribution of all seals is influenced by the annual expansion of sea ice around the continent. The most commonly seen seal, and one of the larger species, is the Weddell seal, which breeds on fast ice close to the coast. Crabeater seals and one of their major predators, the leopard seal, are more common in the outer unconsolidated ice. Ross seals use areas of consolidated pack ice for breeding in summer but may spend much of the rest of the year foraging in the open sea. Southern elephant seals are rarely seen and only in summer when animals stray into the region from breeding and feeding grounds far to the north.

Weddell Seal

The Weddell seal is the most commonly encountered seal in the Ross Sea and is one of the most studied marine mammal species in the world. Ainley (1985) estimated that 32,000 Weddell seals occur in the Ross Sea. The ecology, behaviour and physiology of Weddell seals have been extensively researched by scientists from McMurdo Station and Scott Base since the late 1950s (Table 6), and studies of the demography and ecology of the McMurdo Sound Weddell seal population are probably the most enduring and detailed for any long-lived vertebrate.

Weddell seals are generally associated with inshore fast ice throughout the summer, where they establish breeding colonies and maintain access to the water by using perennial tide cracks. A relatively stable population of around 1,500 adult seals lies in the eastern side of McMurdo Sound (Testa and Siniff 1987), and an aerial survey of the west side of McMurdo Sound in 1981 found just over 500 animals, mostly near the Strand Moraines and Blue Glacier (Ross et al. 1982). Adult seals leave the

C. Rudge, AntNZ Pictorial Collection

G. S. Court, AntNZ Pictorial Collection

Tim Higham, AntNZ Pictorial Collection

Alan Hemmings

Seals of the Ross Sea region. From top: Weddell seal, leopard seal, southern elephant seal, crabeater seal.

Subject	References
Population, distribution and migration	Ainley et al. 1983, Ross et al. 1982, Ainley 1985, Testa and Siniff 1987, Schreer and Testa 1992, Stewart et al. 1998, Testa 1994, Burns et al. 1998
Mating systems	Cline et al. 1971, Bartsh et al. 1992
Diet and prey	Ross et al. 1982, Burns et al. 1998
Diving behaviour	Summaries in Kooyman 1981 and Zapol 1987
Vocalisation	Thomas and Stirling 1983, Morrice et al. 1994

Table 6: Weddell seal ecology. Aspects studied over the last 50 years are noted with selected references.

Kim Westerskov, AntNZ Pictorial Collection

Weddell seal with an Antarctic toothfish. This fish is one of the major food items for Weddell seals in McMurdo Sound.

> Among the most accomplished divers of any marine mammal, Weddell seals can dive for up to 75 minutes and to depths of 600 m.

breeding colonies by April and move northwards but tend to keep to open water using the pack ice habitat. Satellite tracked animals have been followed as far as 500 km north of McMurdo Sound, but most animals remain in the northern part of the sound. Ice conditions, the availability of prey, and the abundance of predators such as killer whales and leopard seals, may well determine where pups and adults go as they disperse from the breeding colonies (Testa 1994).

One of the major foods of Weddell seals in McMurdo Sound is the Antarctic toothfish. Among the most accomplished divers of any marine mammal, Weddell seals can dive for up to 75 minutes and to depths of 600 m. The seals make regular dives to depths of between 100 and 400 m to hunt Antarctic toothfish and a significant increase in the abundance of toothfish in McMurdo Sound from October to mid-November may be one reason why so many Weddell breeding colonies are established in this area (Ross et al. 1982). While Antarctic toothfish are undoubtedly a prized prey, smaller species of fish, as well as squid, probably contribute a greater proportion to the total diet of the Weddell seal (Burns et al. 1998).

Crabeater Seal

The crabeater is a seal of open water or loose pack ice and, despite its common name, feeds almost exclusively on krill. Up to 70 million metric tonnes of krill are estimated to be taken by crabeater seals annually in Antarctica (Oritsland 1977). The crabeater seal is the most abundant of all seals, with a worldwide population estimated at around 15 million animals (Gilbert and Erikson 1977), and is the most numerous seal in the Ross Sea, with an estimated population of 204,000 individuals. Although regularly seen in McMurdo Sound, they are more common in the northern regions of the Ross Sea, concentrated in the pack ice over the Antarctic Slope Front.

Crabeaters are medium sized seals and lithe in appearance, averaging 2.6 m in length and weighing around 250 kg. They are not gregarious, and adults are usually seen either singly or in pairs (Erickson et al. 1971). Because they are relatively difficult to catch, and due to the open water nature of their habitat, much less is known about the ecology and physiology of the crabeater seal than of the Weddell.

Leopard Seal

The leopard seal is one of the largest seals with adult males reaching 3 m and females 3.6 m in length. The Ross Sea population is estimated at around 8,000 individuals. Although seals, predominantly crabeaters, are common prey for the leopard seal, they only make up around 8 percent of its diet, with krill, penguins and fish comprising at least 70 percent (Oritsland 1977). Individual leopard seals are often seen in summer, stalking back and forth off the Adélie penguin rookeries of Ross Island, taking stray penguins as they return to or from their feeding sorties out at sea (Penny and Lowry 1967). Little is known of the biology of leopard seals including details of sex, age and reproductive status. For example, mating has never been observed in the wild and may take place underwater.

Ross Seal

The Ross seal is the smallest seal in the Ross Sea region and the rarest resident seal species with an estimated population of around 5,000. Adults are around 2 m long and weigh up to 175 kg. Like the crabeater, the Ross seal is a seal of pack ice and open waters and seems to prefer dense consolidated pack ice rather than the open pack frequented by crabeaters. Very little is known of the biology of the Ross seal and what is known is mostly limited to observations made from ships or from examinations of dead animals. Unlike the much larger Weddell seal, which is ponderous out of water and easily caught for scientific study, the Ross seal is agile and difficult to catch. Ross seals appear to be mostly solitary animals, only rarely seen in pairs (Wilson 1975), and feed mostly on squid and fish (Oritsland 1977, Skinner and Klages 1994).

Southern Elephant Seal

Southern elephant seals are the largest seals in the world, with adult males reaching up to 5 m in length and weighing over 3,500 kg. Females are much smaller, averaging 2.5 m and 400 kg. Elephant seals do not breed in the Ross Sea, and the nearest colony is situated on Macquarie Island, 2,400 km to the northwest. The most southerly record for the southern elephant seal is a pair of young adult males that spent a week in the vicinity of Scott Base in February 1975 (Brownell and Ainley 1976).

Kim Westerskov, AntNZ Pictorial Collection

Minke whales in broken sea ice, McMurdo Sound.

Whales

Unlike the seals, whales do not generally breed in the Antarctic but migrate to Antarctic waters in summer to feed, mainly on krill. Eight species of baleen whales (Mysticete) and 12 species of toothed whales (Odontocete) occur in the waters of the Southern Ocean south of the Antarctic Convergence (Knox 1994). Of the baleen whales, the blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physatus*), minke whale (*Balaenoptera acutorostrata*) and humpback whale (*Megaptera novaeangliae*) occur in the Ross Sea region. Two other species, the sei whale (*Balaenoptera borealis*) and the dwarf minke whale (*Balaenoptera bonarensis*) occur further to the north of the inner Ross Sea. The sperm whale (*Physeter macrocephalus*) and killer whale or orca (*Orcinus orca*) are the most common toothed whales, although smaller species such as the long-finned pilot whale (*Globicephala melaena*) and the southern bottlenose whale (*Hyperoodon planifrons*) do penetrate into the Southern Ocean south of 60°S (Table 7).

Reviews of the state of knowledge of Antarctic whales include those of Brown and Lockyer (1984), Gambell (1985), Chapman (1988) and Knox (1994), and assessments of Odontocete whales in the Antarctic are given in Kasamatsu and Joyce (1995). Information on the distribution and biomass of Ross Sea whales can be found in Ainley (1985). Surveys of the distribution and abundance of whales in the Ross Sea region have also been carried out by the International Whaling Commission (IWC) and Japanese researchers. Results of these studies show that minke whales are likely to be the most abundant whale in the Ross Sea. It appears that these whales are concentrated along the Antarctic Slope Front and in frontal activity in the western Ross Sea, with the distribution strongly influenced by the position and condition of the ice edge.

Species		Distribution	
Common name	Latin name	60 – 68°S	68 – 77°S
Baleen Whales			
Blue	*Balaenoptera musculus*	+	+
Fin	*Balaenoptera physalus*	+	+
Sei	*Balaenoptera borealis*	+	
Minke	*Balaenoptera acuturostrata*	+	+
Humpback	*Megaptera novaeangliae*	+	+
Toothed Whales			
Sperm	*Physeter macrocephalus*	+	+
Orca	*Orcinus orca*	+	+
Arnoux's beaked	*Berardius arnuxii*	+	+
Southern bottlenose	*Hyperoodon planifrons*	+	+
Long-finned pilot	*Globicephala melas*	+	
Hourglass dolphin	*Lagenorhynchus cruciger*	+	

Table 7: Whale species known to occur in the Ross Sea region. Sources: Cawardine (1995), Kasamatsu and Joyce (1995), Nishiwaki et al. (1997a, 1997b), Stewardson (1997).

D. Geddes, Ant/NZ Pictorial Collection

Killer whales patrolling the ice edge in McMurdo Sound.

High densities of killer whales have been observed in the southern Ross Sea with the southernmost sighting at 78°S. Killer whales migrate into Antarctic waters in early January and leave in late February. The highest densities of sperm whales have been observed in the inner Ross Sea, with the southernmost sightings at 74°S. In general, low numbers of beaked whales (Arnoux's and southern bottlenose whales) have been observed in the Ross Sea, with no sightings of long-finned pilot whales or hourglass dolphins in the inner Ross Sea. Maximum concentrations of these species lie north of 62°S.

Baleen whales and humpback whales feed on krill when south of the Antarctic Convergence, and blue and minke whales also take ice krill over the continental slope (Knox 1994). Before their exploitation, when they were a major consumer of krill, baleen whales impacted on the relative abundance of krill, as well as other krill consumers. Daily krill intakes by whales have been estimated at 4,000 kg for an adult blue whale (Lockyer 1981) and 1,000 kg for humpback whales. Toothed whales consume a more varied diet, with sperm whales feeding mainly on squid but also fish, including the large nototheniid fish *D. mawsoni* and *D. eleginoides*. Killer whales feed on squid, fish, birds, seals and other cetaceans.

Gaps in our Knowledge

There are a number of significant spatial and temporal gaps, as well as gaps of fundamental understanding, in our knowledge about the marine environment of the Ross Sea region. While our knowledge of the origin and distribution of water masses, fronts and water circulation patterns related to the physical oceanography of the Ross Sea region is adequate, it is largely confined to the spring-summer period and needs supplementing for the rest of the year. More data are needed on the detail of circulation patterns, air-sea exchange of heat, moisture and carbon, and the position and changes in the frontal zones. The production of Antarctic Bottom Water, a critical component of global ocean circulation, in the Ross Sea is also poorly understood. While good information is available on the distribution and seasonal variation in the sea ice cover, the thickness of sea ice throughout the Ross Sea is not well researched. Further analysis is also needed of year-to-year variation in sea ice distribution in order to establish long-term trends.

Information on primary production by the phytoplankton is mostly based on measurements carried out during the austral summer and is still insufficient to portray a reliable picture of the spatial patterns and seasonal dynamics (Smith et al. 1996, Saggiomo et al. 2000). Information on spring primary production is much more limited and is essentially based on the results of two cruises and on satellite imagery in late spring (Arrigo and McClain 1994). Data for other months of the year is lacking, and we need to further our understanding of the role of polynyas in primary production, as well as the feeding ecology of higher predators.

Tim Higham, AntNZ Pictorial Collection

Considerable gaps exist in our knowledge about many aspects of the marine environment of the Ross Sea region.

the sea ice microalgae. There is virtually no information available on the distribution and biomass of cephalopods apart from deductions from consumption by predators.

Most research to characterise subtidal habitats in the Ross Sea region has been concentrated in and around McMurdo Sound, and there is almost nothing known of the coastal sub-tidal ecosystems of the northern Victoria Land coast, of offshore islands, or of the eastern Ross Sea. Exploration of sea bed habitats by remote sampling from ships has only provided a snap shot of the biology of the sea floor and usually in relation to deep waters. It is possible that significant latitudinal variation in shallow subtidal habitats exists within the Ross Sea, since the Victoria Land coast contains the most extensive coastal latitudinal gradient in Antarctica, with northern areas remaining ice-free for longer periods through the summer months. If such latitudinal variation does exist, long-term studies of benthic community structure between northern and southern sites may reveal changes associated with climate change. However, care must be taken in interpreting any observed variation in benthic communities with increasing latitude because of the oligotrophic effect of the Ross Ice Shelf (being relatively poor in plant nutrients and containing abundant oxygen in the deeper parts) and the greater persistence of ice in the south.

Antarctic benthic communities are grossly under-sampled, and those in the Ross Sea region are particularly so. Relatively few groups of marine invertebrates have been studied in the Ross Sea, and data are much more readily available for other areas, such as the Antarctic Peninsula. When existing collections of Antarctic marine invertebrates are analysed, a large number of new species are invariably revealed. Most recent studies of shallow benthic communities in the Ross Sea have focused more on ecological interactions than classification, and there is still much to learn about the degree of uniqueness of the benthic fauna of this region. Only one study has succeeded in describing the life forms far beneath the Ross Ice Shelf, and it is possible that new and undescribed fauna live beneath the ice shelves of Antarctica.

> “When existing collections of Antarctic marine invertebrates are analysed, a large number of new species are invariably revealed.”

Research on the production and ecology of the sea ice microbial community has also been geographically and seasonally limited with the only comprehensive work being carried out in McMurdo Sound. Little work has been carried out on the effects of increasing ultraviolet (UV) radiation on these primary producers, an increasingly important issue with the continued presence of the ozone hole over Antarctica each spring (see *Global Influences*). There have been practically no studies of sea ice microbial communities in the Ross Sea pack ice zone, and while the dynamics of secondary production by zooplankton is well known in McMurdo Sound and Terra Nova Bay, processes in the pack ice zone and the polynyas have been little studied.

While we now have a clearer picture of the distribution of krill in the Ross Sea, further research is also required in this area to assess krill biomass and its fluctuations over time. We also need to determine changes in krill spatial patterns in relation to ice cover and to determine the interactions between these changes, krill predator populations, and other euphausiid species. More information is also required on the impact of krill grazing on phytoplankton and

Apart from inshore studies in McMurdo Sound and Terra Nova Bay, data on the biodiversity, distribution, life histories and population dynamics of most fish species in the Ross Sea is virtually non-existent, and new collections inevitably turn up new species. Exploratory fishing in the Ross Sea is providing some biological and taxonomic data, although it is limited to target species and by-catch. Like almost every other group of marine fauna or flora of the region, more work is needed to fully describe the diversity of the fish fauna of the Ross Sea. Assessment of the status of fish stocks and

AntNZ Pictorial Collection

A helicopter prepares to land on Sabrina Island in the Balleny Islands archipelago during a 1964/65 science expedition. Very few scientists have landed on these islands, which are an important site for biodiversity in the Ross Sea region.

population dynamics, especially for species being exploited, must be a priority.

Information on the breeding colonies and population trends of Adélie penguins, emperor penguins, and to a lesser extent, south polar skuas probably represent some of the best data sets for any marine species in the Ross Sea region. However, until recently, our knowledge of emperor penguins in this region was minimal, and considering their numerical importance in the Ross Sea, and their vulnerability to sea ice changes through climate warming, more work is needed to accurately track population trends. Information on other sea bird species is sorely lacking, in particular for snow and Antarctic petrels, including the location of breeding colonies and numbers. Information about important and unique "hot spots" of Ross Sea marine biodiversity that include these and other species, particularly around the Balleny Islands, is also lacking or needs updating.

While the important study by Ainley et al. (1984) of the numbers and habitats of resident and visiting Antarctic sea birds with regard to oceanographic features, the location of productive areas where food is abundant, the occurrence of sea ice, and the location of breeding sites vastly improved our knowledge, this study only covered the summer period. Our knowledge outside this period is almost totally lacking. A better understanding of the pelagic foraging and distribution of sea birds in relation to the distribution and availability of prey is also needed.

Most seal research in the region is shore-based and concentrated on the more accessible Weddell seal with the result that good information is available on the abundance, reproductive parameters and population dynamics of this species. However, very little information exists for other seals in the region, and information on crabeater and Ross seals is poor. Aspects of the biology of these species have been studied in other areas of the Antarctic and subantarctic, where they are more accessible or where ship-based oceanic research is more common. Accurate population data have not been gathered in the Ross Sea region, and although it is likely that vessels have often counted pack ice seals, little of this material has been published.

Good to fair information exists on the status of whale stocks in the Ross Sea, largely due to the IWC's Southern Ocean Whale and Ecosystem Research surveys (SOWER). However, gaps and uncertainties do exist about the distribution patterns of some whale species within the Ross Sea region and about aspects of their feeding ecology, including their influence on prey species.

Unlike several areas around Antarctica where huge research programmes are underway, the Ross Sea region lacks any concentrated effort towards understanding the food chain dynamics of its marine system. Moreover, almost all such efforts elsewhere have involved studies in open oceanic water, and given that the Ross Sea is largely neritic (shallow), these results are of limited use in modelling food web dynamics for the region. Collaborative research into the marine food web of the Ross Sea should be encouraged while it is still in a pristine state.

STATE OF THE MARINE ENVIRONMENT

The Southern Ocean is one of the world's least studied oceans, and the Ross Sea in particular has received comparatively little attention from researchers. Although this paucity of information makes it difficult to assess the state of the marine environment of the region, a general picture does emerge based on the levels of human activities to date (see *Science, Tourism,* and *Fishing and Whaling*), and the data and observations that we do have. Unlike the terrestrial and atmospheric systems, the marine environment has been subject to commercial exploitation, which continues today. Probably the most severely impacted areas lie in the coastal regions, close to the science research stations that have been the main centres of human activity.

Fisheries

Toothfish

The history of the over-exploitation of Antarctic fish stocks elsewhere in the Southern Ocean is well documented (Kock and Koster 1990, Knox 1994), although little large scale fishing has taken place in the Ross Sea region. Current fishing efforts target the Antarctic toothfish and Patagonian toothfish. In 2000/01, 658 tonnes of toothfish were taken from the Ross Sea with a total of 1,748 tonnes taken between 1996 and 2001. The annual catches have been well below the catch limits set by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (see *Ross Sea Region Overview*), assuming that no illegal, unreported or unregulated (IUU) fishing has taken place (see *Fishing and Whaling*). To date there has been no evidence of IUU fishing activity in the Ross Sea. Assuming the catch limits have been set to avoid localised depletion and related adverse effects on the food web and environment, it is likely that the fishing pressure has had a mimimal impact on toothfish stocks or on the ecosystem in the region. Any IUU fishing activity may change this situation and could result in higher catches and consequent environmental effects.

There is potential for future resource exploitation of fish stocks in the Ross Sea region including some benthic or bentho-pelagic species. Examples include the marbled rock cod *Notothenia rossii*, the big-eyed grenadier *Macrourus holtrachus*, the small-eyed moray cod *Muraenolepis microps*, the striped-eyed rock cod *Notothenia kempi* and the green rock cod *Pagothenia hansoni*. A number of pelagic species could also be exploited, including the Antarctic silverfish. There has been little exploitation of this species to date, although it represents a considerable resource. Large-scale fishing of this species could also impact on birds such as emperor and Adélie penguins, and skuas, which rely on it as a major food resource.

Apart from the current direct effects on the target species and any food web interactions, new modes of fishing, such as trawling, that might be developed for these species would pose a significant threat to some parts of the marine environment, particularly in shallower areas. Although most shores are effectively protected by ice shelves and sea ice for much of the year, any bottom trawling in ice-free nearshore environments would cause significant ecological damage by destroying the fragile and long-lived sea floor communities of sponges and other sessile organisms. These communities may also be abundant on oceanic seamounts, such as those found near the Balleny Islands, and may be just as susceptible to trawl damage.

Fisheries By-catch

Fishing can impact on non-target fish species and other marine fauna and flora. Moreover, the fishing method used can have serious implications for birds and mammals as has been illustrated by the sea bird by-catch of longlining vessels in the Southern Ocean. Although targeting Antarctic toothfish, the exploratory fishery in the Ross Sea has resulted in by-catch of non-target species. In 2000/01 85.8 tonnes of by-catch species were caught (see *Fishing and Whaling*), including rat-tails (*Macrourus* spp), skates (*Amblyraja georgiana, Raja* spp.) and small eye moray cod (*Muraenolepis* spp.). The total toothfish catch was 658 tonnes. The levels of by-catch within the Ross Sea are low because of the currently low levels of essentially exploratory activity that are currently undertaken.

Commercial longliners can take a considerable toll on albatrosses and other bird species as the birds are caught on the lines when they go to swallow baits. If the baits are swallowed or snagged in the mouth, the bird is generally dragged under the water and drowned. The principal contributors to the sea bird deaths are the southern bluefin tuna longliners in the southern Pacific Ocean and the Patagonian toothfish longliners in the southern parts of the Atlantic and Indian oceans.

"There is potential for future resource exploitation of fish stocks in the Ross Sea region including some benthic or bentho-pelagic species."

Greenpeace/Hansford

Wandering albatross caught in a longline. Longline fishing can take a considerable toll on seabirds in the Southern Ocean although to date there have been no reports of incidental mortality of sea birds in the Ross Sea region from CCAMLR approved fishing vessels.

Ten species of Southern Ocean sea birds have been recorded captured on fishing gear (Murray et al. 1993). Five of the species that are commonly caught by longliners include the wandering albatross, black-browed albatross, light-mantled sooty albatross, northern giant petrel (*Procellaria acquinoctialis*) and white-chinned petrel. The impact of by-catch on the bird populations can be severe. One estimate noted that as many as 44,000 albatrosses could be killed annually south of 30°S (Brothers 1991). At Bird Island in the south Atlantic Ocean, the breeding population of wandering albatrosses has decreased by 1 percent per annum since 1961 (Croxall et al. 1990). Similar declines have been reported for other colonies for which sufficient data exists, to the extent that the species is now classified as globally threatened (Collar et al. 1994, de la Mare and Kerry 1994). High sea bird mortalities have occurred with the Patagonian toothfish longlining in the Atlantic and Indian Ocean sectors of the Southern Ocean.

Greenpeace/Morgan

Japanese whaler catcher in the Southern Ocean. The direct effect of the current scientific take of 440 minke whales each year by Japan is unknown.

Marine Mammals

Most seal species in the Ross Sea have escaped the large-scale harvesting that decimated other seal populations worldwide during the 19th and early 20th centuries. Limited numbers of all seal species have been taken as food for the early explorers and their sled dogs and more recently to feed sled dogs from McMurdo Station and Scott Base. The Americans stopped the practice in 1959 and the New Zealanders in 1986. Despite the size of the seal cull in the late 1950s, the total McMurdo Sound population actually remained quite stable, presumably due to immigration by animals from other parts of the Ross Sea and also because of increased pup production by the resident animals (Testa and Siniff 1987). However, local changes did occur, such as the rapid reduction in the size of the breeding colony off Scott Base.

> “Increases in longlining for Antarctic toothfish in the Ross Sea,… will add to the risks that Southern Ocean sea birds face.”

There have been no incidental mortality of either sea birds or marine mammals caused by CCAMLR approved vessels fishing in the Ross Sea (Smith and Molloy 1999, Watkins 1999), and CCAMLR has instituted a variety of measures to mitigate the impact of longline fishing on sea birds in the Southern Ocean (see *Fishing and Whaling*). All legal longliners currently operating in the Ross Sea comply with these requirements.

Increases in longlining for Antarctic toothfish in the Ross Sea, depending on the latitude in which it takes place and the future numbers of vessels involved (including any IUU vessels), will add to the risks that Southern Ocean sea birds face. The species of sea birds that breed on the New Zealand subantarctic islands cover great distances in search of food (see Weimerskirch and Robertson 1994, Sagar and Weimerskirch 1996). In contrast to other areas of the Southern Ocean, subantarctic breeding species, apart from the blue petrel, southern giant petrel, thin-billed prion and sooty shearwater, do not range south of the Antarctic Divergence towards the ice shelves. Thus the albatross and petrel species, such as the wandering albatross, black-browed albatross, light-mantled sooty albatross, grey petrel and white-headed petrel would probably not be subjected to mortality from toothfish longliners operating in the Ross Sea to the extent that they have been in the Atlantic.

There is general concern worldwide about the adverse effects of fishing by-catch on marine mammals. Many fisheries have been regulated to alter fishing techniques in order to avoid significant catches of marine animals such as turtles, dolphins and seals. There are currently no estimates of how many seals are taken each year by the krill or toothfish fisheries in the Antarctic, but the number is probably small, and there have been no reports of seal by-catch in the Ross Sea fishery.

Despite the problems surrounding accurate census estimates, there are indications that some Antarctic seal populations have declined dramatically over the last few decades. There are indications of population declines in the southern elephant seal, Ross seal (Bester et al. 1995) and crabeater seal (Erickson and Hanson 1990), although the cause of these declines is uncertain.

Commercial whaling was carried out in the Ross Sea region between 1923 and 1986 (see *Fishing and Whaling*). Prior to the development of Antarctic whaling, the populations of most baleen whales were far larger. The current whale biomass in the Southern Ocean has been estimated at 4 – 8 percent of that in 1900. The best estimates from the IWC Scientific Committee are that blue, fin and sei whale populations are probably still at less than 5 percent of initial abundance (Nishiwaki et al. 1997a), while humpback whale populations may be up to 10 – 15 percent of initial abundance in some areas. Although they are recovering well off the eastern coast of Australia, humpback whales are still rarely seen in the Ross Sea region.

Since 1986, when an international moratorium on commercial whaling took effect, Japan has undertaken a research programme known a JARPA (Japanese Research Programme in Antarctica), which currently takes 440 minke whales each year. The total number of minke whales killed under JARPA is now over 4,500 (see *Fishing and Whaling*). The direct effect of this take on the total population of minke whales in the region is currently unknown.

Shipping Activities

There are about 20 vessel movements into the Ross Sea annually, including research vessels, icebreakers, supply ships, oil tankers, fishing vessels, tourist ships and other private expeditions (see *Science, Fishing and Whaling* and *Tourism*). All of these vessels have some measure of adverse effect on the marine environment, including direct discharges, and all have the potential to cause localised but catastrophic damage in the event of a maritime casualty, such as a grounding or sinking.

Discharges from ships operating in the Ross Sea region do pose a threat to the marine environment and could include general rubbish, plastic, oily substances, ballast water, sewage and food waste. These discharges are largely regulated by the international marine pollution agreement, MARPOL (see *Ross Sea Region Overview*) to which all nations currently with vessels in the region are signatories. However, two aspects of ship discharges, although compliant under MARPOL, are cause for concern. The discharge of poultry food waste from vessels (now banned by New Zealand) has been implicated in causing certain poultry diseases in penguins and other birds, although the risk is thought to be very low. However, the current quality requirement for sewage effluent means that ship discharges will not be free of all pathogenic microorganisms and presents the possibility for the transfer of genetic material from "normal" gut microorganisms to pathogenic organisms of other species. It has been suggested that this is a potential mechanism for transfer of introduced diseases to Antarctic wildlife (Kerry et al. 1999).

Organisms within ballast water discharges could also pose a threat to the marine ecosystems. No evidence exists of such effects in Antarctica, although the exact route of certain pathogenic microorganisms to endemic populations of birds and penguins has yet to be finally determined. Most vessels entering the Ross Sea region do so laden and hence will not carry ballast water into the area. Even if this did occur, the ballast water would have been loaded at ports with far warmer and more nutrient-rich waters, and the chances of any entrained organisms surviving in Antarctic waters are extremely unlikely. However, if a successful invasion or introduction of some form of organism occurred elsewhere around the continent, then there is the possibility that such an organism could be spread further via ballast water. Similar risks are expected to be present with the introduction of foreign marine organisms into the Ross Sea region from hull fouling.

Dave Palmer, AntNZ Pictorial Collection

Kim Westerskov, AntNZ Pictorial Collection

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Greenpeace/Culley

Some of the ships that visit the Ross Sea region. From top: United States Coast Guard icebreaker, the re-supply ship M/V *Greenwave*, the tourist vessel *Kapitan Khlebnikov*, Japanese whale catcher.

There is a potential risk to the marine environment associated with the scraping of hull paint and antifoulant chemicals (for example tri-butyl tin and organo-copper compounds) when vessels are passing through ice or icy waters. However, given the small number of vessel movements each year and the vastness of the region, this is not considered to be a significant risk.

> … the environmental effects of a maritime casualty could be serious, especially if it resulted in the release of oil.

However, the environmental effects of a maritime casualty could be serious, especially if it resulted in the release of oil. The potential will always exist in Antarctic waters for ships to ground or be holed by ice. There are two records of recent sinkings in the Ross Sea (see *Science* and *Tourism*), and although there were no reports of fuel leakages in either instance, the impact on the benthic and wider marine environment is largely unknown. There have also been reports of tourist vessels hitting uncharted rocks near shore. These incidents highlight the lack of adequate and detailed hydrographic charting for much of the Ross Sea region, particularly for areas close to the coast. Hyrdographic surveys carried out in February and March 2001 near Cape Adare, the Possession and Balleny islands, and Cape Hallett aim to provide information needed to update and improve the charts covering shipping corridors in these areas (Mitchell 2001).

The wreck of the *Bahia Paraiso* on the Antarctic Peninsula in January 1989 serves as a case study for the likely environmental impact arising from a similar incident in the Ross Sea region. The grounding resulted in a spill of around 600,000 litres of diesel fuel that contaminated an area of approximately 30 km^2 within four days of the accident (Kennicutt and Sweet 1992). Subsequent studies of the impact of the spill have indicated that the immediate effect on subtidal ecosystems was relatively minor (Kennicutt et al. 1992a, 1992b) and follow-up studies have confirmed that benthic communities were unaffected even at the site of the wreck (Hyland et al. 1994). However, fish captured near the wreck showed evidence of sublethal toxic effects related to exposure to polycyclic aromatic hydrocarbon (PAH) compounds (McDonald et al. 1992), and the long-term effects of the spill on marine birds seems to have been quite dramatic, with significant reductions in breeding success (Penhale et al. 1997). The relatively minor subtidal impact of this spill is probably due to the volatile nature of the fuel and its relatively rapid loss by evaporation and dispersal in a high-energy marine environment. The potential impact on the benthos of heavier fuels, or a spill occurring in a more sheltered environment such as McMurdo Sound, could be significantly greater.

Oceanic Drift Debris

Marine drift debris can originate from disposal by ships of a range of wastes as well as marine disposal of unscreened sewage and trash in populated coastal regions. In addition to anecdotal reports by scientific field parties of marine debris along the shoreline, at least one study has attempted to quantify this material. Gregory et al. (1984), using surface trawling, recorded the presence of litter, such as plastic beads, at 60 ocean stations between New Zealand and the Ross Sea. Although litter is common, and seems to accumulate in the vicinity of the Antarctic Convergence around 61°S, material has been recorded only once in tows further south. However, numerous observations have been made of litter at sea and along shorelines within the Ross Sea region, including ship's garbage and discarded plastic and timber. Some of this material may well have been discarded by field parties or may derive from past waste disposal practices at scientific stations. It is certainly unsightly in a pristine environment, but it also poses a threat to the coastal marine environment, with the possibility of marine birds or mammals becoming entangled in it or ingesting small items.

Coastal Pollution

Scientific stations, although land-based, contribute to pollution of the coastal marine environment through the release of sewage and domestic wastewater directly into the sea, contaminated meltwater runoff, and the accidental release of fuel. Historic activities such as marine dumping of wastes have also resulted in significant localised contamination of the marine environment, which persists today. Research camps, either operating on the sea ice or near the coast, also have the potential to impact on the marine environment (see *Science*).

The largest discharge into the coastal marine environment in the Ross Sea region is at McMurdo Station where up to 270,000 litres of macerated raw sewage and wastewater is discharged each day in summer via an outfall pipe located about 50 m offshore and at a depth of 20 m. Materials such as food and faeces are deposited at the mouth of the outfall, accumulating in a pile up to 2 m high (Conlan et al. 2000). The dispersal of the sewage plume has been studied by following the distribution of the enteric bacterium, *Clostridium perfringens*, which is used as a specific indicator of human faecal pollution (Edwards et al. 1998). Although the predominant current flow is southwards, a near-shore anticlockwise gyre in McMurdo Sound carries material from the outfall northwards towards Winter Quarters Bay, with occasional flow reversals to the south. A measurable but declining plume of sewage extends for up to 1 km along the McMurdo shoreline and up to 300 m seaward from the outfall (Fig. 14).

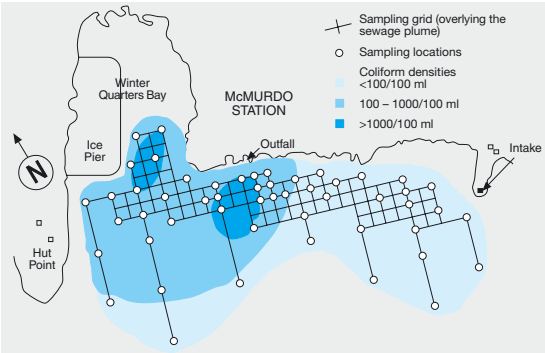


Figure 14: The sewage plume near McMurdo Station, Ross Island, during December 1991. Bacterial coliform densities are mapped. For scale; the small squares are 25 m on each side. Material is carried from the outfall, north into Winter Quarters Bay and the plume extends for up to 1 km along the shoreline. Source: McFeters et al. (1993).

Infaunal benthos has shown sewage influence near the outfall out to about 820 m to the southeast (Lenihan et al. 1990), and sediments also show evidence of sewage contamination through the presence of *C. perfringens*. The sewage discharge is also responsible for some degree of biological enrichment in the local area (Conlan et al. 1998), and although suspension-feeding animals such as soft corals do not show evidence of assimilation, deposit feeders and scavengers do. Enrichment effects that are attributable to the sewage outfall are evident in the main shallow-water scavenging species; the sea urchin *Sterechinus*, the seastar *Odontaster* and the nemertean worm *Parborlasia*.

Similar, but less extensive studies have been undertaken on the smaller sewage and wastewater outfalls at Scott Base and Terra Nova Bay Station. The Scott Base outfall, which discharges up to 17,000 litres of domestic wastewater daily in summer into the sea, also produces a measurable plume extending for some distance from the outfall. Monitoring instigated in the 1995/96 season (Royds Consulting 1996, Redvers 2000) has shown that the effects of the discharge on water quality around the discharge point (in terms of nutrients, biological oxygen demand (BOD), trace metals, copper and zinc, and faecal coliform bacteria) are localised and relatively insignificant. The measurable surface-only effluent field extends up to 175 m alongshore and up to 50 m seawards from the discharge point. Beyond this zone, measured effluent indicators are all close to background levels (Fig. 15). A recent extension of the outfall has resulted in higher measured nutrient concentrations in receiving waters and a slightly larger spatial area measurably affected by the effluent plume (Redvers 2000). Weak and variable tidal currents off Scott Base offer little opportunity for significant initial dilution and dispersion of effluent away from the outfall location, and unlike McMurdo Station, sea ice pressure ridges form each summer offshore, further limiting dispersion.

Elevated metal levels have been recorded in sediments immediately adjacent to the sewage outfall. In particular, copper concentrations reached 0.275 percent (extremely high) and were thought to be caused by metal plumbing pipes used in Scott Base, with traces entering water as it ran through the pipes and being emitted at the outfall (Anderson and Chague-Goff 1996). However, levels of trace metals in sediments away from the outfall were found to be in a complex distribution, with various "hot-spots" of cadmium, silver, arsenic and nickel. More recent monitoring work has found a lack of marine sediments of a useable nature for analysis for trace metals within 100 m of the discharge point (Redvers 2000).

Grant Redvers

Deploying monitoring equipment through the sea ice in front of Scott Base on Ross Island. About 17,000 litres of untreated sewage and domestic waste water is discharged into the sea from the base each day during summer.

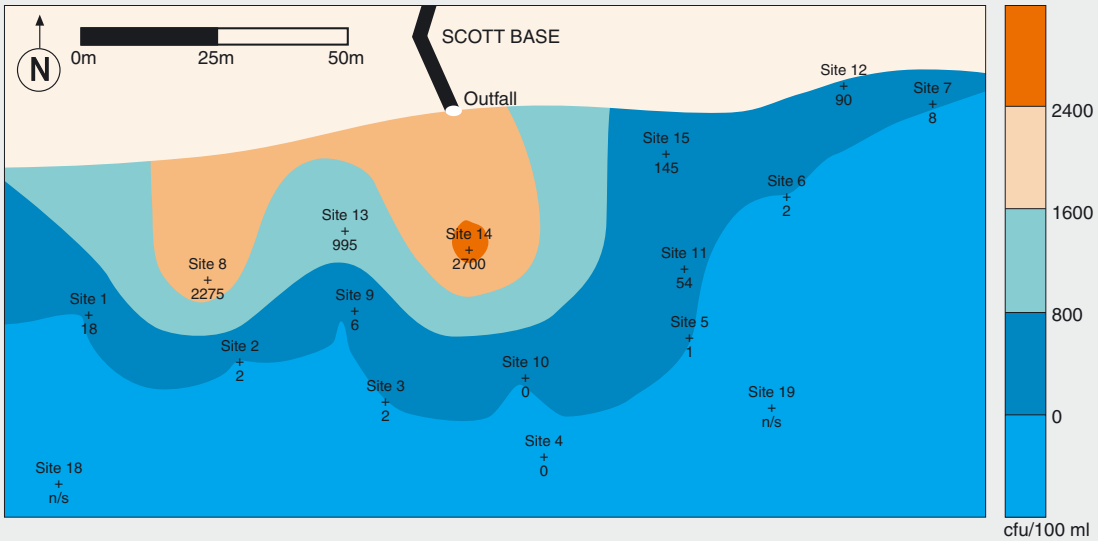


Figure 15: The sewage plume off Scott Base on the outgoing tide on 9 November 1999, indicated by contours of faecal coliform bacteria concentrations (cfu/100ml) at 1m depth off Scott Base. Source: redrawn from Redvers (2000).

The high levels of trace metals immediately adjacent to the sewage discharge point have been implicated in causing a loss of foraminifera species in sediments (Anderson and Chague-Goff 1996). However, more widespread survey work has found no direct evidence of any detrimental effects from land runoff or wastewater discharges. The benthic assemblages have been noted as being very diverse and rich, with the only limitation being one of instability of some rock habitats (Battershill 1992). Foraminifera are marine microorganisms that seem to be particularly sensitive to environmental disturbance and are useful indicator organisms to study the adverse effects of pollutant point-source discharges. Interestingly, foraminifera are also absent from the point where brine from Scott Base's desalination plant is returned to the sea. This brine is returned at a temperature of 12 – 14°C, and it is possible that the elevated temperature or salinity of this discharge is responsible for the observed absence of this faunal group.

Given the results of more recent monitoring of trace metal concentrations within the discharged effluent (Redvers 2000), it is very unlikely that the discharged effluent is the source of the extremely high levels of copper in sediment observed off Scott Base. These levels are now better ascribed to mobilisation and redistribution of land-derived contaminants from around the base and/or the possibility that the near-shore environment was used historically as a dump site for various materials.

At Terra Nova Bay Station, wastewater undergoes biological (secondary) treatment, but high concentrations of faecal bacteria are still observed at sampling sites close to the outfall. Once again, it appears that any impact is quite localised as concentrations declined rapidly with distance (Bruni et al. 1997).

Field parties working at coastal sites have traditionally disposed of human waste and domestic water directly into the sea through tide cracks in the sea ice. Very minor and localised effects are likely from these activities, in particular from nutrient enrichment, solids accumulation and release of microorganisms. Given that the known impact of even a large discharge, such as the McMurdo Station sewage outfall, seems to be highly localised, it is unlikely that occasional disposal of waste by field parties would pose any significant threat to the marine environment. However, the potential for transfer of introduced diseases to Antarctic wildlife through liquid wastes (particularly in the form of contamination by poultry wastes) is a concern, especially if this occurs near bird and seal colonies.

Chemical contamination of the marine environment in the Ross Sea region is thought to be relatively minor, although localised contamination has occurred, particularly in the vicinity of the major research stations and often associated with marine dumping. There is also evidence of atmospheric and oceanic transport of contaminants into the region. Brewerton (1969), for example, found that there was likely to be a local contamination source in the McMurdo Sound area given that residues of dichloro-diphenyl-trichloroethane (DDT) in the fat of Adélie penguins were six times higher here than at Cape Hallett, 640 km to the north. McMurdo Station was assumed to be the source of this material. A recent study to examine the nature of organo-chlorine contamination at McMurdo Station has confirmed the presence of elevated DDT residues in marine sediments (Riseborough et al. 1990).

Localised contamination by compounds such as polychlorinated biphenyls (PCBs) and PAHs from scientific stations and visiting ships is a serious concern and is highlighted in the Ross Sea region by the contamination in Winter Quarters Bay off shore from McMurdo Station (Box 6). Significantly elevated concentrations of petroleum hydrocarbons (in particular), trace metals and some persistent organics have been measured within the bay (Lenihan et al. 1990, Lenihan 1992). The levels of hydrocarbon contamination in the rear of the bay have been described by these researchers as being "greater than those from the most polluted harbours and even large oil spills". Sources of these contaminants include an old shoreline rubbish dump and sea ice waste dumping.

"Chemical contamination of the marine environment in the Ross Sea region is thought to be relatively minor, although localised contamination has occurred…"

J. McNee, AntNZ Pictorial Collection

McMurdo Station, Ross Island in 1989/90. An icebreaker is moored at the ice pier in Winter Quarters Bay which is largely free of sea ice.

Box 6 Pollution in Winter Quarters Bay, McMurdo Sound

Winter Quarters Bay is the most contaminated marine site known in the Ross Sea region. Located immediately adjacent to McMurdo Station, the bay is a small, protected inlet bordered on its south side by the site of an old rubbish dump. It is from this site that much of the pollution in the bay is thought to derive. Another contribution is sea ice waste dumping, which continued in Winter Quarters Bay until the mid – late 1980s.

Sediments in the back of the bay are muddy, smell of fuel oil, and in some places, contain tarry deposits (Riseborough et al. 1990). The sediment is heavily contaminated with a range of organic contaminants, including polycyclic aromatic hydrocarbons (PAHs) and the environmentally persistent organo-chlorine compounds, polychlorinated biphenyls and terphenyls (PCBs and PCTs). The most contaminated sediments in Winter Quarters Bay cover an area of some 80,000 m^2. Elevated concentrations of some heavy metals such as copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn) are present, although levels of most other heavy metals analysed are not significantly different from remote reference sites. Winter Quarters Bay sediments contain up to 1,400 ppb total PCBs, 1,200 ppb total PCTs, 4,500 ppm total purgeable hydrocarbons, 12 ppm Cu, 10 ppm Cd, 83 ppm Pb, and 110 ppm Zn (Lenihan et al. 1990). While the concentrations of heavy metals are only 3- to 10-fold greater than at reference sites, hydrocarbon concentrations are elevated by several orders of magnitude. A steep pollution gradient also exists within and outside Winter Quarters Bay, and levels of most contaminants fall to near-background values by several hundred metres from the bay's mouth.

Some of the contaminants may derive from the McMurdo sewage outfall, although most are thought to have originated from the old dump site at the southern end of the bay. The chemical profile of PAH compounds suggests combustion of dump material, discharge of ship bilge water, and fuel spills as the most likely sources of these hydrocarbon contaminants.

There is evidence that marine animals living in or around McMurdo Station may be adversely affected by these substances. Lenihan et al. (1995) found that the diversity and density of animals living within the sediments were significantly poorer than for those living outside Winter Quarters Bay and that benthic organisms transferred into the bay did not survive. Bivalves and fish from the vicinity of Winter Quarters Bay have been found to contain significantly elevated concentrations of PAH compounds in their tissues (McDonald et al. 1994, 1995). Fish have enlarged livers and up to 37-fold higher levels of detoxifying enzymes of the cytochrome p450 group in their livers (Miller et al. 1999) than individuals collected from pristine sites. These cytochrome p450 enzymes are commonly used as indicators of organo-chlorine exposure in fish.

Major inputs of contaminants to the bay have presumably ceased with closure of the rubbish dump and removal of much of its contaminating material as well as a far more careful approach to the handling of ship visits, wastes and fuel. However, the persistently elevated levels of organic contaminants imply extremely slow dispersal or breakdown, probably due to the very low energy marine environment present in Winter Quarters Bay.

Kim Westerskov, AntNZ Pictorial Collection

Waste material on the shoreline at McMurdo Station in 1982/83. Although this practice has ceased and the site cleaned up, it is thought that much of the pollution now evident in Winter Quarters Bay has derived from coastal and sea ice waste dumping which continued until the mid-late 1980s.

Until the 1980s, marine dumping of wastes onto sea ice was a regular practice at McMurdo Station and Scott Base, and indeed many other scientific bases around Antarctica. Inorganic waste was left on the sea ice, where it would either disperse as the ice broke up and drifted out to sea, or would simply fall through as the ice melted. Dayton and Robilliard (1971) remarked on the abundance of this material on the sea floor off McMurdo station and noted that "Inorganic litter on the bottom at McMurdo is dramatic: fuel lines, barrels, honey buckets, rope, clothing, tractors, pieces of airplanes, thousands of beer cans, and many other types of trash are everywhere. On many of our transects, the beer cans outnumber some of the sponge species. The density of litter decreases as one moves away from the station, but litter is commonly seen as far as 6 km to the north".

A recent study at Winter Quarters Bay found that although confined to the immediate area around the bay and covering an area of less than 20 ha, over 1,000 individual debris objects were present, including 603 drums, 15 vehicles and 26 large shipping containers (Kvitek et al. 1998) (Fig. 16). Benthic sediments and fauna are highly modified due to this pollution (Box 6). Debris is also evident offshore from Scott Base, although it has not been quantified or mapped. Anecdotal reports from divers, as well as recent video evidence indicate that drums, sheet metal and many small pieces of rusted metal are present. This material is likely to have been dumped onto the sea ice during construction, and possibly early years of operation, of the base. Sea ice dumping at Scott Base was halted in the mid-1980s. Battershill (1992) also saw evidence while diving of earth and debris having been bulldozed off the Scott Base shore. There is no detailed information on the nature and extent of this material or of its possible environmental effects. However, recent heavy metal analysis of sea bed material in the vicinity of the base has recorded results higher than would have been expected to occur naturally for some metals (Anderson and Chague-Goff 1996).

Little work has been done at Scott Base on studying chemical contamination in the adjacent marine environment. Elevated levels of silver have been found in near-shore sediments (Anderson and Chague-Goff 1996) and probably came from last-rinse photographic wastewater discharged onto land at the base finding its way down to the shoreline. Elevated levels of certain trace metals, including silver, copper, cadmium, nickel, zinc, mercury, lead and chromium have been found in drains and meltwater in and about Scott Base that eventually discharge to the sea (Sheppard et al. 1997). The levels measured were higher than at any other site surveyed to date in the Ross Island and McMurdo Sound areas. More recent work noted areas of measurable contamination by these trace metals in the soils around Scott Base and described potential mechanisms for these elevated concentrations of trace metals to enter the near-shore marine environment (Sheppard et al. 2000).

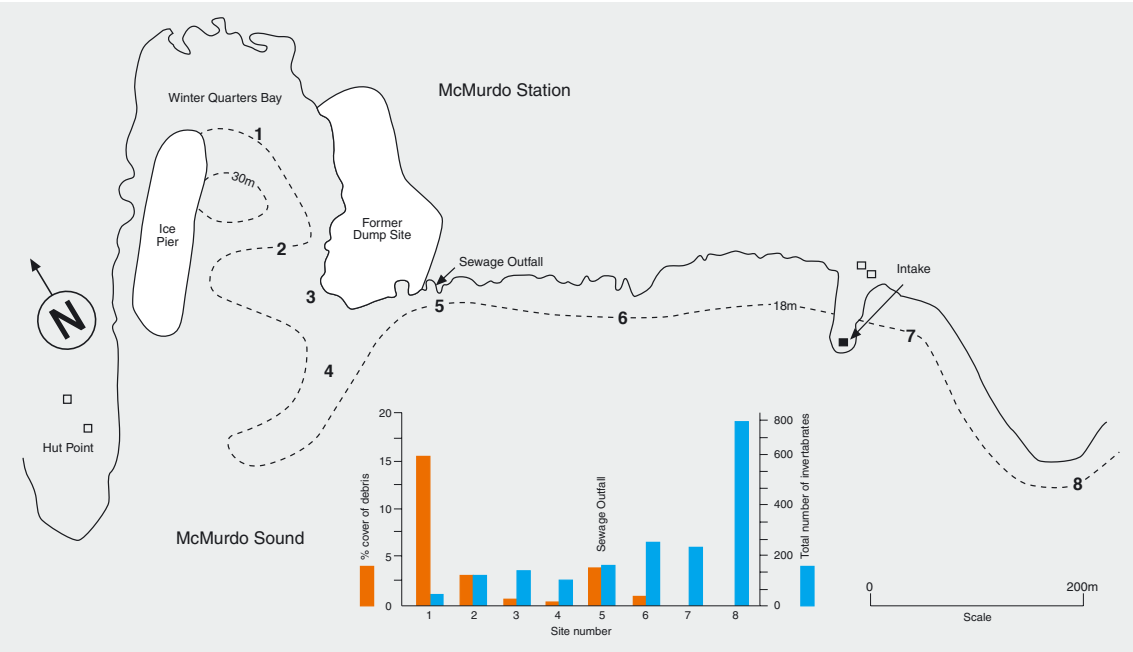


Figure 16: The human impact on Winter Quarters Bay, McMurdo Sound, as reflected in the percentage cover of debris on the sea floor and the numbers of infaunal invertebrates (means of six samples per location, each covering 0.0075 m^2) Source: redrawn from Hansom and Gordon (1998), data from Lenihan et al. (1990).

P. Foster, AntNZ Pictorial Collection

Waste and debris from the former Hallett Station being towed out onto the sea ice at Cape Hallett, northern Victoria Land during the decommissioning and initial clean-up of the station in the mid-1980s.

> “… most studies that have examined levels of persistent organic contaminants in the marine environment of Antarctica have generally found levels of contamination to be very low…”

Studies of marine chemical contamination in the vicinity of Terra Nova Bay Station indicate that although PCB levels are slightly elevated closer to the station, the overall level of contamination is still very low despite 15 years of operation (Focardi et al. 1995).

Marine dumping of rubbish onto the sea ice also occurred at Hallett Station, in northern Victoria Land. This station was operated jointly by the United States and New Zealand from 1957 to 1973. During the decommissioing of the station in the 1980s, sea ice dumping continued and included such refuse as metal cans, empty fuel containers, drums, tanks, rubber fuel lines, steelwork from buildings, a whole wannigan, metal sheets, bearers, trusses and floor joists, small non-burnables packed in drums, various building fittings and vehicles. No work has been done to assess the impacts of this debris and any associated contamination on the near-shore marine environment, although the effects could be expected to be similar to those at McMurdo Station but on a smaller scale.

Long-range Contaminant Transport

Pollutants generated outside Antarctica can find their way into the Ross Sea region through global atmospheric processes and ocean circulation (see *Global Influences*). For example, organo-chlorine compounds have been found in fish taken from Terra Nova Bay, although concentrations were low, and the contamination source was presumed to be atmospheric or via oceanic transport from elsewhere, given that levels were comparable to other uninhabited regions of the Antarctic (Focardi et al. 1992). Concentrations of DDT and PCBs in south polar skuas at Cape Bird were 13 and 22 times higher respectively, than those in the eggs of Adélie penguins located within the same area. Higher levels of PCBs in skuas is thought to be due to this species’ greater exposure to pollutants when they migrate north of the Antarctic Convergence in winter (Focardi et al. 1995, Court et al. 1997).

Pollutant residues, including DDT (Brewerton 1969), chlordane (Kawano et al. 1986) and PCBs (Hidaka et al. 1983, Focardi et al. 1995) have been found in the tissues of Antarctic seals, including those from the Ross Sea. The highest concentrations are usually found in the blubber since the chemistry of such compounds causes them to concentrate in fat. However, the levels are generally very much lower than those found in marine mammals from the northern hemisphere and probably pose no risk to the health of the animals. In fact, most studies that have examined levels of persistent organic contaminants in the marine environment of Antarctica have generally found levels of contamination to be very low and below those common at temperate latitudes (Cripps 1992, Fuoco et al. 1996). There is also good evidence to suggest that DDT residue levels in Antarctic wildlife have dropped substantially, while PCB levels have not shown any dramatic increase (Larsson et al. 1992, Court et al. 1997). In most cases, tissue concentrations of anthropogenic organic compounds in Antarctic marine animals are well below those known to cause toxic effects. However, Antarctic biota may show a propensity to accumulate such compounds to greater degrees than organisms from other marine environments.

Disturbance to Wildlife

Concentrations of wildlife occur along the coast and on the sea ice of the Ross Sea region, usually as breeding colonies of sea birds and seals. These sites are also attractions for researchers and other visitors, including tourists. Few studies specific to the Ross Sea region have been carried out on the impacts of human disturbance on sea bird colonies, in particular penguins. However, elsewhere in the Antarctic, research has found that human activity and aircraft operations can cause declines in breeding success (for example, Woehler et al. 1994, Giese 1996). It is also likely that breeding success in smaller rookeries of Adélie penguins can be significantly affected by human disturbance such as regular nest checking and very frequent recreational visits (Culik et al. 1990, Young 1990, Giese 1998).

Human disturbance is thought to have contributed to the decline in both the Cape Royds and Cape Hallett Adélie penguin colonies. The Adélie penguin population at Cape Royds declined dramatically from 1956 onwards as a consequence of human interference during a period when heavy sea ice cover made the colony particularly susceptible to reduced recruitment. In 1963, United States and New Zealand authorities agreed to restrict activities in the area, and the population has recovered and now exceeds 1956 levels (Fig. 12). At Cape Hallett, between 8,000 and 10,000 pairs of breeding Adélie penguins were evicted from their nests during the construction of the joint New Zealand and United States station (Reid 1964). Further disturbance occurred through scientific work on the population, vehicle operations, and snowdrifts preventing establishment of nests (Wilson et al. 1990). Between 1959 and 1968, the population almost halved, although following the decommissioning of the station in the 1980s, the population rose to pre-disturbance levels. Some buildings and considerable debris still remain at Cape Hallett, and some areas of ground are so heavily compacted that they are unsuitable for nesting birds. While the declines observed at Cape Hallett and Cape Royds occurred during a period when undisturbed colonies were also declining, the rate at which this decline occurred was not as rapid as at the disturbed sites.

AntNZ Pictorial Collection

Adélie penguin rookery at Cape Hallett in late 1960s with the joint New Zealand/United States station visible in the far distance. About 10,000 pairs of penguins were removed from their nests during the construction of the station in 1957/58.

Access is controlled to some penguin colonies in the Ross Sea region, including Sabrina Island in the Balleny Islands, Cape Royds, Cape Crozier and Beaufort Island, through the designation of specially protected areas (see *Ross Sea Region Overview*). Other colonies are subject to regular annual visits by tourists and researchers and while little is known about the cumulative impacts of these visits, visitation levels are an order of magnitude less than many sites on the Antarctic Peninsula. However, some sites, like Cape Bird, can receive visits from several hundred tourists a year. Researchers are also resident for several months conducting intensive long-term studies. Helicopters visit Cape Bird regularly, and further work may be needed to assess ongoing impacts on this colony and other areas that are under similar multiple pressures.

Although often associated with penguin colonies, skuas do not seem to be as susceptible to human disturbance (Young 1990). Human impacts on skuas in the Southern Ocean have been summarised by Hemmings (1990) and in the Ross Sea region have included disturbance to nests, poisoning and choking through exposure to wastes, and general disturbance from station operations. Changes to skua populations in the region have been partly attributed to human activity, primarily through increased food supply via station rubbish dumps. Although such rubbish dumps are no longer present, skuas are a regular feature around McMurdo Station and have recently attempted to breed in close proximity to Scott Base.

Although large numbers of some petrel species breed in the Ross Sea region, particularly in northern Victoria Land, the Balleny Islands and Marie Byrd Land, these areas are remote and are not regularly visited in the same way that many penguin colonies are. However, care is needed to ensure that aircraft overflight of these sites is at an altitude sufficient to avoid disturbance.

Emma Waterhouse

Scientists restraining Adélie penguin chicks in preparation for flipper banding at Cape Bird, Ross Island. Little is known about possible cumulative impacts of visits by researchers and others, including tourists, to the Adélie colonies in the Ross Sea region.

The breeding colonies of Weddell seals in McMurdo Sound are regularly visited throughout the summer season by researchers and other visitors from the scientific stations on Ross Island and are regularly overflown by helicopters and fixed-wing aircraft. However, pup numbers each summer seem to have remained relatively stable across many years. Weddell seals are relatively docile and can be approached at close range on foot, although they are much less tolerant of vehicles. They seem not to be affected by regular human presence as long as vehicles maintain an acceptable distance. Some studies have attempted to gauge stress in seals by measuring levels of stress hormones, such as cortisol, in the blood. Severe disturbance, such as capture and handling, induces a rise in circulating cortisol levels. However, cortisol in Weddell seals is naturally higher than in many other mammals, which may in fact mask any lower-level stress effects caused by human presence (Eisert et al. 1998).

One aspect of marine research that has caused concern is the impacts of seismic survey techniques on wildlife. Ship-based seismic surveys have been undertaken in the Ross Sea, and the Cape Roberts Project used explosives to carry out vertical seismic profiling in each of the three holes drilled (as well as to cut the drill pipe at the cessation of drilling). Procedures were put in place to minimise the impacts on Weddell seals in the area and monitoring was carried out. Research from around the world has produced varying results with regard to the impacts of seismic activity (air guns in particular) on cetaceans and fin fish. Certainly, some fin fish species have been noted to move out of an area subject to seismic activity, to distances of up to 18 km and for as long as five days, and there have been signs of potential impairment of hearing in these species (Norwegian Research Council 1993). Yet other research has shown minimal if any effects for different species (Wardle et al. 1998).

Introduced Disease

Some species of Antarctic wildlife range over large distances and enter many different habitats during the migratory phase of their life cycle (for example, the south polar skua). It is possible that disease could be introduced to the Antarctic avifauna in this way. More likely though, is that disease will be introduced via human activity, such as the incorrect disposal of poultry products, sewage disposal, importation of food and on equipment, vehicles, or clothing. No evidence currently exists for the introduction of disease into Antarctic wildlife populations via human activity. Disease has been suspected in a number of unusual mortality events of birds and one of seals, and there is evidence of the exposure of Antarctic wildlife to infectious disease-causing agents (for example Oelke and Steiniger 1973, Austin and Webster 1993). A recent example is the discovery of evidence of infectious bursal disease virus in emperor penguin chicks and adult Adélie penguins near Australia's Mawson Station in East Antarctica (Gardner et al. 1997).

Climate Change

Antarctica plays a critical role in global climate change because of major interactions between the atmosphere, ice, ocean and biota that affect the entire global system through feedback mechanisms, dynamic biogeochemical cycles, deep ocean circulation, atmospheric transport of energy, and changes in mass balance (Weller 1992, Murphy and King 1997). The most recent assessment of the impacts of global climate change on the Southern Ocean (Anismov and Fitzharris 2001) predicts future long-term changes in physical oceanography and ecology which may be irreversible. Any changes in the Southern Ocean may in turn lead to sudden and very long-term changes that affect global climate as a whole. Changes have most likely already occurred in the surface waters of the Southern Ocean, which have warmed and become less saline over the last 30 years and there is evidence for a reduction in the extent of Antarctic sea ice in the last 100 years (Wu et al. 1999).

"Any changes in the Southern Ocean may in turn lead to sudden and very long-term changes that affect global climate as a whole."

The effects of future climate change (see *Global Influences*) on the Southern Ocean and its ecosystems include changes in the position of the oceanic fronts, the nature of polynyas, sea ice extent and distribution, and associated changes in the distribution and abundance of biota. A decrease in the extent of sea ice for example, could result in major changes in the Ross Sea ecosystem. Reduced amounts of sea ice would affect the development of Antarctic Bottom Water and inhibit the pattern of vertical circulation south of the Antarctic Convergence that produces the high concentration of nutrients, nitrate, phosphate and silicate, which are characteristic of the Antarctic marine environment. A reduction

David Given

Climate change could lead to changes in the extent and thickness of sea ice in the Ross Sea region.

would also impact on the marginal ice zone phytoplankton blooms and would impact on those species that are dependent on the pack ice at various stages of their life cycle, such as the cryopelagic community, krill, seals and sea birds (Fig. 17).

Any increases in temperature could have a marked impact on the species composition and abundance of the microbiota of the pelagic ecosystem. However, there has been only limited research on the direct and indirect impacts of climate change on Antarctic organisms (Anismov and Fitzharris 2001). Marchant (1992) has suggested that blue-green algae, the heterotrophic protozoa that feed on them, and the small phytoplankton (picophytoplankton), which are temperature-limited, would increase in abundance with increased sea water temperatures. This increase would result in a change in the species composition and abundance of the planktonic assemblage, which would in turn change the availability of prey for krill and other grazers. Many Antarctic fish species are obligate stenotherms (with a narrow temperature tolerance range) that cannot survive in warmer water. Krill lives at temperatures in the range of -2°C to about +5°C. Thus an increase in water temperatures could result in the areal extent of these species contracting towards the Antarctic coast and the southward movement of some subantarctic species.

Should the Ross Ice Shelf retreat, benthic communities of the Ross Sea are likely to migrate southwards in line with its recession. Subtle differences in faunal assemblages are also likely to occur due to changes in the extent of sea ice formation in the Ross Sea. Accompanying changes in summer plankton production would also ensue, which could create "bottom-up" stresses on the marine food web. While these alterations in Antarctic communities have occurred regularly in the past throughout cycles of glaciation, the rate of current changes is much faster than in the past (Lorius et al. 1990). Whether the slow-growing benthic communities can respond quickly enough to the predicted rapid changes in marine climate over the coming decades remains to be seen.

The avifauna of the Ross Sea region is likely to be affected in a number of ways as a result of further warming trends. Adélie penguin populations may initially increase in response to reduced winter sea ice maxima and possibly improved pack ice foraging conditions during summer (Smith et al. 1999). If continued warming leads to a more substantial breakout of fast ice, emperor penguins may be seriously disadvantaged through reduction or loss of their breeding areas. For petrels, especially snow petrels, which are pack ice obligate foragers, a serious reduction in the pack ice associated with the continental shelf break could reduce their feeding opportunities and hence overall population. Visiting subantarctic breeding birds may also be affected during their summer incursion south of the Antarctic Convergence if prey populations are affected by reduced annual sea ice. Northern Southern Ocean and subantarctic species may in fact take advantage of the warmer conditions to spread their territories further south.

Spezie and Manzella (1999) have concluded that the Ross Sea could be a good reference site for monitoring possible climate trends by looking at the variability of its water mass function as an indicator of global warming. A greater understanding of the latitudinal gradients (physical and biological) that exist in the Ross Sea region may also help in predicting the effects of future climate changes, particularly on benthic and coastal environments.

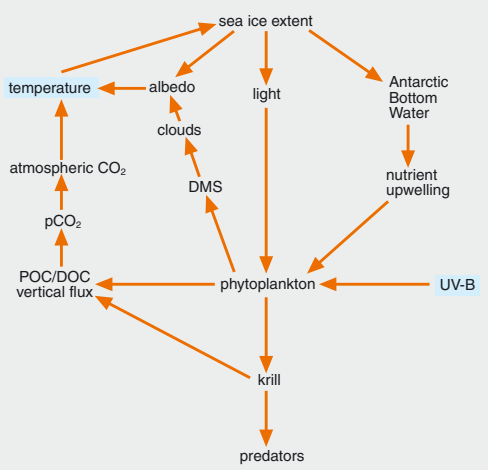


Figure 17: Potential impacts of changes in both temperature and UV irradiance on Ross Sea region marine organisms and processes. Source: Marchant (1992).

Annual ozone depletion over Antarctica results in increased ultraviolet radiation penetrating the atmosphere. The effects of enhanced ultraviolet radiation on organisms have become an active subject for Antarctic terrestrial research in recent years. However, relatively little research has been carried out in the marine environment. Enhanced ultraviolet radiation levels are associated with annual springtime reductions in stratospheric ozone over Antarctica (see *Global Influences*) and have the potential to damage Antarctic marine organisms. Although sea water clarity is extremely high in early spring, sea ice cover is at its most extensive, and ultraviolet penetration will be reduced wherever ice is covered in snow. Ultraviolet radiation is likely to most affect marine organisms beneath areas of clear ice or in open water, such as sea ice microbial communities or surface plankton. Increased levels of ultraviolet radiation may affect shallow benthic and pelagic marine communities in a number of ways. Short wavelength UV-B radiation (280 – 315 nm wavelength) is known to cause direct damage to cells and produces mutations and cancers by damaging genetic material. Rates of growth and productivity of marine phytoplankton and ice algae may also be adversely affected by enhanced ultraviolet levels (Dohler 1998).

Ultraviolet radiation has been shown to inhibit primary production of some Antarctic microalgae (Holm-Hansen et al. 1989, Weiler and Penhale 1994). However, it is recognised more and more that some microalgae have developed a variety of mechanisms to combat the incidence of high levels of ultraviolet radiation, such as the presence of ultraviolet-absorbing pigments or means of repair (Karentz et al. 1991a, 1991b, Karentz 1994, Reigger and Robinson 1997). The production of these compounds is induced by increased illumination, allowing Antarctic marine plants to cope with natural seasonal fluctuations in ultraviolet light. Such responses are thought to be species specific, and the intensity of ultraviolet light may naturally determine depth distribution of some Antarctic macroalgal species (Bischof et al. 1998).

However, cellular damage due to UV-B has recently been documented in Antarctic zooplankton (Malloy et al. 1997). Although levels of ultraviolet protective pigments generally seem to be low in Antarctic marine animals (McClintock and Karentz 1997), most organisms are able to repair ultraviolet-induced damage. Once again, the ability to do so seems to be species specific and is possibly related to the natural depth distributions of the species in question (Malloy et al. 1997).

Due to differential susceptibility to damage from ultraviolet radiation, it is possible for the species composition of the phytoplankton to change. An increase in the alga *Phaeocystis*, for example, which contains high concentrations of ultraviolet radiation absorbing compounds, at the expense of diatoms, would have consequent impacts on the trophodynamics of krill and other grazers (Marchant and Davidson 1991) (Fig. 18). Since the entire Antarctic food web is driven by the annual bloom in phytoplankton productivity that occurs in spring and summer, any major impact on these microscopic plants and bacterioplankton by increased ultraviolet radiation levels in spring could have implications for the entire marine ecosystem. The populations of diatom-feeders, such as krill, could be affected, leading in turn to reduced populations of krill consumers such as squid, fish, seals and whales.

Increased ultraviolet radiation may also affect ecosystem responses to some forms of pollution. Although ultraviolet light significantly shortens the survival time of faecal bacteria in Antarctic sea water (Statham and McMeekin 1994), it also reduces marine bacterial decomposition of diesel fuel (Delille et al. 1998). Furthermore, the toxicity of fuel-derived substances may be enhanced by ultraviolet light. Certain PAH compounds, for example, may be several orders of magnitude more toxic to aquatic organisms in the presence of sunlight. Such effects have been documented in Antarctic invertebrates (Ling et al. 1998) and in organisms exposed to contaminated sediments from Winter Quarters Bay (Cleveland et al. 1997).

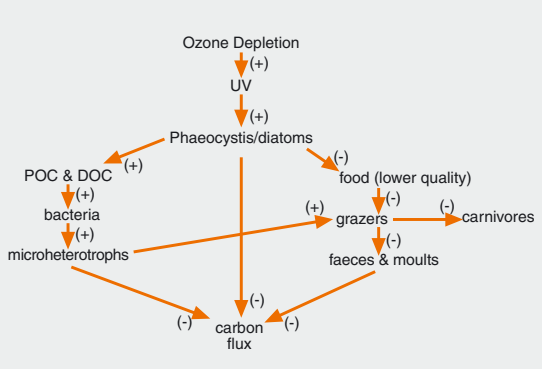
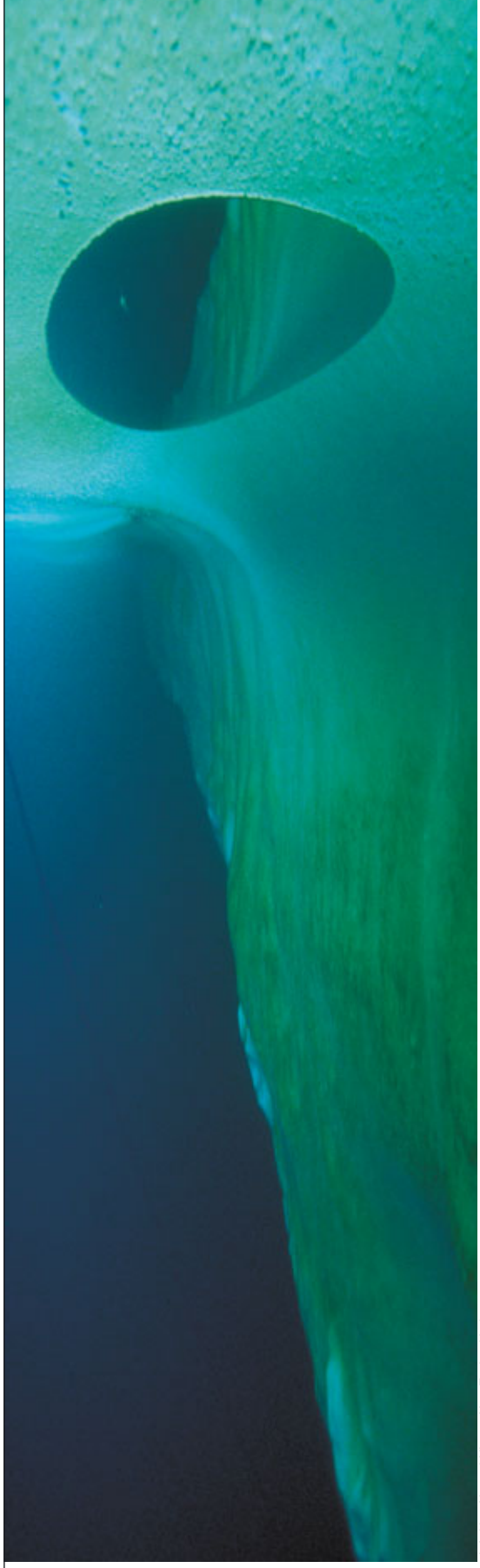


Figure 18: Potential impacts of ozone depletion on Ross Sea region marine processes. The sign, + or -, on arrows indicate the direction of possible changes. Source: Marchant and Davison (1991).



J. Ackley, Natural History New Zealand Ltd

Air bubble trapped under the sea ice.

State of Knowledge	Poor
State of Environment	Excellent
Management of Pressures	Fair

very poor poor fair good excellent

The marine environment in the Ross Sea region has been little affected by human activities to date and is largely in a pristine state. The combination of the significant latitudinal gradient of the region and its pristine state offers a unique environment in which to establish baselines to assess both natural and human induced changes in a way not offered by other marine areas around the globe.

- The Ross Sea, and the area of the Ross Sea polynya in particular, is very productive, with some of the highest levels of primary production that have been recorded in the world's oceans. This primary production provides a platform for substantial populations of higher consumers, especially sea birds. Any disruption to the productive basis of the Ross Sea ecosystem, through for example climate change or resource use, could have a major impact throughout the entire food web.

- The benthic habitats of the Ross Sea region demonstrate high levels of biodiversity and endemism and are among the most spectacular to be found anywhere in the world. New species in this and other habitats are still being described. New discoveries are also likely for sea bird nesting sites in the Ross Sea region.

- The only current exploitation of the living resources is whaling and low levels of fishing for toothfish. The only whale species currently taken is the minke whale and the impact of whaling on minke populations in the Ross Sea region is unknown. Current catches of toothfish are low and are unlikely to be impacting on stocks, and there is currently no evidence of illegal fishing activity in the region. Careful management of the fishery is needed to avoid the over-exploitation that has taken place with the Patagonian toothfish elsewhere and to avoid sea bird by-catch issues that have plagued other Southern Ocean longline fisheries.

- Probably the most significant human impacts have been concentrated in the coastal environment close to the established scientific stations on Ross Island. Significant marine pollution (particularly offshore from McMurdo Station), comparable to highly polluted marine environments found elsewhere in the world, has resulted from poor practices in the past including historic dumping. These impacts are extremely localised although there is potential for mobilisation of some highly persistent organo-chlorine compounds. Debris from the decommissioned Cape Hallett Station also persists, with terrestrial dumps apparently still contributing to marine litter.

- The discharge of untreated sewage from Scott Base and McMurdo Station pollutes the receiving environment, in particular surface waters, around the outfalls. Enrichment of the marine environment (in particular benthic fauna) in the vicinity of the submerged McMurdo outfall has been noted. These discharges may also represent a potential path for the introduction of microorganisms, genetic material and disease.

Emma Waterhouse

Adélie penguins, Cape Bird, Ross Island.

- There is a paucity of detailed environmental information on some of the activities associated with the general operation of bases including contaminated runoff and accumulation of contaminants in marine biota. There is almost no information on the environmental effects of marine research activities, in particular ship-based programmes. However, given their scale, these are believed to be insignificant in the region as a whole.

- While the impacts of shipping associated with science, tourism and fishing activities, are currently thought to be very minor, the potential effects of a catastrophic event, such as a grounding, holing and/or a large fuel spill would be significant, especially if such an incident occurred near breeding populations of birds or seals. The recent imposition of MARPOL standards within the region should ensure that the environmental effects of discharges from ships are reduced. The potential for microorganisms, genetic material and disease to be introduced through discharges from ships and research facilities remains a concern.

- Breeding sites of birds and seals appear to be impacted by human presence in only a minor way, although activities in the past did cause declines in some colonies, which have since recovered. However, ongoing visits to breeding areas by researchers and tourists could be resulting in cumulative impacts at more frequently visited sites, although little research or direct monitoring of impacts has been carried out in the Ross Sea region.

- There is evidence that the surface waters of the Southern Ocean have warmed and become less saline in the last 30 years, and that sea ice is retreating. Future climate change could result in significant impacts on the marine environment through increases in sea temperatures, changes in ocean circulation patterns, alteration of the thickness and extent of the sea ice, and consequent changes in productivity and the composition of the pelagic community and dependent species. Any changes in the Southern Ocean could in turn influence global climate.

- There is potential for increased ultraviolet radiation, as a result of seasonal ozone depletion over Antarctica, to change the species composition of the phytoplankton community and hence overall productivity of the marine environment. There is evidence that such ultraviolet radiation may have resulted already in changes in the marine environment.

- The marine environment of the Ross Sea region faces several threats including increasing exploitation of its marine living resources, increasing pollution potential and, especially as shipping traffic increases, the potential for large-scale fuel spills and threats to the avifauna, including through ongoing visits to breeding areas. However, significant gaps exist in even our basic understanding of the marine ecosystem of the Ross Sea region and our impacts on it, hampering efforts to effectively manage these activities now and in the future.

Emma Waterhouse

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Attachment C

Species Cross Reference

Species / Scientific Name	Common Name
Aptenodytes forsteri	Emperor penguin
Aptenodytes patagonicus	King penguin
Arctocephalus gazella	Antarctic fur seal, Kerguelen fur seal
Balaenoptera acutorostrata	Minke whale, dwarf minke whale
Balaenoptera bonaerensis	Antarctic minke whale
Balaenoptera borealis	Sei whale
Balaenoptera edeni	Bryde's whale, Omura's whale
Balaenoptera musculus	Blue whale, sibbald's rorqual, sulphur-bottom whale
Balaenoptera physalus	Fin whale, common rorqual, fin-backed whale, finback, finner, herring whale, razorback
Berardius arnuxii	Arnoux's beaked whale, Southern four-toothed whale
Caperea marginata	Pygmy right whale
Cephalorhynchus commersonii	Commerson's dolphin
Eubalaena australis	Southern right whale
Globicephala melas	Long-finned pilot whale
Grampus griseus	Risso's dolphin
Hydrurga leptonyx	Leopard seal
Hyperoodon planifrons	Southern bottlenose whale, flatheaded bottlenose whale
Hyperoodon spp	Bottlenose whales
Indopacetus pacificus	Longman's beaked whale
Kogia breviceps	Pygmy and dwarf sperm whales
Kogia sima	Dwarf sperm whale
Lagenodelphis hosei	Fraser's dolphin
Lagenorhynchus australis	Peale's Dolphin
Lagenorhynchus cruciger	Hourglass dolphin
Lagenorhynchus obscurus	Dusky dolphin
Lagenorhyncus cruciger	Hourglass dolphin
Leptonychotes weddellii	Weddell seal
Lissodelphis peronii	Southern Right whale dolphin
Lobodon carcinophagus	Crabeater seal
Megaptera novaeangliae	Humpback whale
Mesoplodon grayi	Gray's beaked whale, southern beaked whale
Mesoplodon layardii	Layard's beaked whale, strap-toothed whale
Mirounga leonina	Southern Elephant Seal
Neophocaena phocaenoides	Finless porpoise
Ommatophoca rossiigray	Ross seal
Orcinus orca	Killer whale, Orca

Species / Scientific Name	Common Name
Oreaella brevirostris	Irrawaddy (snubfin) dolphin
Peponocephala electra	Melon-headed whale
Phocoena dioptrica (Australophocaena dioptrica)	Spectacled porpoise
Physeter macrocephalus	Sperm whale
Pseudorca crassidens	False killer whale
Pygoscelis adeliae	Adelie penguin
Pygoscelis antarcticus	Chinstrap penguin
Pygoscelis papua	Gentoo penguin
Sotalia fluviatilis	Tucuxi dolphin
Sousa chinensis	Indo-Pacific humpbacked dolphin
Steno bredanensis	Rough-toothed dolphin
Tasmacetus shepherdi	Shepherd's beaked whale
Tursiops spp.	Bottlenose dolphins
Tursiops truncatus aduncus	Southern bottlenose dolphin
Ziphius cavirostris	Cuvier's beaked whale

Ross Sea Marine Mammals Sightings Data Sources

Reference (Ross Sea Sightings Data Summary)	Full Title (author)	Cited Observation Area	Proximity of Observation Area to Proposed Study Area [i.e., 76°S to 78° S; 165°W to 170°W]	Observation Period	Numerical Counts (used to estimate density)	Methodology	Comments
Cetaceans							
Marine Ornithology (Ainley 2002)	Marine ornithology forum: the Ross Sea, Antarctica, where all ecosystem processes still remain for study, but maybe not for long (Ainley, D.G.)	South of and shallower than the 3000-m isobath; 69°S, 170°E to 76°S, 155°W. Included is a northward bend of the isobath, around Iselin Bank, to about 69°S, 175°W. The region is about 598 000 km2 and includes the continental slope (500–3000 m) and the continental shelf of the Ross Sea. Ichii et al. (1998) also included both the slope and the shelf to define the Ross Sea.	NA - Entire Ross Sea	1970s - early 1980s	√	Cited from cf. Stirling 1969, Gilbert & Erickson 1977, Ainley 1985 and Butterworth & Best 1982, Ainley 1985	
Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Smith, W.O. Jr., P.N. Sedwick, K.R. Arrigo, D.G. Ainley, and A.H. Orsi. 2012. The Ross Sea in a sea of change. Oceanography 25(3):90–103, http://dx.doi.org/10.5670/oceanog.2012.80.	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])	NA - Entire Ross Sea	NS	√	NS	
Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Whales: Trophic modelling of the Ross Sea (Pinkerton, M.H., J. Bradford-Grieve, P.M. Sagar)	"Ross Sea"	NA - Entire Ross Sea	1970 - 2004 (depending on species and data source)	√	Cited from previously-published sources	
Exploitation (Ainley 2009)	A history of the exploitation of the Ross Sea, Antarctica (David G. Ainley, 2009)**	The Ross Sea, about the size of southern Europe, is defined as the waters overlying the continental shelf and slope extending in a wavering line, including the northward projecting Pennell Bank, from Cape Adare,Victoria Land (71° 17'S, 170° 14'E), to Cape Colbeck, Marie Byrd Land (77° 07'S, 157° 54'W). Not included are waters around the Balleny Islands (66° 55'S, 163° 20' E).	NA - Entire Ross Sea	Population estimates from Ainley, 1985	√	Population estimates from Ainley, 1985	
CCAMLR 2007	CCAMLR WG-EMM-10/11 ROSS SEA BIOREGIONALIZATION - Part I: Validation of the 2007 CCAMLR Bioregionalization Workshop Results Towards Including the Ross Sea in a Representative Network of Marine Protected Areas in the Southern Ocean David G. Ainley, Grant Ballard, John Weller	The Ross Sea, about the size of southern Europe, is defined as the waters overlying the continental shelf and slope (3000m depth contour), including the northward projecting Pennell/Iselin Bank, from Cape Adare, Victoria Land (71° 17’S, 170° 14’E), to Cape Colbeck, Marie Byrd Land (77° 07’S, 157° 54’W) (from Ainley 2010).	NA - Entire Ross Sea	1969 - 2009	√	Cited from previously-published sources	
Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	Trophic interactions within the Ross Sea continental shelf ecosystem (Walker O. Smith Jr, David G. Ainley and Riccardo Cattaneo-Vietti, 2006).	187,000 km2	NA - Ross Sea Continental Shelf	1969 - 1985	√	Cited from previously-published sources	
Minke Abundance (MATSUOKA, HAKAMADA, KIMURA, OKADA, undated)	Influence of sea ice concentration on Antarctic minke whale abundance estimation in the Ross Sea (KOJI MATSUOKA, TAKASHI HAKAMADA, KEISUKE KIMURA AND YOSIHIRO OKADA [no date])	Ross Sea south of 69° S	NA - Entire Ross Sea	2006 - 2009	√	IDCR/SOWER and JARPA II survey data	

Ross Sea Marine Mammals Sightings Data Sources

Reference (Ross Sea Sightings Data Summary)	Full Title (author)	Cited Observation Area	Proximity of Observation Area to Proposed Study Area [i.e., 76°S to 78° S; 165°W to 170°W]	Observation Period	Numerical Counts (used to estimate density)	Methodology	Comments
Interactions (Naganobu, Nishiwaki, Yasuma, Matsukura, Takao, Taki, Hayashi, Watanabe, Yabuki, Yoda, Noiri, Kuga, Yoshikawa, Kokubun, Murase, Matsuoka, Ito, undated)	Interactions between oceanography, krill and baleen whales in the Ross Sea and Adjacent Waters: An overview of Kaiyo Maru-JARPA joint survey in 2004/05 (Naganobu, Nishiwaki, Yasuma, Matsukura, Takao, Taki, Hayashi, Watanabe, Yabuki, Yoda, Noiri, Kuga, Yoshikawa, Kokubun, Murase, Matsuoka, Ito [undated])	Survey area consisted of the western part of IWC Area VI (Area VIW, 170°W-145°W) and the entire Area V (130°E-170°W) in the area between south of 60°S and the ice edge line (total survey distance of 18,712.0 n.m.).	NA - Entire Ross Sea	2004 - 2005	√	Observations from sighting vessel	
CWR (2013)	Center for Whale Research (CWR) http://www.whaleresearch.com/#!member-about-orca/c1qa8; includes all Antarctic/Southern Hem. (Type A, B, C, D) orcas.	Antarctic	NA - Entire Antarctic	NS		NS	
Minke Whales (Branch & Butterworth, 2001)	Southern Hemisphere Minke Whales: Standardised Abundance Estimates from the 1978/79 to 1997/98 IDCR-SOWER Surveys Branch, T.A. and Butterworth, D.S. J. Cetacean Res. Manage. 3(2):143–174, 2001.	IWC Area V: 60°S to 76°S latitude, 130°E to 160°W longitude.	Adjacent to the northern edge of the study area	various	√	DESS database package (IWC Database-Estimation System Software v 3.0)	Compiles data from IWC/IDCR and SOWER 1978/79–1983/84, 1985/86–1990/91 and 1991/92–1997/98 cruises
Occurrence of killer whales (Lauriano et al. 2011)	Occurrence of killer whales (Orcinus orca) and other cetaceans in Terra Nova Bay, Ross Sea, Antarctica (Lauriano, G., Fortuna, C.M., and Vacchi, M. 2011)	Terra Nova Bay, western Ross Sea		5 January - 2 February 2004		Helicopter sightings	Area bordered to the south by the floating Drygalski Ice Tongue, to the north by Cape Washington and the Campbell Glacier Tongue in the middle. Article contains numbers of sightings, but not specific numbers of animals observed in each sighting.
Humpback Abundance (Branch, T.A. n.d.)	Humpback abundance south of 60°S from three completed sets of IDCR/SOWER circumpolar surveys (Branch, T.A. n.d.)	Southern Ocean south of 60°S		1978/79-1983/84, 1985/86-1990/91, 1991/92-2003/04		Cited from previously-published sources	Data compiled from various IDCR/SOWER surveys
IWC SOWER Report, 2002-2003	2002-2003 International Whaling Commission-Southern Ocean Whale and Ecosystem Research (IWC-SOWER) Circumpolar Cruise, Area V (Ensor, et al. 2003). SC-55-IA1	Eastern portion of IWC Area V: 60°S to 70°S latitude, 170°E to 170°W longitude.	Approximately 1,000 km NE of study area	December 2002 - March 2003	√	Alternating closing mode (NSC) and passing mode with independent observers (IO).	Number of sightings in the research area presented in Table 2a of the document. "Unidentified" large whales, small whales, and whales could not be allocated to any species.
Navy Marine Species Density Database (NMSDD)	Commander Task Force 20, 4th, and 6th Fleet Navy Marine Species Density Database Technical Report. Naval Facilities Engineering Command. 2012.	various		various	√	Unknown	Maps with densities for various species for the Southern Ocean, only between 100°W and 80°E. Species occurs south of 60°S in these longitudes
Pinnipeds							

Ross Sea Marine Mammals Sightings Data Sources

Reference (Ross Sea Sightings Data Summary)	Full Title (author)	Cited Observation Area	Proximity of Observation Area to Proposed Study Area [i.e., 76°S to 78° S; 165°W to 170°W]	Observation Period	Numerical Counts (used to estimate density)	Methodology	Comments
Seals: Trophic modelling (Pinkerton, Bradford-Grieve, undated)	Seals: Trophic modelling of the Ross Sea (M.H. Pinkerton, J. Bradford-Grieve)	Seal abundance is estimated from the data of Ainley (1985) for an area bounded by the continental slope which more or less corresponds with our model area although there are more recent estimates for more limited areas (e.g. Cameron & Siniff 2004)	NA - Area of Ross Sea bounded by the continental slope	1985, 2004	√	Cited from previously-published sources	
Distribution, density and abundance (Bengtson, J.L. et al. 2011)	Distribution, density, and abundance of pack-ice seals in the Amundsen and Ross Seas, Antarctica (Bengtson, J.L. et al. 2011)	53,217 km2 in Ross and Amundsen Seas	**See comments**	26 Dec. 1999 - 24 March 2000	√	Ship and helicopter transects	Map showing transects on p. 1262 of article
Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Smith, W.O. Jr., P.N. Sedwick, K.R. Arrigo, D.G. Ainley, and A.H. Orsi. 2012. The Ross Sea in a sea of change. Oceanography 25(3):90–103, http://dx.doi.org/10.5670/oceanog.2012.80.	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])	NA - Ross Sea Continental Shelf bounded by the 700m isobath	NS	√	NS	
Exploitation (Ainley 2009)	A history of the exploitation of the Ross Sea, Antarctica (David G. Ainley, 2009)**	The Ross Sea, about the size of southern Europe, is defined as the waters overlying the continental shelf and slope extending in a wavering line, including the northward projecting Pennell Bank, from Cape Adare,Victoria Land (71° 17'S, 170° 14'E), to Cape Colbeck, Marie Byrd Land (77° 07'S, 157° 54'W). Not included are waters around the Balleny Islands (66° 55'S, 163° 20' E).	NA - Entire Ross Sea	Population estimates from Ainley, 1985	√	Population estimates from Ainley, 1985	
CCAMLR 2007	CCAMLR WG-EMM-10/11 ROSS SEA BIOREGIONALIZATION - Part I: Validation of the 2007 CCAMLR Bioregionalization Workshop Results Towards Including the Ross Sea in a Representative Network of Marine Protected Areas in the Southern Ocean David G. Ainley, Grant Ballard, John Weller	The Ross Sea, about the size of southern Europe, is defined as the waters overlying the continental shelf and slope (3000m depth contour), including the northward projecting Pennell/Iselin Bank, from Cape Adare, Victoria Land (71° 17’S, 170° 14’E), to Cape Colbeck, Marie Byrd Land (77° 07’S, 157° 54’W) (from Ainley 2010).	NA - Entire Ross Sea	1969 - 2009	√	Cited from previously-published sources	
Ross Sea Region (2001)	State of the Ross Sea Region - Marine Environment Ross Sea Region. A State of the Environment Report for the Ross Sea Region of Antarctica., Waterhouse, Emma J. (Hrsg.): New Zealand Antarctic Insitute, 2001	1,000 km wide and extending to 78° S	NA - Entire Ross Sea		√	Cited from previously-published sources	
Distribution of Weddell Seal (1968)	Distribution and Abundance of the Weddell Seal in the Western Ross Sea, Antarctica (Ian Stirling, 1968)	western Ross Sea between Cape Adare and McMurdo Sound	300+ N.M. east of study area	1967-1968	√	Observed from icebreakers and helicopters	

Ross Sea Marine Mammals Sightings Data Sources

Reference (Ross Sea Sightings Data Summary)	Full Title (author)	Cited Observation Area	Proximity of Observation Area to Proposed Study Area [i.e., 76°S to 78° S; 165°W to 170°W]	Observation Period	Numerical Counts (used to estimate density)	Methodology	Comments
APIS Report (2000)	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) Marthan N. Bester, D.Sc., Chief Officer Brent S. Stewart, Ph.D., J.D., Secretary 20 October 2006	18,576 km of pack ice habitat	Could not be determined	45 science days between 20 December and 10 February, 2000	√	Observed from air (helicopter)	
Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	Trophic interactions within the Ross Sea continental shelf ecosystem (Walker O. Smith Jr, David G. Ainley and Riccardo Cattaneo-Vietti, 2006).	187,000 km^2	NA - Ross Sea continental shelf	1969 - 1985	√	Cited from previously-published sources	

NA = Not Applicable
NS = Not Specified

Ross Sea Marine Mammals Sightings Data Sources

Reference	Marine Ornithology (Ainley, 2002)	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Occurrence of killer whales (Lauriano et al. 2011)	Humpback Abundance (Branch, T.A. n.d.)	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Exploitation (Ainley 2009)	CCAMLR 2007	Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	Minke Abundance (Matsuoka, Hakamada, et al, undated)	Interactions (Naganobu, Nishiwaki, et al, undated)	CWR (2013)	Seals: Trophic modelling (Pinkerton, Bradford-Grieve, undated.)	Distribution, density and abundance (Bengtson, J.L. et al. 2011)	Ross Sea Region (2001)	Distribution of Weddell Seal (1968)	APIS Report (2000)	Minke Whales (Branch & Butterworth, 2001)	IWC SOWER Report 2002-2003	Navy Marine Species Density Database (NMSDD) [Note 1]
Observation period	1970s-Early 1980s	(not specified)	5 January - 2 February 2004	1978/79-1983/84, 1985/86-1990/91, 1991/92-2003/04	1970 - 2004 (depending on species and data source)	Population estimates from Ainley, 1985	1969 - 2009	1969 - 1985	2006 - 2009	2004 - 2005	(not specified)	Seal abundance is estimated from the data of Ainley (1985)	26 Dec. 1999 - 24 March 2000	(not specified)	1967-1968	45 science days between 20 December and 10 February, 2000	Various cruises between 1978 -1998	December 2002 - March 2003	various
Numerical counts reported	√	√			√	√	√	√	√	√	√	√	√				√	√	
Cetaceans																			
Mysticetes																			
Blue whale		X																X	X
Fin whale					X													X	X
Humpback whale				X	X													X	X
Minke whale	X	X	X		X	X	X	X	X	X							X	X	X
Sei whale					X														X
Southern right whale																			
Unidentified large baleen whale																		X	
Unidentified large whale																		X	
Unidentified small whale																		X	
Unidentified whale																		X	
Odontocetes																			
Arnoux's beaked whale		X	X		X														X
Grays beaked whale																			Note 2
Hourglass dolphin																		X	
Killer whale	X	X	X		X	X	X	X			X							X	X
Layard's beaked whale																		X	X
Long-finned pilot whale																		X	X
Peale's dolphin																			
Shepards beaked whale																			Note 2
Southern right whale dolphin																			Note 2
Southern bottlenose whale					X													X	X
Spectacled porpoise																			
Sperm whale					X													X	X
Unidentified large whale																		X	
Unidentified small whale																		X	
Unidentified whale																		X	
Pinnipeds																			
Antarctic Fur Seal																			
Crabeater	X	X				X	X	X				X	X	X		X			
Leopard	X	X				X	X	X					X	X		X			
Ross		X				X	X	X				X	X	X		X			
Weddell	X	X				X	X	X				X	X	X	X	X			
Elephant		X				X		X				X							

Notes:

[1] NMSDD presents density data and maps, by season, for species in the Southern Ocean between 100°W and 80°E. Density values from the Weddell and Amundsen Seas (between 40° W and 100° W) will be extrapolated for the Ross Sea (between 170° E and 150°W).

[2] NMSDD density data is available for this species for the Southern Ocean between 100° W and 80° E; however, this species has not been observed in the Ross Sea region in the other references and therefore the NMSDD data will not be used.

Cetaceans Observed and Estimated Densities in the Ross Sea

Common Name	Area Surveyed (km^2) Note 1	Area Surveyed (km, linear survey)	Animals (#)	Animals (# including unidentified)	Corrected Sightings (assume only 20% reported)	Estimated Linear Density (#/km)	Half Strip-width (km) Note 6	Visual Transect Width (km) Note 7	Areal Density (#/ km^2) Note 8	Data Source	Year/Season/Area/Comments
Mysticetes											
Blue whale	466,100	NA	30	30	NA Note 2	NA	NA	NA	0.0000644	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
		8,905	24	58	290	0.0326	2.50	5.00	0.0065132	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.0000510	NMSDD Note 9	Annual, maximum range south of 70° S
Fin whale	300,000	NA	200	200	NA Note 2	NA	NA	NA	0.0006667	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Estimates that fin whales only enter the Ross Sea 2 months out of the year; prefer ice edge habitats, particularly along the continental shelf.
		8,905	238	273	1,365	0.1533	2.50	5.00	0.0306570	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.0011030	NMSDD Note 9	Winter, maximum range south of 70° S
Humpback whale	300,000	NA	150	150	NA Note 2	NA	NA	NA	0.0005000	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Estimated that less that 5% of Southern Ocean population spends any time in the Ross Sea; assumes that humpbacks are present in the Ross Sea for only 2 months per year.
		8,905	277	286	1,430	0.1606	2.50	5.00	0.0321169	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.0000780	NMSDD Note 9	Winter, maximum range south of 70° S
	598,000	NA	14,300	14,300	NA Note 3	NA	NA	NA	0.0239130	Marine Ornithology (Ainley 2002)	Population estimates from surveys conducted during the 1970s and early 1980s.
	300,000	NA	4,766	4,766	NA Note 3	NA	NA	NA	0.0158867	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Assumes that minke whales are present in the Ross Sea for 3 months per year (Dec.-Feb.). Tend to be concentrated in the north and west Ross Sea. Article estimates areal density at **0.02-0.05/km2** in "Ross Sea model area [not defined in article]".
	466,100	NA	21,000	21,000	NA Note 3	NA	NA	NA	0.0450547	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
	300,000	NA	14,280	14,280	NA Note 2	NA	NA	NA	0.0476000	Exploitation (Ainley 2009)	Summary of population estimates of marine mammals in the Ross Sea made on the basis of several cruises during the late 1970s-early 1980s (Ainley 1985).
	300,000	NA	21,000	21,000	NA Note 2	NA	NA	NA	0.0700000	CCAMLR 2007	The Ross Sea, about the size of southern Europe, is defined as the waters overlying the continental shelf and slope (3000m depth contour), including the northward projecting Pennell/Iselin Bank, from Cape Adare, Victoria Land (71° 17'S, 170° 14'E), to Cape Colbeck, Marie Byrd Land (77° 07'S, 157° 54'W) (from Ainley 2010). Population estimate from (T. Branch in Ainley 2010; Ainley 1985).
	187,000	NA	14,000	14,000	NA Note 2	NA	NA	NA	0.0748663	Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	
	300,000	NA	19,400	19,400	NA Note 4	NA	NA	NA	0.0646667	Minke Abundance (Matsuoka, Hakamada, et al, undated)	Area of study was Ross Sea south of 69° S. Counts made during 2006/2007 season (high concentration of sea ice).
	300,000	NA	87,643	87,643	NA Note 4	NA	NA	NA	0.2921433	Minke Abundance (Matsuoka, Hakamada, et al, undated)	Area of study was Ross Sea south of 69° S. Counts made during 2008/2009 season (lower concentration of sea ice).

Cetaceans Observed and Estimated Densities in the Ross Sea

Common Name	Area Surveyed (km^2) Note 1	Area Surveyed (km, linear survey)	Animals (#)	Animals (# including unidentified)	Corrected Sightings (assume only 20% reported)	Estimated Linear Density (#/km)	Half Strip-width (km) Note 6	Visual Transect Width (km) Note 7	Areal Density (#/ km^2) Note 8	Data Source	Year/Season/Area/Comments
Minke whale	NA	18,712	3,045	3,045	NA Note 5	0.1627	2.50	5.00	0.0325460	Interactions (Naganobu, Nishiwaki, et al, undated)	Survey area consisted of the western part of IWC Area VI (Area VIW, 170° W-145° W) and the entire Area V (130° E-170° W) in the area between south of 60° S and the ice edge line.
	714,818								0.8605604	Minke Whales (Branch & Butterworth, 2001) closing mode data	1980-1981. IWC Area V, EN strata
	339,162								1.4752464		1980-1981. IWC Area V, ES strata
	117,319								2.3687732		1980-1981. IWC Area V, WS strata
	339,162								1.2719536		1980-1981. IWC Area V, ES strata
	477,982								0.4993036		1980-1981. IWC Area V, WN strata
	960,184								0.6668828	Minke Whales (Branch & Butterworth, 2001) closing mode data	1985-1986. IWC Area V, EN strata
	359,931								0.5655798		1985-1986. IWC Area V, WS strata
	569,742								0.9982638		1985-1986. IWC Area V, EM strata
	571,242								0.5576816		1985-1986. IWC Area V, WM strata
	369,900								2.1538048		1985-1986. IWC Area V, ES strata
	477,549								0.3650342		1985-1986. IWC Area V, WN strata
	568,083								1.5775796	Minke Whales (Branch & Butterworth, 2001) closing mode data	1991-1992. IWC Area V, EN strata
	201,380								0.3787702		1991-1992. IWC Area V, WS strata
	281,722								0.4340576		1991-1992. IWC Area V, ES strata
	472,979								0.0501364		1991-1992. IWC Area V, WN strata
	960,184								0.6133124	Minke Whales (Branch & Butterworth, 2001) IO mode data	1985-1986. IWC Area V, EN strata
	359,931								1.2413910		1985-1986. IWC Area V, WS strata
	569,742								0.9093232		1985-1986. IWC Area V, EM strata
	571,242								0.7963446		1985-1986. IWC Area V, WM strata
	369,900								3.2386054		1985-1986. IWC Area V, ES strata
	477,549								1.2166662		1985-1986. IWC Area V, WN strata
	568,083								1.0714080	Minke Whales (Branch & Butterworth, 2001) IO mode data	1991-1992. IWC Area V, EN strata
	201,380								1.4460574		1991-1992. IWC Area V, WS strata
	281,722								0.4618730		1991-1992. IWC Area V, ES strata
	472,979								0.1328958		1991-1992. IWC Area V, WN strata
		8,905	753	753	3,765	0.4228	2.50	5.00	0.0845595	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.1301790	NMSDD Note 9	Winter, maximum range south of 70° S
Sei whale	300,000	NA	100	100	NA Note 3	NA	NA	NA	0.0003333	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Assume that only a very small minority of the Southern Ocean population of sei whales spends any time in the Ross Sea due to their preference for open-ocean temperate waters. Estimate is for presence of sei whales in Ross Sea for 2 months out of the year, which may still be an overestimate.
									0.0046340	NMSDD Note 9	Winter, maximum range south of 70° S
Odontocetes											
Arnoux's beaked whale	300,000	NA	50	50	NA Note 3	NA	NA	NA	0.0001667	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Assuming the total population of Arnoux's beaked whales is 10,000 and that these are widely distributed through the Southern Ocean (0.5% in Ross Sea), suggests a Ross Sea population of 50 animals. It is not known if this is reasonable. We assume that these whales are present in the Ross Sea for 3 months of the year.

Cetaceans Observed and Estimated Densities in the Ross Sea

Common Name	Area Surveyed (km^2) Note 1	Area Surveyed (km, linear survey)	Animals (#)	Animals (# including unidentified)	Corrected Sightings (assume only 20% reported)	Estimated Linear Density (#/km)	Half Strip-width (km) Note 6	Visual Transect Width (km) Note 7	Areal Density (#/ km^2) Note 8	Data Source	Year/Season/Area/Comments
	466,100	NA	150	150	NA Note 3	NA	NA	NA	0.0003218	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
									0.0134420	NMSDD Note 9	Winter, maximum range south of 70° S
Hourglass dolphin		8,905	158	169	845	0.0949	2.50	5.00	0.0189782	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
Killer whale	300,000	NA	3,500	3,500	NA Note 2	NA	NA	NA	0.0116667	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	**Population figure given does not distinguish between Type B & Type C**. Type C orca occur over the continental shelf and within the pack ice edge in the Ross Sea (Ainley 1985). Their occurrence in the Ross Sea was associated with the vicinity of the ice edge in the western Ross Sea near Ross Island (Ainley 1985; Andrews et al. 2008). We assume that Ross Sea orca ore mainly Type C and remain in the study are for the summer only (3 months of the year).
	466,100	NA	3,350	3,350	NA Note 3	NA	NA	NA	0.0071873	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
	598,000	NA	3,500	3,500	NA Note 2	NA	NA	NA	0.0058528	Marine Ornithology (Ainley 2002)	Population figure does not differentiate between orca types.
	300,000	NA	3,440	3,440	NA Note 2	NA	NA	NA	0.0114667	Exploitation (Ainley 2009)	Population figure does not differentiate between orca types.
	300,000	NA	3,000	3,000	NA Note 2	NA	NA	NA	0.0100000	CCAMLR 2007	Most of the killer whales are the "Ross Sea" resident fish-eating type [Type C]; there are perhaps just a few dozen type-Bs, the apex predator in this system, although type-As (minke whale predator) could occur along the slope. **R**atio of Type-C to Type-B over ths shelf is about 50:1.
	300,000	NA	25,000	25,000	NA Note 2	NA	NA	NA	0.0833333	CWR (2013)	Estimates range as high as 27,000 individuals (in Antarctic). Does not differentiate between orca types.
	187,000	NA	7,500	7,500	NA Note 2	NA	NA	NA	0.0401070	Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	Does not distinguish orca type.
		8,905	186	186	930	0.1044	2.50	5.00	0.0208872	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.0154510	NMSDD Note 9	Winter, maximum range south of 70° S
Layard's beaked whale		8,905	3	40	200	0.0225	2.50	5.00	0.0044919	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.0014430	NMSDD Note 9	Winter, maximum range south of 70° S
Long-finned pilot whale		8,905	226	356	1,780	0.1999	2.50	5.00	0.0399777	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.0078590	NMSDD Note 9	Winter, maximum range south of 70° S
Southern bottlenose whale	300,000	NA	500	500	NA Note 2	NA	NA	NA	0.0016667	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Estimate revised downward from Branch & Butterworth 2001a and Kasamatsu & Joyce 1995. Assume that southern bottlenose whales are present in the Ross Sea for 3 months of the year.
		8,905	84	105	525	0.0590	2.50	5.00	0.0117912	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.0135650	NMSDD Note 9	Winter, maximum range south of 70° S
Sperm whale	300,000	NA	800	800	NA Note 2	NA	NA	NA	0.0026667	Whales: Trophic Modeling (Pinkerton, Bradford-Grieve, Sagar, undated)	Any occurrence of sperm whales in the Ross Sea is likely to be along the shelf edge. Ross Sea population estimate is subject to considerable uncertainty.

Cetaceans Observed and Estimated Densities in the Ross Sea

Common Name	Area Surveyed (km^2) Note 1	Area Surveyed (km, linear survey)	Animals (#)	Animals (# including unidentified)	Corrected Sightings (assume only 20% reported)	Estimated Linear Density (#/km)	Half Strip-width (km) Note 6	Visual Transect Width (km) Note 7	Areal Density (#/ km^2) Note 8	Data Source	Year/Season/Area/Comments
Sperm whale		8,905	88	88	440	0.0494	2.50	5.00	0.0098821	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V
									0.0015600	NMSDD Note 9	Winter, maximum range south of 70° S

Notes:

NA = Not Available

1. Where the area surveyed was not indicated in the reference document, a value of 300,000 km^2 was used, estimate of Ross Sea area from Google Earth.
2. Assume reported number of animals has been corrected in the reference.
3. Assume reported number of animals has been corrected based on the methodology described in the cited source.
4. Sighting data from JARPA II; assume the reported number of animals has been corrected.
5. Population number as provided in cited source based on research of the authors; however, methodology not explained in article, so number provided is likely a corrected figure.
6. Distances not reported in reference; assumes 2.5 km half strip-width on each side of the vessel.
7. Visual transect width = half strip-width x 2, representing the total width of observations.
8. Estimated areal density [# animals/area surveyed (km2)] is provided either based on reported numbers in the reference or calculated based on the estimated linear density (#/km) x 1/visual transect width (km).
9. Maximum density values for the Weddell and Amundsen Seas (between 40° W and 100° W); extrapolated for use in the Ross Sea (between 170° E and 150 °W)

Cetacean Densities in the Ross Sea

Common Name	Area Surveyed (km^2)	Area Surveyed (km, linear survey)	Animals (#)	Animals (# including unidentified)	Corrected Sightings (assume only 20% reported) [Note 1]	Estimated Linear Density (#/km)	Half Strip-Width (km) [Note 2]	Visual Transect Width (km) [Note 3]	Areal Density (#/ km^2)	Data Source	Year/Season/Area	Comments
Mysticetes												
Blue whale		8,905	24	58	290	0.0326	2.50	5.00	0.0065132	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Fin whale		8,905	238	273	1,365	0.1533	2.50	5.00	0.0306570	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Humpback whale		8,905	277	286	1,430	0.1606	2.50	5.00	0.0321169	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Minke whale		8,905	753	753	3,765	0.4228	2.50	5.00	0.0845595	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Sei whale									0.0046340	NMSDD [Note 4]	Winter, maximum range south of 70° S	
Odontocetes												
Arnoux's beaked whale									0.0134420	NMSDD [Note 4]	Winter, maximum range south of 70° S	
Hourglass dolphin		8,905	158	169	845	0.0949	2.50	5.00	0.0189782	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Killer whale		8,905	186	186	930	0.1044	2.50	5.00	0.0208872	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Layard's beaked whale		8,905	3	40	200	0.0225	2.50	5.00	0.0044919	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Long-finned pilot whale		8,905	226	356	1,780	0.1999	2.50	5.00	0.0399777	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Southern bottlenose whale		8,905	84	105	525	0.0590	2.50	5.00	0.0117912	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	
Sperm whale		8,905	88	88	440	0.0494	2.50	5.00	0.0098821	IWC SOWER Report 2002-2003 (Table 2a)	2002-03 austral summer. Eastern portion of IWC Area V	

Notes:

[1] Sightings data accounts for all individuals observed in groups; corrected sightings assumes only 20% of animals present were observed and reported.

[2] Assumes 2.5 km half strip-width on each side of the vessel.

[3] Visual transect width = half strip-width x 2, representing the total width of observations.

[4] Maximum density values for the Weddell and Amundsen Seas (between 40° W and 100° W); extrapolated for use in the Ross Sea (between 170° E and 150 °W)

Pinnipeds Observed and Estimated Densities in the Ross Sea

Common Name	Area Surveyed (km^2) Note 1	Area Surveyed (km, linear survey)	Animals (#)	Correction Factor	Estimated # in the Water	Estimated Linear Density (#/km)	Half Strip-width (km) Note 2	Visual Transect Width (km) Note 3	Estimated Areal Density (#/ km^2) Note 4	Data Source	Year/Season/Area/Comments
Crabeater	598,000	NA	205,000	NA	NA	NA	NA	NA	0.34281	Marine Ornithology (Ainley 2002)	Population estimates from 1970s and early 1980s (cf. Stirling 1969; Gilbery & Erickson, 1977; Ainley 1985)
	300,000	NA	204,000	NA	NA	NA	NA	NA	0.68000	Seals: Trophic modelling (Pinkerton, Bradford-Grieve, undated)	Reside in the study area for about 3 months of the year over the summer.
	466,100	NA	204,000	NA	NA	NA	NA	NA	0.43767	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
	300,000	NA	203,700	NA	NA	NA	NA	NA	0.67900	Exploitation (Ainley 2009)	Population estimates based on several cruises during the late 1970s to early 1980s.
	300,000	NA	204,000	NA	NA	NA	NA	NA	0.68000	CCAMLR 2007	Surveys made during 1976-1979 (Ainley 1985).
	187,000	NA	200,000	NA	NA	NA	NA	NA	1.06952	Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	Species breeds and probably occur in the Ross Sea region, if not the Ross Sea itself, continuously throughout the year. The remaining seals [other than the Weddell] are denizens of the pack ice, especially along the shelf break and the ice margins of the Ross Sea polynya (Ainley 1985; Ainley et al. 2003b).
	NA	18,576	4,817	NA	NA	0.25931	NA	NA	0.75 near shelf and slope	APIS Report (2000)	Area surveyed is linear distance (18,756 km). **From report:** 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). Surveyed 18,576 km
									0.22 in mid-pack; 0.24 at northern ice edge	APIS Report (2000)	
	53,217	27,365	8,825	NA	98	0.32249	NA	NA	0.16583	Distribution, density and abundance (Bengtson, J.L. et al. 2011)	26 Dec. 1999 - 24 March 2000
	300,000	NA	204,000	NA	NA	NA	NA	NA	0.68000	Ross Sea Region (2001)	Although regularly seen in McMurdo Sound, they are more common in the northern regions of the Ross Sea, concentrated in the pack ice over the Antarctic Slope Front. [No primary source cited for population estimate.]
Leopard	187,000	NA	8,000	NA	NA	NA	NA	NA	0.04278	Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	Species breeds and probably occur in the Ross Sea region, if not the Ross Sea itself, continuously throughout the year.
	466,100	NA	8,000	NA	NA	NA	NA	NA	0.01716	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
	598,000	NA	8,000	NA	NA	NA	NA	NA	0.01338	Marine Ornithology (Ainley 2002)	Population estimates from 1970s and early 1980s (cf. Stirling 1969; Gilbery & Erickson, 1977; Ainley 1985)
	300,000	NA	7,990	NA	NA	NA	NA	NA	0.02663	Exploitation (Ainley 2009)	Population estimates based on several cruises during the late 1970s to early 1980s.
	300,000	NA	8,000	NA	NA	NA	NA	NA	0.02667	CCAMLR 2007	Surveys made during 1976-1979 (Ainley 1985).
		18,576	33	NA	NA	0.00178	0.40	0.80	0.0022206	APIS Report (2000)	Surveyed 18,576 km of pack ice from air (helicopter)
	53,217	27,365	10	NA	10	0.00037	NA	NA	0.0001879	Distribution, density and abundance (Bengtson, J.L. et al. 2011)	26 Dec. 1999 - 24 March 2000

Pinnipeds Observed and Estimated Densities in the Ross Sea

Common Name	Area Surveyed (km^2) Note 1	Area Surveyed (km, linear survey)	Animals (#)	Correction Factor	Estimated # in the Water	Estimated Linear Density (#/km)	Half Strip-width (km) Note 2	Visual Transect Width (km) Note 3	Estimated Areal Density (#/ km^2) Note 4	Data Source	Year/Season/Area/Comments
	300,000	NA	8,000	NA	NA	NA	NA	NA	0.02667	Ross Sea Region (2001)	Individual leopard seals are often seen in summer...off the Adélie penguin rookeries of Ross Island. [No primary source cited.]
Ross	300,000	NA	5,000	NA	NA	NA	NA	NA	0.01667	Seals: Trophic modelling (Pinkerton, Bradford-Grieve, undated)	Ross seals have a circumpolar distribution and are usually found in dense consolidated pack ice, but can also be found on smooth ice floes in more open areas. Ainley (1985) concluded that Ross seals are irregularly distributed with high concentrations in localised areas, and that the Ross Sea is apparently not an area where this species concentrates. [Population estimate from (Ainley 1985).]
	466,100	NA	500	NA	NA	NA	NA	NA	0.00107	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
	300,000	NA	5,050	NA	NA	NA	NA	NA	0.01683	Exploitation (Ainley 2009)	Population estimates based on several cruises during the late 1970s to early 1980s.
	300,000	NA	5,000	NA	NA	NA	NA	NA	0.01667	CCAMLR 2007	Surveys made during 1976-1979 (Ainley 1985).
	187,000	NA	5,000	NA	NA	NA	NA	NA	0.02674	Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	Species breeds and probably occur in the Ross Sea region, if not the Ross Sea itself, continuously throughout the year. The remaining seals [other than the Weddell] are denizens of the pack ice, especially along the shelf break and the ice margins of the Ross Sea polynya (Ainley 1985; Ainley et al. 2003b).
	53,217	27,365	10	NA	10	0.0003654	NA	NA	0.00019	Distribution, density and abundance (Bengtson, J.L. et al. 2011)	26 Dec. 1999 - 24 March 2000
	NA	18,576	79	NA	NA	0.00425	0.40	0.80	0.0053160	APIS Report (2000)	Surveyed 18,576 km of pack ice from air (helicopter)
	300,000	NA	5,000	NA	NA	NA	NA	NA	0.01667	Ross Sea Region	A seal of pack ice and open waters and seems to prefer dense consolidated pack ice rather than the open pack frequented by crabeaters. [No primary source cited.]
	598,000	NA	32,000	NA	NA	NA	NA	NA	0.05351	Marine Ornithology (Ainley 2002)	Population estimates from 1970s and early 1980s (cf. Stirling 1969; Gilbery & Erickson, 1977; Ainley 1985)
	300,000	NA	32,000	NA	NA	NA	NA	NA	0.10667	Seals: Trophic modelling (Pinkerton, Bradford-Grieve, undated)	May range as high as 50,000 individuals; reports estimates from Ainley (1985) as **0.054 individuals per km2**, implying 32,000 individuals in Ross Sea area.
	466,100	NA	30,000	NA	NA	NA	NA	NA	0.06436	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Possibly as high as 50,000 individuals. Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
	300,000	NA	31,990	NA	NA	NA	NA	NA	0.10663	Exploitation (Ainley 2009)	Population estimates based on several cruises during the late 1970s to early 1980s.

Pinnipeds Observed and Estimated Densities in the Ross Sea

Common Name	Area Surveyed (km^2) Note 1	Area Surveyed (km, linear survey)	Animals (#)	Correction Factor	Estimated # in the Water	Estimated Linear Density (#/km)	Half Strip-width (km) Note 2	Visual Transect Width (km) Note 3	Estimated Areal Density (#/ km^2) Note 4	Data Source	Year/Season/Area/Comments
Weddell	300,000	NA	30,000	NA	NA	NA	NA	NA	0.10000	CCAMLR 2007	The Weddell is the only seal species that can be considered a permanent resident of the Ross Sea. It occupies the fast ice areas for pupping and breeding activities. These seals move out into waters overlying the Ross Sea shelf after the breeding season, as do the juveniles produced. [Surveys made during 1976-1979 (Ainley 1985).]
	187,000	NA	32,000	NA	NA	NA	NA	NA	0.17112	Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	**Estimates may be as high as 50,000.** Species breeds and probably occur in the Ross Sea region, if not the Ross Sea itself, continuously throughout the year. The Weddell seal occurs in areas of fast ice, such as McMurdo Sound, which supports the highest concentrations of this species in the world.
		18,576	2,852	NA	NA	0.15353	0.40	0.80	0.1919143	APIS Report (2000)	Surveyed 18,576 km of pack ice from air (helicopter)
	300,000	NA	32,000	NA	NA	NA	NA	NA	0.10667	Ross Sea Region (2001)	The Weddell seal is the most commonly encountered seal in the Ross Sea. [Counts from Ainley, 1985]
	53,217	27,365	2,270	NA	NA	0.0830	NA	NA	0.04266	Distribution, density and abundance (Bengtson, J.L. et al. 2011)	26 Dec. 1999 - 24 March 2000
	14,804	NA	19,097	NA	NA	0.43	NA	NA	1.28999	Distribution of Weddell Seal (1968)	Western Ross Sea between Cape Adare and McMurdo Sound: 77 Weddell seals observed over 178 nm in 1967; 45 observed over 106 nm
	11,064	NA	14,969	NA	NA	0.43	NA	NA	1.35295		
Elephant	300,000	NA	40	NA	NA	NA	NA	NA	0.00013	Seals: Trophic modelling (Pinkerton, Bradford-Grieve n.d.)	Enters the Ross Sea only in the summer from breeding and feeding grounds further to the north. The southern elephant seal is consequently the least common seal in the Ross Sea. Estimates from (Brownell & Ainley 1976; Ainley 1985).
	300,000	NA	40	NA	NA	NA	NA	NA	0.00013	Exploitation (Ainley 2009)	Population estimates based on several cruises during the late 1970s to early 1980s.
	466,100	NA	100	NA	NA	NA	NA	NA	0.00021	Sea of Change (Smith Jr., Sedwick, Arrigo, Ainley, Orsi 2012)	Area equated with size of "Ross Sea Continental Shelf." (Population estimates from Ballard et al. [2011])
	187,000	NA	100	NA	NA	NA	NA	NA	0.00053	Trophic Interactions (Smith Jr, Ainley, Cattaneo-Vietti 2006)	Text states "less than 100" of this species.

Notes:

NA = Not Available

1. Where the area surveyed was not indicated in the reference document, a value of 300,000 km^2 was used, estimate of Ross Sea area from Google Earth.
2. Distances not reported in reference; estimated assuming 400 m half strip-width on each side of the vessel.
3. Visual transect width = half strip-width x 2, representing the total width of observations.
4. Estimated areal density [# animals/area surveyed (km2)] is provided either based on reported numbers in the reference or calculated based on the estimated linear density (#/km) x 1/visual transect width (km).

Pinniped Densities in the Ross Sea

Common Name	Area Surveyed (km)	Animals (#)	Animals (# including unidentified)	Correction Factor Note 1	Estimated # in the Water Note 2	Estimated Linear Density (#/km)	Half Strip-Width (km) Note 3	Visual Transect Width (km) Note 4	Areal Density (#/ km^2)	Data Source	Year/Season/Area	Comments
Crabeater	300,000	NA	204,000	NA	NA	NA	NA	NA	0.6800000	Ross Sea Region (2001)	More common in the northern regions o	No primary source cited for population estimate.
Leopard	300,000	NA	8,000	NA	NA	NA	NA	NA	0.0266700	Ross Sea Region (2001)	Individual leopard seals are often seen i	No primary source cited for population estimate.
Ross	300,000	NA	5,000	NA	NA	NA	NA	NA	0.0166700	Ross Sea Region (2001)	A seal of pack ice and open waters and s	No primary source cited for population estimate.
Weddell	300,000	NA	32,000	NA	NA	NA	NA	NA	0.1066700	Ross Sea Region (2001)	The Weddell seal is the most commonly	Counts from Ainley, 1985]
Elephant	300,000	NA	40	NA	NA	NA	NA	NA	0.0001300	Seals: Trophic modelling (Pinkerton, Bradford-Grieve n.d.)	Enters the Ross Sea only in the summer	Estimates from Brownell & Ainley 1976; Ainley 1985.

Notes:

[1] Correction factor for pinnipeds recommended by NOAA; accounts for animals that may be in the water but were not sighted and reported.

[2] Number of animals x correction factor.

[3] Assumes 400 m half strip-width on each side of the vessel.

[4] Visual Transect Width = visual range x 2, representing the total width of observations.

Projected Number of Cetacean and Pinniped Takes in the Proposed Study Area

Common Name	Areal Density (#/ km^2)	Estimated Level B Harassment Takes (#) [Note 1]
Mysticetes		
Blue whale	0.0065132	23
Fin whale	0.0306570	108
Humpback whale	0.0321169	113
Minke whale	0.0845595	297
Sei whale	0.0046340	16
Odontocetes		
Arnoux's beaked whale	0.0134420	47
Hourglass dolphin	0.0189782	67
Killer whale	0.0208872	73
Layard's beaked whale	0.0044919	16
Long-finned pilot whale	0.0399777	141
Southern bottlenose whale	0.0117912	41
Sperm whale	0.0098821	35
Pinnipeds		
Crabeater	0.6800000	2,392
Elephant	0.0001300	0.5
Leopard	0.0266700	94
Ross	0.0166700	59
Weddell	0.1066700	375

Notes:

[1] Calculated take for all animals estimated by using areal density multiplied by the (3,518 km2) area ensonified to 160 dB (rms) around the planned seismic lines. (1,005 m x 2 x 1750 km)

Projected Number of Cetacean and Pinniped Takes during Potential Icebreaking Activities

Common Name	Areal Density (#/ km^2)	Estimated Level B Harassment Takes (#) [Note 1]
Mysticetes		
Blue whale	0.0065132	140
Fin whale	0.0306570	660
Humpback whale	0.0321169	692
Minke whale	0.0845595	1,821
Sei whale	0.0046340	100
Odontocetes		
Arnoux's beaked whale	0.0134420	290
Hourglass dolphin	0.0189782	409
Killer whale	0.0208872	450
Layard's beaked whale	0.0044919	97
Long-finned pilot whale	0.0399777	861
Southern bottlenose whale	0.0117912	254
Sperm whale	0.0098821	213
Pinnipeds		
Crabeater	0.6800000	14,647
Elephant	0.0001300	2.8
Leopard	0.0266700	574
Ross	0.0166700	359
Weddell	0.1066700	2,298

Notes:

[1] Calculated take for all animals estimated by using areal density multiplied by the 21,540 km^2 area ensonified to 120 dB (rms) around the estimated icebreaking tracklines. (21.54 km x 2 x 500 km)

Attachment E
Antarctic Multichannel Seismic-Reflection (MCS) Cruises (through 2008)

Cruise	Season	Group	Country	MCS (km)
Antarctic Peninsula (including Bellingshausen, Scotia, and northern Weddell Seas)				
BAS-84S	85	BAS	UK	3514
ANT VII/2	88	AWI/IG	Germany	1700
SA500	88	PB	Brazil	552
U39	91	MoG	China	2015
EW9101	91	NSF: UT/LDEO	USA	7200
U6	79/80	PAS	Poland	1100
TH80	80/81	JNOC	Japan	3280
TH86	86/87	JNOC	Japan	2655
A5	87/88	PB	Brazil	4914
TH87	87/88	JNOC	Japan	2265
D172	87/88	BAS	UK	3640
TH88	88/89	JNOC	Japan	2200
IT90AP	89/90	OGS	Italy	3406
SAE-35	89/90	SMG	USSR	3010
IT91AP	90/91	OGS	Italy	3560
ANT92	91/92	IAGM. CSIC/UG	Spain	1525
SCOTIA92	91/92	IEO	Spain	1500
IT92AP	91/92	OGS	Italy	3423
RAE-37	91/92	PMGRE	Russia	3000
KSL93	92/93	KORDI	Korea	900
HESANT92/93	92/93	IAGM. CSIC/UG	Spain	3560
JCR04	92/93	BAS	UK	1520
U67	93/94	IAGM. CSIC/UG	Spain	1520
IT95AP	94/95	OGS	Italy	1847
IT95AP	94/95	OGS	Italy	2622
NBP95-7	94/95	NSF:UT	USA	350
TH96	96/97	JNOC	Japan	2475
SCAN97	96/97	IACT/CSIC/UG	Spain	3778
IT96AP	96/97	OGS	Italy	2799
TH97	97/98	JNOC	Japan	1790
ANTPAC 97/98	97/98	IACT/CSIC/UGR	Spain	2685
KSL98	98/99	KORDI	Korea	980
KSL99	99/00	KORDI	Korea	830
KSL00	00/01	KORDI	Korea	750
KSL01	01/02	KORDI	Korea	580
ANT-XIX/2	01/02	AWI	Germany	2930
HEO78	01/02	UB/ICM-CSIC/OGS	Spain/Italy	1260
KSL02	02/03	KORDI	Korea	570
KSL03	03/04	KORDI	Korea	640
KSL04	04/05	KOPRI	Korea	740
SCAN 2004	04/05	IACT/CSIC/UGR	Spain	2791
KSL05	05/06	KOPRI	Korea	680

Attachment E
Antarctic Multichannel Seismic-Reflection (MCS) Cruises (through 2008)

Cruise	Season	Group	Country	MCS (km)
Marie Byrd Land				
ANT-XI/3	93/94	AWI	Germany	3448
ANT-XII/4	94/95	AWI	Germany	989
ANT-XVIII/5a	00/01	AWI/VI	Germany/Russia	572
ANT-XXIII/4	05/06	AWI/BAS/VI	Germany/UK/Russia	2227
Enderby Land				
RAE-47	01/02	PMGRE	Russia	4208
RAE-46	00/01	PMGRE	Russia	4537
SAE-33	87/88	SMG	USSR	3710
RAE-36	90/91	PMGRE	USSR	700
RAE-45	99/00	PMGRE	Russia	4390
Prydz Bay				
BMR-33	82	BMR	Australia	5006
MD47	86	EOST	France	1612
MD67	91	EOST	France	1194
TH84	84/85	JNOC	Japan	2350
SAE-31	85/86	SMG	USSR	930
SAE-32	86/87	SMG	USSR	3070
SAE-33	87/88	SMG	USSR	3710
TH89	89/90	JNOC	Japan	1835
RAE-36	90/91	PMGRE	USSR	700
RAE-39	93/94	PMGRE	Russia	2550
RAE-40	94/95	PMGRE	Russia	3429
TH98	98/99	JNOC	Japan	2490
TH99	99/00	JNOC	Japan	2195
RAE-48	39481	PMGRE	Russia	4352
Queen Maud Land				
TH85	85/86	JNOC	Japan	2430
RAE-41	95/96	PMGRE	Russia	3451
RAE-43	97/98	PMGRE	Russia	4396
RAE-44	98/99	PMGRE	Russia	4492
U68	01/02	NPD/PMGRE	Norway	2600
U69	02/03	NPD/PMGRE	Norway	2440
U70	03/04	NPD/PMGRE	Norway	2950
Ross Sea				
BGR-80	80	BGR	Germany	6743
ATC82	82	IFP	France	1800
SAE-32	87	SMG	USSR	4320
SAE-34	89	SMG	USSR	1224
NBP03-1	39481	NSF:UCSD	USA	?
NBP03-1A	39481	NSF:UCSD	USA	?
TAN0602	39574	LINZ	New Zealand	3400
TH82	82/83	JNOC	Japan	1670
L284	83/84	USGS	USA	1850

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Antarctic Multichannel Seismic-Reflection (MCS) Cruises (through 2008)

Cruise	Season	Group	Country	MCS (km)
IT88RS	87/88	OGS	Italy	2323
IT89RS	88/89	OGS	Italy	4202
IT90RS	89/90	OGS	Italy	2503
IT91RS	90/91	OGS	Italy	554
TH91	91/92	JNOC	Japan	3290
TH92	92/93	JNOC	Japan	2765
IT94RS	93/94	OGS	Italy	851
NBP94-7	93/94	NSF:UA	USA	100
TH95	95/96	JNOC	Japan	1980
NBP96-1	95/96	NSF:UC	USA	2480
NBP96-2	95/96	NSF:Scripps	USA	1400 ?
NBP97-2	96/97	NSF:Scripps	USA	1600 ?
Wilkes Land				
ATC82	82	IFP	France	3100
RAE-49	03/04	PMGRE	Russia	4122
RAE-50	04/05	PMGRE	Russia	4090
RAE-51	06/07	PMGRE	Russia	4850
RAE-53	07/08	PMGRE	Russia	1590
GA227	00/01	Geoscience Australia	Australia	3427
GA228	00/01	Geoscience Australia	Australia	10612
GA229	01/02	Geoscience Australia	Australia	9607
TH82	82/83	JNOC	Japan	680
TH83	83/84	JNOC	Japan	3700
L184	83/84	USGS	USA	1800
TH90	90/91	JNOC	Japan	2095
TH93	93/94	JNOC	Japan	3040
TH94	94/95	JNOC	Japan	2375
WEGA	99/00	GA/OGS	Aus/Italy	1827
Weddell Sea				
BGR-78	78	BGR	Germany	4625
NARE-85	85	UB	Norway	2642
ANT V/4	87	AWI	Germany	2800
ANT-VIII/6	90	BGR	Germany	3213
NARE-77	76/77	UB	Norway	910
NARE-79	78/79	UB	Norway	1229
SAE-26	80/81	SMG	USSR	750
TH81	81/82	JNOC	Japan	1420
U40	81/82	SMG	USSR	820
U41	82/83	SMG	USSR	700
SAE-30	84/85	SMG	USSR	734
ANT-IV/3	85/86	BGR	Germany	6263
SAE-34	88/89	SMG	USSR	1224
ANT VIII/5	89/90	AWI	Germany	4112
ANT X/2	91/92	AWI	Germany	3885

Attachment E
Antarctic Multichannel Seismic-Reflection (MCS) Cruises (through 2008)

Cruise	Season	Group	Country	MCS (km)
ANT-XII/3	94/95	AWI	Germany	2062
BGR-96	95/96	BGR	Germany	3600
ANT-XIII/3	95/96	AWI	Germany	1500
ANT-XIV/3	96/97	AWI	Germany	4415