UNITED STATES
AMLR ANTARCTIC MARINE LIVING RESOURCES PROGRAM

AMLR 2008/2009 FIELD SEASON REPORT

Objectives, Accomplishments and Tentative Conclusions

Edited by
Amy M. Van Cise

May 2009

NOAA-TM-NMFS-SWFSC-445

Southwest Fisheries Science Center
Antarctic Ecosystem Research Group

The U.S. Antarctic Marine Living Resources (AMLR) program provides information needed to formulate U.S. policy on the conservation and international management of resources living in the oceans surrounding Antarctica. The program advises the U.S. delegation to the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), part of the Antarctic treaty system. The U.S. AMLR program is managed by the Antarctic Ecosystem Research Group located at the Southwest Fisheries Science Center in La Jolla.

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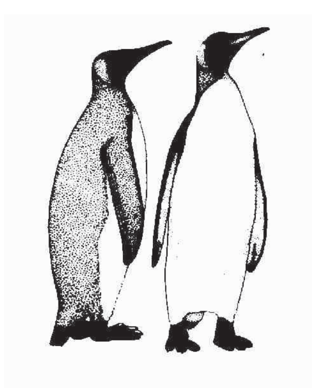

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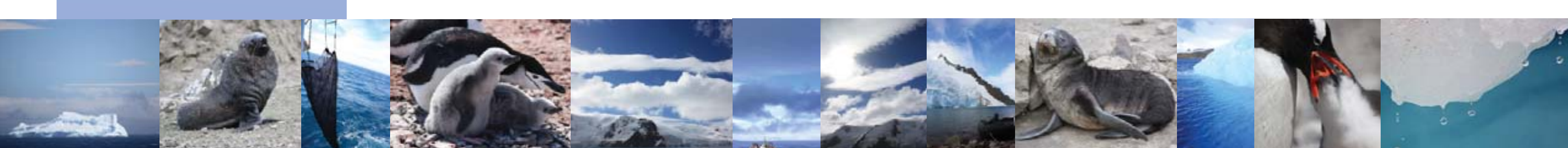

Photos: A. M. Van Cise

Introduction

The 2008/09 U.S. Antarctic Marine Living Resources (U.S. AMLR) field season continues a long-term series of studies of the Antarctic ecosystem, designed to provide scientific support for the conservation and management of Antarctic marine fisheries as outlined by the international Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). The U.S. AMLR Program is managed by the Antarctic Ecosystem Research Division (AERD).

The research completed in the field is used to describe the Antarctic ecosystem as a function of the relationships among Antarctic krill (*Euphausia superba*), their predators and the physical and biological oceanographic conditions of Antarctic waters. Two working hypotheses have been proposed based on the data collected: 1) krill predators respond to changes in the availability of their food source, and 2) the distribution of krill is affected by both physical and biological aspects of their habitat.

Since the conception of the U.S. AMLR research program, annual field studies have been conducted in the vicinity of the South Shetland Islands (Figure 1), which are located to the north of the Antarctic Peninsula. These field studies include annual land-based observation of pinniped and seabird ecology, between October and March, at Cape Shirreff on Livingston Island and Admiralty Bay on King George Island (Figure 1), and two identical surveys of the waters surrounding the South Shetland Islands (Figure 2), completed in January and February. In the austral summer of 2008/09 the U.S. AMLR Program omitted the second South Shetland Island survey in order to include a demersal finfish and benthic survey of the South Orkney Islands and northeast Antarctic Peninsula (Figure 3).

Research at the field stations includes studies on the breeding success and foraging ecology of chinstrap, gentoo, and Adélie penguins, as well as Antarctic fur seals. Additional studies on fur seal genetics, elephant seal energetics and penguin foraging ecology are completed in collaboration with the University of California system.

Shipboard research is focused on ecosystem interactions supporting commercially important resources such as Antarctic krill and finfish. During Leg I, observations were made of krill distribution, as well as environmental factors affecting that distribution (e.g., sea surface temperature, wind speed and direction, primary production), and the at-sea distribution of krill-dependent predators. During Leg II, observations were made of finfish distribution and benthic community composition in the South Orkney Islands, as well as local oceanography and krill distribution.

This is the 21st issue in the series of U.S. AMLR field season reports, documenting the 23rd year of Antarctic research.

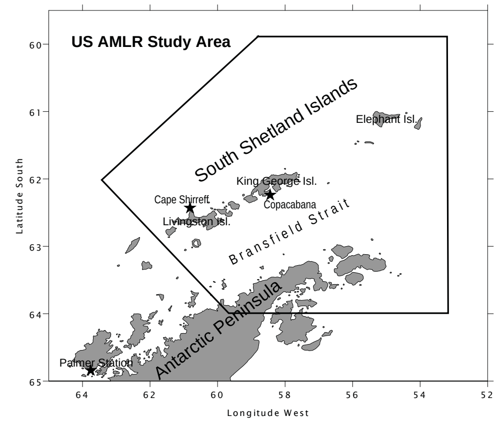

Figure 1. Location of the U.S. AMLR field research program: AMLR study area; Cape Shirreff, Livingston Island; Copacabana, King George Island.

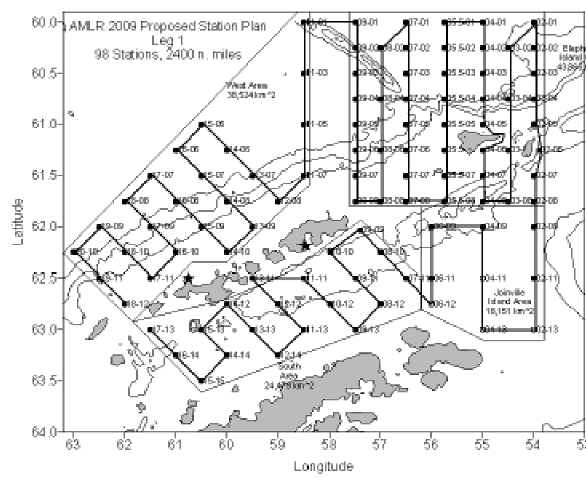

Figure 2. The survey design for AMLR 2008/09 (Leg I) in the South Shetland Islands; field camp locations indicated by a star. The survey contains four strata outlined by thin lines and labeled West Area, Elephant Island Area, Joinville Island Area and South Area. Depth contours are 500 m and 2000 m. Black dots indicate the location of biological/oceanographic sample stations; heavy lines indicate transects between stations.

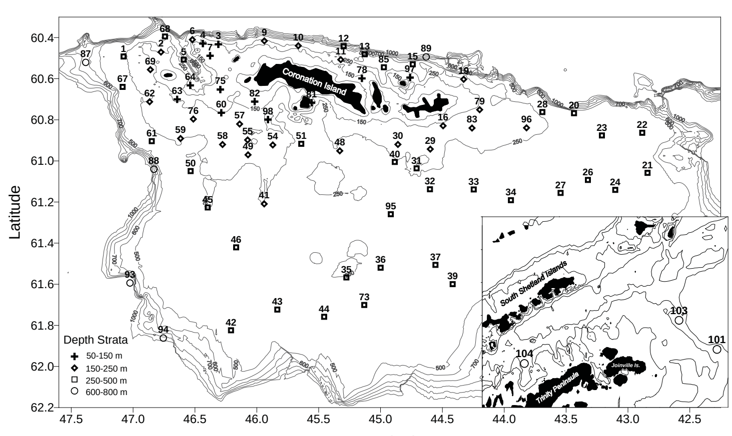

Figure 3. Station locations by depth strata from Leg II of the 2008/09 AMLR Survey, in the South Orkney Islands. Figure inset shows the three trawls taken on the slope of the northern Antarctic Peninsula.

2008/09 AMLR Survey Objectives

Shipboard research

1. Conduct an oceanographic, bioacoustic and net-based survey in the vicinity of the South Shetland Islands (Leg I) in order to map meso-scale features of water mass structure, phytoplankton biomass and productivity, zooplankton constituents, and the dispersion and population demography of krill.
2. Conduct an oceanographic, net-based, photographic and acoustic finfish survey in the vicinity of the South Orkney Islands and northeast of the Antarctic Peninsula (Leg II) in order to map the distribution of finfish, benthic community composition, and zooplankton distribution, as well as monitor the recovery of commerically important species of finfish.
3. Calibrate the shipboard acoustic system in Admiralty Bay at the beginning of Leg I and again near the end of Leg II.
4. Collect continuous measurements of ship's position, sea surface temperature, salinity, turbidity, fluorescence, air temperature, barometric pressure, relative humidity, and wind speed and direction.
5. Collect underway observations of seabirds and marine mammals.
6. Deploy 15 drifter buoys in cooperation with the NOAA/Atlantic Oceanographic and Meteorological Laboratory's Global Drifter Program (GDP).
7. Provide logistical support to field camps at Cape Shirreff, Livingston Island and Admiralty Bay, King George Island. Support will include transfer of personnel, equipment, building materials, supplies, and provisions.
8. Prepare fur seal milk for lipid analysis, process shore-based collections of fur seal diet samples, collect fur seal and penguin prey (krill, squid and fish) for lipid analysis and bomb calorimetry, and measure krill for validation of krill carapace-to-total-length relationship.

Land-based Research (Cape Shirreff)

1. Estimate chinstrap and gentoo penguin breeding population size.
2. Band 500 chinstrap and 200 gentoo penguin chicks for future demographic studies.
3. Determine chinstrap penguin foraging trip durations during the chick rearing stage of the reproductive cycle.
4. Determine chinstrap and gentoo penguin breeding success.
5. Determine chinstrap and gentoo penguin chick weights at fledging.
6. Determine chinstrap and gentoo penguin diet composition, meal size, and krill length/frequency distributions in the diet.
7. Determine chinstrap and gentoo penguin breeding chronologies.
8. Deploy time-depth recorders (TDRs) on chinstrap and gentoo penguins during chick rearing for diving studies.
9. Record at-sea foraging locations for chinstrap penguins during their chick-rearing period using Argos satellite-linked platform terminal transmitters (PTT).
10. Monitor female Antarctic fur seal attendance behavior.
11. Collaborate with Chilean researchers in collecting Antarctic fur seal pup mass for 100 pups every two weeks through the season.
12. Collect 10 Antarctic fur seal scat samples every week for diet studies.
13. Collect a milk sample at each female Antarctic fur seal capture for fatty acid signature analysis and diet studies.
14. Record at-sea foraging locations for female Antarctic fur seals using Platform Terminal Transmitters (PTT) and GPS units.
15. Deploy time-depth recorders (TDR) on female Antarctic fur seals for diving studies.
16. Tag 500 Antarctic fur seal pups for future demographic studies.
17. Collect teeth from selected Antarctic fur seals for age determination and other demographic studies.
18. Deploy a weather station for continuous summer recording of wind speed, wind direction, ambient temperature, humidity, and barometric pressure.
19. Conduct an archipelago-wide survey of Antarctic fur seal pup production.
20. Instrument southern elephant seals with conductivity–temperature–depth satellite-relayed data loggers (CTD-SRDLs).
21. Capture and instrument leopard seals for studies of top-down control of fur seal populations in the South Shetland Islands.

Summary of 2008/09 AMLR Survey Results

Shipboard mapping of the waters around the South Shetland Islands indicates that several water masses converge in the area, forming a hydrographic front along the shelf break north of the archipelago. This front is associated with high densities of phytoplankton and Antarctic krill, although there is great variability in the seasonal presence and reproductive success of krill, which is strongly correlated with multi-year trends in the physical environment.

During Leg I of the 2008/09 U.S. AMLR Survey, in the South Shetland Islands, net-based estimates of krill abundance decreased while acoustic estimates of krill biomass increased, possibly indicating a weak recruitment from the 2007/08 austral summer. Observed penguin populations increased compared to the 2007/08 breeding season; however, the populations are still below the 12-year mean. Antarctic fur seal pup production decreased slightly from the 2007/08 austral summer, but females spent less time foraging and more time with their pups this year. Neonate mortality decreased, and a smaller percentage of pups were lost to leopard seal predation.

During Leg II of the 2008/09 AMLR Survey, the first finfish trawl in the South Orkney Islands since 1998/99 was completed to monitor the recovery of commercially important finfish species such as *Champsocephalus gunnari, Gobionotothen gibberifrons* and *Notothenia rossii*. Benthic studies showed distinct patterns in vulnerable invertebrate taxa, which were found to the north, west and east of the islands. Photographic images, acoustic data, CTD casts and zooplankton trawls were also completed to complement the finfish and benthic survey.

Leg I

Oceanographic data

The Antarctic Circumpolar Current (ACC), characterized by warm, nutrient-poor waters, was north of 59°30'S during the U.S. AMLR field season. The water around the South Shetland Islands was transitional between the two local sources, the ACC and the Weddell Sea. Three stations near the Shackleton Fracture Zone had ACC-type water, and several stations in the southern Joinville Island Area had Weddell Sea-type water.

Phytoplankton data

Chl-*a* concentrations in the waters surrounding the South Shetland Islands were below average during January 2009. U.S. AMLR data show that primary production in the area is limited by nutrients in the nutrient-poor ACC, and by light in the cold, deeply-mixed Weddell Sea; highest levels of production exist where there is a mixture from the two sources. This year Chl-*a* production was higher than average in transitional waters but was very limited in nutrient-poor and light-poor waters, causing an overall decrease in primary production.

Bioacoustic data

In the South Shetland Islands, acoustically-derived biomass estimates of Antarctic krill were greater than measured during the 2007/08 field season. In the Elephant Island Area, the biomass of krill was at its highest since 1996. Krill biomass was lower in other areas and was lowest in the Bransfield Strait.

Two consecutive years of acoustic transects in the South Orkney Islands show that the region to the northwest of Coronation Island, where the krill fishery is usually located, has had the largest krill biomass. This year's results will be compared to those from the 2007/08 field season for continued analysis.

Net-sampling data

Antarctic krill abundance, as measured by net sampling, decreased in the South Shetland Islands from the last field season. Postlarval krill exhibited a relatively uniform distribution of modest concentrations across the survey region in January 2009. Krill in the 29.5 mm length category, determined to be 1-year-old krill, represented 2% of the krill sampled, indicating a very small proportional recruitment from krill hatched during the 2008 breeding season. A large proportion of the krill sampled were adult females, and the presence of many krill larvae indicates peak spawning activity during the survey period.

The zooplankton species *Salpa thompsoni* was numerically dominant this year, which is often an indication of the presence of warmer, ACC-type water. Overall, the zooplankton distribution patterns were very mixed, suggesting greater than normal hydrographic complexity across the region.

Shipboard seabird and marine mammal observation data

Seabird feeding aggregations were patchily distributed throughout the South Shetland Islands, in a pattern similar to the 2006 seabird distribution, which was a year when krill biomass was very low. Cape petrels and fulmars were the most prevalent seabirds observed during the field season.

Fin whales occurred in larger numbers and had a wider distribution during the 2008/09 field season than has been observed during the U.S. AMLR Program, extending farther into pelagic waters and farther south than previously recorded.

Leg II

Finfish survey data

During the first finfish survey of the South Orkney Islands completed since the 1998/1999 AMLR Survey, it was found that total finfish biomass was greatest to the northwest of the South Orkney Islands. Sixty-five species were found, the highest diversity of which was located in the 150-250 m depth range. Catch size of *Pleurogramma antarcticum* increased substantially since the last finfish survey of the South Orkney Islands, which, although not commercially important, is notable because of the importance of this species as a prey item to several Antarctic predators.

Benthic community data

Fifteen taxa of vulnerable invertebrates were encountered during the survey of the South Orkney Islands. Porifera, the largest of the taxa by mass, were found to the west and east of the island chain, exhibiting the same distributional pattern as the overall invetebrate community. Other vulnerable taxa, however, were distributed to the north of the South Orkney Islands.

Photographic/Video data

The photographic/video system was deployed a total of 21 times throughout the course of Leg II, collecting more than 17 hours of video footage and more than 2,000 photographic images of the seafloor and benthic communities surrounding the South Shetland Islands. Many vulnerable taxa were documented, including Bryozoa, Hexactinellida, Porifera and the delicate sea pen, *Umbellula sp.*

Net-sampling data

A total of 19 net tows were completed during Leg II. Krill were caught mainly to the northwest of Coronation Islands, the site of an active krill fishery. Krill in the South Orkney Islands had a unimodal length-frequency distribution around 44-48 mm.

Seabird Research

The penguin rookery at Cape Shirreff consisted of 19 sub-colonies of gentoo and chinstrap penguins during the 2008-09 breeding season: a total of 879 gentoo penguin nests and 4,026 chinstrap penguin nests were counted. Gentoo penguins had the most nests since the 2001/02 breeding season; chinstrap penguin nests also increased in number, however the number is still more than 30% below average.

Annual chick production was estimated using population censuses and studies of reproductive success in each species. The gentoo chick count was 1,010 chicks, 86% higher than the 2007-08 count but only 6% higher than the previous 12-year mean. The chinstrap chick count was 4,332 chicks, 282% higher than the 2007-08 count but still 33% lower than the previous 12-year mean. Overall, breeding population counts and reproductive success of both gentoo and chinstrap penguins were significantly higher then last year's counts.

Pinniped Research

Data collected during the 2008/09 Antarctic fur seal breeding season indicated the second year of poor overwintering conditions. Fur seal pup production at the U.S. AMLR study site decreased from last year; however, summer conditions were more favorable. Females spent less time at sea and more time onshore, resting and feeding their pups. Overall pup mortality decreased, with fewer neonate deaths and fewer animals caught by leopard seals.

Diet studies show that the majority of the fur seal diet during the 2008/09 breeding season was from krill, especially in December and early January. In February, fur seals began to incorporate more myctophids into their diet, eating primarily two species: *Electrona antarctica* and *Gymnoscopelus nicholsi*.

Decsription of Operations

Shipboard Research

For the 14th consecutive year, the cruise was conducted aboard the chartered research vessel R/V *Yuzhmorgeologiya*. Operations were conducted according to the following schedule:

Leg I:		
Transit to Copacabana	3	08-10 Jan
Transfer personnel to Copacabana, calibrate in Admiralty Bay	1	11-Jan
Transfer personnel to Cape Shirreff	1	12-Jan
Conduct large-area survey	17	13-29 Jan
Transfer personnel from Cape Shirreff	1	30-Jan
Transit to Punta Arenas	3	31 Jan -2 Feb
Total Days	**26**	
Leg II:		
Transit to South Orkney Islands	3	6-8 Feb
Finfish and benthic survey	24	9 Feb-4 Mar
Transit to Copacabana	1	5-Mar
Transfer personnel from Cape Shirreff	1	6-Mar
Transfer personnel from Copacabana/Calibrate	1	7-Mar
Survey around Antarctic Peninsula	2	8-9 Mar
Transit to Punta Arenas	3	10-12 Mar
Total Days	**35**	

1. The R/V *Yuzhmorgeologiya* departed Punta Arenas, Chile via the eastern end of the Strait of Magellan and arrived at Cape Shirreff to deliver personnel and supplies to the field camp. The ship then transited to Admiralty Bay to deliver additional personnel and supplies to the Copacabana field camp.
2. The acoustic transducers were calibrated in Admiralty Bay, King George Island. Beam patterns for the hull-mounted 38, 70, 120 and 200 kHz transducers were mapped and system gains were determined.
3. Leg I survey components included acoustic mapping of zooplankton, direct sampling of zooplankton, Antarctic krill demography studies, physical oceanography and phytoplankton observations. Leg I, consisting of 103 Conductivity-Temperature-Depth (CTD) and 101 net sampling stations, separated by acoustic transects, was conducted in the vicinity of the South Shetland Islands (Figure 2). Operations at each station included: (a) vertical profiles of temperature, salinity, oxygen, fluorescence, light transmission and collection of water samples at discrete depths; and (b) deployment of an IKMT (Isaacs-Kidd Midwater Trawl) to obtain samples of zooplankton and micronekton. Acoustic transects were conducted between stations at 10 knots, using hull-mounted 38 kHz, 70 kHz, 120 kHz, and 200 kHz down-looking transducers.
4. Seabird and marine mammal observations were collected continuously throughout Leg I.
5. Fifteen drifter buoys were deployed, in collaboration with NOAA/Atlantic Oceanographic and Meteorological Laboratory's GDP, for oceanographic data.
6. Optical oceanographic measurements were conducted, which also included weekly downloads of SeaWiFS satellite images of surface chlorophyll distributions and in-situ light spectra profiles.
7. Leg II was conducted in the South Orkneyy Islands and to the northeast of the Antarctic Peninsula. A total of 78 hauls were completed; 75 of those were in the South Orkney Islands and 3 of those were along the Antarctic Peninsula. Survey components included acoustic mapping of zooplankton as well as acoustic detection of seabed structure, sampling of demersal finfish, physical oceanography observations, and photographic/video and net sampling of benthic communities. Operations varied by station and included: (a) net-trawl of the sea bottom, (b) deployment of an IKMT to obtain samples of zooplankton and micronekton, (c) deployment of a CTD to characterize oceanographic features at the sample station, and (d)photographic transects of the seabed. Acoustic transects were conducted between stations.
8. Continuous environmental data were collected throughout Leg I and Leg II including measurements of ship position, sea surface temperature and salinity, fluorescence, air temperature, barometric pressure, relative humidity, wind speed, and wind direction.
9. Fur seal milk was prepared for lipid analysis, shore-based collections of fur seal diet samples

were processed, fur seal and penguin prey (krill, squid and fish) were collected for lipid analysis and bomb calorimetry, and krill were measured for validation of krill carapace-to-total-length relationship.

Land-based Research (Cape Shirreff)

1. A five-person field team (M. Goebel, R. Burner, S. Freeman, J. Breeden and K. Pietrzak) arrived at Cape Shirreff, Livingston Island, on 24 October 2008 via the R/V *Lawrence M. Gould*. Equipment and provisions were also transferred from the R/V *Lawrence M. Gould* to Cape Shirreff.
2. Three additional personnel (C. Bonin, L. Hückstadt and R. Vasquez del Mercado), along with supplies and equipment, arrived at Cape Shirreff via the R/V *Yuzhmorgeologiya* 12 January 2009. On 31 January M. Goebel and L. Hückstadt were picked up and D. Krause disembarked the ship and remained on the island until camp closing.
3. Antarctic fur seal pups and female fur seals were counted at four main breeding beaches every other day from 9 November through 31 December 2008. The first pup was born on 15 November.
4. Attendance behavior of 29 lactating female Antarctic fur seals was measured using radio transmitters. Females and their pups were captured, weighed, and measured from 4-13 December 2008.
5. The CCAMLR protocol for estimating Antarctic fur seal pup growth was implemented and four samples of pup weights were collected. Measurements of mass for a random sample of 100 pups were begun 30 days after the median date of pupping (4 December 2008) on 3 January 2009 and continued every two weeks until 18 February 2009.
6. Information on Antarctic fur seal diet was collected using scat (random collection of 10 per week) and fatty-acid signature analyses of milk collected at every capture of an adult lactating female.
7. Eighteen Antarctic fur seals were instrumented with TDRs for studies of dive behavior.
8. Fourteen Antarctic fur seal females were instrumented with GPS satellite-linked time depth recorders for studies of at-sea foraging location and diving from 6 December 2008 to 16 February 2009.
9. Five hundred Antarctic fur seal pups were tagged at Cape Shirreff by U.S. researchers for future demography studies. Of the 500, 20.8% (104) were pups of tagged mothers.
10. Weather data recorders (Davis Instruments, Inc.) were set up at Cape Shirreff for wind speed, wind direction, barometric pressure, temperature, humidity, and rainfall.
11. A single post-canine tooth was extracted from 15 adult lactating female fur seals for aging and demographic studies.
12. Two leopard seals were captured and instrumented with Mark 9 TDRs. One TDR was successfully retrieved after collecting dive and temperature data for one month.
13. Three-hundred and thirty-nine DNA samples were collected from four species of pinnipeds. All samples have been catalogued and stored in the Southwest Fisheries Science Center DNA archives.
14. The annual censuses of active gentoo and chinstrap penguin nests were conducted on 12 November and 29 November 2008, respectively. Reproductive success was studied by following a sample of 100 chinstrap penguin pairs and 50 gentoo penguin pairs from egg laying to crèche formation.
15. Radio transmitters were attached to 18 chinstrap penguins on 7 January 2008 and remained attached until their chicks fledged in early March 2008. These instruments were used to determine foraging trip duration during the chick-rearing phase.
16. PTTs were deployed on adult chinstrap and gentoo penguins 26 times for seven- to ten-day deployments. The first deployment coincided with the chick-guard phase, when penguin pairs alternate between attending the nest and foraging. The second deployment was made during the chick crèche phase when both parents forage simultaneously.
17. Diet studies of chinstrap and gentoo penguins during the chick-rearing phase were initiated on 6 January 2009 and continued through 10 February 2009. Forty chinstrap and 20 gentoo adult penguins were captured upon returning from foraging trips, and their stomach contents were removed by stomach lavage.

18. Counts of all gentoo and chinstrap penguin chicks were conducted on 20 January and 6 February 2009, respectively. Fledging weights of chinstrap and gentoo penguin chicks were collected.
19. Five hundred chinstrap penguin chicks and 200 gentoo penguin chicks were banded for future demographic studies.
20. Reproductive studies of brown skuas and kelp gulls were conducted throughout the season at all nesting sites around Cape Shirreff.
21. TDRs were deployed a total of 44 times on chinstrap and gentoo penguins for seven to ten days at a time. The first deployment coincided with the chick-guard phase, when penguin pairs alternate between attending the nest and foraging. The second deployment was made during the chick crèche phase when both parents forage simultaneously.
22. The Cape Shirreff field camp was closed for the season on 7 March 2009. All U.S. personnel were retrieved by the R/V *Yuzhmorgeologiya*. Due to extreme weather conditions, some equipment and gear could not be transported to the ship and were left inside the camp at Cape Shirreff until the next season.

Scientific Personnel

Chief Scientist:
Christian Reiss, Southwest Fisheries Science Center (Leg I)
Christopher Jones, Southwest Fisheries Science Center (Leg II)

Physical Oceanography:
Derek Needham (Leg I)
André Hoek (Legs I and II)

Phytoplankton:
Douglas Krause, Southwest Fisheries Science Center (Leg I)
Nicolas Sanchez Puerto (Leg I)

Bioacoustic Survey:
Anthony Cossio, Southwest Fisheries Science Center (Legs I and II)

Krill and Zooplankton Sampling:
Valerie Loeb (Leg I)
Kim Dietrich (Legs I and II)
Ryan Driscoll (Legs I and II)
Nicolas Sanchez Puerto (Leg I)
Jasmine Fry (Leg I)
Joelle Sweeney (Leg I)
Maria Andrade Martinez (Leg I)
Allan Ligon (Leg I)

Finfish Sampling:
Tom Near (Leg II)
Kristen Kuhn (Leg II)
Jillian Pennington (Leg II)
Jon Moore (Leg II)
Karl-Hermann Kock (Leg II)
Malte Damerau (Leg II)
Kim Deitrich (Leg II)
Susanne Schöling (Leg II)
Christina Morgan (Leg II)

Benthic Sampling:
Susanne Lockhart (Leg II)
Eric Lazo-Wasem (Leg II)
Ryan Driscoll (Leg II)
Nerida Wilson (Leg II)

Benthic Video Collection:
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Fur Seal Energetics Studies:
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Jennifer Gafney (Leg II)

Seabird and Marine Mammal Observation Studies:
Jarrod A. Santora, College of Staten Island (Leg I)
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Michael Force (Leg I)

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Douglas Krause, Camp Leader, Southwest Fisheries Science Center (1/31/09-3/7/09)
Ryan Burner (10/24/08-3/7/09)
Jimmy Breeden (10/24/08-3/7/09)
Scott Freeman (10/24/08-3/7/09)
Kevin Pietrzak (10/24/08-3/7/09)
Carolina Bonin (1/12/09-3/7/09)
Raul Vasquez Del Mercado, Southwest Fisheries Science Center (1/12/09-3/7/09)
Luis Hückstadt (1/12/09-1/31/09)

Physical Oceanography and Underway Environmental Observations

Derek Needham and André Hoek

Abstract During the 2008/09 AMLR Survey, 142 CTD/carousel casts were completed at pre-determined stations on the AMLR Survey grid and during transits between surveys. Environmental observations were made continually throughout the survey period, and 121 XBTs were deployed. Data were collected from the South Orkney Island region during Leg II. The results from 2008/09 include:

- The southern boundary of the polar front fluctuated between 57°25'S and 59°30'S throughout the summer months (January – March).
- There was very little presence of Antarctic Circumpolar Current water around the South Shetland Islands; instead, most of the water was from the Bransfield Strait/Weddell Sea or transitional between the two sources.

Introduction

Objectives during the 2008/09 AMLR Survey were to collect and process physical oceanographic data in order to identify hydrographic characteristics and map oceanographic frontal zones, and to collect and process environmental data continually while underway in order to describe sea surface and meteorological conditions experienced during the surveys. These data may be used to describe the physical circumstances associated with various biological observations, as well as provide a detailed record of the ship's movements and the environmental conditions encountered.

Methods

Oceanography

A total of 103 CTD/carousel casts were completed during Leg I (Introduction, Figure 2), and 39 CTD casts at selected locations during Leg II (Introduction, Figure 3), to complement the trawling operations. CTD casts were also completed during acoustic calibrations in Admiralty Bay at the beginning of Leg I and at the end of the Leg II.

For Leg I, water profiles and samples were collected with a Sea-Bird SBE-911plus CTD system and Sea-Bird SBE-32 carousel water sampler equipped with 11 eight-liter sampling bottles. A pumped Sea-Bird SBE-43 dissolved oxygen sensor, Chelsea Instruments Aqua^{tracka} III fluorometer and WET Labs C-Star red transmissometer made up the auxiliary sensors. The above equipment was serviced and calibrated by Sea-Bird Electronics, Inc. prior to the cruise. A Biospherical QCP-2300 2 pi PAR sensor was also mounted on the CTD frame, but swapped to the older QCP200L PAR sensor. CTD scan rates were set at 24 scans/second during both down- and up-casts. Sample bottles were only triggered during the up-casts. Profiles were limited to a depth of 750 m, or 5 m above the sea bottom when shallower than 750 m. A Datasonics altimeter was used to stop the CTD descent 5 to 10 m from the seabed on shallow casts (Table 1.1). Standard sampling depths were 750, 200, 100, 75, 50, 40, 30, 20, 15, 10 and 5 m.

Deck sheets were generated for every station, CTD data was logged and bottles were triggered using Sea-Bird Seasave Win32 Version 5.30a software. CTD "mark" files (reflecting data from the cast at bottle-triggering depths) were also collected. Data was processed using SBE Data Processing Version 5.30a software, averaged over one meter bins, and saved separately as up- and down-traces during post-processing. Downcast data was re-formatted using a SAS script and then imported into Ocean Data View (ODV) format for further presentation.

Water samples were collected on CTD casts during Leg I at 11 discrete depths and used for salinity and phytoplankton analysis. These were drawn from Niskin bottles by the Russian scientific support team. Salinity calibration samples were analyzed on board, using a Guildline Portasal salinometer. Comparisons of dissolved oxygen levels in the carousel water samples and levels measured via the CTD's SBE-43 DO sensor were completed using an automatic potentiometric titrator.

For Leg II, the CTD was rebuilt on a smaller frame for deployment over the port side of the ship. The carousel, fluorometer, transmissometer and PAR sensor were removed.

A total of 121 expendable bathythermographs (XBTs) were deployed during Legs I and II to complement the data collected by the CTD system. Twenty-one XBTs were dropped on the initial south-bound transit during January. An additional 57 XBTs were deployed during Leg I, including 21 on the transit from the South Shetland Islands to Punta Arenas at the end of the Leg. Forty-two XBTs were deployed during Leg II. Of the XBTs dropped during Leg II, 17 were deployed on the final south-to-north transit in March. The remaining XBTs were deployed during transits between stations and at cancelled stations around the South Orkney Islands.

Comparisons of the Sea-Bird SBE-21 thermosalinograph (TSG) with CTD data were performed during the main survey. Compared with 5 m CTD salinity data, the TSG salinity reading was, on average, -0.075 ppt (n=55) lower than the CTD reading.

Table 1.1. SCS and CTD sensor installation summary (Legs I & II).

SCS Sensor Installation Summary (2009)				
Sensor	Manufacturer	Model	Serial No.	Date Calibrated
Weather Station	Coastal Environmental Systems	WEATHERPAK-2000	798	30-May-08
PAR sensor (2 pi)	LI-COR	LI-190SZ Quantum	Q40069	12-Jul-08
PAR sensor (4pi)	Biospherical Instruments Inc.	QSR-2100	10281	1-Jun-06
Thermosalingraph	Sea-Bird Electronics, Inc.	SBE 21	2971	17-Jul-08
GPS navigator	Trimble Navigation Limited	-	-	-
Gyro compass	Guiys	-	-	-

Environmental Observations

Environmental and vessel positional data were collected during the transits to and from Punta Arenas and during the surveys on both Leg I and Leg II via the Scientific Computer System (SCS) software package. The SCS software (SCS Version 3.3a) ran on a Windows XP-based Pentium IV Dell PC with an Edgeport-8 USB serial port expander. A Coastal Environmental Systems Company WEATHERPAK system, a LI-COR 2 pi quantum PAR sensor and a Biospherical Instruments 4 pi QSR-2100 PAR sensor were installed on the port side of the forward A-frame in front of the bridge and were used as the primary meteorological data acquisition system. The above equipment was serviced and calibrated by Coastal Environmental Systems Company prior to the cruise.

Weather data inputs included relative wind speed and direction, barometric pressure, air temperature and irradiance. The relative wind data were converted to true speed and true direction by the internally derived functions of the SCS logging software.

Measurements of sea surface temperature and salinity were received by the SCS, in serial format, from the Sea-Bird SBE-21 thermosalinograph (TSG) and integrated into the logged data. This TSG system was serviced and calibrated by Sea-Bird Electronics prior to the cruise.

Ship position and heading were provided in NMEA format via a Trimble GPS Navigator and Guiys Gyro in the ship's navigation room. Serial data lines were interfaced to the Pentium 4 (Windows XP Professional based) logging PC via an Edgeport 8 serial RS232 to USB interface (Table 1.1).

Results

Environmental Observations

Environmental data were recorded for the duration of the surveys and for the transits between Punta Arenas and the survey area. Processed data were averaged and filtered over one and five minute intervals (Figures 1.1 and 1.2).

Oceanography

AMLR 2008/09 - Leg I (South Shetland Islands)

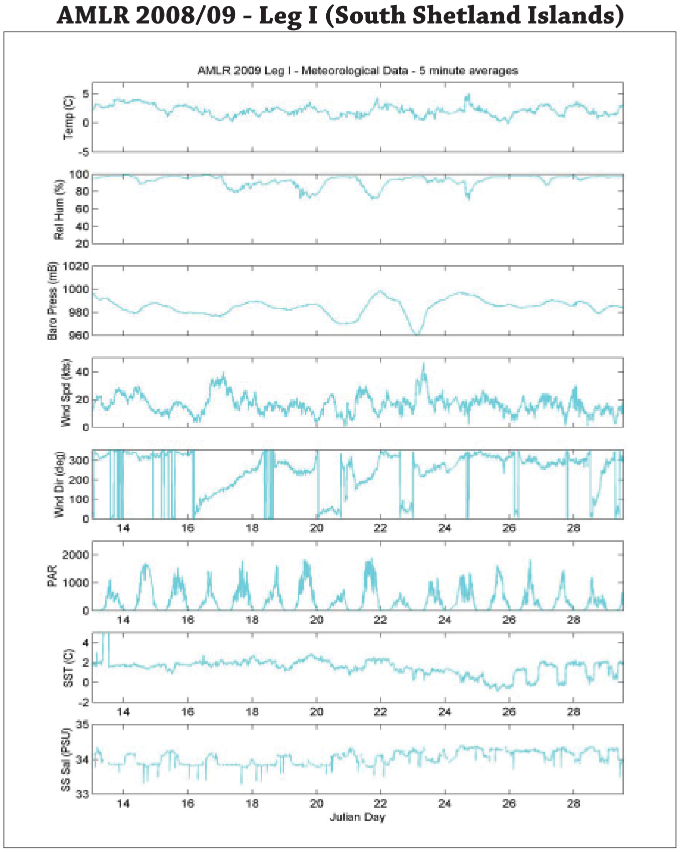


Figure 1.1. Meteorological data (5 minute averages) recorded between January 13th and January 29th during Leg I of the AMLR 2008/09 cruise.

AMLR 2008/09 - Leg II (South Orkney Islands)

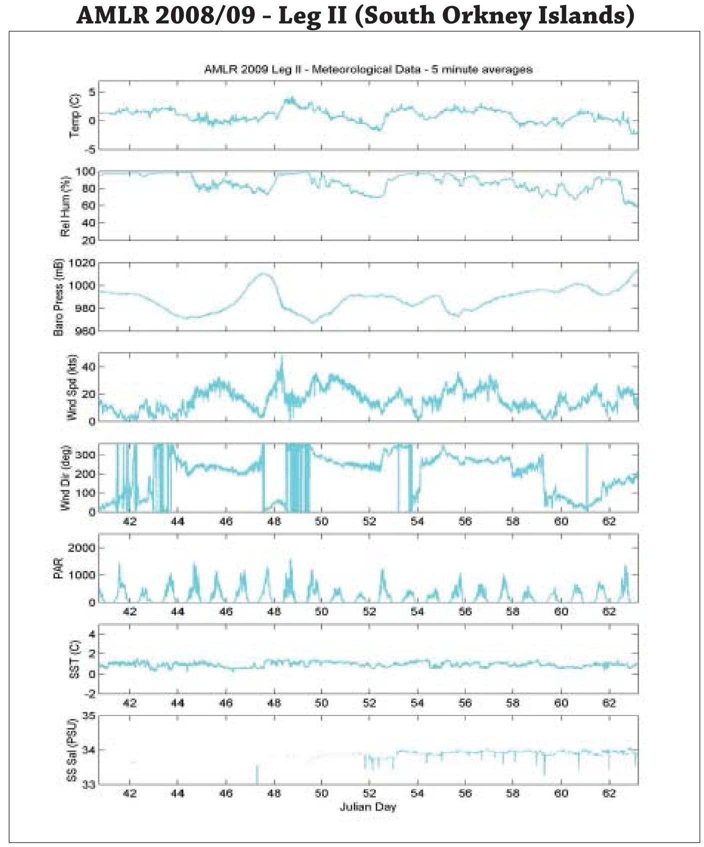


Figure 1.2. Meteorological data (5 minute averages) recorded between February 4th and March 4th during Leg II of the AMLR2008/09 cruise.

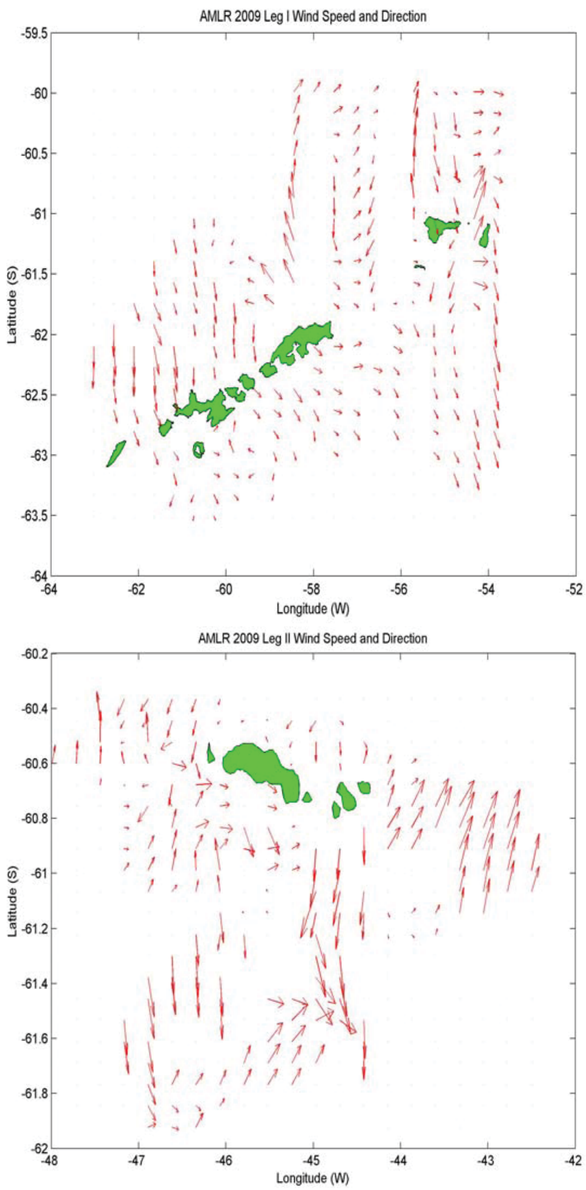


Figure 1.3. Vectors representing wind speed and direction for Legs I (top) & II (bottom), derived from data recorded by the SCS logging system during AMLR 2008/09.

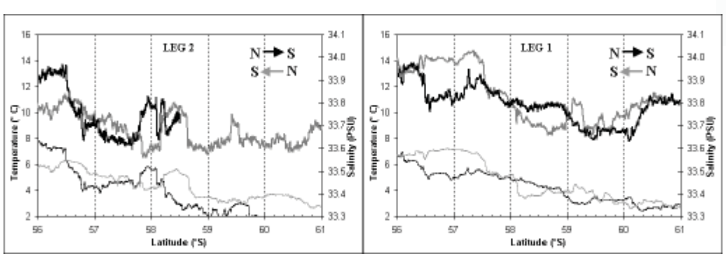


Figure 1.4. The position of the polar fronts during AMLR 2009/09 Legs I (top) and II (bottom), as determined from measurements of sea surface temperature and salinity, for the south- and north-bound transits to and from the South Shetland Islands.

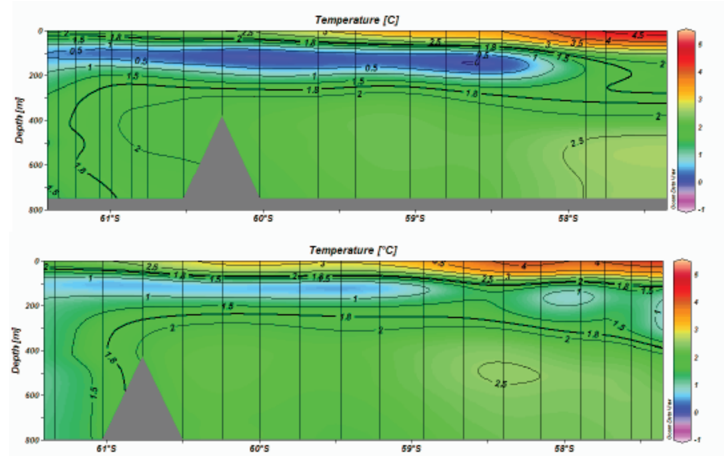


Figure 1.5. XBT temperature data for AMLR 2008/09: Leg I (top) & Leg II (bottom) northbound transects.

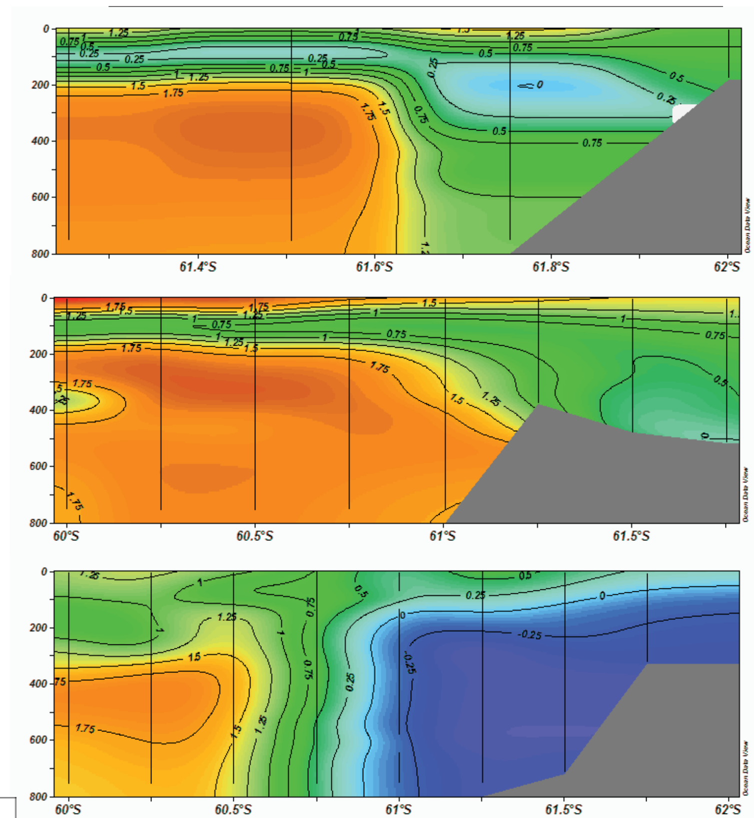


Figure 1.6. Vertical temperature profiles derived from CTD data recorded on three transects, W 05 (top), EI 03 (middle) and EI 07 (bottom), during Leg I of the the 2008/09 AMLR Survey.

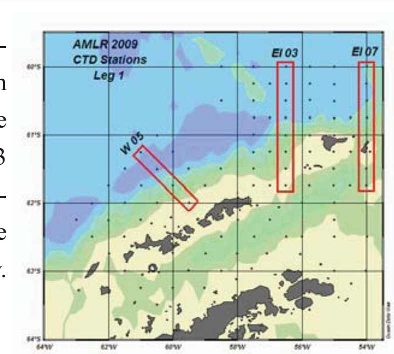
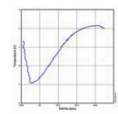
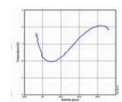
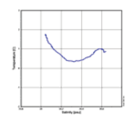
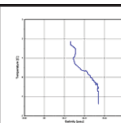
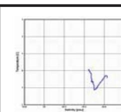


Table 1.2. Water Zone definitions applied during the 2008/09 AMLR Survey.

Water Zone Definition	T/S Relationship			
	Left	Middle	Right	Typical T/S Curve (from 2002)
Water Zone I (ACC)	Pronounced V shape with V at <0 C			
Warm, low salinity water, with a strong subsurface temperature minimum, Winter Water, approx. -1°C, 34.0 ppt salinity, and a temperature maximum at the core of the CDW near 500m.	2 to >3°C at 33.7 to 34.1 ppt	<0°C at 33.3 to 34.0 ppt	1 to 2°C at 34.4 to 34.7ppt (generally >34.6 ppt)	
Water Zone II (Transition)	Broader U-shape			
Water with a temperature minimum near 0°C, isopycnal mixing below the temperature minimum and CDW evident at some locations.	1.5 to >2°C at 33.7 to 34.2 ppt	-0.5 to 1°C at 34.0 to 34.5 ppt (generally >0°C)	0.8 to 2°C at 34.6 to 34.7 ppt	
Water Zone III (Transition)	Backwards broad J-shape			
Water with little evidence of a temperature minimum, mixing with Type II transition water, no CDW and temperature at depth generally >0°C	1 to >2°C at 33.7 to 34.0 ppt	-0.5 to 0.5°C at 34.3 to 34.4 ppt	< 1°C at 34.7 ppt	
Water Zone IV (Bransfield Strait)	Elongated S-shape			
Water with deep temperature near -1°C, salinity 34.5 ppt, cooler surface temperatures.	1.5 to >2°C at 33.7 to 34.2 ppt	-0.5 to 0.5°C at 34.3 to 34.45 ppt	<0°C at 34.5 ppt (salinity <34.6ppt)	
Water Zone V (Weddell Sea)	Small fish-hook shape			
Water with little vertical structure and cold surface temperatures near or < 0°C.	Aprox. 1°C at 34.1 to 34.4 ppt	-0.5 to 0.5°C at 34.5 ppt	<0°C at 34.6ppt	

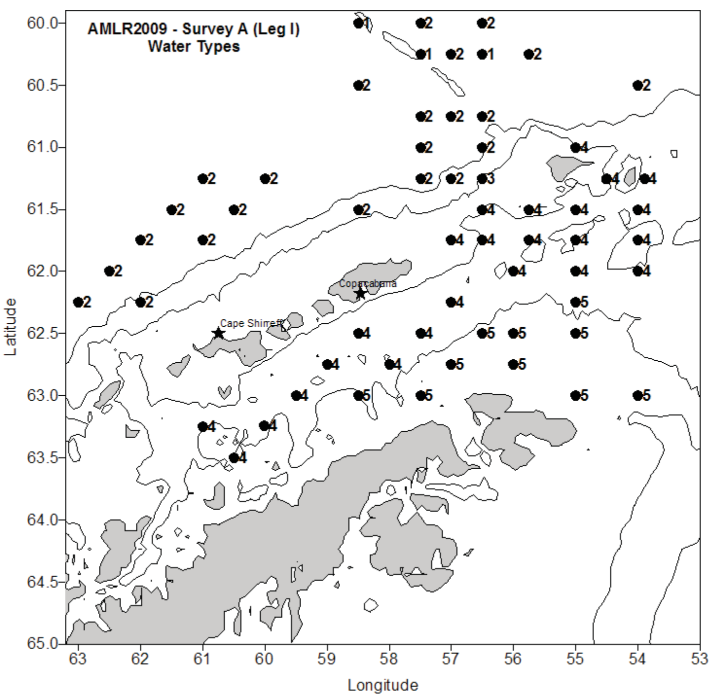


Figure 1.7 Classification of water zones for Leg I for AMLR 2008/09, as defined in Table 1.2

The position of the polar frontal zone, identified by pronounced sea surface temperature and salinity change, was located from the logged SCS data during the two transits between Punta Arenas and the South Shetland Islands. This frontal zone is normally situated between 57-58° S.

During the south-bound transit of Leg I, a broad front was encountered between 57°30'S and 59°30'S, where sea surface temperature (SST) changed from 5.8°C to 3°C. On the north-bound transit, the front was more defined around 58°10'S to 57°25'S, where SST changed from 3.5°C to 6.8°C. On the south-bound transit of Leg II, the front was well defined between 58°05' S and 59°S, where SST decreased from 6°C to 2°C. On the return transit, at the end of Leg II, the zone was located between 58° 40' S and 57° 50' S, where SST increased from 4.0°C to 6.5°C (Figure 1.4).

The two northbound XBT transects across the Drake Passage were plotted in Figure 1.5. The 1.8°C temperature isotherm was highlighted to show the polar fronts, which coincided with the data obtained from the SCS.

Three vertical temperature transects were chosen for plotting using ODV software – the same transects that were plotted for previous reports were chosen for comparison (Figure 1.6). These transects are W05 in the West Area and EI03 and EI07 in the Elephant Island Area of the survey.

As in previous years, an attempt was made to group stations with similar temperature and salinity profiles into five water zones, as defined in Table 1.2. The tentative water zone classifications, according to the criteria in Table 1.2, were sometimes prone to ambiguity, particularly in the coastal regions around King George & Livingston Islands and in the south and southeast of Elephant Island. Classifications of Zone IV (Bransfield Strait) and Zone V (Weddell Sea) waters could also change if other oceanographic data, such as density, are considered. For the purpose of this report, in which only tentative conclusions are reported, only the criteria contained in Table 1.2 were used. The geographic distribution of Water Zones are shown in Figure 1.7.

With a reduced salinometer processing routine (see Protocol Deviations), close agreements between CTD measured salinity and the Portasal values were obtained, with an average error of 0.0047%. The final CTD/Portasal correlation produced an r^2=0.993 (n= 283) during the cruise.

Discussion

During Leg I, only three stations exhibited characteristics of the Zone I (ACC) water type. These were encountered around the Shackleton Fracture Zone. The majority of the offshore stations to the west of Elephant Island exhibited characteristics of Zone II (Transition) type water. Mixed Zone II/III water types were found north and northeast of Elephant Island. Zone IV (Bransfield Strait) water was encountered around Elephant Island, between Elephant and Livingston Islands, the northern Joinville Island Area stations and the majority of the South Area stations. A cluster of Zone V (Weddell Sea) water types were encountered at the southern stations of the Joinville Island Area and southeast stations of the South Area. Figure 1.3 shows the stations with classifications similar to the defining parameters in Table 1.2. Stations with more complex structures, not readily defined according to the first attempt field classification criteria, are not shown in Figure 1.3.

Protocol Deviations

At the start of the main survey grid of Leg I, an additional station (A15-10) was added north of Cape Sherriff. Two stations (A11-05 and A03-02) had to be abandoned due to rough sea conditions; the CTD logged only a downcast at station A02-02 due to a PC crash. Station A02-03 was re-cast after replacing the CTD/SCS PC, owing to another PC crash during the first attempt at A02-03. Downtime due to technical problems was limited to the 2.5 hours it took to replace and reload the CTD/SCS PC and associated software. Disturbed salinity traces at stations A05.5-04, A04-06 and A02-05, at an average depth of 68-133m, coincided with a salp layer. Very few icebergs were encountered in the south of the Joinville Area allowing an additional station to be sampled (A03-14).

An initial problem with a worn mechanical clutch inside the salinometer was rectified. This repair was not ideal as the parts needed to be replaced and no spares were available. To extend the life of the temporary repair a reduced number of samples were processed to cover a range of salinities over the entire survey grid.

Disposition of Data

Data are available from Christian Reiss, NOAA Fisheries, Antarctic Ecosystem Research Division, 3333 Torrey Pines Court, Room 412, La Jolla, CA 92037. Ph: 858-546-7127, FAX: 858-546-5608

Acknowledgements

The co-operation and assistance of the Russian technical support and deck staff was once again outstanding. All requests for assistance were dealt with effectively and in a professional manner.

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Schlitzer, R., Ocean Data View, http://www.awi.bremerhaven.de/GEO/ODV, 2001.

Phytoplankton Studies in the South Shetland Islands

Christopher D. Hewes, Osmund Holm-Hansen, José Luis Iriarte, Nicolas Sanchez Puerto, Douglas Krause, and Nelson Silva

Abstract Hydrographic, chemical, and biological data relevant to phytoplankton productivity in the South Shetland Islands region were collected in January and Febrary of 2009. According to the 2008/09 AMLR Survey:

- A total of 104 phytoplankton samples were taken at stations on the AMLR Survey grid.
- Mean Chl-*a* concentrations in the Upper Mixed Layer (UML) were lowest in the Elephant Island (~0.7 mg m^{-3}) and West (~0.4 mg m^{-3}) Areas, but comparable to the historical mean. Highest mean Chl-*a* concentrations were measured in the Joinville Island Area and the South Area.
- Two stations in the Joinville Island Area had unexpectedly high Chl-*a* concentrations. This area might need further investigation to understand .

Introduction

The ability to ultimately manage various trophic groups in the Antarctic, as envisioned by CCAMLR, must be based on a thorough understanding of food web dynamics, including the food resources available to Antarctic krill and other zooplankton in the region. It is thus important to develop a better understanding of the distribution of phytoplankton (the primary producers) at seasonal and inter-annual scales.

Our research component is primarily concerned with documenting the magnitude and quality of food available to zooplankton, and with improving our understanding of the relationships between the physical, chemical and optical water properties, which determine the amount of food available throughout the summer season. Here, we give preliminary results from the 2009 field season of the AMLR Survey. We also refine our understanding of these relationships in the South Shetland Islands with respect to biomass and productivity of phytoplankton.

Methods

Water column data were obtained from a conductivity-temperature-depth (CTD) sensor carousel, which held the water sampling bottles and a number of other instruments and sensors. The carousel was lowered to 750 m depth or to within 10 m of the bottom at the shallower stations. The bottles were closed on the up-cast at 5, 30, 50, 75, and 100 m target depths for Chl-*a* analyses. At the time of bottle closure, a ~1 second binned record was obtained of all data recorded by sensors on the carousel. Additionally, 24 samples from 30 m depth were (1) preserved for floristic analyses and (2) frozen for nutrient analyses.

A complete list of instruments on the CTD can be found in the Physical Oceanography section in this report (Needham, 2009). In addition to CTD instrumentation, a LI-COR Quantum Sensor (LI-190) was mounted in a shade-free area above the bridge to measure (1 minute intervals) incident photosynthetically available radiation (PAR) (see Physical Oceanography report for details).

Sensor Calibrations and Internal Correlations

The Chelsea Aqua[tracka] III fluorometer mounted on the CTD carousel has a log voltage output. This was converted to a linear Chl-*a* concentration equivalent by exponential regression (Figure 2.1) of extracted Chl-a concentration and fluorometer voltage obtained during CTD bottle firing for samples obtained in the Upper Mixed Layer (UML) (n = 254, r^2 = 0.68) as:

$$\text{mg Chl}_{\text{fluor}}\ \text{m}^{-3} = 0.0168 \cdot \exp(2.3791 \cdot \text{Volts}).$$

Measurements and Data Acquired

The types of measurements and the data acquired during the 2009 AMLR Survey were:

(A) Chlorophyll-*a* concentrations: Chl-*a* concentrations of water samples were determined by measurement of

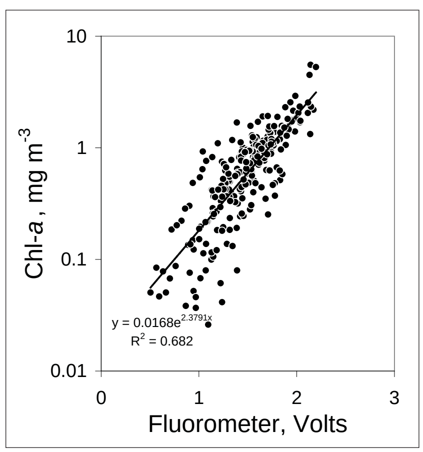

Figure 2.1. Chelsea Aqua[tracka] III calibration. Concentrations of Chl-*a* determined from water bottle samples obtained within the UML plotted against fluorometer voltage obtained at the time of water bottle firing. The fluorometer has a log voltage output with respect to Chl-*a* concentration. The equation (and r^2) is the exponential function used to provide equivalent Chl-a concentrations ($\text{Chl}_{\text{fluor}}$) as derived from the fluorometer. Line is the exponential regression for the relationship.

Chl-*a* fluorescence after extraction in an organic solvent. Water samples (100 mL; for routine measurements) were filtered through glass fiber filters (Whatman GF/F, 25 mm) at reduced pressure (maximal differential pressure of 1/3rd atmosphere). The remaining particulate material was placed in 10 mL of absolute methanol, in 15 mL tubes, at 4 °C for at least 12 hours to extract the photosynthetic pigments from the filter. The samples were then shaken, centrifuged, and the clear supernatant poured into cuvettes (13 x 100 mm) for measurement of Chl-*a* fluorescence before and after the addition of two drops of 1.0 N HCl (Holm-Hansen et al., 1965; Holm-Hansen and Riemann, 1978). Fluorescence was measured using a Turner Designs Fluorometer (TD-700) that had been calibrated using purified Chl-*a* concentrations (Sigma C-6144).

(B) Continuous profiles of Chl-*a* and PAR: Profiles of Chl-*a* obtained with the *in situ* fluorometer were used to analyze Chl-*a* concentration in relation to physical, chemical, and optical conditions in the water column.

(C) Beam attenuation (C_p): The attenuation of light, as recorded by the transmissometer, is the result of both scattering and absorption of light quanta. As the light in the transmissometer that was used is 660 nmi (within the red absorption band for Chl-*a*), the attenuation is a good indicator of both Chl-*a* concentrations and total particulate organic carbon (Villafañe et al., 1993).

Transmission of light though water with the near-absence of particulate matter was obtained from the mean of all transmissometer voltages (V_0) from CTD casts in pelagic waters (bottom depth > 2000 m) measured at depths 700-750 m. The transmissometer has a path-length of 0.25 m and has a linear output in Volts, thus C_p was estimated as:

$$C_p\ (\text{meters}^{-1}) = -\ln(\text{Transmittance}),$$

and

$$\text{Transmittance} = [(V_0 - \text{Volts}) / V_0] / 0.25\ \text{m}.$$

(D) Phytoplankton taxonomy: Seawater samples (100 mL) were obtained within the upper mixed layer and preserved with 0.5% (final dilution) buffered formalin at 24 stations. These samples were delivered to J. L. Iriarte (Universidad Austral de Chile, Puerto Montt, Chile) for taxonomic analysis of phytoplankton species.

(E) Inorganic macronutrient concentrations: Water samples were taken for measurement of macronutrient concentrations at 30 m for 22 stations, plus two stations in the Drake Passage at 10, 30, 50, 75, and 100 m target depths, poured into acid-washed 120 mL polypropylene bottles, and immediately frozen. All frozen samples were delivered to N. Silva (Universidad Católica de Valparaiso, Valparaiso, Chile) and analyzed by auto-analyzer for nitrate, phosphate, and silicate concentrations (Atlas et al., 1971).

(F) UML depth (Z_{UML}): Depth of the UML was calculated as the depth at which potential density differed by 0.05 kg m^{-3} from the mean potential density measured between 5 and 10 m depth (Mitchell and Holm-Hansen, 1991; Hewes et al., 2008a). Values representing the UML were obtained by averaging all samples taken above the UML depth (1 m binned data for sensor data and individual bottle data for Chl-*a*).

(G) Estimation of PAR: The PAR sensor on the CTD carousel used the calibration factor determined in 2008 (Hewes, 2008):

$$\mu\text{Eins m}^{-2}\text{ s}^{-1} = 0.0616 \bullet 10^{\text{Volts}}.$$

This PAR sensor was inter-calibrated with the sensor measuring incident PAR in 2008 and determined to have negligible drift between field seasons (Hewes, 2008).

(H) Depth of the euphotic zone (Z_{eu}): Euphotic zone depth is defined as the depth where incident PAR is attenuated to 1% of surface light. Only daytime (08:00 – 24:00 hrs, GMT) stations were used. Transmittance at 5 m was measured by the ratio of incident PAR to PAR measured at the 5 m target depth during bottle firing. A mean (50 stations) transmittance value for 5 m = 34.6 ± 11.4% was obtained. Subsequently, Z_{eu} was de-

Table 2.1. Mean historical values of hydrographic and Chl-*a* data found in each of the areas in the AMLR Survey compared with the 2008/09 field season. The four areas are the Elephant Island Area (EI), Joinville Island Area (JI), South Area (SA), and West Area (WA). The Joinville Island Area had one sample, station A02-13, that was an outlier; this data was removed and corresponding statistics were listed beside JI*.

Area	No. Stations	Temperature, °C	Salinity	Density, kg m^{-3}	Chl-a, mg m^{-3}	Zeu, m	Zuml, m
Historical AMLR, 1990-2008							
EI	1937	1.36 ± 0.83	34 ± 0.2	27.2 ± 0.2	0.75 ± 0.79	63 ± 40	60 ± 36
JI	83	-0.06 ± 0.96	34.3 ± 0.1	27.5 ± 0.1	0.86 ± 0.53	52 ± 13	110 ± 71
SA	395	1.05 ± 0.88	34.2 ± 0.2	27.4 ± 0.2	1.19 ± 1.06	51 ± 12	56 ± 40
WA	594	1.49 ± 0.64	33.9 ± 0.2	27.2 ± 0.2	0.64 ± 0.68	67 ± 22	52 ± 20
AMLR, 2009							
EI	48	1.74 ± 0.63	34.1 ± 0.2	27.3 ± 0.2	0.72 ± 0.47	59 ± 17	62 ± 35
JI	11	-0.54 ± 0.16	34.4 ± 0	27.6 ± 0	1.2 ± 0.72	50 ± 6	103 ± 71
SA	20	0.87 ± 1.14	34.3 ± 0.1	27.5 ± 0.1	1.05 ± 0.49	46 ± 12	65 ± 44
WA	23	1.75 ± 0.31	34 ± 0.1	27.2 ± 0.1	0.44 ± 0.48	71 ± 19	43 ± 12
JI*	10	-0.06 ± 0.76	34.3 ± 0.1	27.6 ± 0.1	0.93 ± 0.28	50 ± 6	82 ± 58

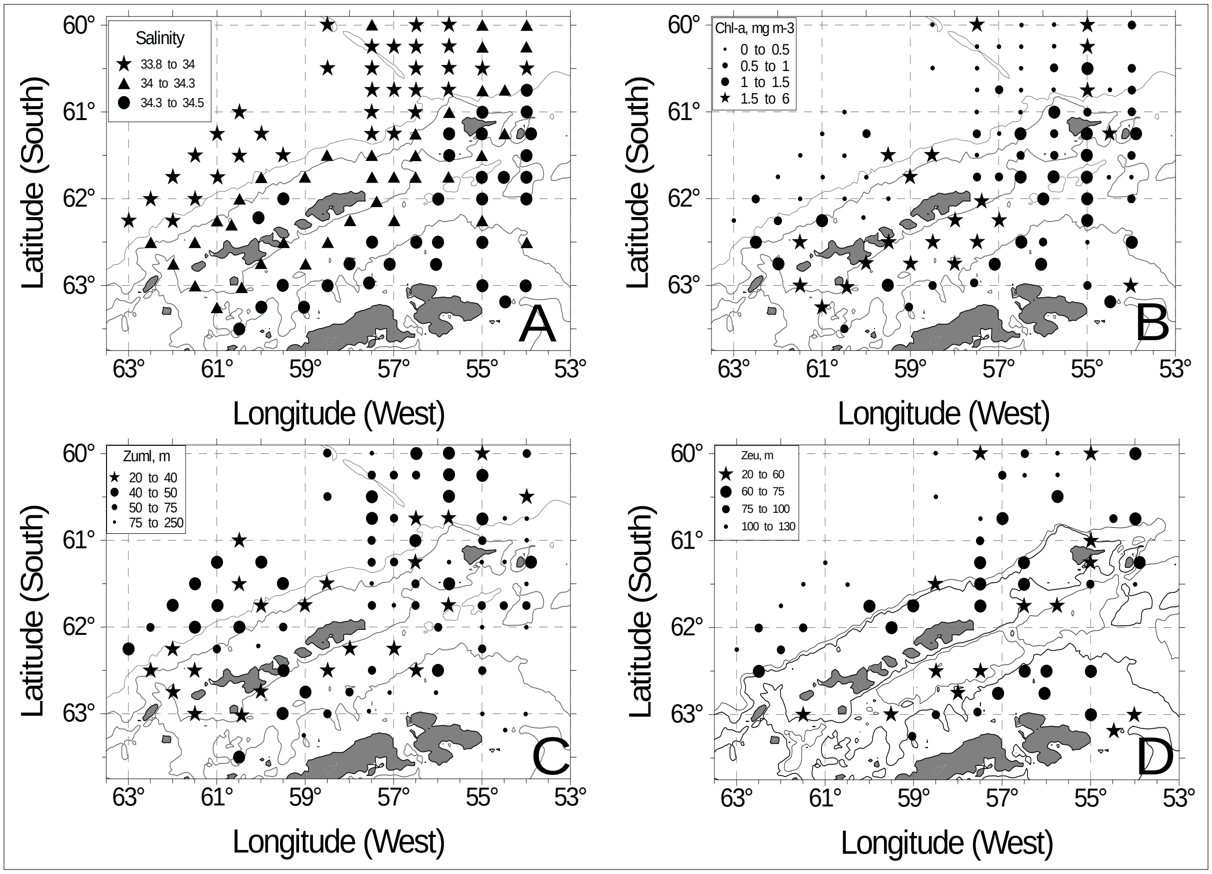

Figure 2.2. Horizontal structure of hydrographic, physical, optical and biological characteristics in the South Shetland Islands: (A) Mean salinity of the UML, grouped into three categories. (B) Surface (5 m target depth) Chl-*a* concentration grouped into four categories. (C) Depth of the UML (meters) grouped into four categories. (D) Depth of the euphotic zone (meters) grouped into four categories; only stations having 5 m PAR > 5 μEin m^{-2} s^{-1} were considered. Contours for 1000 and 2000 m are shown; landmasses are gray.

fined from downcast PAR data as that depth at which:

Transmittance = (PAR at depth) / [(PAR at 5 m) / 34.6)] = 1%.

One percent of incident PAR is defined as measurements having 99.5 – 100.5%, with depth of multiple values within these bounds for a station cast averaged.

(I) Estimation of the mean optical density for incident PAR (OD_{PAR}) in the UML: Optical density is defined as $-log_{10}$(transmittance), and used here to describe transmittance of incident PAR in the UML. The OD_{PAR} was obtained at those stations where Z_{eu} was measured during the CTD downcast and binned at 1 m intervals. The OD_{PAR} values obtained within the UML were averaged to obtain a mean OD_{PAR}.

(J) Historical data from the South Shetland Islands used in this report are from a database for AMLR Survey data 1990-2007, as reported by Hewes et al. (2009), as well as data from 2008 reported by Hewes et al. (2008b).

Results

A total of 104 phytoplankton samples were collected during the 2008/09 AMLR Survey. The mean Chl-*a* concentrations for the UML in the four areas, together with the long-term mean from previous AMLR seasons (1990-2008), are summarized in Table 2.1. Mean Chl-*a* concentrations in the UML were lowest in the Elephant Island (~0.7 mg m^{-3}) and West (~0.4 mg m^{-3}) Areas, but comparable to the historical mean. Highest mean values were in the Joinville Island Area and the South Area. The Joinville Island Area had a higher mean Chl-*a* value than the historical mean, but station A02-13 was anomalously high (> 5 mg Chl-*a* m^{-3}), whichbiased the mean. Therefore, the Joinville Island Area is listed twice in Table 2.1, showing statistical values with and without station A02-13, as included in the calculations.

The South Shetland Islands can be divided into three biogeochemical regions based on salinity and depth of the UML (Figure 2.2). Using the 2009 data, stations were grouped into three categories of equal intervals, "low", "medium", and "high", according to salinity. Both low- and high-salinity waters generally contain low surface Chl-*a* concentrations, and are considered the two High Nutrient, Low Chlorophyll (HNLC) regions of the South Shetland Islands (Figure 2.2B).

A condition analogous to a "reverse-estuary" is found when high-salinity water from the Weddell Sea flows into the Bransfield Strait to mix with low-salinity Antarctic Surface Water, or AASW. Mid-salinity waters are found encircling the South Shetland Islands and generally contain the highest

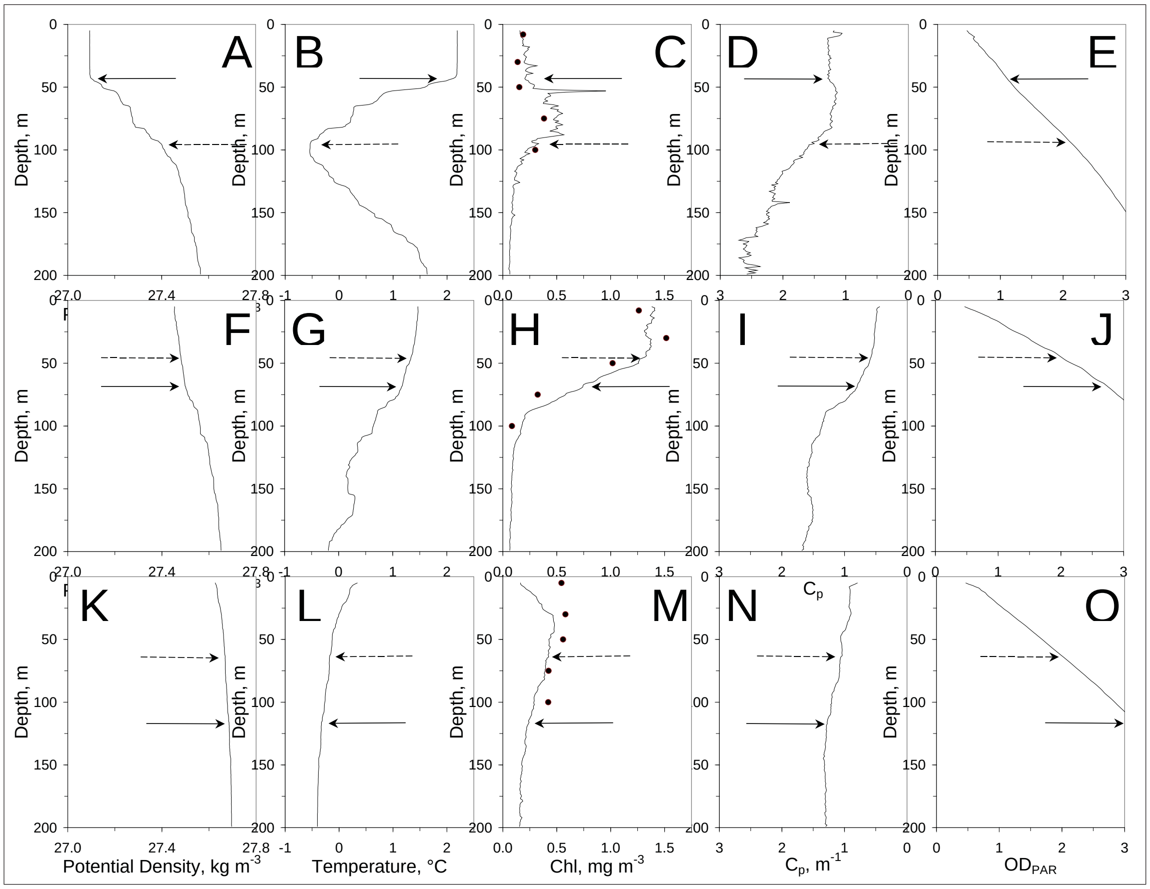

Figure 2.3 Density, temperature, Chl-*a*, beam attenuation, and optical density of incident irradiance in relation to depth for three stations representing different biogeochemical regions observed during Leg I of the AMLR Survey. Station A-0904 (A-E) was of low salinity (mean UML salinity = 33.93), Station A-0408 (F-J) was of intermediate salinity (mean UML salinity = 34.32), and Station A-1214 was of high salinity (mean UML salinity = 34.44). Potential density, temperature, Chl-*a* concentration (as estimated from in situ fluorescence [line] and directly from water bottle sample extracts [filled circles]), beam attenuation and ODPAR are shown for each station. For all stations, depth of the UML (potential density 0.05 kg m^{-3} less than the upper 10 m) is shown as the solid arrow, and depth of the euphotic zone (OD_{PAR} = 2) shown as the dotted arrow.

Chl-*a* concentrations. High-salinity Bransfield Strait waters are associated with deep UML depths, whereas low-salinity Drake Passage waters are associated with relatively shallow UML depths (Figure 2.2C). In turn, low-salinity Drake Passage waters are associated with deep euphotic zones, and contrast with mid-salinity Bransfield Strait waters having shallower Z_{eu} (Figure 2.2D).

Nitrate, phosphate and silicate concentrations at 30 m decrease linearly with the dilution of high-salinity Weddell Sea shelf waters with low-salinity AASW. However, for all waters around the South Shetland Islands, concentrations of these nutrients are well above those considered limiting for phytoplankton biomass.

Three stations, A09-04, A04-08, and A12-14, representing low-, mid-, and high-salinity waters, respectively, are used to illustrate the hydrographic, biological, and optical properties in the upper 200 m of the water column in each biogeochemical region (Figure 2.3).

For low-salinity waters (e.g. station A09-04), the UML is well mixed from the surface to the pycnocline (Figure 2.3A), with warm surface waters overlying cold winter water remnant (Figure 2.3B). Chl-*a* concentrations are uniformly mixed in the UML, as shown by Chl-*a*, Chl_{fluor} (Figure 2.3C), and beam attenuation (Figure 2.3D). Within the pycnocline and above the temperature minimum, there is a deep Chl-*a* maximum. The increased Chl-*a* concentration in the deep Chl-*a* maximum attenuates more incident irradiance than the UML, indicated by the inflection for OD_{PAR} (Figure 2.3E)

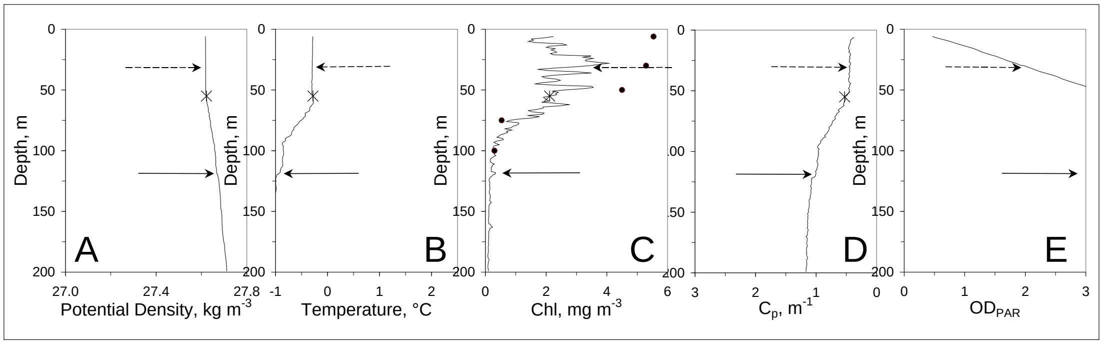

Figure 2.4. Anomalous Station A02-13: Potential density, temperature, Chl-*a* concentration (as estimated from in situ fluorescence [line] and directly from water bottle sample extracts [filled circles]), beam attenuation and ODPAR are shown. Depth of the UML (potential density 0.05 kg m-3 less than the upper 10 m) shown as the solid arrow, and depth of the euphotic zone (ODPAR = 2) shown as the dotted arrow. Note the scaling for Chl-*a* in C is different than used in Fig. 2.3. The beginning of the thermocline at 55 m is indicated by X.

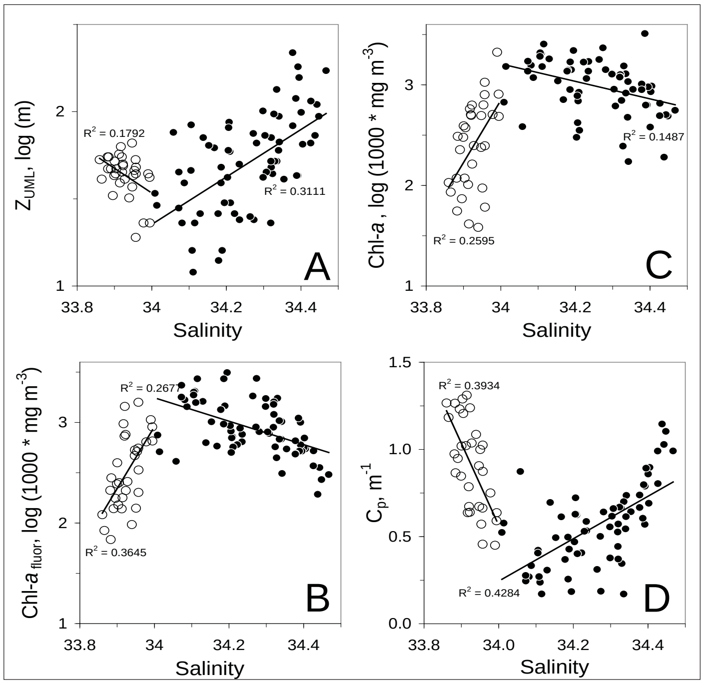

Figure 2.5. Proxies of phytoplankton biomass as functions of UML depth. (A) Log mean Chl-*a* concentration of the UML, (B) mean transmittance of the UML, and (C) log mean Chl_{fluor} of the UML were significantly ($p < 0.01$) correlated with UML depth for salinities >34 (solid symbols) but not correlated for salinities <34. However, all proxies of phytoplankton biomass were significantly lower (ANOVA, $p < 0.01$) for low-salinity waters in relation to their Z_{UML}.

between the UML and euphotic zone depths. In addition, the 1% value of incident irradience (OD_{PAR} = 2) corresponded with the base of the deep Chl-*a* maximum (Figure 2.3C, D). Furthermore, the depth at 1% incident irradiance (Figure 2.3E) extended much deeper than the depth of the UML (Figure 2.3A).

For mid-salinity waters (e.g. station A04-08), the difference in potential density between the surface and depth (Figure 2.3F) was less pronounced than for low-salinity waters. UML temperatures are lower (Figure 2.3G), and Chl-*a* (Figure 2.3H) and beam attenuation (Figure 2.3I) decline slightly between the depth of 1% incident irradiance and UML depth, which is reflected in a slight bend in the attenuation of incident irradiance at depth (Figure 2.3J). Station A04-08 contained ~5 times more Chl-*a* in the UML than Station A09-04 (Figure 2.3C, H), which resulted in greater attenuation of incident irradiance at depth (Figure 2.3E, J) and reduced depth of the euphotic zone by ~50%.

For high-salinity waters (e.g. station A12-14), the water column was weakly stratified (Figure 2.3K), associated with a deep UML. However, water temperature was not vertically uniform (Figure 2.3L), indicative of weak stratification. Both Chl-*a* (Figure 2.3M; photoinhibition of Chl-*a* fluorescence occurred in the upper 30 m) and beam attenuation (Figure 2.3N) also indicate that mixing in the UML was not uniform.

Station A02-13 was of high-salinity, deeply mixed water, and yet had the highest Chl-*a* concentration measured during the AMLR Survey (Figure 2.4). In contrast to either Stations A04-08 or A12-14, Station A02-13 had a very uniform UML from the surface to 55 m (Figure 2.4A), as evidenced by temperature (Figure 2.4B). Below 55 m, temperature gently eroded to about -1 °C at ~125 m that was considered the bottom of the UML (i.e., 0.05 kg m^{-3} difference from the surface).

For high- to mid-salinity waters, ln Chl-*a* (Figure 2.5C) and ln Chl_{fluor} (Figure 2.5B) are negatively correlated with UML depth ($p < 0.01$). No significant correlation was found in low-salinity waters, although Chl-*a* and Chl_{fluor} values were lower, and C_p values higher (ANOVA, $p < 0.01$) than found in higher salinity waters with the same Z_{UML}.

Historical comparison

For low-salinity water, Z_{UML} was deep compared to the historical (1990-2007) mean, while mid-salinity waters had shallower Z_{UML} than the historical mean (Figure 2.6A). Mean Chl-*a* of the UML in low-salinity waters was lower than the historical mean, while both mid- and high-salinity waters were slightly above the historical mean (Figure 2.6B). The data from the 2009 AMLR Survey were similar to those of the 2008 AMLR Survey with respect to both Z_{UML} and mean Chl-*a* of the UML (Figure 2.6).

Discussion

In 2009 (as well as 2008; see Hewes et al., 2008b), Chl-*a* concentrations were lower than average and UML depths were deeper than the historical average, suggesting that light and iron both controlled phytoplankton biomass in low-salinity waters. There is evidence that low light conditions increase the iron demand of phytoplankton for synthesis of

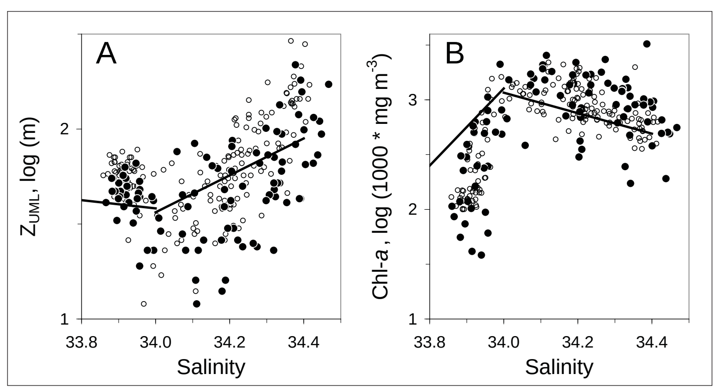

Figure 2.6. Comparison of 2009 Chl-*a* concentration and UML depth with historical data. Unimodal distributions of (A) Depth of the UML, and (B) mean UML Chl-*a* concentration in relation to salinity for 2009 (filled symbols) compared with 2008 data (open symbols). Lines drawn are for the historical (1990, 1992-1994, 1996-2007) means; 1991 and 1995 were anomalous years, therefore excluded. Both 2008 and 2009 had deeper UML depths and lower mean UML Chl-*a* concentrations at low-salinities than the 16-year mean, while both 2008 and 2009 had shallower UML depths and higher mean UML Chl-*a* concentrations than the 16-year mean.

proteins in photoreceptors (Sunda and Huntsman, 1997; Strzepek and Harrison, 2004), and an iron/light co-limitation could be an explanation for the lower Chl-*a* concentration found corresponding with deeper Z_{UML} in the presumably iron-controlled HNLC area of the Drake Passage.

The mean Chl-*a* concentration of the UML for mid-salinity waters measured during the 2008/09 AMLR Survey was higher than the 1990-2007 mean. Temperature of the UML in both the South Area and the Elephant Island Area was warmer than average.

Lastly, stations A02-13 and A03-14, near Joinville Island, were anomalous, having deeply mixed UMLs and Chl-*a* concentrations >1 mg m^{-3}. UML depth is defined as the depth at which there is a 0.05 kg m^{-3} difference from surface pressure; the UML depth at station A02-13 is 125 m. However, there was a broad thermocline beginning at 55 m, with a uniform UML above 55 m and decreasing Chl-*a* below 55 m. Therefore, the operational definition of UML, using the 0.05 mg m^{-3} difference from surface density, may be too large a value under certain hydrographic conditions.

CTD casts have been completed at 80 stations in the Joinville Island Area since 1990, approximately 40 of these completed south of 62.25°S. Of these, 10 stations had UML depths >75 m and Chl-*a* concentrations >0.5 mg m^{-3}; four stations had >1 mg Chl-*a* m^{-3}. With so few data, however, it is speculative to assign causes for these anomalies, although such exceptions are curious and worthy of further investigation.

Protocol Deviations

Chl-*a* measurements were restricted to bottle sample depths of 5, 10, 30, 50, 75, and 100 m for this survey period. Samples for phytoplankton taxonomy are in the process of being analyzed at the time of this report.

Disposition of the Data

Data are available from Christian S. Reiss, NOAA Fisheries, Antarctic Ecosystem Research Division, 3333 Torrey Pines Court, Room 412, La Jolla, CA 92037. Ph: 858-546-7127, FAX: 858-546-5608

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Bioacoustic Survey

Anthony M. Cossio and Christian Reiss

Abstract Multi-frequency acoustic data were collected around the South Shetland and South Orkney Islands, Antarctica from January through March 2009. Data were collected to determine the distribution and biomass of krill and to infer the acoustic characteristics of the benthos.

- Around the South Shetland Islands in January, mean krill abundance was 25, 63, and 17 g/m² for the West, Elephant Island, and South Areas, respectively. During Leg II, krill abundance ranged from 0 to 794 g/m² per nautical mile.
- Highest densities of krill were observed around Elephant Island and northwest of the South Orkney Islands.
- More than 2,225 nautical miles of acoustic data were collected to characterize benthic properties around the South Orkney Islands.

Introduction

The primary objectives of the bioacoustic survey were to map the meso-scale dispersion of Antarctic krill (*Euphausia superba*) in the vicinity of the South Shetland Islands and to determine their association with predator foraging patterns, water mass boundaries, spatial patterns of primary productivity, and bathymetry. The survey was also conducted to map the distribution of myctophids and to determine their relationship with water mass boundaries and zooplankton distribution. Finally, transects were completed in order to characterize krill distribution and the benthic environment around the South Orkney Islands for future analysis.

Table 3.1. Range of total lengths (TL, mm) and acoustic ΔS_v applied to assess biomass of Antarctic krill in the Elephant Island, South and West Areas of the South Shetland Islands between 1998 and 2009, using the simplified SDWBA model (Conti and Demer, 2005; CCAMLR, 2005).

Cruise	Elephant Island krill length	120-38	200-120	West krill length	120-38	200-120	South krill length	120-38	200-120
1996A	18-59	2.5 to 14.7	-0.5 to 2.1	x	x	x	x	x	x
1996D	20-57	2.5 to 14.7	-0.5 to 2.1	x	x	x	x	x	x
1997A	19-58	2.5 to 14.7	-0.5 to 2.1	17-58	2.5 to 17.7	-0.5 to 6.8	15-52	2.5 to 17.7	-0.5 to 6.8
1998A	17-53	2.5 to 17.7	-0.5 to 6.8	15-52	2.5 to 17.7	-0.5 to 6.8	16-44	4.6 to 17.7	-0.5 to 6.8
1998D	21-52	2.5 to 14.7	-0.5 to 2.1	19-53	2.5 to 14.7	-0.5 to 2.1	19-48	4.6 to 14.7	-0.5 to 2.1
1999A	32-54	2.5 to 11.1	-0.5 to 0.4	30-54	2.5 to 11.1	-0.5 to 0.4	26-52	2.5 to 14.7	-0.5 to 2.1
1999D	35-56	2.5 to 11.1	-0.5 to 0.4	36-51	4.6 to 11.1	-0.5 to 0.4	x	x	x
2000D	39-58	2.5 to 7.7	-0.5 to -0.3	39-59	2.5 to 7.7	-0.5 to -0.3	40-55	2.5 to 7.7	-0.5 to -0.3
2001A	18-57	2.5 to 14.7	-0.5 to 2.1	40-60	2.5 to 7.7	-0.5 to -0.3	22-55	2.5 to 14.7	-0.5 to 2.1
2001D	26-60	2.5 to 14.7	-0.5 to 2.1	26-60	2.5 to 14.7	-0.5 to 2.1	28-57	2.5 to 14.7	-0.5 to 2.1
2002A	17-59	2.5 to 17.7	-0.5 to 6.8	18-60	2.5 to 17.7	-0.5 to 6.8	20-45	4.6 to 14.7	-0.5 to 2.1
2002D	21-59	2.5 to 14.7	-0.5 to 2.1	20-56	2.5 to 14.7	-0.5 to 2.1	20-49	4.6 to 14.7	-0.5 to 2.1
2003A	13-53	2.5 to 17.7	-0.5 to 6.8	13-54	2.5 to 17.7	-0.5 to 6.8	13-45	4.6 to 17.7	-0.5 to 6.8
2003D	15-53	2.5 to 17.7	-0.5 to 6.8	19-54	2.5 to 14.7	-0.5 to 2.1	16-49	4.6 to 17.7	-0.5 to 6.8
2004A	21-55	2.5 to 14.7	-0.5 to 2.1	24-57	2.5 to 14.7	-0.5 to 2.1	20-57	2.5 to 14.7	-0.5 to 2.1
2004D	29-58	2.5 to 11.1	-0.5 to 0.4	22-55	2.5 to 14.7	-0.5 to 2.1	18-56	2.5 to 17.7	-0.5 to 6.8
2005A	20-59	2.5 to 14.7	-0.5 to 2.1	21-57	2.5 to 14.7	-0.5 to 2.1	20-57	2.5 to 14.7	-0.5 to 2.1
2005D	28-57	2.5 to 14.7	-0.5 to 2.1	39-55	2.5 to 7.7	-0.5 to -0.3	19-53	2.5 to 14.7	-0.5 to 2.1
2006A	25-61	2.5 to 14.7	-0.5 to 2.1	41-60	2.5 to 7.7	-0.5 to -0.3	26-59	2.5 to 14.7	-0.5 to 2.1
2007A	16-60	2.5 to 17.7	-0.5 to 6.8	19-58	2.5 to 14.7	-0.5 to 2.1	19-55	2.5 to 14.7	-0.5 to 2.1
2008A	19-57	2.5 to 14.7	-0.5 to 2.1	19-57	2.5 to 14.7	-0.5 to 2.1	16-56	2.5 to 17.7	-0.5 to 6.8
2008D	19-58	2.5 to 14.7	-0.5 to 2.1	x	x	x	21-51	4.6 to 14.7	-0.5 to 2.1
2009A	19-58	2.5 to 14.7	-0.5 to 2.1	20-57	2.5 to 14.7	-0.5 to 2.1	14-51	4.6 to 17.7	-0.5 to 6.8

Methods

Acoustic data were collected using a multi-frequency echo sounder (Simrad EK60) configured with down-looking 38, 70, 120, and 200 kHz split-beam transducers mounted in the hull of the ship. System calibrations were conducted before and after the survey, using standard sphere techniques (Foote, 1989), while the ship was at anchor in Ezcurra Inlet, King George Island. During the surveys pulses were transmitted every two seconds, at one kilowatt for one millisecond duration at all four frequencies. Geographic positions were logged simultaneously every two seconds. Ethernet communications were maintained between the EK60 and a Windows XP workstation. The workstation was used for primary system control, data logging, and data processing with Myriax's Echoview software.

During Leg I, acoustic surveys completed in the South Shetland Islands were divided into four areas (See Figure 2 in Introduction): (1) a 43,865 km^2 area centered on Elephant Island (Elephant Island Area) was sampled with seven north-south transects; (2) a 38,524 km^2 area along the north side of the southwestern portion of the South Shetland archipelago (West Area) was sampled with seven transects oriented northwest-southwest and one oriented north-south; (3) a 24,479 km^2 area in the western Bransfield Strait (South Area) was sampled with seven transects oriented northwest-southwest; and (4) an 18,151 km^2 area north of Joinville Island (Joinville Island Area) with three north-south transects. During Leg II, acoustic data were collected whenever IKMT net tows were completed to quantify krill aggregations. Acoustic data were also collected between tows to characterize benthic properties around the South Orkney Islands.

Acoustic data recorded while on biological sampling stations were discarded from analyses. Further, only daytime data were used in this analysis due to possible bias from diurnal vertical migration of krill above the transducer depths at night (Demer and Hewitt, 1995).

Data Analysis

Krill are delineated from other scatters by use of a three frequency ΔS_v method (Hewitt et al., 2003; Reiss et al., 2008). The ΔS_v range is dynamic and is based on krill length ranges present in each area (CCAMLR, 2005). This differs from previous work when analyses were conducted using a constant range of ΔS_v ($4 \leq$ (Sv,120 – Sv,38) ≤ 16 dB and $-4 \leq$ (S_v,200 – S_v,120) ≤ 2 dB). Table 3.1 shows the ranges of krill lengths as well as the dynamic ΔS_v ranges used between 1996 and present.

For the purpose of delieating myctophids, a ΔS_v win-

Table 3.2. Daytime integrated krill density estimates by area and transect for Leg I of the AMLR Survey; n = 1 nautical mile.

Area	Transect	n	Krill density (g/m²)
West Area			
	Transect 1	39	38.3
	Transect 2	39	14.2
	Transect 3	42	53.7
	Transect 4	43	42.9
	Transect 5	59	44.9
	Transect 6	53	13.3
	Transect 7	102	0.4
Elephant Island Area			
	Transect 1	98	19.3
	Transect 2	65	24.2
	Transect 3	96	19.5
	Transect 4	85	73.6
	Transect 5	115	99.7
	Transect 6	35	39.9
	Transect 7	108	125.6
South Area			
	Transect 1	44	11.1
	Transect 2	40	30.8
	Transect 3	40	17.5
	Transect 4	26	0
	Transect 5	44	28.7
	Transect 6	0	n/a
	Transect 7	37	8.4

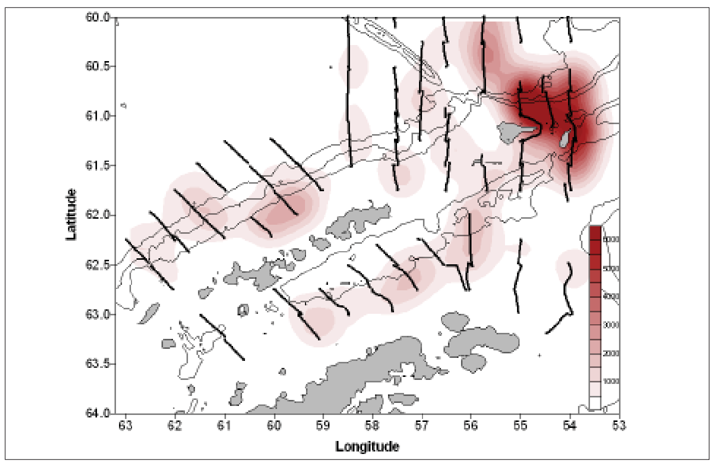

Figure 3.1. Normalized krill NASC values for Leg I at 120 kHz using daytime data (Latitude is south and longitude is west).

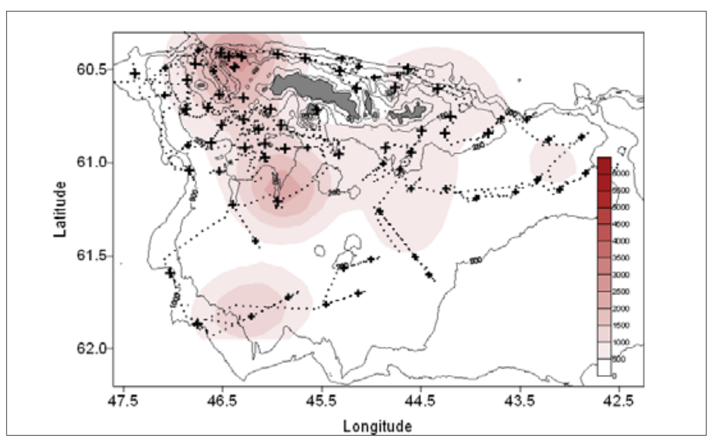

Figure 3.2. Normalized krill NASC values for Leg II at 120 kHz using daytime data. (Latitude is south and longitude is west).

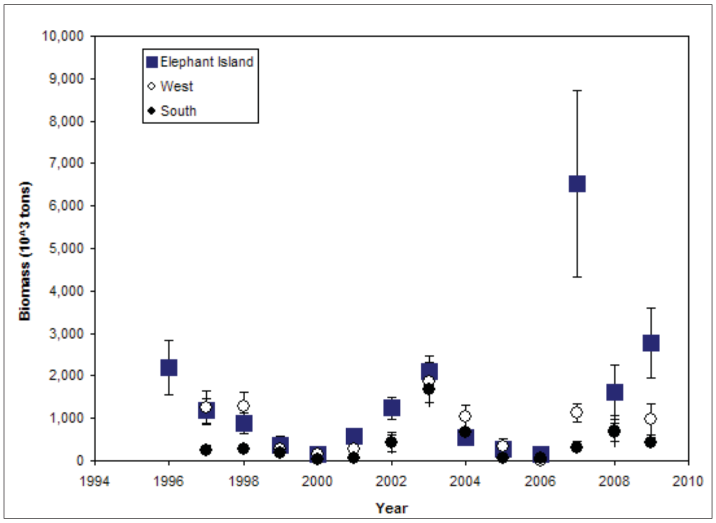

Figure 3.3. Historical (1996-2009) krill biomass (10^3 tons) values for Elephant Island, West and South Areas.

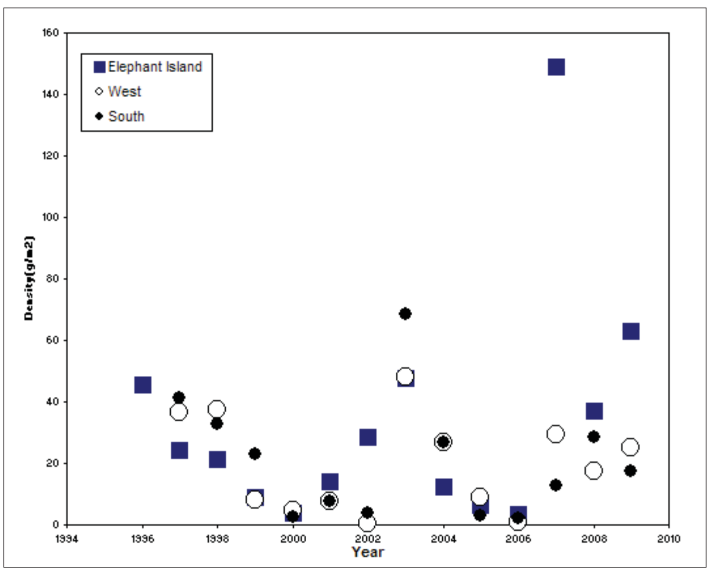

Figure 3.4. Historical (1996-2009) integrated krill density (g/m^2) values for Elephant Island, West and South Areas.

dow of -5 to 2 dB was applied using a two-frequency (38 kHz and 120 kHz) method. This range was chosen based on observed differences in myctophid backscattering values between 38 kHz and 120 kHz.

Backscatter values were averaged over 5 m by 100 s bins. Time-varied gain (TVG) noise was subtracted from the echogram and the ΔSv range was applied. TVG values were based on levels required to erase the rainbow effect plus 2 dB. The remaining volume backscatter classified as krill was integrated over depth (500 m) and averaged over 1,852 m (1 nautical mile) distance intervals.

Integrated krill nautical area scattering coefficient (NASC) (Maclennan and Fernandes, 2000) was converted to estimates of krill abundance (ρ) by dividing the sum of the weighted-mean masses per animal (W; g/krill) by the sum of the backscattering cross-sectional area of krill (σ) ($\sigma = 4\pi r10^{TS/10}$ where r is the reference range of 1 m; Hewitt and Demer, 1993). The length-to-weight relationship

$$(1) \qquad W\,(g) = 2.236 * 10^{-3} * TL^{3.314}$$

was based on net samples collected during the international krill biomass survey of the Scotia Sea conducted during January 2000 (Hewitt et al., 2004), where TL is the total length of a krill. Krill abundance was estimated according to Hewitt and Demer (1993):

$$(2) \qquad \rho\,(g/m2) = \frac{\sum_{i=1}^{n} f_i W(l_i)}{\sum_{i=1}^{n} f_i \sigma(l_i)} \text{NASC}$$

where f_i equals the relative frequency of krill of standard length l_i. Krill biomass was then estimated by multiplying ρ by the area surveyed.

For each area in the survey, mean biomass density attributed to krill and its variance were calculated by assuming that the mean abundance along a single transect was an independent estimate of the mean abundance in the area (Jolly and Hampton, 1990). We used the cluster estimator of Williamson (1982) to calculate the variance of NASC within each area and to expand the abundance estimate for the South Shetland Islands.

No myctophid biomass estimates were made because of the lack of target strength data and length-frequency distributions. Instead, the NASC attributed to myctophids was integrated using Myriax's Echoview software and then mapped across the South Shetland Islands using SURFER (Golden Software, Inc. Golden, CO). However, owing to large amounts of noise in the acoustic data this year, we did not produce a map of myctophid associated NASC.

Results

Mean integrated krill density for each transect line in each area is presented in Table 3.2; NASC values for each Leg of the AMLR Survey are in Figures 3.1 (Leg I) and 3.2 (Leg II). For comparison, historical krill biomass and mean integrated density values are presented in Figures 3.3 and

3.4, respectively. Mean integrated krill density was 25, 63, and 17 g/m² for the West, Elephant Island, and South Areas, respectively, during Leg I. Highest densities were seen around Elephant Island, which is consistent with historical data. Abundance estimates measured in the South Orkney Islands during Leg II ranged from 0 to 794 g/m² for a given nautical mile.

Additionally, more than 2,225 nautical miles of acoustic data were collected to characterize benthic properties around the South Orkney Islands. The data await analysis in the Southwest Fisheries Science Center.

Discussion

Our data indicated that krill biomass was greater than last year, and, in the Elephant Island Area, was the second greatest observed in the since 1996. In the South Shetland Islands, integrated krill density was highest around Elephant Island, which is where krill are historically distributed.

The highest integrated krill density observed in the South Orkney Islands was in the canyon northwest of Coronation Island. This is where the highest integrated density of krill was found in 2008, as well as where the krill fishery is historically located. Refining our calculation of the biomass data collected in the South Orkney Islands in 2008 and 2009 will allow more accurate analysis of the region.

Protocol Deviations

Due to high amounts of acoustic noise recorded during the survey, integration was only completed to 250 m.

Acknowledgements

We would like to thank the crew of the R/V *Yuzhmorgeologiya* for their continued support throughout the field season.

Disposition of Data

All integrated acoustic data will be made available to other U.S. AMLR investigators in ASCII format files. The analyzed echo-integration data use approximately 10 MB. The data are available from Anthony Cossio, Southwest Fisheries Science Center, 3333 North Torrey Pines Court, La Jolla, CA 92037; phone/fax – (858) 546-5609/546-5608; e-mail: Anthony.Cossio@noaa.gov.

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Distribution, Abundance and Demography of Krill

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Abstract The results presented here are based on analysis of postlarval and larval krill collected by 101 net samples in the South Shetland Island and Bransfield Strait region during January 2009.

- Postlarval krill exhibited a relatively uniform distribution of modest concentrations across the survey region.
- Relatively small proportions of one-year-old krill, in conjunction with generally low krill concentrations in the Bransfield Strait, suggest reduced recruitment from 2007/08 compared to 2006/07, 2005/06 and 2004/05 year classes.
- An actively reproductive krill population with large proportions of advanced female maturity stages and presence of early calyptopis stage larvae indicate peak spawning activity during the survey period.

Introduction

Here we provide information on the distribution, abundance and demographic structure of Antarctic krill (*Euphausia superba*) in the vicinity of the South Shetland Islands (Livingston, King George, and Elephant Islands) and the Bransfield Strait (Joinville Island). Abundance statistics (frequency of occurrence, mean, standard deviation and median) reveal information about krill distribution patterns that are related to hydrography and krill demography. Essential krill demographic information includes length, sex ratio, maturity stage composition, reproductive condition as well as distribution, abundance and developmental composition of the larval stages. Information useful for determining the relationships between krill distribution patterns and ambient environmental conditions was derived from net samples taken at established CTD/phytoplankton stations. Results from Leg I are compared to those from previous AMLR Surveys to assess inter-annual differences in krill demography and abundance over the 1992-2009 period.

Methods

Krill were obtained from a 1.8 m Isaacs-Kidd Midwater Trawl (IKMT) fitted with a 505 µm mesh plankton net. Flow volumes were measured using a calibrated General Oceanics flow meter mounted on the frame in front of the net. All tows were fished obliquely to 170 m or to ca. 10 m above bottom in shallower waters. Real-time tow depths were derived from a depth recorder mounted on the trawl bridle. Tow speeds were ca. two knots with flow volumes averaging 5,005 (+/- 755) m^3 based on a calibration factor of 0.0752, calculated from the net's fishing dimensions.

Sample data are considered with respect to the four distinct areas in the survey region. All samples were processed on board. For diel considerations, twilight samples are defined as those collected one hour before to one hour after local sunrise and sunset.

Demographic analyses of krill postlarvae were made using fresh or freshly frozen specimens. Postlarval krill were removed and counted prior to other sample processing. All krill from samples of <100 individuals were analyzed. For larger samples, at least 100 individuals were measured, sexed, and staged. Measurements were made of total length (mm), and krill maturity stages were based on the classification scheme of Makarov and Denys (1981). Length-at-age estimates were based on Siegel (1987) and Siegel and Loeb (1994). Data on the larval stages were obtained from zooplankton sample analysis described by Loeb et al. (Chapter 5). Recruitment indices (R), indicating the relative reproductive success and survival of each year class, were based on the proportion of one-year-old krill (by length) relative to total krill (all year classes) sampled in the Elephant Island Area each year, calculated according to the methods presented by Siegel et al (2002).

Statistical Analyses

Data from the total survey region and four areas were analyzed inter- and intra-annually. Analyses include a variety of parametric and nonparametric techniques: Index of Dispersion (ID) to demonstrate the evenness or patchiness of krill distribution; Analysis of Variance (ANOVA) with Post-Hoc comparison of means (Tukey Honest Significant Difference) to establish abundance differences at the 95% probability level; Kolmogorov-Smirnov D_{MAX} values to indicate similar length-frequency distributions; Kendall's Tau (T) correlation coefficients to

Table 4.1. Krill abundance (No. per 1,000 m^3) and distribution attributes in the South Shetland Islands during January 2009 relative to January-February 2001-2008. N is number of samples within each area. The Joinville Island Area was not sampled in 2001. Largest concentrations typically reflect juveniles, hence recruitment success from the previous year's spawn (R1). Index of Dispersion (ID) is a measure of distribution; smaller numbers indicate evenness and larger numbers patchiness. Inter-annual variation in distribution patterns reflects demographic and hydrographic differences.

Krill Abundance AMLR Survey Leg I									
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
West Area N=	30	25	25	24	25	25	23	22	23
Mean	8.3	27	24.6	7.3	5.4	6.4	27.7	31.7	5.6
SD	12	90.8	55.2	13.7	8.4	8.1	43.5	60	6.8
Median	1.5	0.3	5.1	1.4	1.5	5.1	11.3	5.5	2.2
ID	17.3	305.7	124	25.6	13	10.3	68.4	113.3	8.2
Elephant Island Area	60	44	38	46	48	48	48	34	47
Mean	13.3	25.1	204.5	38.5	17.5	15.3	42.7	119.9	23.2
SD	23.6	60	891.6	109.7	21.2	30.7	62.1	400.1	74.1
Median	3.8	4.8	19.9	2	9.9	7.1	21.4	14.3	3.3
ID	41.8	143.5	3887.5	312.4	25.7	61.4	90.3	1335.5	236.5
Joinville Island Area	n.a.	9	3	5	6	6	7	10	11
Mean	-----	50.4	323	0.2	17.8	61.1	237.2	165.9	1.3
SD	-----	98.7	428.7	0.3	36.2	119.3	457.3	251.6	2.2
Median	-----	6.6	38.6	0	1.2	10.2	2	1.5	0.2
ID	-----	193.2	569.1	0.3	73.8	232.8	881.5	381.7	3.6
South Area	11	17	17	16	20	20	20	20	20
Mean	74.7	104	56.2	41.9	8.8	16.9	102.1	25.7	52.4
SD	115.6	251.2	123.3	72.1	23.8	38.9	205.6	83.7	129.4
Median	14.5	0.5	0.7	0.8	0.6	5	14	1	0.9
ID	178.7	606.4	270.9	124.1	64.7	89.8	413.9	271.9	319.8
R1		0.403	0.478	0.001	0.014	0.2	0.23	0.373	

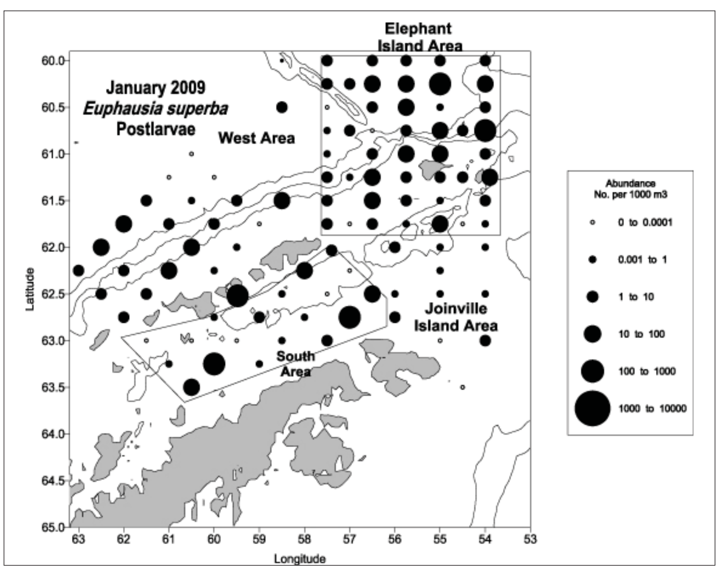

Figure 4.1. Distribution and concentration of postlarval krill, January 2009. Locations of sampling stations within the West, Elephant Island, Joinville Island and South Areas are included.

identify the joint variation of environmental parameters over time; Percent Similarity Indices (PSI) to indicate similarity in proportions of maturity stages; and Cluster Analysis to define distribution patterns of different krill length/maturity stages. Cluster analysis applied here is based on the proportional length-frequency distributions in each net sample containing at least 17 krill and uses Euclidean distance and Ward's linkage method, with significant groupings (clusters) distinguished by a distance of 0.30 to 0.70. Statistical analyses were performed using Statistica (StatSoft) and NCSS software.

Results

Postlarval Krill

A total of ca. 11,000 postlarval krill were collected during the survey. Krill were present in 85 of the total 101 samples with an overall mean abundance of 23 (+/- 79) per 1,000 m^3 and a median catch of 2.3 per 1,000 m^3. These values, and index of dispersion of 273, indicate a

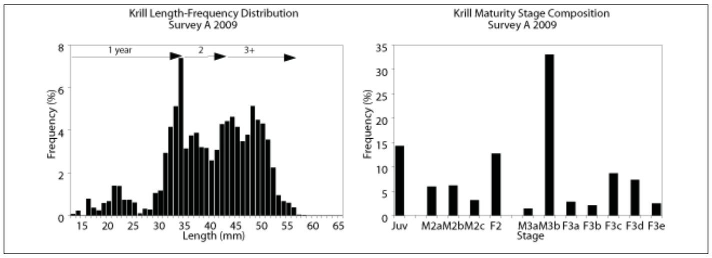

Figure 4.2. Overall krill length-frequency distribution and maturity stage composition, January 2009. Arrows denote approximate ages associated with the different length modes (Siegel, 1987).

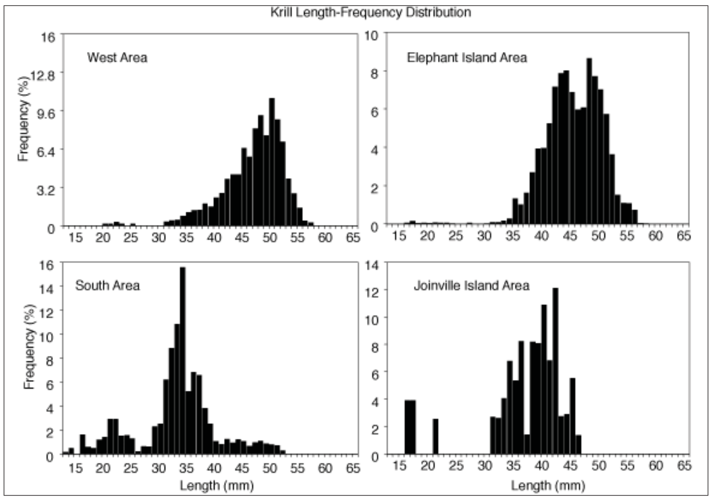

Figure 4.3. Krill length-frequency distributions in four survey areas, January 2009

relatively uniform distribution of modest krill concentrations across the region.

Two of the five largest concentrations (471-2,338 individuals, 106-562 per 1,000 m^3) were in the northeast Elephant Island Area, while the three others were in the south and central Bransfield Strait, within the South Area (Figure 4.1).

Night catches were greatest, with a mean of 56 (+/-146) per 1,000 m^3, followed by twilight and day with respective mean concentrations of 38 (+/-113) and 11 (+/- 34) per 1,000 m^3. These differences were not significant, however, due to catch variability within each diel period (ANOVA, P>0.05). As with all Leg I surveys, the number of day samples (69) vs. night and twilight samples (16 each) suggests that the overall mean is a conservative estimate.

Despite a relatively even overall krill distribution, the four areas exhibited regional catch differences. Krill were least frequent (75% of samples) but had greatest mean abundance in the South Area (52 per 1,000 m^3), reflecting a patchy distribution there relative to the other areas (Figure 4.1). This is also indicated by the low median (0.9 per 1,000 m^3) and relatively high ID (320) values (Table 4.1). In contrast, moderate concentrations were distributed more evenly across the Elephant Island Area, where krill were present in 92% of samples with mean and median values of 23 and 3.3 per 1,000 m^3, respectively. Only small catches were made in the Joinville Island Area, where nine of the 11 samples netted a total of only 74 individuals (1.3 and 0.2 per 1,000 m^3 mean and median, respectively). Catch frequency was relatively low in the West Area, where 700 individuals were caught in 18 of 23 samples (78%) with respective mean and median concentrations of 5.6 and 2.2 per 1,000 m^3.

Krill lengths ranged from 12-58 mm and demonstrated a polymodal distribution with similar proportions of one-, two- and three-year and older individuals, representatives of the 2007/08, 2006/07 and 2005/06 and older year classes (Figure 4.2). Overall, individuals < 35 mm (generally one-year old), 36-44 mm (two-year old) and > 45 mm (three-year old and older) each represented 33% of the catch. Of note is the bimodal length distribution of one-year old krill, one group comprised of small individuals with lengths centered around a 21 mm mode and a second, more abundant group of individuals with an apparent 34 mm mode, most likely augmented by the contribution of small two-year old individuals. This bimodal length distribution is interesting in that it suggests the input of krill from two different sources (i.e., spatially and/or temporally separated reproductive efforts) during the 2007/08 spawning season.

Overall, juveniles comprised 14%, immature stages 28% and mature stages 58% of the krill sampled (Table

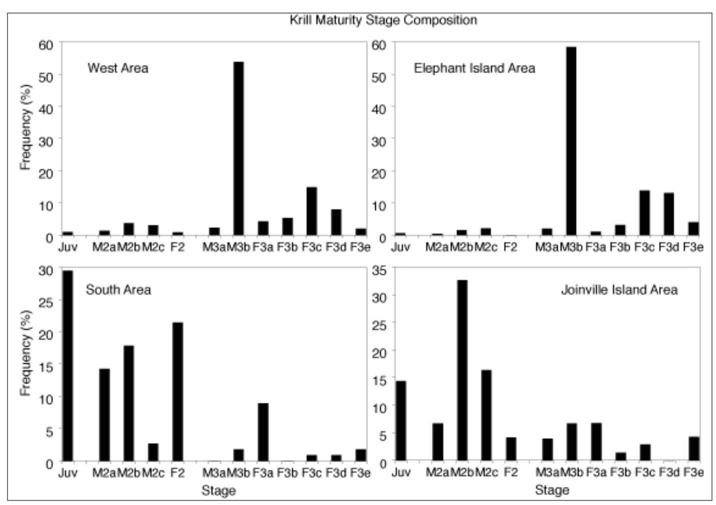

Figure 4.4. Krill maturity stage composition in four survey areas, January 2009

4.2). Mature males outnumbered mature females by 50% and most (80%) mature females were in advanced stages with developing ovaries, gravid or spent, indicating peak seasonal spawning activity.

Different krill length/maturity stages were represented in each area: large, mature individuals were primarily offshore of smaller immature and juvenile stages. Latitudinal gradients also reflect different mixtures of the various length/maturity categories (Figures 4.3 and 4.4), likely due to hydrographic processes such as advective transport, fronts and gyres occurring across the region.

While a wide range of krill lengths was represented across the region, catches in the West and Elephant Island Areas were overwhelmingly dominated by individuals >35 mm (Figure 4.3). The length-frequency distribution in the West Area had 50 mm modal and 48 mm median lengths, while that in the Elephant Island Area was bimodal at 44 mm and 48 mm with a 45 mm median. Mature males outnumbered females by 80% and the majority of animals were in mating condition. Advanced reproductive stages constituted 72% and 88% of mature females in the West and Elephant Island Areas, respectively. The increased proportion of advanced female stages in the Elephant Island Area compared to the West Area (Figure 4.4) reflects the advancing season and/or an earlier onset of reproductive activity in the Elephant Island Area.

Demographic information for Joinville Island Area krill is limited by the small sample size, but, like the South Area, 93% of individuals were <45 mm, representatives of the 2007/08 and 2006/07 year classes. One-year old length krill (<35 mm) comprised 69% and 32% of the South and Joinville Island Areas, respectively. The dichotomous one-year old size groups were represented in both areas, although the larger (30-35 mm) group was not as well represented in the Joinville Island Area. Juvenile and immature krill comprised 86% of the South Area krill catch, and 74% in the Joinville Island Area. Elevated patchiness in the South Area was due to infrequent, relatively dense concentrations of these young krill. The few mature krill collected in the South and Joinville Island Areas were, for the most part, not reproductively active. Mature females were primarily unmated (F3a) or spent (F3e), suggesting that spawning had already taken place in the Bransfield Strait.

Cluster analysis performed on length-frequency data from 42 samples resulted in three distinct krill groupings with spatially coherent distribution patterns (Figures

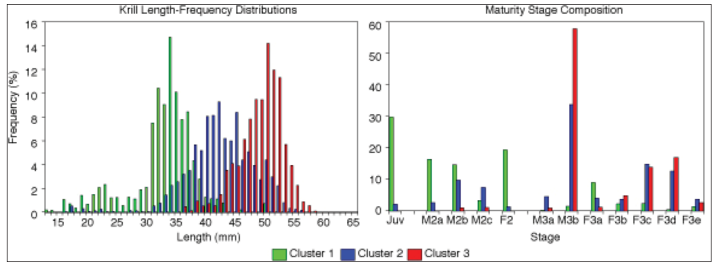

Figure 4.5. Length-frequency distribution and maturity stage composition of krill clusters, January 2009.

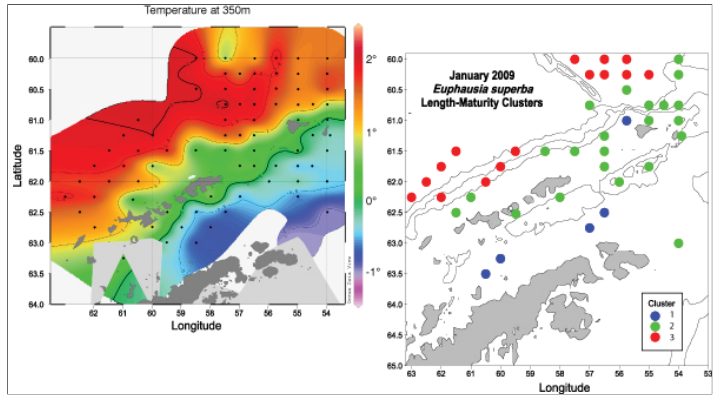

Figure 4.6. Distribution of krill length/maturity clusters in relation to hydrographic features, January 2009. Temperature at 350 m shows major hydrographic features in the region: 2oC isotherm denotes core waters of the ACC; 1.8oC the ACC southern front; 0oC the ACC southern boundary. The region between the southern boundary and southern front is characterized by mixing of ACC-derived and coastal waters.

4.5, 4.6). The smallest of these, Cluster 1, was represented at four stations in the southwest Bransfield Strait and one station over the northwest shelf of Elephant Island. Virtually all of the krill (99%) were <44 mm and 69% were in the one-year-old length class (<35 mm).

Cluster 2, the most frequent group, occurred at 22 stations primarily over and adjacent to the South Shetland Island shelves; an exception was one station in the southeast Bransfield Strait (Figure 4.6). The majority of individuals (66%) were 35-45 mm representatives of the two-year old (2006/07) year class. Smaller krill made up only 7% of the total (Figure 4.5). Mature males and females were similarly represented (each ca. 38% of total) and 80% of the females were in advanced reproductive stages, mostly with developing ovaries and gravid.

Cluster 3 occurred at 15 stations, largely offshore of the island shelves (Figure 4.6). Most (88%) individuals were >45 mm (i.e., three-years old and older) with a 50 mm median and modal length. Virtually all (98%) were mature and, like Cluster 2, most of the females (85%) were in advanced reproductive stages (Figure 4.5). Males outnumbered females by 50%, suggesting that a substantial number of large spawning females may have been located

4.2. Overall larval krill stage composition (%) and abundance (numbers per 1,000 m^3) during Leg I of the AMLR Survey. n.a. indicates no survey was conducted. R is the proportional recruitment index associated with larval abundance for each year class.

Larval Krill Stage Composition														
Stage (%)	A96	A97	A98	A99	A00	A01	A02	A03	A04	A05	A06	A07	A08	A09
Calyptopis	100	93	68	100	n.a.	100	70	100	95	99	100	100	99.8	99.5
Furcilia	---	7	32	---	n.a.	---	30	---	5	1	---	---	0.2	0.5
No. 1,000 m^{-3}														
Mean	2.7	15.4	1	103.1	n.a.	100.3	12.8	2.4	4.5	11.9	646.6	9.2	33	8.6
STD	7.5	27.1	4.5	587.4	n.a.	445.2	31.4	7.5	9.4	43	2381.8	32.3	64.4	29.6
Median	0	0.8	0	2.6	n.a.	8.1	0	0	0.1	0.3	2.7	0.1	6.2	0
February-March														
Stage (%)	D96	D97	D98	D99	D00	D01	D02	D03	D04	D05	D06	D07	D08	D09
Calyptopis	86	100	99	97	97	98	85	89	44	85	n.a.	n.a.	100	n.a.
Furcilia	14	---	1	3	3	2	15	11	56	15	n.a.	n.a.	---	n.a.
No. 1,000 m^{-3}														
Mean	13.9	25	1.6	49.8	1374.5	439.2	39.5	2.5	75.2	117.8	n.a.	n.a.	94.8	n.a.
STD	40.2	81.4	14.1	119.3	4682.1	2320.4	142.1	6.7	340.9	540.7	n.a.	n.a.	391	n.a.
Median	3	0	0	9	22	6.2	0	0	13.1	0	n.a.	n.a.	4.9	n.a.
R	0.198	0.12	0	0	0.573	0.403	0.478	0.001	0.014	0.2	0.23	0.373		

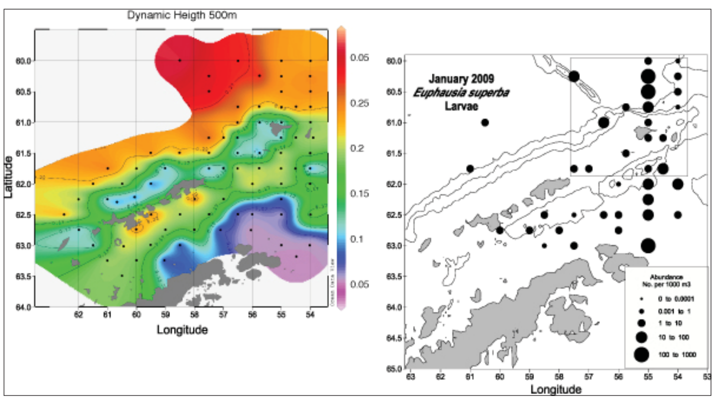

Figure 4.7. Distribution and abundance of larval krill in relation to implied flow (dynamic height at 500 m relative to the surface) across the survey region, January 2009. Box indicates the Elephant Island Area. Dynamic height indicates generally northeast flow through central Bransfield Strait and Drake Passage, a large eddy east of the Shackleton Fracture Zone, clockwise gyral circulation in southeast Bransfield Strait and over the island shelf regions.

farther offshore during the survey period.

Larval Krill

Krill larvae were present in 38 of 101 samples, with an overall mean concentration of 8.6 (+/-29.6) per 1,000 m^3 (Table 4.3, Figure 4.7). They were most frequent in the Joinville Island Area, present in nine of the 11 samples (82%). The largest catch (226 per 1,000 m^3) was also in the Joinville Island Area, resulting in relatively large mean and median abundance values of 32 (+/- 62) and 7.8 per 1,000 m^3, respectively. Concentrations here were significantly greater than in the other areas (ANOVA, $P<0.03$). Two other relatively large catches (103 and 123 per 1,000 m^3) occurred north of Elephant Island. While larvae were present in 40% of samples in both the Elephant Island and South Areas, their mean abundance was almost an order of magnitude greater in the Elephant Island Area (10.4 vs. 1.2 per 1,000 m^3). Small numbers of larvae were present in only two of 23 West Area samples, yielding a mean of 0.4 per 1,000 m^3. Krill larvae exhibited diel catch differences with night and twilight mean concentrations nearly twice what they were during day (12-13 vs. 6.7 per 1,000 m^3), possibly due to vertical migration into surface layers. As with the postlarvae these differences were not significant due to catch variability.

Calyptopis stages made up 99.5% of larvae sampled. Overall, 82% were Calyptopis stage 1 (C1), the first feeding stage to reach surface waters from hatching at depth. Older C2 and C3 stages comprised 16% and 1.6% of total larvae. South Area samples differed from the other areas in that, despite low concentrations, they contained the greatest variety of larval stages. Here C1-3 stages represented 39%, 16% and 35%, respectively, and more advanced Furcilia F1-2 stages contributed 7% and 3%, respectively, of the total.

Using the data from the Elephant Island Area, we determined the length-density contribution of krill to calculate the proportional recruitment of krill for 2009. Length-density was determined using the CMIX program (de la Mare, 1994). A small proportion of krill less than 25 mm were present in the Elephant Island Area; these were pooled into the 25 mm length class before sunning the CMIX program.

CMIX analysis determined that the most abundant krill lengths were 29.5, 42 and 49 mm, representing 2%, 56% and 42% of the krill in the Elephant Island Area, respectively. Krill in the 29.5 mm length class were considered to be from the 2008 cohort. Therefore, proportional recruitment of krill hatched during the previous breeding season was extremely low during the 2009 AMLR Survey.

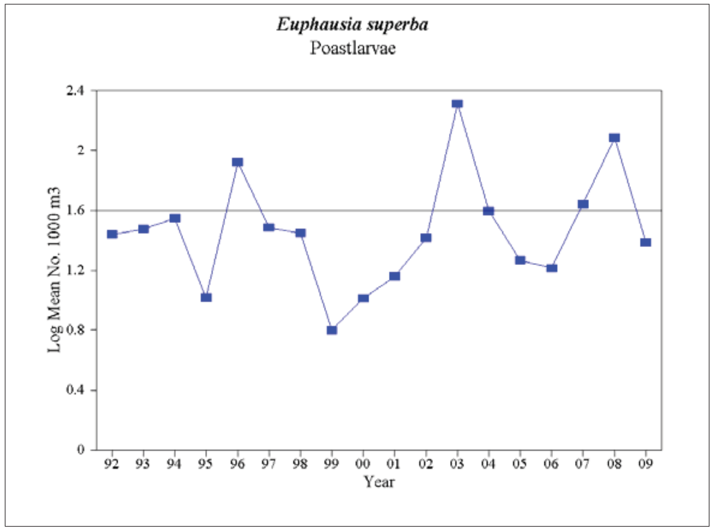

Figure 4.8. Inter-annual variation in mean abundance of postlarval krill in the Elephant Island Area during Leg I of the 1992-2009 AMLR Survey. Leg II is used for 2000, when there was no Leg I.

Discussion

Postlarval Krill

Mean krill abundance in the Elephant Island Area during January 2009 (23.2±74.1 per 1,000 m^3) was below the 18-year mean (39.7±220.3 per 1,000 m^3), similar to that observed in 1992 and 2002, but was moderately high compared to abundance in 1995 and 1999-2001 (Figure 4.8). The median krill abundance was about half the long-term value (3.3 vs. 5.9 per 1,000 m^3). However, with the exception of 1996, all of these values were significantly less than the 2003 and 2008 means (ANOVA, $P<0.05$), reflecting comparatively small contributions of one-year old individuals and low recruitment success from the previous years spawn.

Krill length-frequency distribution in the Elephant Island Area was most similar to January 1994 and 1999 (D_{MAX}=12.2-12.8), periods characterized by low recruitment from the previous two to three years (Figure 4.9). This is unusual given the extremely good recruitment success observed in 2008 (the 2006/07 year class) and suggests the advective loss of a substantial portion of these individuals to downstream regions (Atkinson et al., 2008). The paucity of individuals >53 mm is also notable in light of the relatively good recruitment success of the 2004/05 and 2005/06 year classes, now three- and four-year-old animals.

As indicated in Table 4.1, there is a great deal of interannual variability in krill distribution patterns that could affect assessment of recruitment success due to variable representation of one-year-old krill in the Elephant Island Area. In this respect, the relative abundance pattern of krill across the four areas during January 2009 was quite similar to that during January 2004, with highest concentrations in the South and Elephant Island Areas and extremely low concentrations in the Joinville Island Area. The paucity of small krill, particularly in the Joinville Island Area, despite the relatively intense sampling effort there this year, lends support to the idea that there was relatively low recruitment from the 2007/08 spawning season. Poor recruitment success was anticipated based on the low proportions of advanced female maturity stages observed during January 2008 (Loeb et al., 2008).

The unusual bimodal length distribution of one-year-old krill this year suggested input from two different sources during the 2007/08 spawning season. This could be explained by the observation of an early initiation of reproduction in the Bransfield Strait and a delayed spawning period in the Elephant Island Area that extended into early March (Loeb et al., 2008).

Within the Elephant Island Area the overall krill maturity stage composition was similar to that during January 1995 and 2006 (PSI=87 and 97), reflecting the overwhelming dominance of mature forms. The proportions of individual maturity stages were most similar to those in 1995, when gravid and spent females contributed 27-33% of all krill sampled. Over the 1992-2009 period recruitment success was significantly correlated with proportions of advanced female stages during January (N=15, T = +0.41, P=0.03), suggesting the potential for good recruitment of the 2008/09 year class.

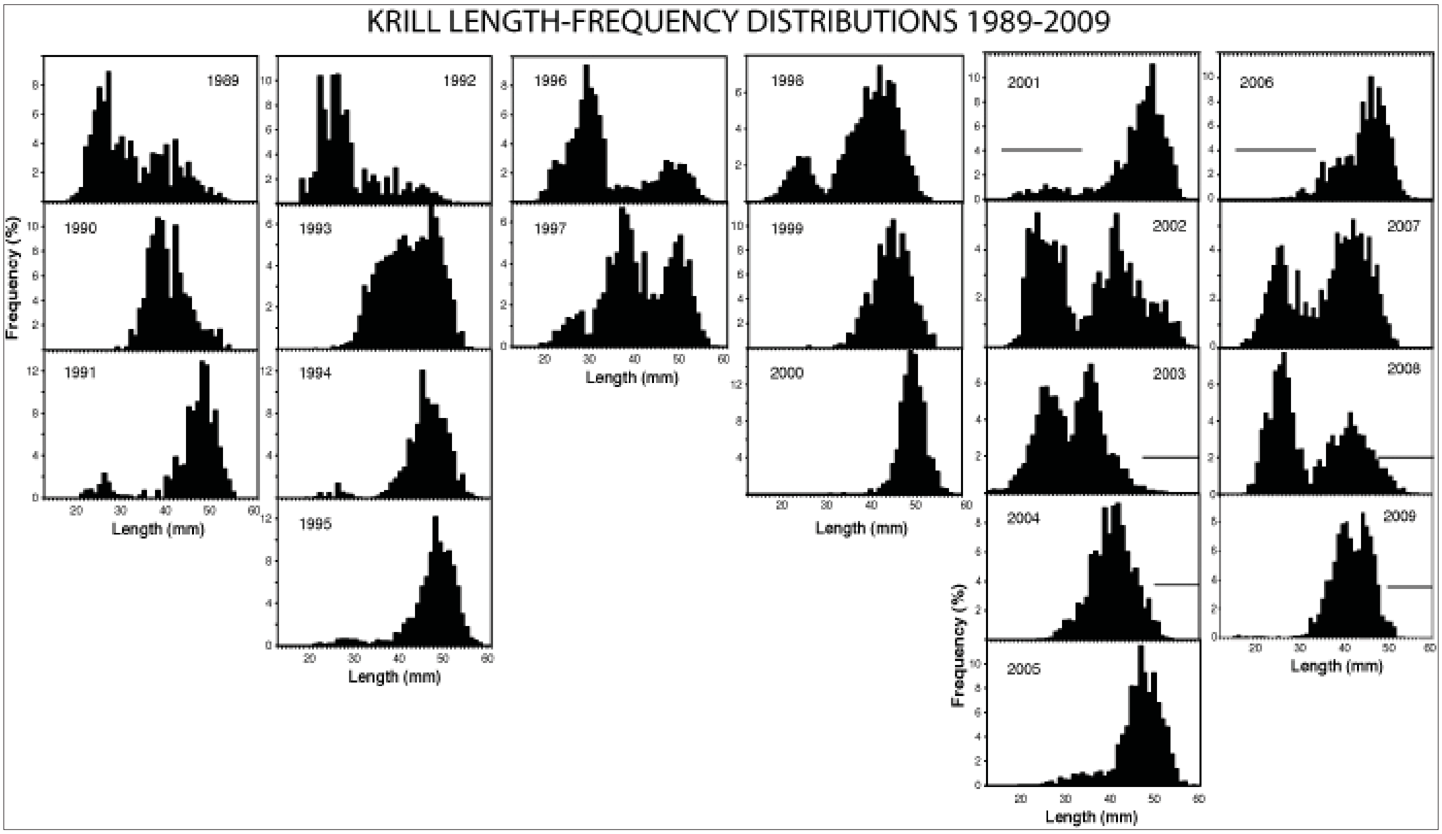

Figure 4.9. Krill length-frequency distribution in the Elephant Island Area during Leg I, 1989-2009, showing the progression of successful year classes as they age. Leg II used for 2000, when there was no Leg I. The horizontal lines indicate possible under sampling of either small or large length categories due to their variable between-year distribution patterns relative to the Elephant Island Area.

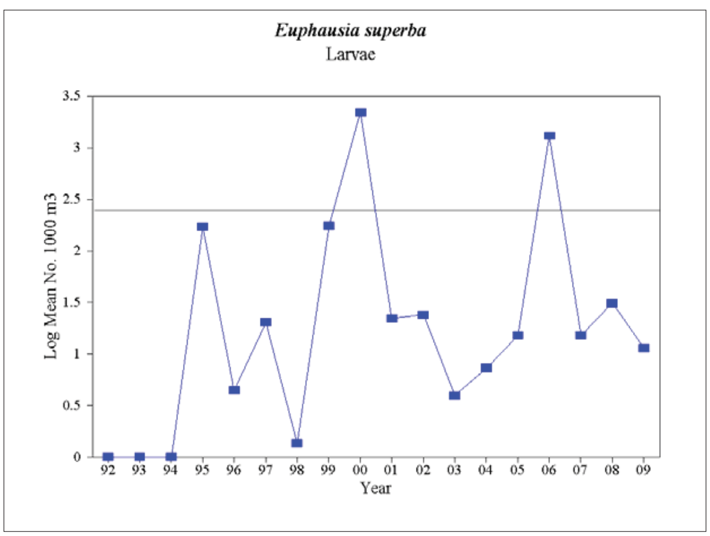

Figure 4.10. Interannual variation in mean abundance of larval krill in the Elephant Island Area during January surveys 1995-2009. February data used for 2000, when there was no January survey.

Larval Krill

As with most years, mean larval krill abundance in the Elephant Island Area in 2009 was significantly lower than the extreme highs monitored in January 2006, when there was an extremely early onset of seasonal reproductive activity, and in February 2000 (ANOVA, $P<0.05$) suggesting that the January value is more an indication of timing, rather than output, of reproductive effort (Figure 4.10).

The overall distribution pattern, abundance and stage composition of larval krill was quite similar to what was observed during January 2007, a year characterized by strong recruitment. Larval krill abundance and stage composition in the AMLR Survey areas are highly variable from year to year. However, back-to-back surveys typically demonstrate seasonal increases in larval abundance and stage development. Notable exceptions were 1998 and 2003, when few larvae were encountered during either survey. Over the 2000-2009 period, greatest larval krill concentrations typically were in the Joinville Island and Elephant Island Areas. As observed during 2009, this is likely due to prevailing northeast advection and concentration in frontal zones and eddies in these areas. Exceptions to this were both 2001 surveys and the 2002 February-March survey, when greatest concentrations occurred in the West Area, possibly in association with the nearshore location of the ACC.

Recruitment success does not appear related to either larval stage composition or location of maximum abundance each year, but is significantly correlated with the total mean larval abundance observed during February-March surveys (N=10, T=+0.54, P=0.03). These results are consistent with the relationship between recruitment success and proportions of advanced female maturity stages in January and indicate the importance of optimally timed seasonal reproductive output. The timing of this year's spawning peak is favorable as it allows the larvae sufficient time to feed, grow and develop to advanced overwintering stages (Siegel and Loeb, 1995).

Protocol Deviations

There were no changes to standard sampling and analytical techniques used during AMLR field work.

Acknowledgements

It was wonderful to once again enjoy the facilities and personnel of the R/V *Yuzhmorgeologiya*. Captain Sasha was superb in his command of the ship and crew and in his positive interactions with the scientific party! Thanks to the krill and zooplankton team members who also helped out with phytoplankton sample collection and analysis, and to the AMLR "Family" members who worked hard together in such a harmonious and congenial manner! Again, it was quite satisfying to have the Santora-Force underway bird and mammal team keeping us informed of the exciting wildlife that surrounds us while we toil way below decks.

Disposition of Data

Data are available from Christian Reiss, NOAA Fisheries, Antarctic Ecosystem Research Division, 3333 Torrey Pines Court, Room 412, La Jolla, CA 92037. Ph: 858-546-7127, FAX: 858-546-5608

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Distribution and Abundance of Zooplankton

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Abstract The results presented here are based on analysis of zooplankton and nekton taxa collected by 101 net samples in the South Shetland Island and Bransfield Strait region, January 2009.

- *Salpa thompsoni* outnumbered copepods in the Elephant Island Area, with mean concentrations of 883 and 809 individuals per 1,000 m^3, respectively.
- *Salpa thompsoni* dominance was less extreme and copepods represented larger proportions than previous salp dominated years, reflecting a greater influence by the Antarctic Circumpolar Current.
- A salp catch of 18,490 per 1,000 m^3 surpassed previous records but preponderance of small individuals due to a seasonally lagged bloom period minimized salp catch volume and carbon biomass.
- Zooplankton assemblages demonstrated mixed distribution patterns suggesting greater than normal hydrographic complexity across the region.

Introduction

Here we provide information on the abundance and distribution of zooplankton and nekton taxa in the vicinity of the South Shetland Islands (Livingston, King George, and Elephant Islands) and southeast Bransfield Strait (Joinville Island) during January, 2009. We describe the zooplankton assemblages present across the entire survey region as well as those within the four areas. Information useful for determining the relationship between zooplankton distribution patterns and the environment was derived from net samples taken at established CTD/phytoplankton stations.

Biomass-dominant copepod species, *Salpa thompsoni* and *Ihlea racovitzai* receive special attention because the inter-annual abundance variations of these relatively short-lived taxa reveal underlying hydrographic processes influencing the Antarctic Peninsula ecosystem. Results from Leg I are compared to those from previous AMLR Surveys to assess inter-annual differences in zooplankton composition and abundance over the 1992-2009 period. While postlarval and larval stages of Antarctic krill (*Euphausia superba*) are considered here as part of the overall zooplankton-nekton assemblage, specifics on their distribution, abundance and demography are treated separately in a companion report (Chapter 4).

Methods

Zooplankton and nekton were obtained from a 1.8 m Isaacs-Kidd Midwater Trawl (IKMT) fitted with a 505 µm mesh plankton net. Flow volumes were measured using a calibrated General Oceanics (model 2030R) flow meter mounted on the frame in front of the net. All tows were fished obliquely to a depth of 170 m, or 10 m above bottom in shallower waters. Real-time tow depths were derived from a depth recorder mounted on the trawl bridle. Tow speeds were two knots with flow volumes averaging 5,005 (+/- 755) m^3 based on a calibration factor of 0.0752, which was calculated from the nets' fishing dimensions.

All samples were processed on board. Large taxa, primarily postlarval krill and salps, were removed prior to processing the other zooplankton components. For larger samples the numbers of salps in one to two liter subsamples were used to estimate total abundance. For samples with <100 salps the two life stages (aggregate/sexual and solitary/asexual) were enumerated and internal body length (Foxton, 1966) measured to the nearest mm. Representative subsamples of >100 individuals were analyzed in the same manner for larger catches. All adult myctophids were identified, measured to the nearest mm (Standard Length, SL), and frozen. The remaining zooplankton fraction was then analyzed. All of the larger organisms (e.g., other postlarval euphausiids, amphipods, pteropods, polychaete worms) were sorted, identified to species if possible, and enumerated. Following this aliquots of the sample were enumerated and smaller zooplankton (e.g., copepods, chaetognaths, euphausiid larvae) identified to species, if possible, under maginfication. After analysis the zooplankton samples (without adult fish, postlarval krill, and most of the salps) were preserved in 10% buffered formalin for long-term storage. Specimens of pteropods belonging to genera with calcareous shells, *Limacina sp*. and *Clio sp.*, were preserved separately in buffered 95% ethanol for use in ocean acidification studies.

Abundance estimates are generally expressed as numbers per 1,000 m^3 water filtered; however, salp length-frequency plots are based on total numbers per m^2 sea surface area. For diurnal considerations, twilight samples are defined as those collected one hour before to one hour after local sunrise and sunset.

Statistical Analyses

Data from the total survey region and four component areas are analyzed here for inter- and intra-annual comparisons. Zooplankton species abundances are related to hydrography using Water Zones, as described by Needham et al. (Chapter 1). These Water Zones, numbered I to V, represent a variety of mixtures between Antarctic Circumpolar Current (ACC) (I), ACC-derived (II and III), Bransfield Strait (IV) and high latitude Weddell Sea shelf water (V).

Analyses include a variety of parametric and nonparametric techniques: Analysis of Variance (ANOVA) with Post-Hoc comparison of means (Tukey Honest Significant Difference) to establish abundance differences at the 95% probability level; Kolmogorov-Smirnov D_{MAX} values to indicate similar length-frequency distributions; Kendall's Tau (T) correlation coefficients to identify the joint variation of environmental parameters over time; Percent Similarity Indices (PSI) to indicate similarity in proportions of zooplankton taxa between regions or years; and Cluster Analysis to define distribution patterns based on aggregate salp lengths and zooplankton species assemblages. Salp cluster analysis is based on the proportional length-frequency distributions in each net sample containing at least 80 individuals while zooplankton clusters are based on log-transformed sample abundance data (N+1) for taxa present in at least 18 samples. Both analyses use Euclidean distance and Ward's linkage method with significant groupings (clusters) distinguished by a distance of 0.30 to 0.70. Statistical analyses were performed using Statistica (StatSoft) and NCSS software.

Results

Overall Composition and Abundance

A total of 117 taxonomic categories, including 10 copepod species, were identified from the 101 samples (Table 5.1). Copepods, present in all samples, comprised the most frequent taxon. The largest catch (75,400 individuals, 13,370 per 1,000 m^3), almost entirely *Metridia gerlachei*, was located over the eastern Bransfield Strait basin (Figures 5.1A; 5.2C). Other relatively large concentrations (2,200-7,900 per 1,000 m^3) were located in the eastern Bransfield Strait and offshore west of the Shackleton Fracture Zone. The most frequent and abundant constituents were small

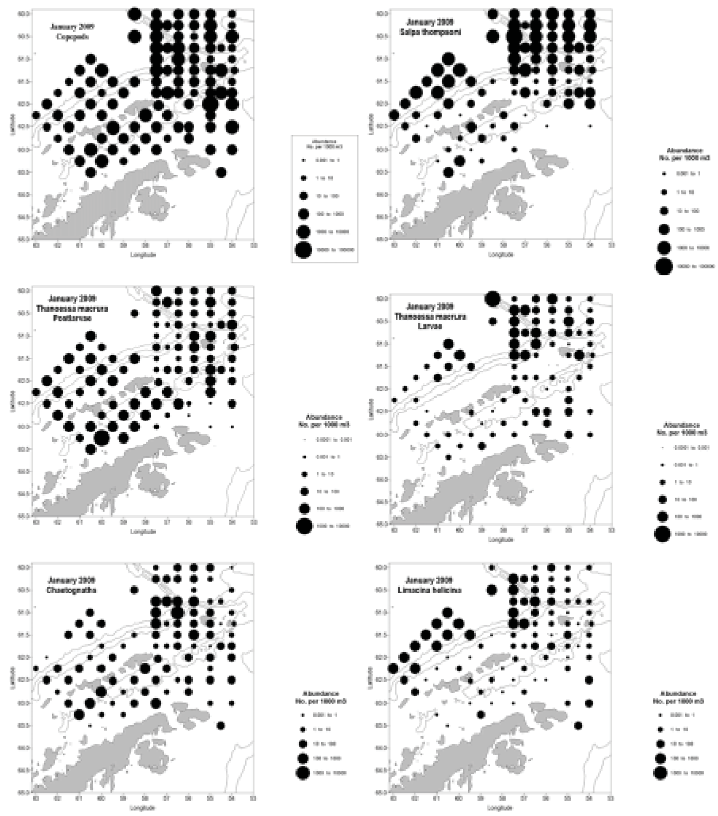

Figure 5.1. Distribution and abundance of (A) copepods, (B) *Salpa thompsoni*, (C) postlarval *Thysanoessa macrura*, (D) larval *T. macrura*, (E) chaetognaths and (F) *Limacina helicina*, January 2009.

unidentified species ("other" copepods), which accounted for nearly half of the individuals enumerated. *Calanoides acutus* and *Calanus propinquus* were also widespread (94-97% of samples) but with smaller mean numbers than the less-common *M. gerlachei* due to the patchy distribution of this more "coastal" species.

While *Salpa thompsoni* was less frequent than copepods (88% of samples) its overall mean abundance was greater (883 vs. 809 per 1,000 m^3) due to exceptionally large concentrations at 15 stations. The largest catch, adjacent to the Shackleton Fracture Zone, contained an estimated 100,500 individuals with a concentration of 18,486 per 1,000 m^3. Other large catches (11,725-32,190 individuals, 2,180-6,615 per 1,000 m^3) primarily occurred offshore of the island shelf region (Figure 5.1B). Overall salps comprised 42% of total mean abundance compared to 38% for copepods. Postlarvae of the euphausiid *Thysanoessa macrura* (97% of samples, 116 per 1,000 m^3 mean) followed copepods in frequency and mean abundance. The largest *T. macrura* catches were in the western Bransfield Strait (Figure 5.2C). Other frequent and relatively abundant taxa included chaetognaths, pteropod *Limacina helicina* and larval

Table 5.1. Frequently occurring zooplankton and nekton taxa in the South Shetland Islands, January 2009. Taxa present in at least 11 of the total 101 samples are listed. F(%) is frequency of occurrence. N(%) is percent of total mean abundance represented by each taxon. (L) denotes larval stages.

	F(%)	Mean	STD	Median	Maximum	N(%)
Copepods	100.0	808.8	1613.5	313.6	13368.3	38.4
"Other" copepods	99.0	324.0	511.1	129.8	2818.1	15.4
Calanus propinquus	97.0	57.2	78.5	28.4	465.6	2.7
Calanoides acutus	94.1	106.0	406.1	27.9	3932.4	5.0
Rhincalanus gigas	77.2	36.2	84.8	10.5	657.2	1.7
Metridia gerlachei	72.3	256.3	1288.7	6.5	12645.0	12.2
Pareuchaeta spp.	55.4	22.9	44.3	1.7	253.7	1.1
Haloptilus ocellatus	13.9	1.2	6.4	0.0	58.6	0.1
Pleuromama robusta	12.9	2.3	11.0	0.0	81.2	0.1
Pareuchaeta antarctica	10.9	0.3	1.8	0.0	18.3	0.0
Thysanoessa macrura	97.0	116.2	218.6	49.7	1827.0	5.5
Chaetognaths	91.1	53.2	143.9	13.4	1301.7	2.5
Limacina helicina	90.1	42.3	86.8	3.1	595.4	2.0
Salpa thompsoni	88.1	883.2	2178.0	96.6	18485.7	42.0
Vibilia antarctica	87.1	7.9	11.6	4.5	88.3	0.4
Euphausia superba	84.2	22.6	78.6	2.3	561.8	1.1
Themisto gaudichaudii	84.2	15.7	27.6	4.9	173.0	0.7
Thysanoessa macrura (L)	82.2	66.5	168.3	6.3	1203.1	3.2
Spongiobranchaea australis	74.3	1.5	2.8	0.6	17.9	0.1
Primno macropa	72.3	3.3	5.6	1.6	46.5	0.2
Tomopteris spp.	61.4	2.0	4.4	0.4	36.1	0.1
Euphausia frigida	58.4	8.1	18.7	0.6	118.7	0.4
Clione limacina	56.4	1.5	3.9	0.2	23.1	0.1
Ostracods	47.5	6.4	14.1	0.0	95.8	0.3
Cyllopus magellanicus	41.6	2.1	6.1	0.0	44.2	0.1
Lepidonotothen larseni (L)	39.6	1.3	5.4	0.0	50.2	0.1
Euphausia superba (L)	37.6	8.6	29.6	0.0	225.6	0.4
Radiolaria	36.6	14.3	133.9	0.0	1353.2	0.7
Cyllopus lucasii	33.7	0.2	0.5	0.0	2.5	0.0
Electrona spp. (L)	23.8	0.3	0.6	0.0	3.6	0.0
Diphyes antarctica	23.8	0.1	0.3	0.0	2.3	0.0
Barnacle (L)	17.8	1.5	4.4	0.0	22.2	0.1
Acanthophyra pelagica	17.8	0.1	0.3	0.0	1.5	0.0
Lepidonotothen kempi (L)	15.8	0.2	0.6	0.0	5.3	0.0
Euphausia frigida (L)	12.9	0.8	3.0	0.0	21.6	0.0
Clio pyramidata spp?	12.9	0.2	1.4	0.0	14.1	0.0
Rhynchonereelia bongraini	12.9	0.2	0.8	0.0	6.0	0.0
Notolepis coatsi (L)	11.9	0.1	0.2	0.0	1.0	0.0
Hyperiella dilatata	11.9	0.0	0.2	0.0	1.5	0.0
Euphausia crystallorophias	10.9	1.0	7.2	0.0	71.7	0.0
Total		2105.1	3012.1	796.3	20588.8	
Taxa	117	21	5	22	34	

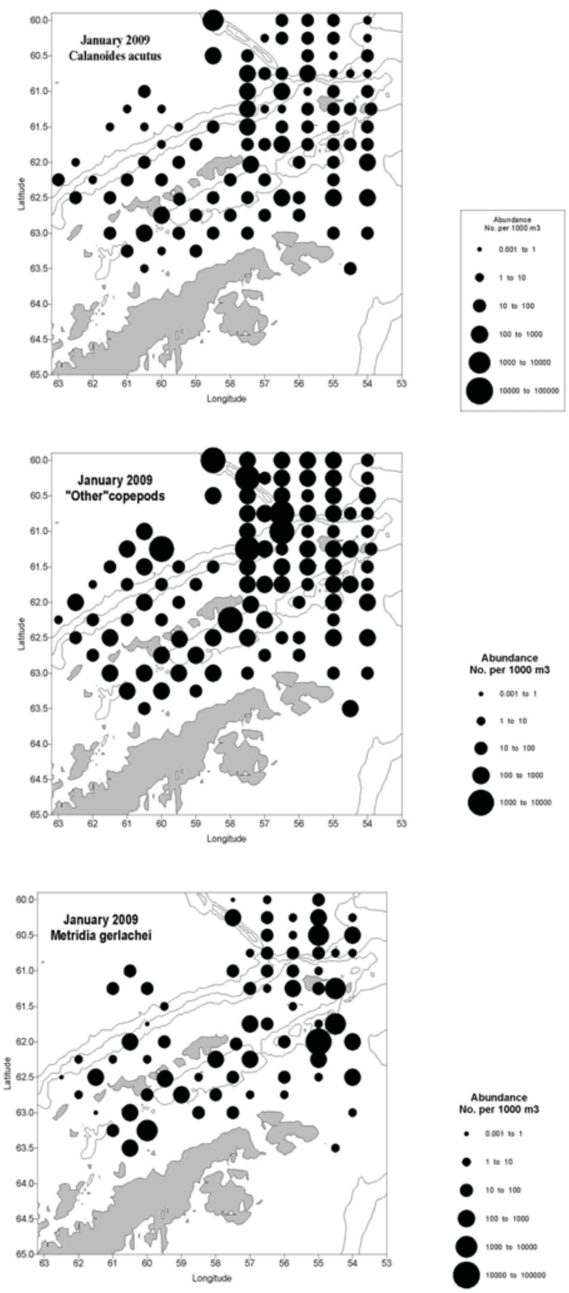

Figure 5.2. Distribution and abundance of (A) *Calanoides acutus*, (B) small unidentified "other" copepod species and (C) *Metridia gerlachei*, January 2009.

T. macrura. Greatest concentrations of *L. helicina* and larval *T. macrura* were offshore of the island shelves while those of chaetognaths were primarily west of the Shackleton Fracture Zone and in the western Bransfield Strait (Figure 5.1D-F). Postlarval krill (*Euphausia superba*) was also relatively abundant (Chapter 4). It was present in 84% of samples and contributed 1% to total mean abundance, ranking as the seventh most abundant taxon overall. The salp *Ihlea racovitzai*, an indicator species for high latitude Weddell Sea shelf water (Loeb et al., 2009), was represented by a total of eight individuals from two stations.

Spatial and Temporal Considerations

Although the four survey areas had relatively similar overall concentrations of zooplankton and nekton (means 1,175-2,478 per 1,000 m^3) they differed greatly in their taxonomic composition and abundance relationships (Table 5.2). *Salpa thompsoni* numerically dominated in the West and Elephant Island Areas, where it constituted 49% and 54% of total mean abundance, respectively. In each area copepod mean abundance was half that of salps and made up an additional 27% and 32%, respectively. In the West Area postlarval *T. macrura* and *L. helicina* followed copepods and salps in mean abundance (together 11%); their counterparts in the Elephant Island Area were larval *T. macrura* and chaetognaths (7%).

In contrast, copepods numerically dominated in the Joinville Island and South Areas, where salps accounted for <4% of total mean abundance. In the Joinville Island Area copepods constituted 83% of total mean abundance (largely due to the extremely large catch of *M. gerlachei*) while *Euphausia crystallorophias* ("ice krill"), *S. thompsoni* and postlarval *T. macrura* constituted another 15%. Postlarval *T. macrura* was present in all South Area samples, ranked second to copepods in mean abundance and constituted 25% of the total while chaetognaths and postlarval krill together contributed another 9%.

Four taxa demonstrated significantly greater abundance in one area than the others: greatest concentrations of *Limacina helicina* and amphipod *Themisto gaudichaudii* were in the West Area (ANOVA, $P<0.01$) while barnacle larvae and sipunculids were most abundant in the Joinville Island Area ($P<0.001$ and $P<0.05$, respectively), reflecting their higher latitude sources.

Concentrations of postlarval *T. macrura* in the South Area were greater than in the Elephant Island and Joinville Island Areas ($P<0.05$). As typical, the larval and postlarval stages of *T. macrura* were distributed with the larvae centered in offshore regions ($T=-0.20$, $P<0.01$; Figure 5.2C,D). Additionally, larval *E. superba* were more abundant in the Joinville Island Area vs. the West and South Areas ($P<0.05$).

In terms of overall taxonomic composition, the West and Elephant Island Area assemblages were most similar (PSI=86) and the South and Joinville Island Area assemblages most different (PSI=9). PSI values from other comparisons are also low (37-44), indicating a high degree of

Table 5.2. The 10 most frequent and/or abundant zooplankton and nekton taxasample in the South Shetland Islands, January 2009. R is rank of mean abundance as numbers per 1,000 m^3. F(%) is frequency of occurrence in (N) samples from each area. N(%) is percent of total mean abundance contributed by each taxon. (L) denotes larval stages.

	West Area (N=23)					Elephant Island Area (N=47)					Joinville Island Area (N=11)					South Area (N=20)				
Taxon	R	F(%)	Mean	STD	N(%)	R	F(%)	Mean	STD	N(%)	R	F(%)	Mean	STD	N(%)	R	F(%)	Mean	STD	N(%)
Copepods	2	100	594.4	1424.3	27.0	2	100	785.6	1000.0	31.7	1	100	1654.3	3740.1	82.9	1	100	644.7	544.3	54.9
"Other" Copepods		100	308.1	605.3			100	400.2	573.7			100	164.5	170.8			95.0	250.7	273.2	
Calanus propinquus		91.3	44.5	63.8			100	78.4	98.8			90.9	17.6	9.4			100	43.7	33.7	
Calanoides acutus		87.0	189.6	798.6			93.6	72.2	150.8			100	138.1	235.6			100	71.6	52.1	
Metridia gerlachei		56.5	24.1	56.0			68.1	152.6	441.6			90.9	1266.6	3605.3			90.0	211.3	353.0	
Rhincalanus gigas		47.8	15.9	42.4			83.0	55.3	116.4			90.9	17.3	16.0			90.0	24.9	25.1	
Pareuchaeta spp.		21.7	8.9	23.6			48.9	20.7	46.4			100	49.6	61.9			85.0	29.4	37.7	
Pleuromama robusta		13.0	0.5	1.7			10.6	4.2	15.7			9.1	0.1	0.4			20.0	0.9	2.9	
Heterorhabdus sp.		8.7	0.3	1.2			4.3	0.2	1.5			0.0	0.0	0.0			5.0	0.3	1.4	
Pareuchaeta antarctica		8.7	0.1	0.5			2.1	0.4	2.6			36.4	0.1	0.2			20.0	0.2	0.6	
Haloptilus ocellatus		4.3	2.5	12.0			14.9	1.2	3.9			18.2	0.3	0.6			20.0	0.2	0.5	
Copepodites		0.0	0.0	0.0			0.0	0.0	0.0			0.0	0.0	0.0			5.0	11.5	50.2	
Themisto gaudichaudii	7	100	41.2	32.1	1.9		93.6	7.3	9.1	0.3		27.3	0.2	0.4	0.0	6	75.0	14.5	37.7	1.2
Vibilia antarctica	10	100	10.7	9.1	0.5	8	93.6	10.7	14.4	0.4		54.5	1.9	3.1	0.1		75.0	1.5	1.5	0.1
Salpa thompsoni	1	95.7	1077.1	1511.1	48.8	1	100	1334.5	2897.4	53.9	3	45.5	72.4	137.6	3.6	5	75.0	46.0	84.9	3.9
Thysanoessa macrura	3	95.7	129.3	139.7	5.9	5	97.9	50.2	50.6	2.0	4	90.9	57.2	86.8	2.9	2	100	288.5	408.3	24.6
Limacina helicina	4	95.7	121.7	139.9	5.5	6	93.6	28.9	48.1	1.2		81.8	5.6	6.6	0.3		80.0	2.7	6.4	0.2
Chaetognaths	8	82.6	20.8	22.6	0.9	4	89.4	76.4	201.8	3.1	6	100	17.7	13.0	0.9	3	100	55.6	71.0	4.7
Euphausia superba		78.3	5.6	6.8	0.3	7	91.5	23.2	74.1	0.9		81.8	1.3	2.2	0.1	4	75.0	52.4	129.4	4.5
Primno macropa		78.3	2.9	4.1	0.1		74.5	4.1	7.4	0.2		36.4	0.6	1.2	0.0		80.0	3.4	2.8	0.3
Tomopteris spp.		78.3	1.6	2.5	0.1		46.8	2.2	5.8	0.1		63.6	2.2	3.3	0.1		75.0	2.1	2.1	0.2
Spongiobranchaea australis		78.3	1.2	1.3	0.1		78.7	2.2	3.7	0.1		72.7	0.7	0.8	0.0		60.0	0.7	1.4	0.1
Thysanoessa macrura (L)	5	65.2	89.5	252.7	4.1	3	87.2	94.0	162.1	3.8	7	81.8	10.8	8.0	0.5	8	90.0	6.1	5.9	0.5
Clione limacina		65.2	3.7	6.1	0.2		46.8	1.2	3.3	0.0		72.7	0.3	0.3	0.0		60.0	0.4	0.5	0.0
Euphausia frigida		56.5	10.2	20.8	0.5		55.3	8.4	20.3	0.3	8	36.4	9.6	20.1	0.5		80.0	4.0	6.7	0.3
Radiolaria	6	43.5	59.7	275.8	2.7		31.9	1.1	2.5	0.0		72.7	1.4	2.0	0.1		20.0	0.0	0.1	0.0
Euphausia spp. (L)	9	43.5	13.4	25.3	0.6	10	48.9	9.9	21.9	0.4		54.5	5.4	8.5	0.3		20.0	0.6	1.3	0.0
Ostracods		30.4	4.1	8.6	0.2		40.4	5.7	15.5	0.2	10	54.5	7.7	12.7	0.4	7	80.0	10.0	15.8	0.8
Lepidonotothen larseni (L)		13.0	2.4	10.2	0.1		25.5	0.5	1.9	0.0		72.7	2.9	4.1	0.1		85.0	1.1	1.8	0.1
Siphonophora (unid)		8.7	0.5	2.4	0.0		23.4	2.1	6.2	0.1		45.5	1.5	2.2	0.1	9	65.0	5.8	7.6	0.5
Euphausia superba (L)		8.7	0.4	1.4	0.0	9	40.4	10.4	27.9	0.4	5	81.8	31.7	62.5	1.6		40.0	1.2	1.9	0.1
Barnacle *(L)*		4.3	0.0	0.2	0.0		8.5	0.3	1.6	0.0	9	72.7	9.5	7.7	0.5		25.0	1.5	4.4	0.1
Limacina spp.		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		27.3	3.1	5.1	0.2	10	30.0	5.0	9.5	0.4
Euphausia crystallorophias (L)		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	2	63.6	79.1	120.2	4.0		15.0	0.6	1.5	0.1
Total			2205.4	2528.5				2477.8	3453.6				1994.4	3894.4				1174.6	939.5	
Taxa			19.0	4.8				19.3	2.9				26.6	4.1				23.1	5.6	

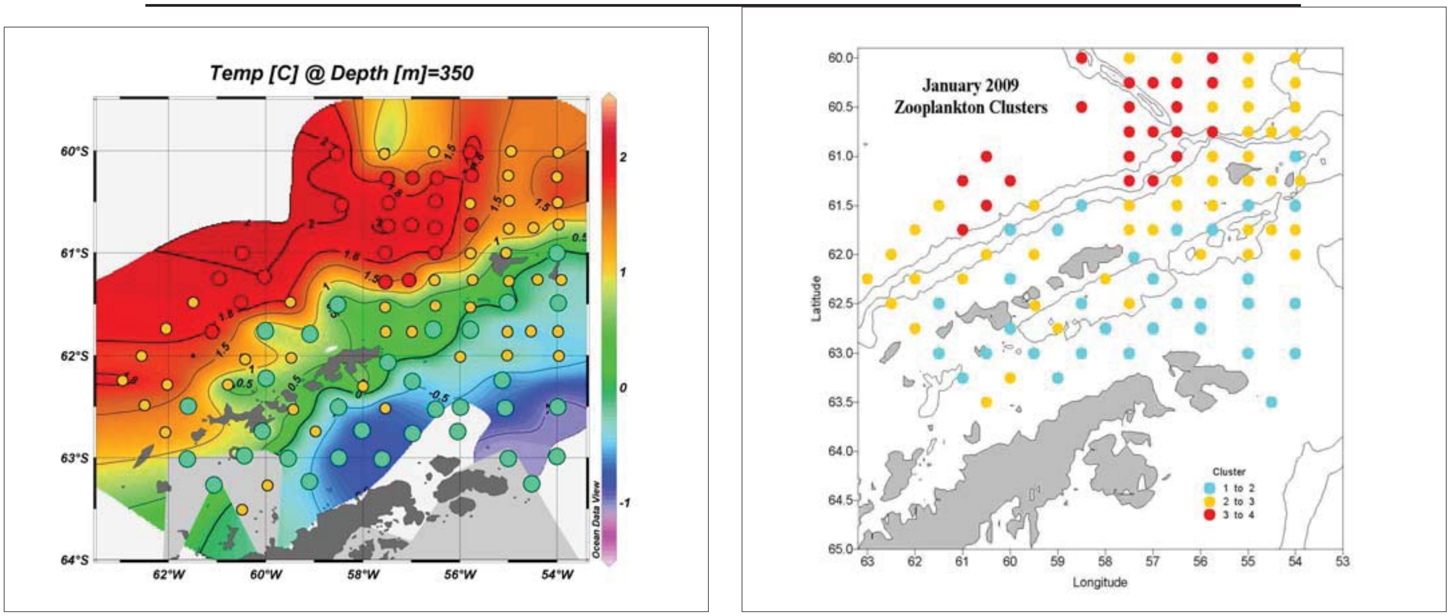

Figure 5.3. Distribution of three zooplankton clusters in relation to hydrography, January 2009. Temperature at 350 m depth indicates the major hydrographic features of this region: the 2°C isotherm denotes core waters of the ACC, 1.8°C isotherm is the southern front of the ACC and 0°C isotherm is the ACC southern boundary.

heterogeneity across most of the region. With respect to copepod taxa, the composition in the Elephant Island Area was most similar to the South and West Areas (PSI=81 and 76, respectively) reflecting shared numerical dominance by "other" species (Table 5.2). Copepods in the Joinville Island Area differed from the rest (PSI=26-56) due to the large catch of *M. gerlachei*.

Despite generally widespread distributions and apparently well-mixed hydrographic conditions, various zooplankton taxa had significantly greater concentrations within certain Water Zones. Concentrations of larval *T. macrura*, *C. acutus*, "other" copepod species, *Hyperiella dilitata*, *Beroe cucumis* and radiolaria at two of the three offshore stations represented by Water Zone I were significantly greater than in all other water types (ANOVA, P<0.01). Larval *T. macrura*, *C. propinquus*, *S. thompsoni*, *Vibilia antarctica* and *L. helicina* concentrations in Water Zone II were significantly greater than in Water Zones III-V (i.e., Transition I, Transition II and Weddell Sea waters; P<0.05). Barnacle larvae and juvenile *Pleurogramma antarcticum* were more abundant in Weddell Sea shelf water vs. other waters (P<0.05).

Diel catch size differences of some species resulted from their vertical migrations into the upper 170 m from greater depths at night. Significantly greater night vs. day concentrations occurred for *Euphausia frigida* and *M. gerlachei* while *S. thompsoni* catches during twilight were greater than during day (P<0.05).

Zooplankton Assemblages

Cluster analysis applied to 23 zooplankton taxa yielded three groupings with spatially coherent distributions. As typical, these clusters generally corresponded to coastal, offshore and intermediate environments (Figure 5.3).

Cluster 1, the more coastal group, occurred at 32 stations within the Bransfield Strait and over the South Shetland Island northern shelves. This was a fairly depauperate assemblage with total mean abundance almost an order of magnitude less than Cluster 3. Copepods dominated, representing 61% of the total. Postlarval *T. macrura* ranked second (20%), followed by chaetognaths and *Themisto gaudichaudii* (9%). The relative abun-

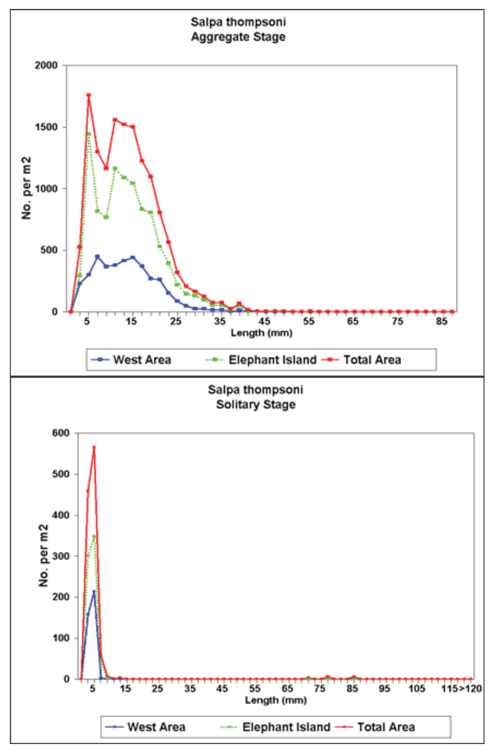

Figure 5.4. Length -frequency distributions of aggregate and solitary stages of *Salpa thompsoni* in the West Area, Elephant Island Area and total survey area, January 2009.

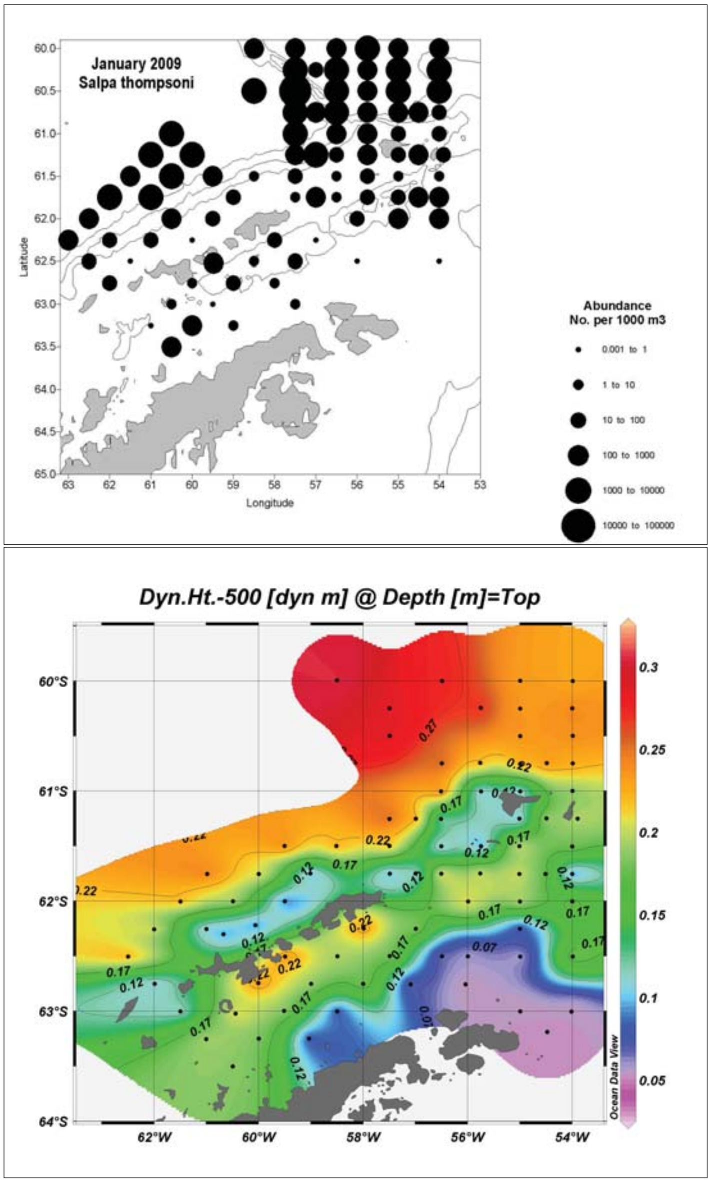

Figure 5.5. Distribution and abundance of *Salpa thompsoni* in relation to implied flow (dynamic height at 500 m relative to the surface) across the survey region. Dynamic height indicates generally northeast flow through the central Bransfield Strait and the Drake Passage, and counter-clockwise flow where the ACC is deflected northward by the Shackleton Fracture Zone.

dance of these latter two taxa suggests an oceanic water influence. Barnacle larvae were significantly more abundant here than in the other clusters reflecting a Weddell Sea shelf water source.

Cluster 2 was the most widespread group, present at 47 stations generally located between Clusters 1 and 3. However, it was also represented in offshore waters to the west and east of Cluster 3 and in a pocket surrounded by Cluster 1 in the eastern Bransfield Strait. Its overall mean abundance values were around twice those of Cluster 1. Copepods dominated and constituted 51% of total mean abundance. Although mean abundance of *S. thompsoni* was an order of magnitude less than in Cluster 3, it was second most abundant, contributing 30% to the total mean abundance. Postlarval *T. macrura* and krill were highly concentrated within this group and followed *S. thompsoni* in abundance. Larval krill were equally represented in Clusters 1 and 2. PSI values were relatively high between Clusters 1 and 2 (68) and 2 and 3 (64) due to overlapping distributions of their component taxa, but the dichotomy between composition of the coastal and offshore groups was indicated by a low PSI of 36.

Cluster 3, represented at 22 predominantly offshore stations, had by far the largest zooplankton concentrations. This was numerically dominated by *S. thompsoni* (58% total mean abundance) and copepods (28%). Larval *T. macrura*, chaetognaths and *L. helicina* were also relatively abundant (10%). With the exception of copepods, the concentrations of these taxa, along with amphipod *Cyllopus magellanicus* and pteropods *Clione limacina* and *Spongiobranchaea australis*, were significantly greater than in the other two clusters (ANOVA, $P<0.05$).

The sexual aggregate (chain) stage comprised 93% of total *S. thompsoni* individuals collected. These ranged from 4-60 mm, but the majority (94%) were immature lengths, <25 mm (Foxton, 1966), and the median length was 14 mm. Given an estimated growth rate of ca. 0.44 mm per day, the length-frequency distribution (Figure 5.4) suggests an onset of seasonal chain production in early October, with major output starting in mid- to late-November and over half of the chains released within the past month (i.e., mid-December) which is unusually late.

Solitary individuals were 4-113 mm, but 98% were < 9 mm resulting from recent release of embryos by sexually reproductive aggregates. The overall stage composition and length-frequency distributions were similar in the West and Elephant Island Areas, where the vast majority of salps occurred. In the Bransfield Strait, where fewer salps were found, there was less evidence of recent chain production. In the Joinville Island Area, 20% of the aggregates were reproductive size, >25 mm, and 14% of total salps were recently released solitary forms. In the South Area, nearly half of the solitaries were large reproductive forms, >75 mm in length, and 22% of the aggregates had been produced nearly two months earlier.

These results suggest that bloom conditions (i.e., explosive budding of aggregate chains by large overwintering solitary forms) were restricted to offshore waters and/or that the bloom would occur even later inshore. In contrast to most years, cluster analysis did not yield any spatially coherent aggregate size groups. Similar to zooplankton distribution, this is likely due to the unusually complex hydrographic conditions.

As noted above, the distribution of *S. thompsoni* was linked to the ACC; highest salp concentrations were found in Type III (Transition) water. The dynamic height plot in Figure 5.5, indicating implied flow at 500 m relative to the surface, shows a correlation between the northeasterly water flow and the off-shore distribution of salps, as well as an association between large salp concentrations and current deflection over the Shackleton Fracture Zone. Northeastward flow also explains the relatively homogeneous salp size and stage composition across the West and Elephant Island Areas.

Discussion

The overall taxonomic composition of zooplankton and nekton sampled during January 2009 was typical for the region and reflected overlapping distributions of taxa affiliated with oceanic and coastal environments. As usual, the absolute and relative abundance of taxa differed greatly from other years due to interannual variability in abundance of taxa resulting from hydrographic and atmospheric processes (Loeb et al., 2009). The most notable feature was numerical dominance of *S. thompsoni*, which has been relatively scarce since 2005. Mean abundance of *S. thompsoni* in the Elephant Island Area was three times greater than the long-term mean (Figure 5.6). This marks a dramatic abundance shift from extremely low concentrations observed in 2008.

Copepod abundance, like most other years, was significantly lower than the peaks observed in January 2002 and (lacking an earlier survey) February 2000. However, the Elephant Island Area concentrations were similar to those

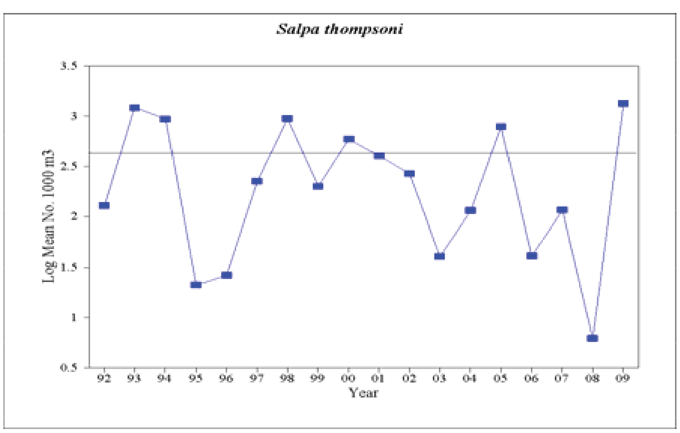

Figure 5.6. Inter-annual abundance of zooplankton *S. thompsoni*, 1992-2009.

from the previous two years, only slightly below the long-term mean and substantially larger than prior years of high salp abudance.

Among other typically abundant taxa, the concentrations of *Euphausia frigida*, postlarval and larval *T. macrura*, and chaetognaths were close to their long-term means. *L. helicina* abundance in 2009 was about average, but it is important to note that this species experiences high inter-annual variability. In contrast to previous years of high salp productivity, *I. racovitzai* was essentially absent. The total mean zooplankton abundance in the Elephant Island Area (2,478 per 1,000 m^3) was slightly above the long term average (2,238 per 1,000 m^3) and considerably higher than average concentrations recorded during 1993-1999 surveys.

Cluster analysis of AMLR zooplankton data typically yields three more-or-less spatially coherent groups conforming to coastal, offshore and intermediate assemblages. The messy pattern observed during January 2009 was unusual and suggests greater than normal hydrographic complexity. A similarly mixed zooplankton distribution was observed during the January 1998 survey (Loeb et al., 1998). Hydrographic conditions then were reported to be more variable and with less distinct zonation than usual (Amos et al., 1998). While the 1998 period, as well as the 1994 and 2005 salp-dominated years, were marked by El Niño events and negative Southern Oscillation Index (SOI) values (Loeb et al., 2009) the 2008-2009 period was characterized by weak La Niña conditions and positive SOI values suggesting a different atmospheric-hydrographic process underlying the 2009 salp-dominated year. The fact that record numbers of small *S. thompsoni* were also reported from the West Antarctic Peninsula (Doug Martinson and Debbie Steinberg, pers. comm.) and dense salp concentrations were observed downstream in the Scotia Sea (Angus Atkinson, pers. comm.) during January-March 2009 indicates that this was not a localized phenomenon. One feature that stands out is that strong northwest winds prevailed off the Antarctic Peninsula for much of 2008, as indicated by an average speed of 4.84 ±2.37 m/s, well above the annual mean of 3.65±0.87 m/s for 1997-2008. The hydrographic complexity noted this year may well have resulted from enhanced wind-driven mixing throughout the preceding year; this somehow proved favorable for chain production by *S. thompsoni*.

Despite the huge reproductive output by the *S. thompsoni* solitary stage, the relatively narrow length range and preponderance of small recently budded aggregates observed in January 2009 suggest a seasonally lagged production period compared to other years (Figure 5.7). The

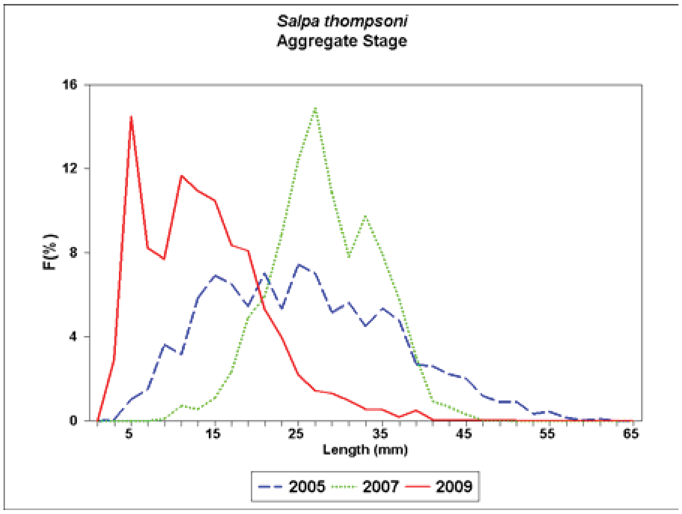

Figure 5.7. Length-frequency distributions of *S. thompsoni* aggregates during January 2005, 2007 and 2009, to demonstrate interannual variability in seasonal production by the overwintering solitary stage. During the 2005 year of high salp abudance, production started in early to mid-September with elevated production between early November and late December. Elevated chain production began almost a month later in spring 2008.

small body size minimized salp catch volume and carbon biomass associated with elevated abundance compared to other years of high salp production.

Like the overall zooplankton assemblage, the component taxa making up the copepod assemblage exhibit a great deal of interannual variability. During January 2009 the numerical dominance by small unidentified copepods differed from the previous eight years. *Metridia gerlachei* typically is the most abundant copepod in the Elephant Island Area in terms of mean concentrations due to its patchy distribution and extremely large numbers in a few samples. However, its mean value this year ranked second while its median value rivaled the lows observed during 2003 and 2005 AMLR Surveys. The widespread distribution of moderate concentrations of *C. acutus*, *C. propinquus* and *R. gigas* in 2009 reflects the ACC influence and mixing of ACC-derived waters in the Elephant Island Area.

Protocol Deviations

There were no changes to standard sampling and analytical techniques used during AMLR fieldwork.

Disposition of Data

Data and samples are available from Christian Reiss, NOAA Fisheries, Antarctic Ecosystem Research Division, 3333 Torrey Pines Court, Room 412, La Jolla, CA 92037. Ph: 858-546-7127, FAX: 858-546-5608

Acknowledgements

It was wonderful to once again enjoy the facilities and personnel of the R/V *Yuzhmorgeologiya*. Captain Sasha was superb in his command of the ship and crew and in his positive interactions with the scientific party! Thanks to the krill and zooplankton team members who also helped out with phytoplankton sample collection and analysis, and to the AMLR "Family" members who worked hard together in such a harmonious and congenial manner! Again, it was quite satisfying to have the Santora-Force underway bird and mammal team keeping us informed of the exciting wildlife that surrounds us while we toil way below decks.

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Seabird Research at Cape Shirreff, Livingston Island, Antarctica, 2008-09

Kevin W. Pietrzak, James H. Breeden, Aileen K. Miller and Wayne Z. Trivelpiece

Abstract Land-based seabird data were collected during the Antarctic breeding season, October 24, 2008 through March 6, 2009. Results from the research period include:

- The gentoo chick count was 1,010 chicks, 86% higher than the 2007-08 count but only 6% higher than the previous 12-year mean.
- The chinstrap chick count was 4,332 chicks, 282% higher than the 2007-08 count but still 33% lower than the previous 12-year mean.
- Diet samples were collected from 20 gentoo and 40 chinstrap penguins between 6 January and 10 February 2009. 100% of the gentoo penguin diet samples contained evidence of fish, and 42% of chinstrap penguin diet samples contained evidence of fish. Antarctic krill (*Euphausia superba*) comprised the majority of diet in 100% of chinstrap penguin samples and 68% of gentoo penguin samples.

Introduction

The U.S. Antarctic Marine Living Resources (AMLR) program conducted its 12th field season of land-based seabird research at the Cape Shirreff field camp on Livingston Island, Antarctica (62º 28'S, 60º 46'W), during the austral summer of 2008-09. Cape Shirreff is a Site of Special Scientific Interest; long-term monitoring of predator populations are conducted in support of US participation in the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR).

The objectives of the seabird research program for the 2008-09 season were the following, according to the CCAMLR 2004 long-term monitoring protocol:

1. To estimate chinstrap (*Pygoscelis antarctica*) and gentoo penguin (*P. papua*) breeding population size (Std. Method A3);
2. To band 500 chinstrap and 200 gentoo penguin chicks for demography studies (Std. Method A4);
3. To determine chinstrap penguin foraging trip durations during the chick rearing stage of the reproductive cycle (Std. Method A5);
4. To determine chinstrap and gentoo penguin breeding success (Std. Methods 6a,b&c);
5. To determine chinstrap and gentoo penguin chick weights at fledging (Std. Method 7c);
6. To determine chinstrap and gentoo penguin diet composition, meal size, and krill length-frequency distributions (Std. Methods 8a,b&c); and
7. To determine chinstrap and gentoo penguin breeding chronologies (Std. Method 9).

Methods

We arrived at Cape Shirreff on 24 October 2008 via the National Science Foundation vessel R/V *Laurence M. Gould*. We conducted research until we closed camp on 7 March 2009. The AMLR chartered vessel R/V *Yuzhmorgeologiya* provided logistical support and transit back to Punta Arenas, Chile at the field season's conclusion.

Breeding biology

We conducted nest censuses for gentoos on November 12, 2008 and for chinstraps on 29 November 2008, approximately one week after mean clutch initiation for each species. Chick censuses were conducted for gentoo penguins on 20 January 2009 and for chinstrap penguins on 6 February 2009, approximately one week after mean crèche.

Reproductive success was also measured by following a sample of 50 pairs of breeding gentoo penguins and 100 pairs of breeding chinstrap penguins from clutch initiation through to crèche formation (Std. Methods 6b). Because chick mortality is typically low following crèche, these numbers are also an estimate of fledging success

Fledging weights were collected from chinstrap penguin chicks as a measure of chick condition. Chinstrap penguin fledglings were caught on the beaches just before fledging, between 18 and 26 February 2009.

In addition to penguins, the breeding success of all skuas at Cape Shirreff and nearby Punta Oeste was followed During the breeding season. The reproductive performance of kelp gulls (*Larus dominicanus*) nesting on Cape Shirreff was also followed throughout the season.

Foraging Ecology

Diet samples were collected from 20 gentoo and 40 chinstrap penguins between 6 January and 10 February 2009. Adults were captured at their nest sites upon returning from foraging trips, to assure they were feeding chicks, and the total stomach contents were collected using the wet-offloading technique (Wilson 1984). A sub-sample of 50 individual Antarctic krill from each diet sample were measured and sexed to determine length and sex frequency distributions of the krill selected by foraging penguins.

Radio transmitters were deployed on 18 breeding adult chinstrap penguins during the chick rearing phase in order to determine their foraging trip durations. Colony attendance was logged between 7 January 2009 and 1 March 2009 using a remote receiver and data collection computer.

Gentoo and chinstrap penguins were also instrumented with satellite transmitters (PTTs), to provide geographic data on adult foraging locations during the chick rearing period. Twenty-six PTTs were deployed during the brooding phase for each species: 10 on gentoo penguins in late December and 16 on chinstrap penguins in early and mid January. Nineteen PTTs were deployed during the crèche phase for each species: 10 on gentoo penguins and nine on chinstrap penguins in late January and early February, respectively.

Time-depth recorders (TDRs) were also attached to chinstrap and gentoo penguins to collect penguin diving behavior data during the chick-rearing period. Twenty-four TDRs were deployed while these adults were brooding chicks: 10 on gentoo penguins in early January and 14 on chinstrap penguins in late December to mid January. Twenty TDRs were deployed during the crèche phase, when nests are unattended and both parents forage simultaneously: 10 on gentoo penguins in mid January and 10 on chinstrap penguins in early February.

All data were collected according to the Standard Methods delineated in the CCAMLR Ecosytem Monitoring Program: Standard Methods (2004).

Results

Breeding biology

The penguin rookery at Cape Shirreff consisted of 19 sub-colonies of gentoo and chinstrap penguins during the 2008-09 breeding season. A total of 879 gentoo penguin nests were counted (Figure 6.1), a 44% increase from last year's census. This count represents an 8% increase over the previous 11-year average and is the highest since the 2001-02 season. A total of 4,026 chinstrap penguin nests were counted. While this is a 33% increase from last year's census, it is still 32% lower than the previous 11-year average of 5,958. This count could be interpreted as a rebound from last year's very low nest census but still represents a general trend of decline in the chinstrap penguin breeding population at Cape Shirreff.

The gentoo chick count was 1,010 chicks, 86% higher than the 2007-08 count but only 6% higher than the previous 12-year mean (Figure 6.1). The chinstrap chick count was 4,332 chicks, 282% higher than the 2007-08 count but still 33% lower than the previous 12-year mean (Figure 6.2).

Based on census data, overall gentoo penguin fledging success was 1.15 chicks/nest. This is 3% lower than the previous 11-year mean. Overall chinstrap penguin fledging success was 1.08 chicks/nest. This is 7% higher than the previous 11-year mean. Based on data from our reproductive study, gentoo penguins fledged 1.34 chicks/nest and chinstrap penguins fledged 1.16 chicks/nest.

Nests of known-age penguins that initiated clutches were also followed to crèche. Thirty-three known-age gentoo penguin nests (at least one member of the pair was of known age) fledged 0.67 chicks/nest. Thirty-three known-age chinstrap penguin nests fledged 0.79 chicks/nest.

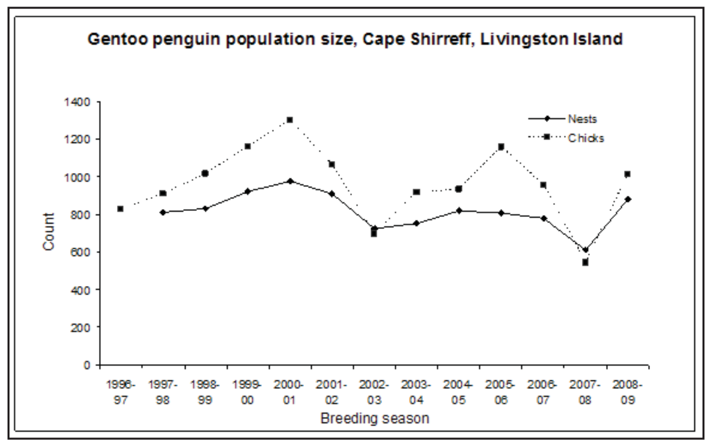

Figure 6.1. Gentoo penguin population size during breeding season at Cape Shirreff, Livingston Island, Antarctica, 1996-97 to 2008-09.

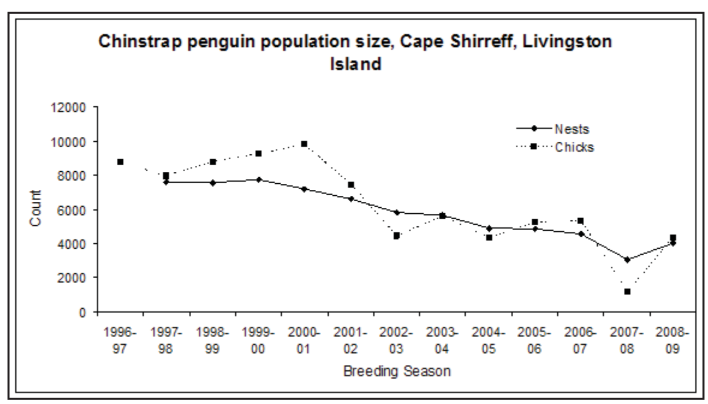

Figure 6.2. Chinstrap penguin population size during breeding season at Cape Shirreff, Livingston Island, Antarctica, 1996-97 to 2008-09.

A sample of 200 gentoo and 500 chinstrap penguin chicks was banded for future demographic studies. The banded chicks that survive and return to the colony as adults will be observed for age-specific survival and reproductive success.

Fledging chicks had an average mass of 3,245 g (n = 304; S.D. = 354). This is slightly higher (4%) than the previous 12-year mean. Gentoo penguin chicks are usually weighed 85 days after their mean clutch initiation date; approximately the age at which other *Pygoscelis sp.* chicks fledge. However, conditions at the colony did not allow us to collect gentoo penguin chick weights at this time, so fledge weights are not available for the 2008-09 field season.

There were 25 skua pairs holding breeding territories, all of which were brown skuas (*Catharacta lonnbergi*) with the exception of one pair, which are likely hybrid brown-South Polar skuas (*C. maccormicki*). Clutches were initiated by 16 pairs of skuas, and overall fledging success was 0.52 fledglings/pair. This is 30% lower than the previous 11-year average. Kelp gulls initiated 40 nests; overall fledging success was 0.95 fledglings/pair.

Foraging ecology

Antarctic krill (*Euphausia superba*) was present in samples and comprised the majority of diet in 100% of chinstrap penguin samples and 68% of gentoo penguin samples. Fish was the next largest component, while squid and other marine invertebrates represented <1% of penguin diets.

During the 2008-09 season, 100% of the gentoo penguin diet samples contained evidence of fish. This is the third consecutive year of our study in which all gentoo penguin diet samples contained evidence of fish. Previous to that only 75% of gentoo diet samples contained evidence of fish. Similarly, 42% of chinstrap penguin diet samples contained evidence of fish, which is higher than the previous 11-year average of 30%. Still, fish represented 25% of the gentoo penguin diet by mass and <1% of the chinstrap penguin diet by mass.

Krill in gentoo penguin samples were larger on average (48 ± 6 mm) than krill in chinstrap penguin samples (43 ± 5 mm) (Figure 6.3). Penguin diets were composed of 4% juvenile krill (those less than 36 mm in length), 58% males and 38% females (Figure 6.4).

The average chick meal mass for chinstrap penguins was 660 g; this is 8% higher than the previous 11-year mean of 611 g. The ratio of fresh to digested portions in the chinstrap penguin's diet samples was comparable to the previous nine seasons. We only collected the fresh portion of diet samples from gentoo penguins, so chick meal mass was not evaluated.

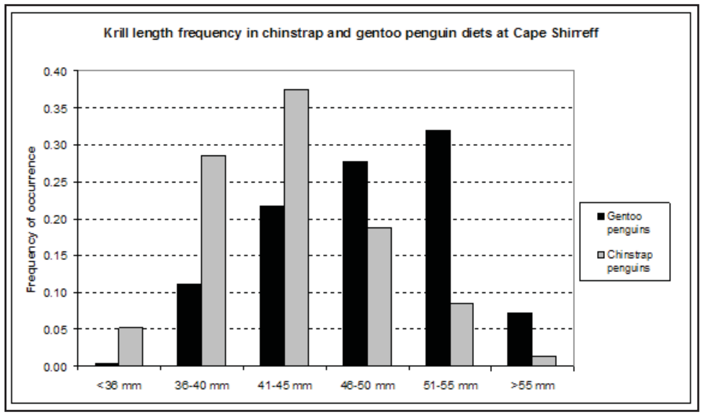

Figure 6.3. Krill length-frequency distribution in gentoo and chinstrap penguin diet samples at Cape Shirreff, Livingston Island, Antarctica, 2008-09.

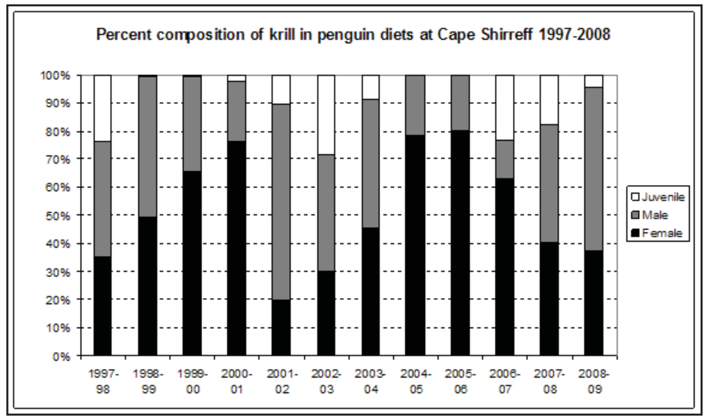

Figure 6.4. Demographic composition of Antarctic krill (Euphausia superba) in gentoo and chinstrap penguin diet samples at Cape Shirreff, Livingston Island, Antarctica, 1997-98 to 2008-09.

Chinstrap penguin foraging trips averaged 14.2 ± 3.4 hr. PTT and dive data for both chinstrap and gentoo penguins are awaiting analysis.

Discussion

Our 12th season of seabird research at Cape Shirreff allows us to assess trends in penguin population size, as well as inter-annual variation in reproductive success, diet and foraging behavior.

Breeding population counts and reproductive success of both gentoo and chinstrap penguins were significantly higher then last year's counts. Gentoo penguin nest and chick censuses were the highest seen in seven years. While there was an increase from last year, overall the chinstrap breeding population at Cape Shirreff has continued to decline. Fledging weights for chinstraps were comparable to the previous 11-year average.

Diet composition of both species was comparable to previous seasons; all gentoo penguin samples contained fish and overall the samples contained a relatively high proportion of male krill. Gentoo penguins on average took larger krill than chinstrap penguins. The interpretation of these diet patterns may be aided by analysis of foraging location and diving behavior data.

Protocol Deviations

There were no deviations from the protocol, as described in the CCAMLR Ecosystem Monitoring Program: Standard Methods (2004).

Disposition of Data

Land-based seabird data are available from Dr. Wayne Trivelpiece, NOAA Fisheries, Antarctic Ecosystem Research Division, 3333 N. Torrey Pines Ct, La Jolla, CA 92037. Ph: 858-546-5607, FAX: 858-546-5608

Acknowledgements

We would like to sincerely thank Scott Freeman, Ryan Burner, Mike Goebel, Douglas Krause, Carolina Bonin, and Raul Vasquez Del Mercado for their invaluable assistance and companionship in the field. We are grateful to the crew of the NSF research vessel R/V *Laurence M. Gould* for our smooth transit to Cape Shirreff and for their help with camp opening, and to the crew of the AMLR chartered research vessel R/V *Yuzhmorgeologiya* for their efforts in resupplying our camp and for providing transit back to Punta Arenas, Chile.

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Pinniped research at Cape Shirreff, Livingston Island, Antarctica, 2008/09

Michael E. Goebel, Douglas Krause, Scott Freeman, Ryan Burner, Carolina Bonin, Raul Vasquez del Mercado, Amy Van Cise, and Jennifer Gafney.

Abstract Field biologists researched Antarctic fur seals, elephant seals and leopard seals at Cape Shirreff, Livingston Island between 24 October 2008 and 7 March 2009. The results of this field season include:

- The estimated number of total pups born (live plus cumulative dead) for the U.S. AMLR study site in 2008/09 was 1,569 (st. dev. = 4.6). Our count this year represents a 13.3% reduction in pup production over 2007/08.
- An estimated 46.2% of pups were lost to leopard seals by mid-February.
- Most scats, 94.0% (94/100) of those collected, contained krill. In addition, 1,851 otoliths were collected from 34.0% of the scat samples.
- The mean foraging trip duration for attending females' first six trips to sea was 2.70 days (±0,17).

Introduction

As upper trophic level predators, pinnipeds are a conspicuous component of the marine ecosystem around the South Shetland Islands. They respond to spatio-temporal changes in physical and biological oceanography and, in the case of Antarctic fur seals, are directly dependent upon availability of krill (*Euphausia superba*) for maintenance, growth, and reproduction during the austral summer. Because of their current numbers and their pre-exploitation biomass in the Antarctic Peninsula region and Scotia Sea, Antarctic fur seals are recognized to be an important "krill-dependent" upper trophic level predator. The general objectives for U.S. AMLR pinniped research at Cape Shirreff (62°28'S, 60°46'W) are to monitor population demography and trends, reproductive success, and status of pinnipeds throughout the summer months. The Antarctic fur seal, *Arctocephalus gazella*, is the most abundant pinniped at Cape Shirreff and our studies are focused to a large degree on the foraging ecology, diving, foraging range, energetics, diet, and reproductive success of this species.

The 2008/09 field season began with the arrival at Cape Shirreff of a five person field team via the R/V *Laurence M. Gould* on 24 October 2008. Research activities were initiated soon after and continued until closure of the camp on 7 March 2009. Our specific research objectives for the 2008/09 field season were to:

- Monitor Antarctic fur seal female attendance behavior (time at sea foraging and time ashore attending a pup);
- Monitor pup growth collecting mass measures for a random sample of 100 fur seal pups every two weeks throughout the research period, beginning 30 days after the median date of births;
- Document the phenology of fur seal pup production at designated rookeries and estimate total pup production on Cape Shirreff;
- Collect and analyze fur seal scat contents on a weekly basis to document trophic interactions and the timing and incidence of prey switching;
- Collect a milk sample at each adult female fur seal capture for fatty acid signature analysis as an independent non-biased measure of trophic interactions between fur seals and their prey;
- Deploy time-depth recorders on adult female fur seals for diving and at-sea foraging studies;
- Record at-sea foraging locations for adult female fur seals using GPS or ARGOS satellite-linked transmitters (most deployments coincidu with the U.S. AMLR Survey);
- Tag 500 fur seal pups for future demographic studies;
- Re-sight tagged known-aged animals for population demography studies;
- Monitor over-winter survival and natality of the tagged adult female population of fur seals;
- Extract a lower post-canine tooth from tagged adult female fur seals for aging studies;
- Deploy a weather station for continuous recording of wind speed, wind direction, ambient temperature, humidity and barometric pressure during the study period;
- Record any pinnipeds carrying marine debris (i.e., entanglement);
- Record any other tagged pinnipeds observed on the Cape;

- Capture, tag and instrument leopard seals for studies of top-down control of fur seal and penguin populations;
- Monitor pup production of southern elephant seals breeding at Cape Shirreff; and
- Deploy over-winter CTD-PTT instruments on 12 adult female southern elephant seals to monitor temperature and salinity profiles of the Southern Ocean along migration routes and in their foraging areas.

Methods

Female Fur Seal Attendance Behavior

Lactation in otariid females is characterized by a cyclical series of trips to sea and visits to shore to suckle their offspring. The sequential sea/shore cycles are commonly referred to as attendance behavior. Measuring changes in attendance behavior (especially the duration of trips to sea) is one of the standard indicators of a change in the foraging environment and availability of prey resources. Generally, the shorter the duration of trips to sea, the more resources a female can deliver to her pup during the period from birth to weaning.

We instrumented 30 lactating females from 4-13 December 2008. Twenty-nine of these were females with a single pup and one was a female suckling two pups (this female was excluded from estimates of trip duration). The study was conducted according to CCAMLR protocol (CCAMLR Standard Method C1.2 Procedure A) using VHF radio transmitters (Advanced Telemetry Systems, Inc., Model 7PN with a pulse rate of 40 ppm). Standard Method C1.2 calls for monitoring of trip durations for the first six trips to sea. All females were instrumented zero to two days post-partum (determined by the presence of a newborn with an umbilicus) and were left undisturbed for at least their first six trips to sea. Pups were captured at the same time as their mothers, and were weighed, measured, and marked with an identifying bleach mark. The general health and condition of the pups was monitored throughout the study by making daily visual observations. Presence or absence on shore was monitored for each female every 30 minutes for 30 seconds for the first six trips to sea using a remote VHF receiving station with an automated data collection and storage device. Data were downloaded weekly. Daily visual observations of instrumented females were conducted to validate automated data collection and to confirm proper functioning of the remote system.

Fur Seal Pup Growth

Measures of fur seal pup growth were collected every 15 days. At least 50 pups of each sex were weighed for each sample. The first sample of weights were initiated 30 days after the median date of pupping (4 Dec 2008) and the last sample was taken 18 February (four bi-weekly samples; collection dates: 3 Jan, 18 Jan, 2 Feb, and 18 Feb 2009).

Fur Seal Pup Production

Fur seal pups (live and dead) and females were counted by U.S. researchers at four main breeding beaches on the east side of the Cape, which comprise the U.S.-AMLR study site. Censuses for pups (live and dead) were conducted every other day from 2 November through 31 December. Only recently dead pups are counted at each census.

Neonate mortality is defined as pup mortality occurring from the start of the breeding season (~15 Nov) until up to one month after the median date of pupping (6 January). It occurs before the start of leopard seal predation (~early-January). It is measured by recording the number of new pup carcasses on our census beaches at each count and calculating a cumulative mortality every other day (i.e. at each census) from the start of births (this year 15 November) until the last of pupping (early January).

To estimate the extent of leopard seal predation on neonates we calculated the loss of pups from our tagged population of females. We assumed that once pups survived to one month of age, their disappearance was due to leopard seal predation. We included only females whose pup status could be confirmed, excluding female/pup pairs whose status was uncertain.

Diet Studies

Information on fur seal diet was collected using three different sampling methods: collection of scats, enemas, and fatty acid signature analysis of milk. In addition to scats and enemas, an occasional regurgitation is found in female suckling areas. Regurgitations often provide whole prey that is only minimally digested. Scats are collected from around suckling sites of females or from captured animals that defecate while captive. In addition to diet information from captive animals, ten scats were collected opportunistically from female suckling sites every week beginning 18 December. The weekly scat samples are collected by systematically walking transects of female suckling areas and collecting any fresh scats within a short range of the observer. This method prevents any bias associated with the difference in visibility between krill laden scats, which are bright pink, and fish laden scats, which are gray to brown, and blend in with the substrate more easily.

In total, we collected and processed 100 scats from 18 December 2008 through 23 February 2009. Diet samples that could not be processed within 24 hours of collection were frozen. All samples were processed by 26 February. Up to 25 krill carapaces were measured from each sample that contained krill. A total of 2,267 krill carapaces were measured according to Goebel et al. 2007. Discriminant equations determined sex and age class, after which independent regression equations for juvenile, male and female lengths were applied. Otoliths were sorted, dried, and identified to species. Squid beaks were counted and preserved in 70% alcohol for later identification.

Fatty Acid Signature Analysis of Milk

In addition to scats, we collected 90 milk samples from 60 female fur seals. Each time a female was captured (either to instrument or to remove instruments), ≤30 mL of milk was collected by manual expression. Prior to collection of the milk sample, an intra-muscular injection of oxytocin (0.25 mL, 10 UI/mL) was administered. Milk was returned (within several hours) to the lab where two 0.25 mL aliquots were collected and each stored in a solvent-rinsed glass tube with 2 mL of chloroform with 0.01% butylated hydroxytoluene (BHT, an antioxidant). Samples were flushed with nitrogen, sealed, and stored frozen until later extraction of lipid and trans-esterification of fatty acids.

Diving Studies

Nine of 29 females outfitted with transmitters for attendance studies also received a time-depth recorder (TDR, Wildlife Computers Inc., Mark 9s, 66 x 18 x 18mm, 31g, N=7; Mk-10: N=2) on their first visit to shore. All females carried their TDRs for at least their first six trips to sea. In addition, three more females captured for studies of at-sea foraging locations in December brought the total number of females with GPS-TDRs or ARGOS PTTs to 11. A total of 20 dive records were collected from 18 females in 2008/09. No TDRs were lost this season.

Adult Female Foraging Locations

We instrumented 11 females with GPS (Global Positioning System) TDRs (Mk10-F; Wildlife Computers, Inc.) with fast-loc technology. Three females carried both an Mk10-F and an ARGOS satellite-linked transmitter (SPOT5; Wildlife Computers, Inc.). The first five of these deployments were from 18 December – 27 January.

Demography and Tagging

We tagged 500 fur seal pups (259 females, 239 males, two unknown) from 2 February to 1 March 2009. All tags used at Cape Shirreff were Dalton Jumbo Roto or Flexi tags with white tops and orange bottoms. Each pup was tagged on both fore-flippers with identical numbers. Series numbers for 2008/09 were 6001-6500 (the sex for tags 6140 and 6224 was recorded as uncertain).

In addition to the 500 pups tagged, we also added fourteen new tags to the adult female population (432-445).

Age Determination Studies

We began an effort of tooth extraction from adult female fur seals for age determination in 1999/00. Tooth extractions are made using gas anesthesia (isoflurane, 2.5-5.0%), oxygen (4-10 liters/min), and midazolam hydrochloride (1cc). A detailed description of the procedure was presented in the 1999/00 annual report. This year we took a single post-canine tooth from 16 adult females.

Weather at Cape Shirreff

A weather data recorder (Davis Weather Monitor II) was set up at the U.S.-AMLR field camp at Cape Shirreff from 26 October 2008 to 28 February 2009. The recorder archived wind speed and direction, barometric pressure, temperature, humidity, and rainfall at 15-minute intervals. The sampling rate for wind speed, temperature, and humidity was every eight seconds; the averaged value for each 15-minute interval was stored in memory. Barometric pressure was measured once at each 15-minute interval and stored. When wind speed was greater than 0, the wind direction for each 8-second interval was stored in one of 16 bins corresponding to the 16 compass points. At the end of the 15-minute archive interval, the most frequent wind direction was stored in memory.

Entangled pinnipeds

We recorded one adult male fur seal with marine debris around its neck. The debris was identified as plastic line. Attempts to remove the debris failed.

Other pinnipeds: leopard seals

To better understand the role of Leopard seals within the region and their influence on krill-dependent predators we began a study of foraging range and dispersal. In 2008/09, we captured and instrumented two Leopard seals with Mk9 time depth recorders (Wildlife Computers. One of the two was successfully retrieved without recapture and had recorded over a month of diving behavior. No leopard seals were instrumented with ARGOS PTTs (Platform Terminal Transmitter) in 2008/09.

Other pinnipeds: Southern elephant seals

U.S. AMLR, in collaboration with University of California researchers, instrumented 12 adult female elephant

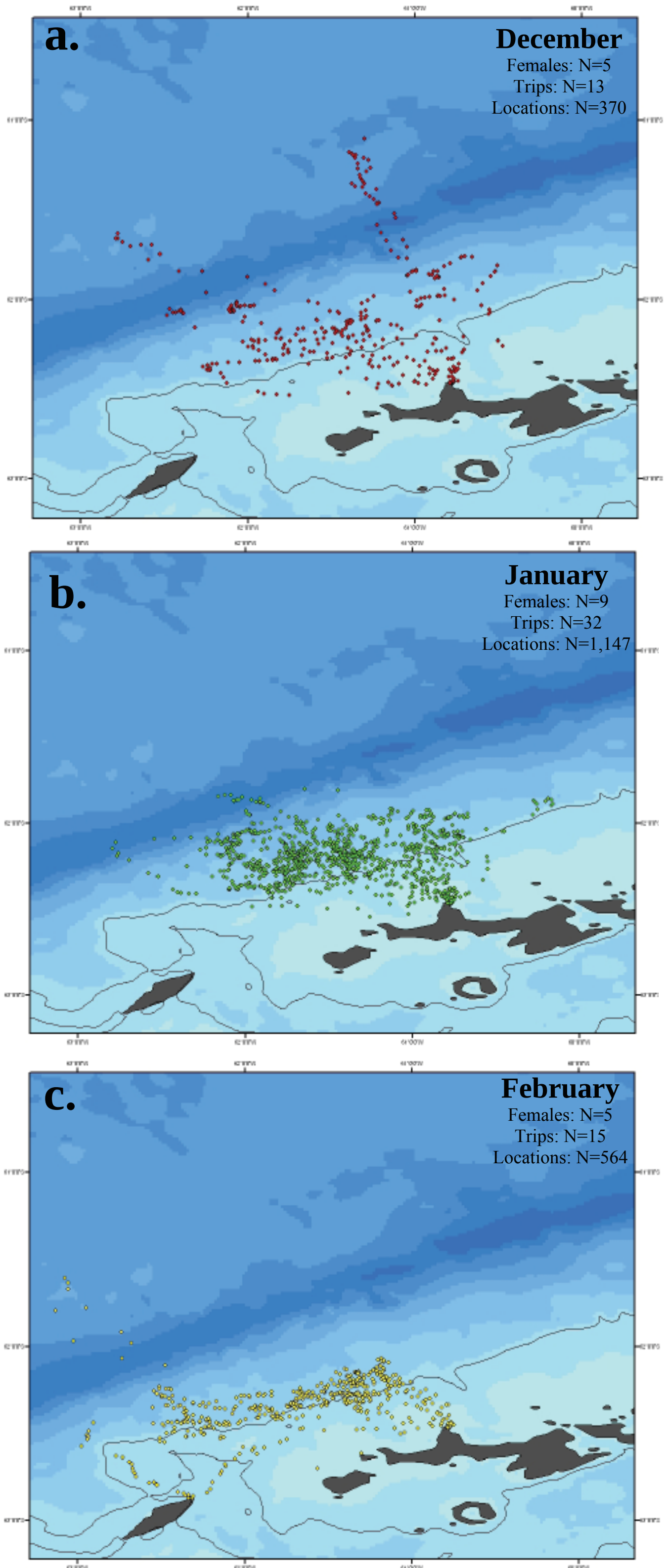

Figure. 7.1. At-sea locations of lactating Antarctic fur seals in a) December (red), b) January (green), and c) February (yellow) foraging from Cape Shirreff, Livingston Island, South Shetland Islands, 2008/09. The 500 m bathymetry is outlined to show the location of the continental shelf edge.

seals with ARGOS satellite-linked CTD-PTT transmitters for post-molt dispersal at sea. In addition, U.S. AMLR personnel captured and weighed 33 elephant seal pups within 48 hours of weaning. A total of 34 pups were born on Cape Shirreff (33 live, one dead) and an additional six were born on a small sandy point between Cape Shirreff and Punta Oeste. Thirty-one of the 39 pups sexed were male.

Results

A total of 53 trips to sea were recorded with GPS and ARGOS instruments for three sampling periods (December, January, February) in 2008/09. The tracklines of those trips are in the process of being analyzed, and can be seen in Figure 7.1.

The first female in our study to begin her foraging cycles did so on 10 December. All females had completed six trips to sea by 24 January. Four females lost their pups before completion of six trips to sea. The mean trip duration for the first six trips to sea was 2.70 days (±0.17, NFemales=29, NTrips=168, range: 0.33-5.35). There was no significant difference in duration for the first six trips (ANOVA: F5,165 =0.32, P=0.899; Figure 7.2). The mean duration for the first six non-perinatal visits was 1.70 days (±0.12, NFemales=29, NVisits=163, range: 0.35-4.08 days; Figure 7.1).

Ten of the 29 females in our sample size also carried time-depth recorders (Wildlife Computers, Redmond, WA; Mk9: N=8; Mk10: N=2). There was no significant difference in trip duration between females instrumented with only a VHF transmitter and those instrumented with a VHF-TDR pair of instruments (ANOVA: F1,166 =0.13, P=0.72).

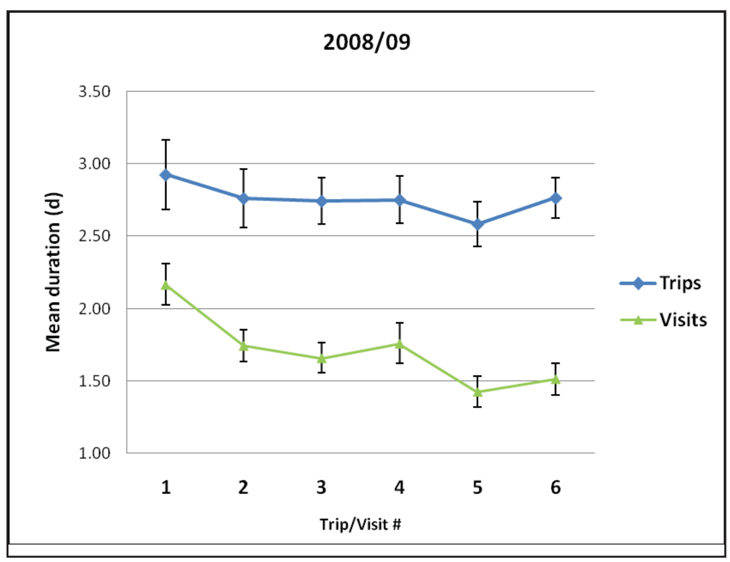

Figure 7.2. Antarctic fur seal mean trip and visit duration (with standard error) for females rearing pups at Cape Shirreff, Livingston Island. Data plotted are for the first six trips to sea and the first six non-perinatal visits following parturition.

The estimated number of total pups born (live plus cumulative dead) for the combined four beaches in 2008/09 was 1,569 (st.dev: 4.6; based on counts by three observers). Our count this year represents a 13.3% reduction in pup production over 2007/08. The median date of parturition was 4 December (two days earlier than last year). Throughout the season male fur seal pups grew, on average, 104.3g per day. Females grew 85.6g per day (Figure 7.3). Neonate mortality was 3.04%, a decrease over last year (4.2 %); The long-term average (based on ten years of data, 1998-2008), is 4.5% ±0.60.

Our estimate of pup mortality due to leopard seal predation, calculated 24 February, 82 days after the median date of pupping, was based on daily tag resights of adult females. By that date, 46.2% of pups were lost to leopard seals.

Our diet study this year showed that most scats, 94.0%

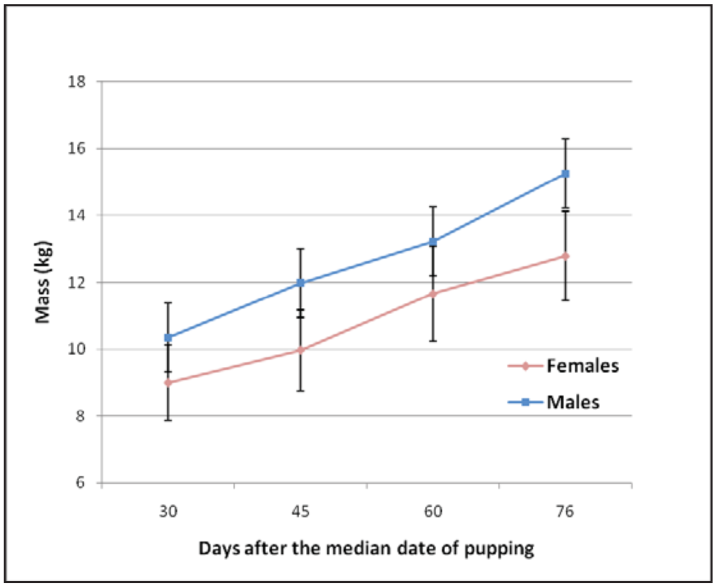

Figure 7.3. Antarctic fur seal pup growth. Four samples of pup weights were collected, every two weeks beginning 30 days after the median date of pupping (4 Dec 2008). Sample sizes were 64, 52, 53, and 49 for males and 48, 49, 47, and 51 for females.

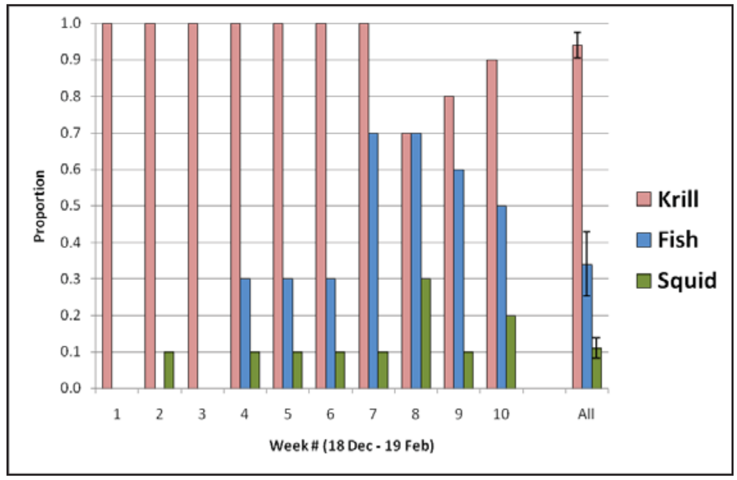

Figure 7.5. The weekly proportions of three types of prey in Antarctic fur seal diet 18 December – February 19 2009. The last series of histogram bars are the season average plotted with standard error. Most fish otoliths (87.2%; 1,614/1,851) recovered from fur seal scats in 2008/09 were from two species of myctophid fish (*Electrona antarctica*, N=201 and *Gymnoscopelus nicholsi*, N=1413). No *Electrona carlsbergi* otoliths were collected from any scats in 2008/09.

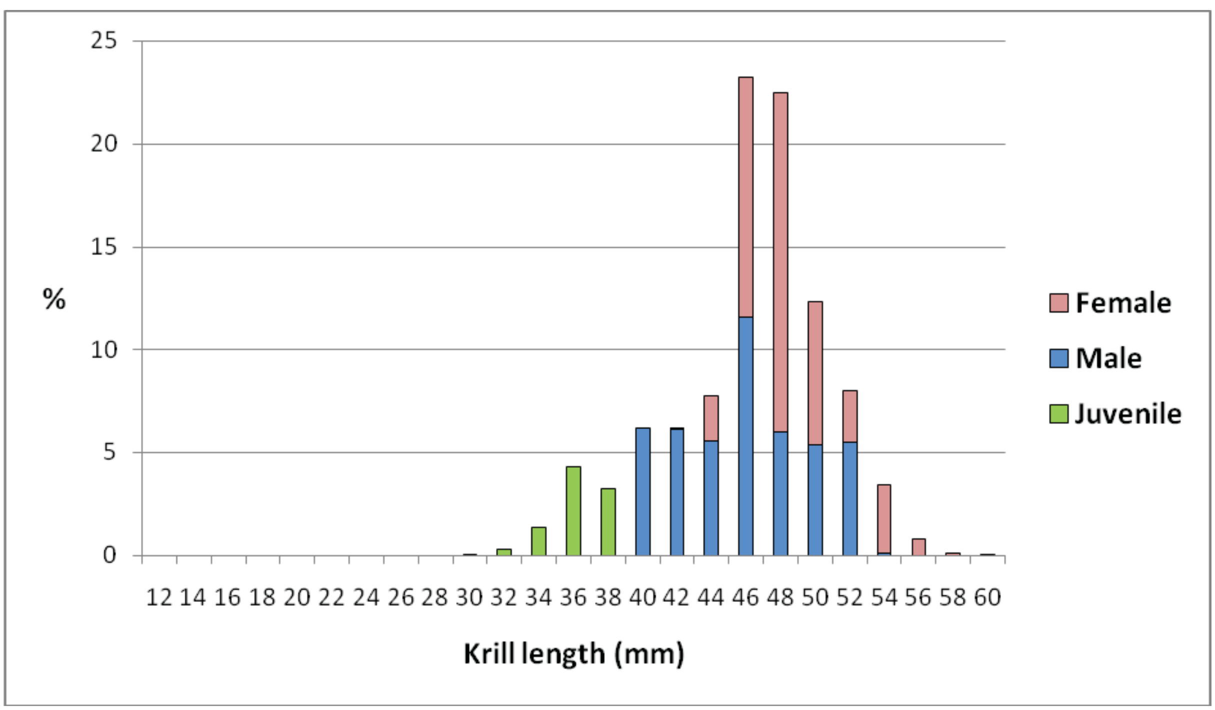

Figure 7.4. Krill length distribution in Antarctic fur seal diet from measures of 2,267 carapaces collected from fur seal scats. Data are derived by sampling 25 krill carapaces from each scat, measuring length and width, applying a discriminant function and independent regression equations for calculating total length of krill. A first order smoothing function is applied to two millimeter length bins.

(94/100) of those collected, contained krill. In addition, 1,851 otoliths were collected from 34.0% of the scats collected. As in previous years the incidence of fish in fur seal diet increased over the 10-week sampling period from 18 December to 19 February (Figure 7.5). Mean total length of krill in the fur seal diet was 46.5 mm (st.dev. ±4.45, N=2267). Juveniles comprised 8.6% of the sample (Figure 7.4) and the male:female sex ratio was 1.05. Most (87.2%, 1,614 otoliths) were from two species of myctophid fish (*Electrona antarctica*, n=201 and *Gymnoscopelus nicholsi*, n=1,413); an additional 3.7% (n=69) were eroded and unidentified otoliths. A total of 113 squid beaks (preliminary ID: *Brachioteuthis picta*) were collected from 11.0% of the scats.

Discussion

Fur seal pup production in 2008/09 at U.S. AMLR study beaches showed a decline (13%) over the previous year. This is the second year of double digit decline in pup production. The decline suggests poor environmental conditions over-winter or soon after weaning in 2008. However, the summer environment appeared to be one of the more favorable seasons for female foraging and reproductive success. Early season neonate mortality (3.0%) was lower than the long-term average of 4.5%. The median date of pupping, based on pup counts, was two days earlier than last year and the earliest on record. The mean foraging trip duration (2.7 days ±0.17) was one of the shortest mean trip durations on record and a day shorter than the long-term mean (3.8 days ±0.36; 1998-2008). Diet studies of fur seals indicated a high proportion of krill, especially in December and early January. The krill measured in fur seal diet indicated a bi-modal distribution with 8.6% juvenile krill and a second mode at 46 mm. No *Electrona carlsbergi* were recorded in fur seal diet this year. In general, winter conditions were less favorable compared to previous years but indices reflecting summer conditions were above average resulting in good predator performance.

During the summer months (Nov-Feb, the only months of human occupation of Cape Shirreff) leopard seals are frequently observed hauling out on beaches around Cape Shirreff and preying on fur seal pups and penguins. Our measures of fur seal neonate mortality extend only to the end of pupping (early January). In most years, neonate mortality experiences a peak during the perinatal period or soon after females begin their trips to sea. However, another peak in pup mortality occurs later, when young, inexperienced pups enter the water for the first time around one month of age and become vulnerable to leopard seal predation. Since remains are rare, evidence of this type of mortality is more difficult to quantify. However, we estimate that during January and February, leopard seals consume as much as half of all fur seal pups born on the Cape. Leopard seal predation is significant and may be an important top-down factor controlling recovery of fur seal populations (Boveng et al., 1998) as well as penguins populations, in the South Shetland Islands.

Protocol Deviations

Measures of fur seal pup growth were collected according to CCAMLR protocol (CEMP Standard Method C2.2 Procedure B) with the exception of weights being sampled every 15 days instead of every 30 days.

Disposition of Data

All raw and summarized data are available from Mike Goebbel at the Antarctic Ecosystem Research Division of the National Marine Fisheries Service, Southwest Fisheries Science Center, 3333 N. Torrey Pines Ct., La Jolla, CA 92037.

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The National Science Foundation provided support and transportation to the Cape Shirreff field site for the opening camp crew. We thank the captain, crew and science staff of the November cruise of the R/V *Laurence M. Gould*. We thank Kevin Pietrzak and Jimmy Breeden for their help with pinniped studies. We are, likewise, grateful to Anthony Cossio, Christian Reiss, and all the AMLR personnel, and the Russian crew of the R/V *Yuzhmorgeologiya* for their invaluable support and assistance to the land-based AMLR personnel. We thank Stephanie Sexton for her support of field camp communications and for downloading ARGOS data from three females carrying ARGOS PTTs. All pinniped research at Cape Shirreff was conducted under Marine Mammal Protection Act Permit No. 774-1847-03 granted by the Office of Protected Resources, National Marine Fisheries Service. Elephant seal research at Cape Shirreff in 2008/09 was supported by a National Science Foundation grant to D. Costa, University of California-Santa Cruz, D. Crocker, Sonoma State University, and M. Goebel, U.S. AMLR Program.

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Distribution, abundance and behavior of seabirds and mammals at sea

Jarrod A. Santora, Michael P. Force, Kristen Ampela and Amy Van Cise

Abstract The at-sea distribution and density of seabirds and marine mammals was estimated through observations made during the 2008/09 AMLR Survey. A total of 3,301 km of survey effort was completed on the AMLR grid. This year's observations included:

- the largest number and broadest spatial distribution of fin whale sightings on a January AMLR survey;
- a pod of killer whales feeding on a kill north of Elephant Island;
- a large influence of sub-Antarctic seabirds on avian community composition; and
- seabird feeding aggregations that were patchy and observed in fewer locations than in previous field seasons, presumably due to the variability of the southern ACC front and patchy distribution of krill.

Introduction

This investigation focused on the at-sea distribution and density of seabirds and marine mammals during the 2008/09 AMLR Survey. The primary objective was to map the density and distribution of seabirds and mammals at sea. The resulting data set, summarized in this report, will be used to investigate:

1. the influence of krill abundance and patchiness on seabird and mammal distributions at sea,
2. community structure and habitat selection by predator groups, and
3. inter-annual spatial variability of foraging seabirds and mammals at sea.

Methods

Three predator observers were on rotation (2 per transect) inside the observation platform on the flying bridge (~13m) during underway shipboard operations. Data on predator abundance and behavior were collected using binoculars during daylight hours. Surveys for birds followed strip transect methods (Tasker et al., 1984) and counts were made within an arc of 300 m directly ahead and 90 degrees to one side of the ship. In this report, transects are defined as the duration of travel and space covered while the vessel was underway between stations. Sea state (Beaufort scale) and visibility were continuously monitored by the primary observer. Each sighting record was assigned a time and position directly fed by the ship's navigational computer, which was synchronized with the ship's data acquisition computer and the hydro-acoustic system used to collect krill biomass estimates.

Individual birds, or flocks of birds, were assigned a behavioral code. The behaviors were: flying, sitting on water, milling (circling), feeding, porpoising (penguins, seals, and dolphins) and ship-following. Ship-followers were entered when encountered and were ignored thereafter. Predators that were flying or porpoising were assigned a direction of travel.

Observations of baleen whales were made within an arc of 180 degrees in front of the vessel. Data recorded for baleen whales included behavior, traveling direction, distance and bearing from the ship's trackline.

When weather conditions permitted (i.e., no fog), there were always two observers on duty. This enabled better survey coverage for marine mammals and maximized survey effort on a daily basis (i.e. more transects are sampled). The senior avian observer on effort was responsible for collecting strip-transect data on birds. The role of the second observer was spotting and tracking baleen whales using high-powered image stabilized 20x60 Zeiss binoculars provided by SWFSC. All sightings were downloaded, error checked and stored in a database each day.

Underway observations of predators were successfully conducted during Leg I of the 2008/09 AMLR Survey. Distribution maps were made using ArcView (ESRI 2007); the location of Southern Ocean fronts, described in Orsi et al. (1995), were superimposed on predator distribution maps for reference only. Survey effort information is presented in Table 8.1, and the relative abundance (per km) of seabirds and marine mammals is presented in Table 8.2. A brief summary of the observations collected in each AMLR regions follows.

Table 8.1. Survey effort for underway observations of seabirds and marine mammals during Leg I of the 2008/09 AMLR Survey.

Region	Hours	km
Elephant	72.53	1343.32
West	56.33	1043.29
South	32.53	602.52
Joinville	16.85	312.06
TOTAL	178.24	3301.19

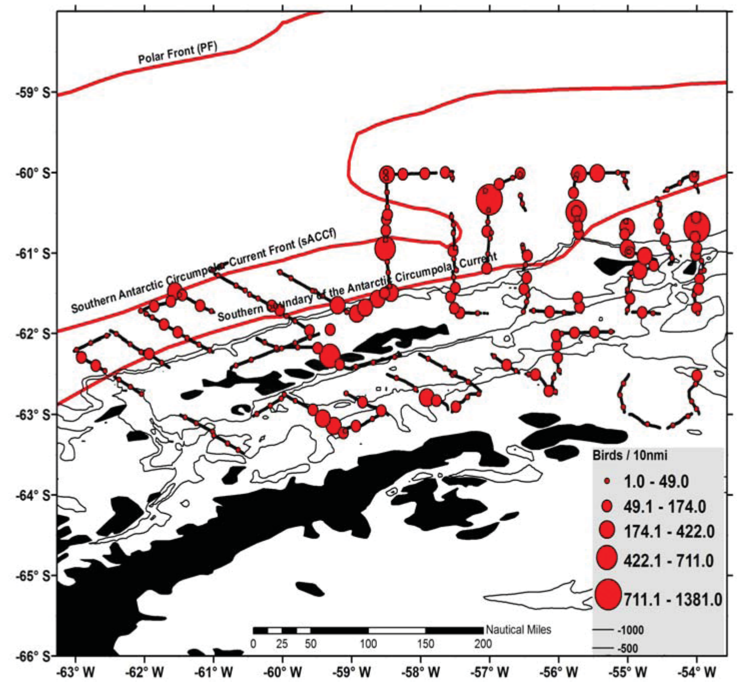

Figure 8.1. Spatial distribution and abundance of total seabirds during Leg I of the 2008/09 AMLR Survey..

Results

West Area

Twenty-one transects were completed, totaling approximately 1,043 km of survey effort (Table 8.1, Figure 8.1). The seabird community consisted primarily of (percentage-wise; see Table 8.2 for scientific names): cape petrels, chinstrap penguin, southern giant petrel, blue petrel, Antarctic prion, Antarctic fulmar, white-chinned petrel, black-browed albatross, Wilson's storm petrel, black-bellied storm petrel, gray-headed albatross, and wandering albatross (Table 8.2a). In addition, eight royal albatross (last recorded in the 2006 AMLR survey), three Antarctic petrels, and five soft-plumaged petrels were observed.

Seabird feeding aggregations (primarily cape petrels) were patchily distributed and were observed in four locations (Figure 8.2). A known feeding aggregation 'hotspot', detected north of King George Island during previous AMLR Surveys, contained numerous feeding birds. Another dense feeding aggregation was located ~40 nautical miles north of Livingston Island.

A total of 24 fin whales (16 sightings), 12 humpback whales (nine sightings), and two minke whales (two sightings) were observed (Table 8.2b, Figure 8.3). In addition, 25 long-finned pilot whales were recorded during transit to the northern edge of the West Area, near the Shackleton Fracture Zone. As in previous AMLR surveys, fur seals were concentrated to the north-west of Livingston Island (Table 8.2b, Figure 8.3).

Elephant Island Area

Forty transects were collected, totaling approximately 1,343 km of survey effort (Table 8.1, Figure 8.1). The seabird community consisted primarily of (percentage-wise): cape petrel, chinstrap penguin, prions, blue petrel, southern fulmars, white-chinned petrel, black-browed albatross, gentoo penguin, Wilson's storm petrel, black-bellied storm petrel, gray-headed albatross, southern giant petrel, light-mantled albatross, and wandering albatross. Interestingly, blue petrels, prions, and white-chinned petrels were highly conspicuous in offshore waters, especially near the Shackleton Fracture Zone. A strikingly similar pattern was observed in 2005, which may suggest a link between seabird community composition and changes in oceanographic conditions (Santora et al., 2005).

Seabird feeding aggregations (composed of cape petrels, black-browed albatrosses, gray-headed albatross, white-chinned petrel, and prions) displayed a high degree of patchiness and were distributed in a few locations situated along the shelf-break west of Elephant Island, north of Clarence Island, and offshore in the northeast corner of the Elephant Island grid (Figure 8.2). We found a similar spatial arrangement of seabird aggregations during 2006, when krill biomass was exceptionally low (Santora et al., 2009). At-sea observations of Antarctic fur seals indicated that they were concentrated to the northeast of Elephant Island and also further offshore, near the Shackleton Fracture Zone (Figure 8.4).

On 19 January we encountered a pod of five killer whales (-60.34, -57) on a kill. We were unable to determine what they were eating, but some video footage was captured. Thousands of birds, mostly cape petrels, albatrosses, storm petrels, white-chinned petrels, and prions, congregated around the feeding frenzy.

A total of 225 fin whales (114 sightings) were observed (Table 8.2b). This is the highest number of sightings ever recorded during Leg I of the AMLR Survey. In the last six-AMLR Surveys, fin whales tend to concentrate in offshore waters of the Elephant Island Area, especially in the northeast corner (Santora et al., 2005, 2007). However, this year fin whales were more broadly distributed throughout pe-

Table 8.2a. Relative abundance (number per km) of seabirds recorded during underway transit on Leg I of the 2008/09 AMLR Survey.

Common Name	Latin Name	Elephant	Joinville	South	West	Total
Adélie penguin	*Pygocelis adleie*	0.00000	0.14100	0.23451	0.00000	0.05634
Gentoo penguin	*Pygocelis papua*	0.12060	0.00000	0.15689	0.00767	0.08027
Chinstrap penguin	*Pygocelis antarctica*	0.86353	0.29161	0.81748	0.90195	0.81395
Macaroni penguin	*Eudyptes chrysolophus*	0.00074	0.00000	0.00000	0.00000	0.00030
Wandering albatross	*Diomedea exulans*	0.02084	0.00320	0.00165	0.02492	0.01696
Royal albatross	*Diomedea epomorpha*	0.00298	0.00000	0.00000	0.00671	0.00333
Black-browed albatross	*Thalassarche melanophrys*	0.26278	0.08011	0.03303	0.07572	0.14449
Gray-headed albatross	*Thalassarche chrysostoma*	0.08338	0.01282	0.01817	0.02300	0.04574
Light-mantled sooty albatross	*Phoebetria palpebrata*	0.01936	0.00320	0.00165	0.01054	0.01181
Southern giant petrel	*Macronectes giganteus*	0.14516	0.08652	0.09744	0.11023	0.11996
Northern giant petrel	*Macronectes halli*	0.00521	0.00000	0.00000	0.00767	0.00454
Un-identified giant petrel	*Macronectes spp.*	0.02308	0.00000	0.00000	0.00000	0.00939
Southern fulmar	*Fulmarus glacialoides*	0.32978	0.69858	1.74396	0.08627	0.54738
Antarctic petrel	*Thalassoica antarctica*	0.01266	0.00000	0.00330	0.00192	0.00636
Cape petrel	*Daption capense*	3.10053	0.35570	0.44094	3.27713	2.41186
White-chinned petrel	*Procellaria aequinoctialis*	0.36030	0.08011	0.02147	0.07764	0.18266
Soft-plumaged petrel	*Pterodroma mollis*	0.01489	0.00000	0.00000	0.00479	0.00757
Snow petrel	*Pagodroma nivea*	0.00074	0.00000	0.00000	0.00000	0.00030
Antarctic prion	*Pachyptila desolata*	0.14591	0.00000	0.00000	0.10448	0.09239
Un-identified prion	*Pachyptila spp.*	0.59554	0.00000	0.00000	0.00383	0.24355
Blue petrel	*Halobaena caerulea*	0.50323	0.00000	0.00000	0.10927	0.23931
Wilson's storm petrel	*Oceanites oceanicus*	0.12134	0.28841	0.10239	0.05847	0.11390
Black-bellied storm petrel	*Fregetta tropica*	0.11092	0.07691	0.02312	0.04793	0.07179
Brown skua	*Catharacta antarctica*	0.00298	0.00000	0.01156	0.00192	0.00394
South Polar skua	*Catharacta maccormicki*	0.02382	0.00641	0.04954	0.01629	0.02454
Kelp gull	*Larus dominicanus*	0.00074	0.00000	0.00000	0.00000	0.00030
Antarctic shag	*Phalacrocorax bransfieldensis*	0.00074	0.00000	0.00000	0.00000	0.00030
Antarctic tern	*Sterna vittata*	0.01861	0.00320	0.02312	0.00671	0.01424
Snowy sheathbill	*Chionis alba*	0.00000	0.00000	0.00826	0.00096	0.00182

Table 8.2b. Relative abundance (number per km) of marine mammals recorded during underway transit on Leg I of the 2008/09 AMLR Survey.

Common Name	Latin Name	Elephant	Joinville	South	West	Total
Antarctic fur seal	*Artcocephalus gazella*	0.12804	0.15061	0.11891	0.03738	0.09996
Elephant seal	*Mirounga leoina*	0.00074	0.00000	0.00000	0.00000	0.00030
Leopard seal	*Hydrurga leptonyx*	0.00000	0.00320	0.00000	0.00000	0.00030
Humpback whale	*Megaptera novaeangliae*	0.00447	0.04166	0.14533	0.01150	0.03605
Fin whale	*Balaenoptera physalus*	0.16750	0.07050	0.00991	0.02300	0.08391
Minke whale	*Balaenoptera bonaerensis*	0.00223	0.00000	0.00165	0.00192	0.00182
Un-identified whale	*Balaenoptera species*	0.01266	0.00320	0.00330	0.00000	0.00606
Southern bottlenose whale	*Hyperoodon planifrons*	0.00149	0.00000	0.00000	0.00000	0.00061
Killer whale	*Orcinus orca*	0.00372	0.00000	0.00000	0.00000	0.00151
Long-finned pilot whale	*Globicephala melas*	0.00000	0.00000	0.00000	0.02396	0.00757
Hourglass dolphin	*Lagenorhynchus cruciger*	0.00372	0.00000	0.00000	0.00000	0.00151

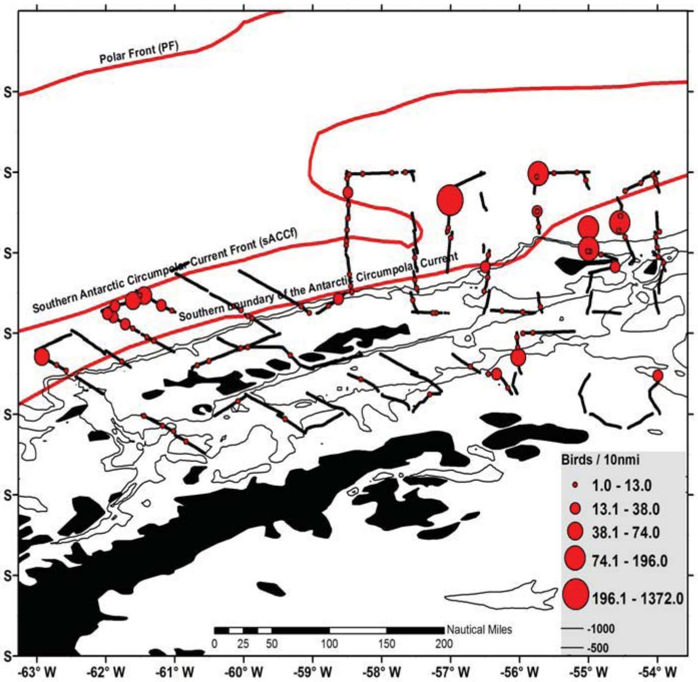

Figure 8.2: Spatial distribution and abundance of feeding seabirds (petrels and albatrosses) during Leg I of the 2008/09 AMLR Survey.

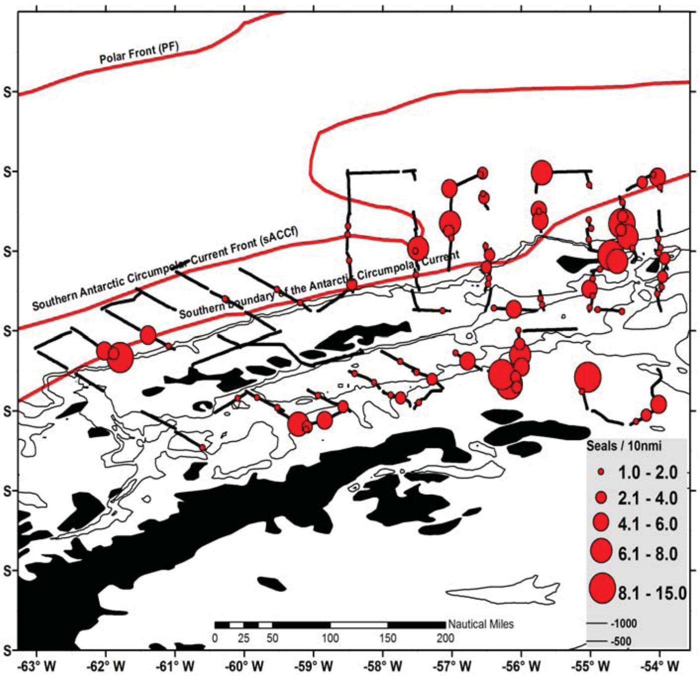

Figure 8.4. Spatial distribution and abundance of Antarctic fur seals during Leg I of the 2008-09 AMLR Survey.

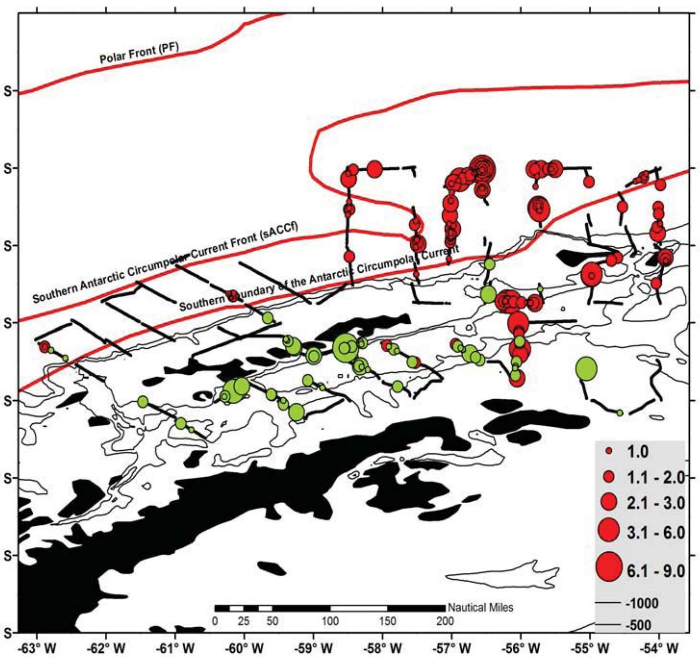

Figure 8.3: Spatial distribution of sightings and group size of fin whales (red) and humpback whales (green) during Leg I of the 2008/09 AMLR Survey.

lagic waters, the shelf-break region, and in waters farther south of Elephant Island. In addition, an all-time low count of humpback whales was recorded in the Elephant Island Area (three sighting, six animals). Two southern bottlenose whales sightings were recorded near the Shackleton Fracture Zone.

Joinville Island and South (Bransfield Strait) Areas

Twenty-two transects were completed, totaling approximately 914 km of survey effort (Table 8.1, Figure 8.1). The seabird community consisted primarily of (percentage-wise): southern fulmar, chinstrap penguin, cape petrel, Adélie penguin, Wilson's storm petrel, gentoo penguin, southern giant petrel, black-browed albatross, white-chinned petrel, black-bellied storm petrel, and South Polar skua (Table 8.2a).

The presence of fin whales in the AMLR Survey grid continued well into the Joinville Island and South Areas (Table 8.2b, Figure 8.3). A total of 28 fin whales were recorded (10 sightings) and were mainly clustered within the northeastern deep basin of the Bransfield Strait (Figure 8.3). As in past AMLR Surveys, we detected a spatial shift from fin to humpback whales as we surveyed farther south and east through the Bransfield Strait. A total of 101 humpback whales were recorded (52 sightings), which were predominantly concentrated in three hotspots detected during previous AMLR surveys (Figure 8.3, see also Santora et al., 2005, 2007).

Discussion

The unique oceanographic conditions observed during AMLR 2009 undoubtedly influenced the foraging behavior and spatial distribution of seabirds and marine mammals.

Seabird feeding aggregations were very patchy, due possibly to the high patchiness of Antarctic krill (a condition observed in 2006). Large numbers of prions, blue petrels, and white-chinned petrels (sub-Antarctic breeders) dominated the offshore avifauna, while fin whales were present in the largest numbers ever recorded during a January AMLR Survey. This survey will yield interesting comparisons with previous and future field seasons.

Protocol Deviations

There were no major deviations from the marine mammal and seabird observation protocol.

Disposition of Data

After all data have been thoroughly proofed, a copy will be available from Jarrod Santora, phone:(917) 647-4692; email: jasantora@gmail.com

Acknowledgements

We would like to thank everyone involved in the 2008/09 AMLR field season, and especially the captain and crew of the R/V *Yuzhmorgeologiya* for maintaining the viewing platform on the flying bridge. We are grateful for the use of the image-stabilized binoculars provided by the SWFSC.

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Demersal Finfish Survey of the South Orkney Islands

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Abstract A random, depth-stratified bottom trawl survey of the South Orkney Islands (CCAMLR Subarea 48.2) finfish populations was completed as part of Leg II of the 2008/09 AMLR Survey. Data collection included abundance, spatial distribution, species and size composition, demographic structure and diet composition of finfish species within the 500 m isobath of the South Orkney Islands. Additional slope stations were sampled off the shelf of the South Orkney Islands and in the northern Antarctic Peninsula region (Subarea 48.1). During the 2008/09 AMLR Survey:

- Seventy-five stations were completed on the South Orkney Island shelf and slope area (63-764 m);
- Three stations were completed on the northern Antarctic Peninsula slope (623-759 m);
- A total of 7,693 kg (31,844 individuals) was processed from 65 finfish species;
- Spatial distribution of standardized finfish densities demonstrated substantial contrast across the South Orkney Islands shelf area;
- The highest densities of pooled finfish biomass occurred on the northwest shelf of the South Orkney Islands, at stations north of Inaccessible and Coronation Islands, and the highest mean densities occurred within the 150-250 m depth stratum;
- The greatest species diversity of finfish occurred at deeper stations on the southern shelf region;
- Additional data collection of environmental and ecological features of the South Orkney Islands was conducted in order to further investigate Antarctic finfish in an ecosystem context.

Introduction

Commercial exploitation of finfish in the South Orkney Islands (CCAMLR Statistical Subarea 48.2) occured between 1977/78 and 1989/90. The main reported species captured in the region during this time period were *Champsocephalus gunnari*, *Gobionotothen gibberifrons* and *Notothenia rossii* (CCAMLR, 1990a; 1990b). Other reported finfish species included *Lepidonotothen squamifrons*, *Pseudochaenichthys georgianus*, *Chaenocephalus aceratus*, *Dissostichus eleginoides* and unspecified finfish species. The first year of fishing yielded a reported catch of almost 140,000 metric tons of *C. gunnari*, supported mainly by 1973/74 and 1974/75 cohorts (Kock and Jones, 2005). Both cohorts were largely exhausted within two years, and overall catches declined by almost two orders of magnitude within a few years. Catches increased slightly in the mid-1980s, primarily as a result of the 1980/81 cohort, and decreased substantially once that cohort was exhausted (Jones et al. 2000). The rapid declines of catch size and catch rate led CCAMLR, in 1990/91, to impose a moratorium on all directed fishing for finfish in the South Orkney Islands (CCAMLR CM73/XVII). At present, this moratorium remains in effect (CCAMLR CM 32-03).

To characterize finfish stock biomass and biological characteristics and determine whether shelf areas can be re-opened to possible finfish exploitation, a random, depth-stratified bottom trawl survey of the South Orkney Islands was undertaken during Leg II of the 2008/09 AMLR Survey. This survey represents the first comprehensive scientific characterization of demersal fish along the fishable and accessible shelf regions of the South Orkney Islands since the 1998/99 AMLR Survey.

The survey objectives included data collection to be used for estimates of biomass, distribution, species and size composition, demographic structure, and diet composition of finfish species, primarily within the 500 m isobath of the South Orkney Islands. A number of additional hauls were taken on slope areas (600-800 m) of both the South Orkney Islands and northern Antarctic Peninsula regions. Several other sampling efforts and biological experiments were conducted during the course of this survey, including buoyancy measurements, DNA collections, otolith sampling for age and growth studies, and other specimen/tissue collections for biological, physiological, and phylogenetic studies. Other components of the South Orkney Island shelf ecosystem examined during Leg II included the physical oceanography (Chapter 1), krill density and distribution (Chapter 12), benthic invertebrate megafauna (Chapter 10), and underwater camera/ video deployments (Chapter 11). The overall goals of Leg II were to collect information to be used toward an ecosystem-based assessment of the biomass and spatial distribution of demersal fish in the South Orkney Islands; to characterize feeding patterns; and to examine relationships between benthic and pelagic components of the Antarctic ecosystem and their influence on demersal finfish.

Methods

Bottom Trawling

The at-sea protocols used to conduct the bottom trawl survey were based on those used during the 1998/99 AMLR Survey of the South Orkney Islands (Jones et al. 1999), with some modifications to include additional research activities. A hard-bottom snapper trawl with vented V-Doors (Net Systems, Inc. Bainbridge Island, WA) was used. The trawl was deployed using a 6’6” wide by 12’7” diameter net reel, an 11’9” long by 12” diameter stern roller, two trawl winches, instrumented trawl blocks, and a third wire slip ring winch. The headrope transducer platform of the trawl was instrumented with a Simrad FS25 trawl sonar system to monitor the geometry of the mouth of the trawl as it was deployed, record contact with the bottom, and measure the trawl mouth dimensions in real time while sampling the station.

Trawling operations were conducted aboard the R/V *Yuzhmorgeologiya* on 9 February 2009 through 9 March 2009 (Table 9.1). There were a total of 75 hauls completed on the South Orkney Island shelf and slope area, and three hauls taken off the northern Antarctic Peninsula slope area (Figure 9.1). The sampling strategy for the South Orkney Islands survey was based on a random, depth-stratified survey design, and stations were positioned to account for as wide a geographic range as time, sea, and ice conditions permitted. Estimates of seabed areas and bathymetric features were taken from Jones (2000). In all cases, a haul was taken only after initial acoustic reconnaissance verified that bottom conditions were suitable for trawling. All final decisions regarding sampling operations during the survey were made by the chief scientist in consultation with the fishing master and ship captain.

In the South Orkney Islands there were three targeted designated depth strata: 50-150 m, 150-250 m, and 250-500 m; a limited number of hauls were taken in an additional depth stratum (on the slope) between 600-800 m. These hauls were included on an exploratory basis to increase collections of rare deep sea notothenioid species for ecological, taxonomic and physiological studies, as well as characterize benthic invertebrate megafauna. The numbers of hauls within

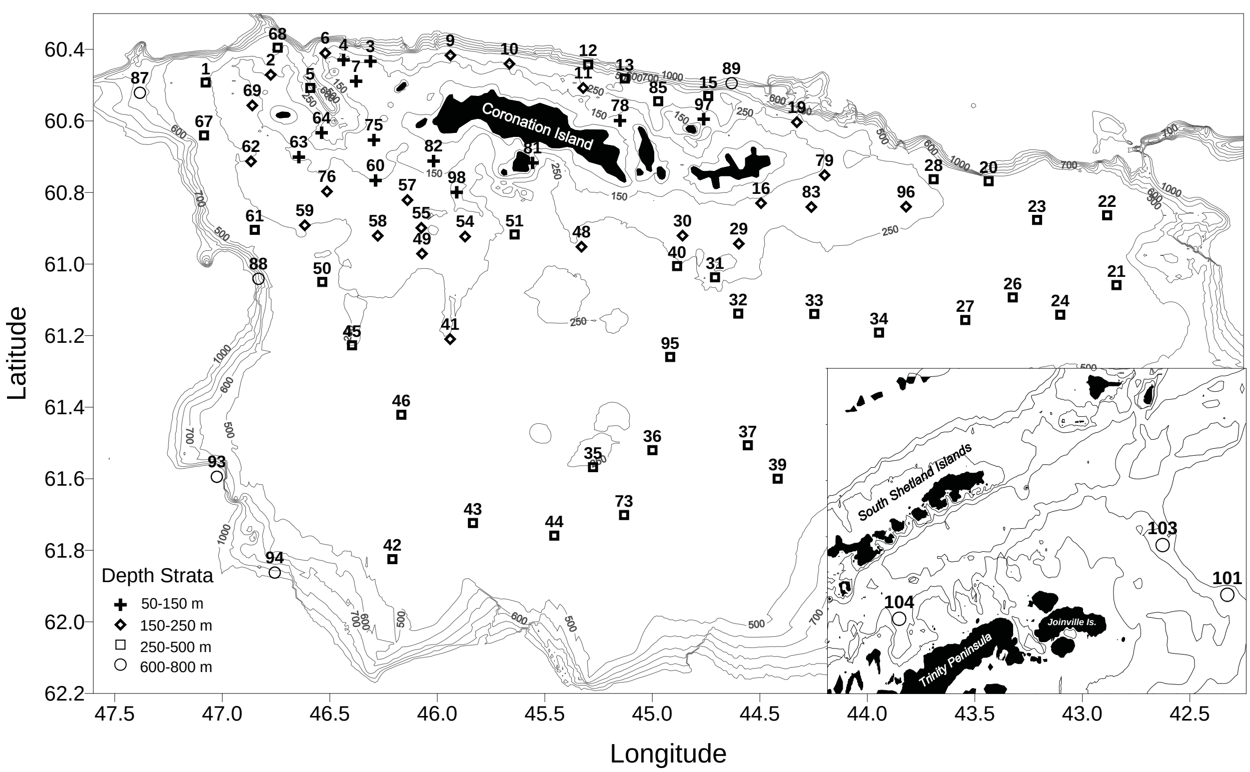


Figure 9.1. Station locations, by depth strata, from Leg II of the 2008/09 AMLR Survey, in the South Orkney Islands. Figure inset shows the three trawls taken on the slope of the northern Antarctic Peninsula.

Table 9.1. Station and finfish catch information for the 2008/09 AMLR Survey bottom trawl in the South Orkney Islands and along the northern Antarctic Peninsula slope.

Station No.	Date	Latitude (S)	Longittude (W)	Avg. Depth	Number Finfish Species	Finfish Catch (Kg)	Total Number Finfish
4	9-Feb-09	60°25.77	46°26.16	142	9	81.42	239
3	10-Feb-09	60°26.00	46°18.66	142	11	236.23	790
9	10-Feb-09	60°25.00	45°56.34	228	10	588.80	1433
10	10-Feb-09	60°26.41	45°39.87	237	9	378.66	830
11	11-Feb-09	60°30.48	45°19.29	240	10	222.91	659
13	11-Feb-09	60°28.89	45°07.68	350	13	149.62	442
12	11-Feb-09	60°26.52	45°17.91	497	11	33.59	225
78	11-Feb-09	60°35.94	45°09.01	98	9	46.17	179
85	12-Feb-09	60°32.69	44°58.36	371	13	120.09	398
15	12-Feb-09	60°31.82	44°44.39	310	11	183.96	340
97	12-Feb-09	60°35.72	44°45.66	118	11	87.03	180
89	12-Feb-09	60°29.67	44°37.86	798	14	5.26	71
19	13-Feb-09	60°36.21	44°19.67	211	12	42.76	183
79	13-Feb-09	60°45.09	44°11.92	166	6	872.39	1098
83	13-Feb-09	60°50.43	44°15.62	182	11	52.66	187
96	13-Feb-09	60°50.37	43°49.18	221	8	16.20	55
28	14-Feb-09	60°45.77	43°41.50	262	8	61.15	142
20	14-Feb-09	60°46.10	43°26.14	309	7	14.44	41
23	14-Feb-09	60°52.59	43°12.63	336	12	80.94	232
22	14-Feb-09	60°58.51	42°53.07	359	6	56.43	99
21	15-Feb-09	61°03.53	42°50.48	425	11	25.33	293
24	15-Feb-09	61°08.49	43°06.16	469	14	55.51	335
26	15-Feb-09	61°05.59	43°19.41	439	13	21.10	167
27	16-Feb-09	61°09.38	43°32.66	455	12	13.90	226
34	16-Feb-09	61°11.49	43°56.74	426	15	111.87	3766
33	16-Feb-09	61°08.37	44°14.80	337	13	77.85	271
32	16-Feb-09	61°08.30	44°36.03	314	12	72.92	290
31	16-Feb-09	61°02.20	44°42.51	254	10	34.10	256
40	17-Feb-09	61°00.33	44°53.08	258	9	73.12	258
30	17-Feb-09	60°55.23	44°51.56	235	11	66.61	314
16	17-Feb-09	60°49.78	44°29.65	172	8	140.25	299
29	17-Feb-09	60°56.58	44°35.86	234	11	87.25	298
39	18-Feb-09	61°35.99	44°25.02	390	15	51.76	729
37	18-Feb-09	61°30.39	44°33.35	380	13	212.96	1551
95	18-Feb-09	61°15.57	44°55.01	322	10	74.28	228
36	20-Feb-09	61°31.20	44°59.96	321	12	39.02	305
35	20-Feb-09	61°34.05	45°16.55	259	10	36.05	105
73	20-Feb-09	61°42.08	45°07.88	375	18	106.84	906
44	20-Feb-09	61°45.54	45°27.36	375	13	39.59	229

Station	Date	Latitude (S)	Longittude (W)	Avg. Depth	Number Finfish Species	Finfish Catch (Kg)	Total Number Finfish
43	21-Feb-09	61°43.41	45°50.04	398	9	42.33	189
42	21-Feb-09	61°49.47	46°12.52	453	10	16.84	102
94	21-Feb-09	61°51.73	46°45.25	750	20	20.25	135
93	21-Feb-09	61°35.67	47°01.52	629	16	14.58	56
46	22-Feb-09	61°25.27	46°09.97	352	14	97.88	272
45	22-Feb-09	61°13.62	46°23.79	274	12	70.07	199
41	22-Feb-09	61°12.59	45°56.41	240	15	86.22	245
48	23-Feb-09	60°57.09	45°19.74	236	11	50.33	182
81	23-Feb-09	60°43.03	45°33.40	63	5	8.49	108
98	24-Feb-09	60°47.97	45°54.57	126	9	13.07	111
82	24-Feb-09	60°42.72	46°01.02	96	7	24.38	188
57	25-Feb-09	60°49.26	46°08.33	195	8	127.05	524
60	25-Feb-09	60°45.98	46°17.22	150	10	51.57	198
75	25-Feb-09	60°39.20	46°17.69	104	5	54.46	194
64	25-Feb-09	60°37.98	46°32.27	130	7	86.77	229
51	26-Feb-09	60°55.04	45°38.43	294	12	88.05	2569
54	26-Feb-09	60°55.38	45°52.24	208	13	120.71	303
55	26-Feb-09	60°53.92	46°04.44	187	6	16.94	62
58	26-Feb-09	60°55.24	46°16.62	227	10	55.76	138
50	26-Feb-09	61°03.00	46°32.10	287	8	25.94	84
76	27-Feb-09	60°47.82	46°30.78	210	15	64.65	249
59	27-Feb-09	60°53.49	46°36.98	231	8	25.20	70
61	27-Feb-09	60°54.25	46°50.94	308	7	8.88	42
88	27-Feb-09	61°02.47	46°49.91	764	18	17.60	83
1	28-Feb-09	60°29.55	47°04.62	259	10	116.29	379
67	28-Feb-09	60°38.43	47°05.08	299	7	44.28	177
2	28-Feb-09	60°28.26	46°46.48	162	7	146.40	378
5	28-Feb-09	60°30.47	46°35.45	457	19	108.70	454
68	1-Mar-09	60°23.71	46°44.54	282	10	419.29	878
6	1-Mar-09	60°24.63	46°31.26	220	13	410.72	1204
7	1-Mar-09	60°29.34	46°22.65	106	8	199.42	1481
63	1-Mar-09	60°42.06	46°38.62	142	11	46.01	173
49	3-Mar-09	60°58.26	46°04.26	236	9	22.10	125
62	3-Mar-09	60°42.77	46°51.98	242	8	15.53	59
69	3-Mar-09	60°33.39	46°51.62	176	10	105.25	370
87	3-Mar-09	60°31.28	47°22.98	657	0	0	0
101	4-Mar-09	63°01.08	52°24.34	623	13	60.15	210
103	5-Mar-09	62°34.51	53°47.78	731	9	76.30	218
104	9-Mar-09	63°13.92	59°27.47	759	33	63.87	557

the four depth strata were 12, 23, 35, and 8, respectively. All targeted strata were sampled and the survey design was completed successfully.

All hauls, with the exception of those taken in the fourth strata, were conducted during daylight hours with a targeted haul time of 30 minutes. Trawling time started as the footrope made contact with the bottom. Once contact with the bottom was made, time, geographic coordinates, ship speed, bearing, headrope depth, bottom depth, and net mouth geometry were recorded. Recordings were made every five minutes thereafter throughout the course of the haul. The area of seabed sampled during the haul was determined using the latitude and longitude coordinates taken with GPS from the start to the end of the trawl's bottom contact and the average of the trawl mouth width recorded while on the bottom. Supplementary data collected for each haul included ship course, air temperature, wind direction and speed, weather, cloud conditions, sea state, light and ice conditions.

Haul Processing

After a successful haul, the contents of the trawl were emptied onto the deck and transferred to a sorting table, where fish were identified, separated by species, and placed into baskets or trays. Organisms other than fish (benthic and pelagic invertebrates) were processed separately (Chapter 10). Baskets and trays were weighed to obtain total catch weights by species. Where catches of a single species were very large, a subsample of the catch was taken (see Sub-sampling Protocol).

There were two categories of haul processing. Category 1 included length (nearest cm below), sex, and gonad maturity stage. Length types were collected as total length (length from tip of snout to end of caudal fin) for all species except myctophid species and *Pleurogramma antarcticum*, where length was measured in mm as standard length (length from tip of snout to end of caudal peduncle). Maturity was classified on a scale of 1 to 5 (immature, maturing virgin or resting, developing, gravid, spent) according to the method of Kock and Kellermann (1991). The gonado-somatic index GSI (Kock, 1989) was collected from several species to describe the individual developmental stage of the gonads and to estimate the time of spawning. Category 2 processing included full biometric data including length, weight, sex, maturity, gonad (ovary or testis) weight, diet composition, eviscerated weight, and otolith and fin clip sampling. All weights were measured as total fresh weight to the nearest gram.

An examination of the diet composition of finfish was conducted across all regions of the shelf for most species. Stomach content information included content weight (to the nearest g); a measure of the filling degree according to a scale of 0-5 (empty, 25% full, 50% full, 75% full, 100% full, regurgitated); and a measure of the degree of digestion according to a scale of 1-3 (fresh, moderately digested, fully digested). Dietary items were identified to general common taxonomic groupings (with the exception of krill, *E. superba*), and to species whenever possible. The relative volume of each species present within a stomach was recorded by assigning each dietary component a proportion from 0-10, with the total score for each stomach equal to 10.

Otoliths and fin clips were taken from several species in order to estimate age and construct age-length keys, which will allow age-based models to be used in assessing the population biology and stock status of several species.

Sub-sampling Protocol

When species yield was too great to process in its entirety due to time constraints, sub-sampling was performed using randomized techniques for either Category 1 or Category 2 processing. When using a straightforward simple random sampling with each fish as an independent sampling unit was logistically impractical, we used full baskets of fish as primary sampling units (PSUs). Two forms of sampling strategies were then used: cluster sampling, where all fish within a basket were sampled, and multi-stage sampling, were only some of the fish within a basket were sampled at random. Sampling effort was adjusted for each haul to allow sampling to be completed before the next haul was on deck. Additional details on these methods and statistical rationale is provided in Ashford and Jones (2001).

Results

Total yield and patterns of distribution

A total of 7,693 kg (31,844 individuals) from 65 finfish species were processed from all hauls (Table 9.2). The dominant element of the Antarctic fish fauna in terms of biomass and numbers was within the suborder Notothenioidei (Perciformes). The highest standardized densities of undifferentiated finfish biomass occurred at stations north of Inaccessible and Coronation Islands (Figure 9.2A), and the highest mean densities occurred within the 150-250 m depth stratum.

The ten most prominent finfish species encountered during the course of the survey (all with over 700 individuals) were *Chaenocephalus aceratus*, *Chionodraco rastrospinosus*, *Champsocephalus gunnari*, *Electrona Antarctica*, *Gobionotothen gibberifrons*, *Gymnoscopelus nicholsi*, *Lepidonotothen larseni*, *L. squamifrons*, *Pleuragramma antarcticum*, *Pseudochaenichthys georgianus* (Table 9.2).

The species with the greatest catch in numbers was *G. gibberifrons* (11,178 individuals, 2,628 kg,) followed by *P. antarcticum* (6,156 individuals, 94 kg.) and *C. rastrospinosus* (2,679 individuals, 618 kg). The species with greatest yield in kilograms was *G. gibberifrons* followed by *C. rastrospinosus*, C. aceratus (1,920 kg, 2447 individuals) and *P. georgianus* (656 kg, 769 individuals).

The mean density of undifferentiated finfish biomass for all stations, pooled, was 10.7 tonnes/nmii^2 (σ=14.5). The greatest standardized density of fish at a single station was 94 tonnes/nmi^2, found at Station 79, east of Laurie Island in the eastern shelf area, (Figures 9.1, 9.2A) at a depth of 166 m. This station was dominated (by weight) by *C. aceratus* (91%), followed by *G. gibberifrons* (8%); four other species made up the remaining percentage. Station 9 (228 m) was also dom-

Table 9.2. Total nominal weight (kg), numbers and biological information recorded for finfish by species from Leg II of the 2008/09 AMLR Survey bottom trawl of the South Orkney Islands and northern Antarctic Peninsula slope.

Species	Total Catch (kg)	Total Number	Number Stations Species Occurred	Length, Sex, and Maturity Collected	Weights Collected	Evisc. Weights Collected	Gonad Weights Collected	Diet Collected	Otoliths Collected
Aethotaxis mitopteryx	1.74	37	4	37	37	-	-	27	-
Antimora rostrata	1.13	11	1	-	-	-	-	-	-
Artedidraco skottsbergi	0.02	4	4	4	4	-	-	1	-
Bathydraco marri	0.33	4	3	4	4	-	-	2	-
Bathyraja eatonii	38.94	5	2	4	4	-	-	-	-
Bathyraja maccaini	64.38	27	10	19	18	-	-	-	-
Bathyraja species 2	16.94	46	15	34	34	-	-	-	-
Chaenocephalus aceratus	1919.7	2447	58	1915	1060	392	318	792	460
Chaenodraco wilsoni	6.12	67	2	67	34	-	-	1	-
Champsocephalus gunnari	575.42	2259	55	1835	1261	325	169	946	356
Chionodraco hamatus	0.28	2	1	-	-	-	-	-	-
Chionodraco myersi	1.12	3	3	3	3	-	-	2	-
Chionodraco rastrospinosus	617.85	2679	62	1809	580	280	164	547	262
Cryodraco antarcticus	25.34	122	19	122	117	23	17	106	21
Cyclothone microdon	0.02	2	1	2	-	-	-	-	-
Dacodraco hunteri	0.06	1	1	1	1	-	-	1	-
Dissostichus mawsoni	21.21	12	5	12	12	5	3	10	5
Electrona antarctica	8.69	700	27	558	123	5	1	2	69
Gobionotothen gibberifrons	2628.28	11178	72	6779	406	269	98	285	343
Gymnodraco acuticeps	2.7	22	6	23	23	-	-	6	-
Gymnoscopelus braueri	4.04	49	6	49	16	-	-	-	15
Gymnoscopelus nicholsi	76.68	2188	27	648	137	24	17	3	117
Gymnoscopelus opisthopterus	0.27	8	3	1	-	-	-	-	-
Krefftichthys anderssoni	0.02	4	3	4	4	-	-	-	1
Lepidonotothen larseni	37.68	888	61	907	245	119	37	167	142
Lepidonotothen nudifrons	0.84	30	15	30	26	11	11	18	10
Lepidonotothen squamifrons	505.48	892	44	1021	271	184	65	222	161
Lycenchelys species	0.02	1	1	1	1	-	-	-	-
Macrourus whitsoni	38.71	127	6	73	75	8	-	8	8
Magnisudis prionosa	0.61	6	3	5	5	-	-	4	-
Melanostigma species	0.62	42	2	57	57	-	-	1	-
Muraenolepis microps	4.87	16	11	7	6	-	-	-	-
Muraenolepis species	6.38	16	7	24	23	-	-	3	-
Myctophidae	0.22	19	1	-	-	-	-	-	-
Neopagetopsis ionah	6.46	17	5	13	13	-	-	13	-
Notolepis coatsi	0.39	14	4	11	11	-	-	2	-
Notothenia coriiceps	109.84	81	22	81	78	49	49	51	39
Notothenia rossii	48.57	23	17	22	22	19	18	21	16
Ophthalmolycus amberensis	0.94	15	2	15	15	-	-	-	-
Pachycara brachycephalum	0.25	2	1	2	2	-	-	-	-
Pagetopsis macropterus	0.14	1	1	1	1	-	-	1	-
Parachaenichthys charcoti	3.12	21	10	21	21	2	1	15	2
Paradiplospinus gracilis	1.03	11	4	14	13	1	-	-	-
Paraliparis gracilis	0.26	3	1	-	-	-	-	-	-
Paraliparis meganchus	1.15	11	4	7	7	-	-	-	-
Paraliparis species	1.23	38	4	38	38	-	-	-	-
Pleuragramma antarcticum	94.18	6156	22	637	231	16	8	18	136
Pogonophryne barsukovi	5.09	80	9	82	82	-	-	9	-
Pogonophryne macropogon	0.41	1	1	1	1	-	-	-	-
Pogonophryne scotti	12.84	52	18	53	51	-	-	39	-
Prionodraco evansii	0.03	3	3	3	3	-	-	2	-
Pseudochaenichthys georgianus	655.61	769	42	762	289	237	74	259	240
Racovitzia glacialis	0.15	1	1	1	1	-	-	-	-
Raja georgiana	10.75	7	2	7	7	-	-	-	-
Trematomus bernacchii	1.16	5	4	5	5	-	1	5	-
Trematomus eulepidotus	92.24	413	56	418	280	125	154	189	128
Trematomus hansoni	30.52	95	39	99	90	36	13	75	38
Trematomus loennbergii	0.49	6	3	6	6	-	-	1	-
Trematomus newnesi	7.55	75	17	75	56	36	13	43	40
Trematomus nicolai	0.6	7	4	7	7	-	-	6	-
Trematomus pennellii	0.12	1	1	1	1	-	-	1	-
Trematomus scotti	0.09	2	2	2	2	-	-		1
Trematomus tokarevi	1.27	16	11	17	17	-	-	13	-
Vomeridens infuscipinnis	0.06	3	1	3	3	-	-	1	-
Zoarcidae species 1	0.07	1	1	1	1	-	-		-
Total	7693.3	31844	-	18460	5941	2166	1231	3918	2610

Table 9.3. Standardized densities (kg/nmi^2) of finfish species for non-zero hauls by depth strata from the 2009 AMLR survey of the South Orkney Islands and northern Antarctic Peninsula slope.

Species	Depth Strata			
	1	2	3	4
A. mitopteryx			126	14
A. rostrata				75
A. skottsbergi	1	1		
B. marri			14	3
B. eatonii			1394	1740
B. maccaini		1762	686	209
Bathyraja SP2		49	115	120
C. aceratus	1941	7607	556	
C. wilsoni		19		350
C. gunnari	1349	1230	982	
C. hamatus				16
C. myersi			46	11
C. rastrospinosus	128	428	1506	250
C. antarcticus			108	125
C. microdon				1
D. hunteri				4
D. mawsoni		63	652	454
E. antarctica		2	43	12
G. gibberifrons	5565	6207	2327	95
G. acuticeps		4	13	65
G. braueri			83	1
G. nicholsi		5	376	18
G. opisthopterus			1	17
K. anderssoni		0.2	1	0.4
L. larseni	28	107	49	
L. nudifrons	6	7		
L. squamifrons		1441	1339	221
Lycenchelys sp.				1
M. whitsoni				428
M. prionosa				13
Melanostigma sp.				15
M. microps	5	55	51	27
Muraenolepis sp.	9	59	171	74
Myctophidae			20	
N. ionah			64	87
N. coatsi				6
N. coriiceps	862	342		
N. rossii	231	209	398	
O. amberensis				28
P. brachycephalum				15
P. macropterus				8
P. charcoti	43	27		
P. gracilis			11	24
Paraliparis gracilis				15
P. meganchus				17
Paraliparis sp.				16
P. antarcticum		1	612	85
P. barsukovi			12	85
P. macropogon				26
P. scotti		120	63	10
P. evansii		1		
P. georgianus	211	1629	1775	
R. glacialis			18	
R. georgiana				273
T. bernacchii	45	25		
T. eulepidotus	12	50	83	777
T. hansoni	46	39	92	75
T. loennbergii				9
T. newnesi	63	39		48
T. nicolai		20	14	
T. pennellii		13		
T. scotti		5		3
T. tokarevi		3	16	11
V. infuscipinnis			7	
Zoarcidae sp1				4

inated by *G. gibberifrons*, (62%), *C. aceratus* (29%) and eight other species. Also on the northern shelf, Station 68 (282 m) had the third most abundant catch, dominated by *L. squamifrons* (51%), with nine other species making up the remaing percentage.

The spatial distribution of standardized finfish densities demonstrated substantial contrast across the shelf area. The number of species encountered at each station ranged from five to 33, with an average of 11 species per haul. The greatest species diversity of finfish species occurred on the southern shelf region within deeper strata (Figure 9.2B).

The zoogeographical position of the South Orkney Islands results in a region where two ichthyofaunal elements meet, the ichthyofauna of both the low-Antarctic and high-Antarctic fish communities. Low-

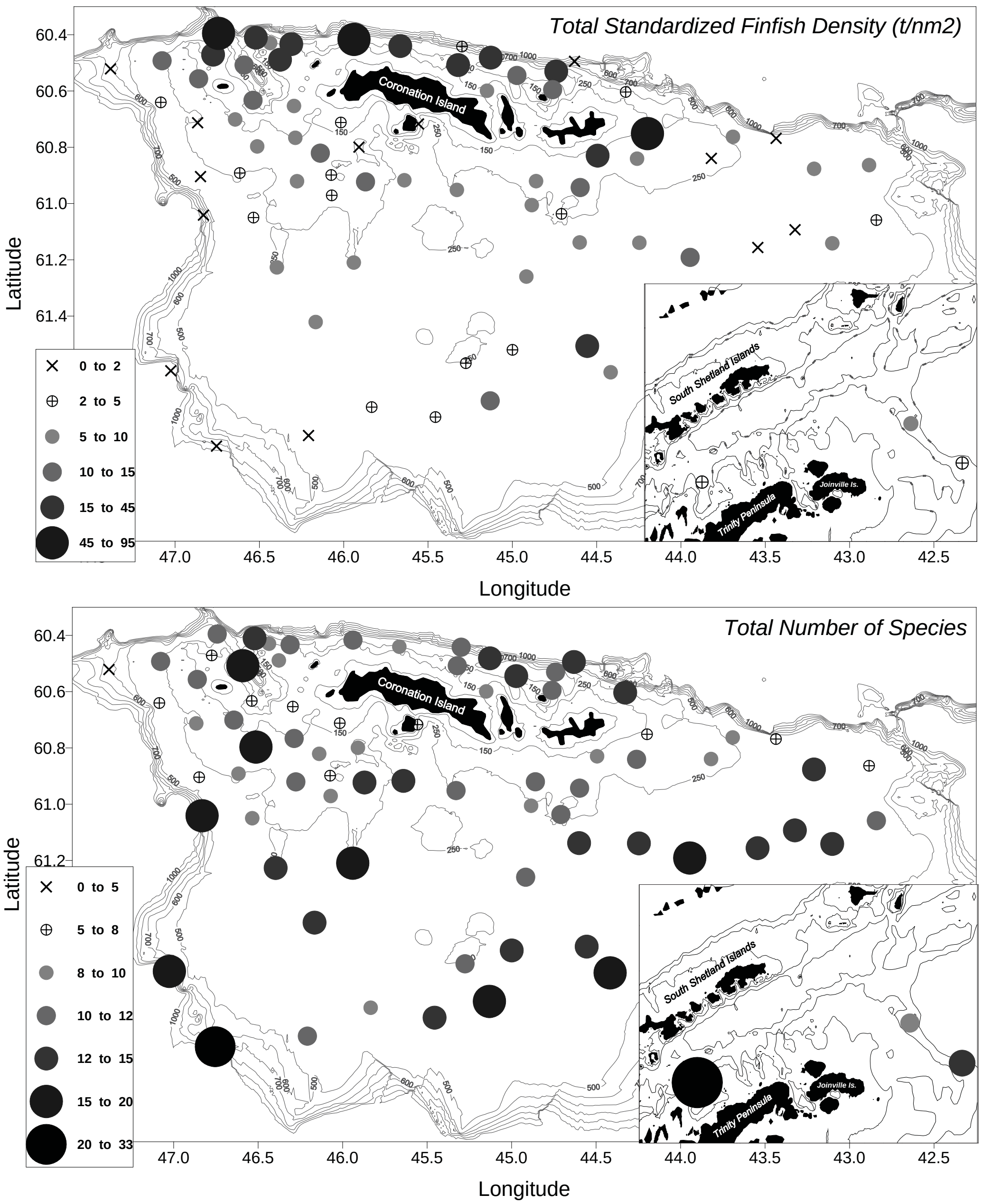


Figure 9.2. A) Total standardized finfish density in t/nmi^2, and B) total number of species from the 2008/09 AMLR finfish survey of the South Orkney Islands. Figure inset shows the three trawls taken on the slope of the northern Antarctic Peninsula.

Antarctic (or peri-Antarctic) species are those more common to the lower latitude regions of the Southern Ocean and archipelagos. High Antarctic species are those associated with Antarctic continent and high latitude regions. Low-Antarctic species dominate the ichthyofauna of the upper 300 m, with *G. gibberifrons*, *C. gunnari*, *C. aceratus* and *P. georgianus* as the most prominent finfish species. In waters deeper than 300 m, species such as *L. squamifrons*, a nototeniid without antifreeze glycoprotein in its blood, and *C. rastrospinosus* becomes more dominant. Mesopelagic myctophids such *E. antarctica* and *G. nicholsi* form another important element of the outer shelf ichthyofauna of the islands. High-Antarctic species dominate in terms of the number of species but are usually only represented by a small number of individuals. One of the few low-Antarctic species still found in small numbers below 500 m was G. gibberifrons.

The remainder of this report will focus on the catch, distribution, and characteristics of finfish in the South Orkney Islands region, where the primary effort of this research cruise was concentrated. The results include detailed information on the spatial distribution of densities and demographics of the eight most abundant demersal finfish species, as well as notes on other important and rare finfish taxa.

Abundant demersal finfish

Chaenocephalus aceratus: The channichthyid *C. aceratus* (Scotia Sea icefish), a relatively sluggish and sedentary demersal finfish, was a frequently encountered species during the survey. A total of 1,920 kg (2,447 individuals) was captured from 58 stations (Table 9.2), and the overall average standardized density for the area surveyed was 2,706 kg/nmii^2. The spatial distribution of standardized density (Figure 9.3) demonstrates *C. aceratus* occurring throughout the shallow shelf regions of the South Orkney Islands and mostly densely distributed on the northern shelf region. The largest catch was taken when a pre-spawning aggregation of *C. aceratus* northeast of Laurie Island (eastern South Orkney Islands) was encountered. Fish were encountered within all shelf strata, with the greatest average densities occurring in the 150-250 m depth strata Table 9.3).

As has been noted during previous AMLR finfish surveys in the Southern Scotia Arc region, the size distribution of *C. aceratus* was among the greatest of any species captured, ranging from 17 to 71 cm. The strongest length mode occurred around 45 cm, with weaker modes appearing around 27 cm, 37 cm, and 59 cm (Figure 9.4). Average lengths by sex were 39 cm and 47 cm for males and females, respectively. Maximum lengths of specimens were 62 cm in males and 71 cm in females. This difference provides further evidence of sexual dimorphism found in growth of males and females.

Fish were found at all stages of maturity. Most fish (40%) were maturing virgin/developing (maturity stage 2) with 25%, 32%, 3%, and 0.1% observed at maturity stages 1, 3, 4 and 5, respectively. The small number of spent females encountered toward the middle of the survey indicates that spawning likely starts in late February/early March. The maturation of gonads appears to be more synchronized than in channichthyids such as *C. gunnari*. Consequently, *C. aceratus* spawning time is likely to be shorter than that of a channichthyids species and is unlikely to extend 6 – 8 weeks. Eggs close to spawning were sticky, which is consistent with the observation of this species using a benthic nesting parental care strategy, as has been observed in other island groups in the Southern Ocean (Detrich et al. 2005).

Feeding intensity of *C. aceratus* was low, with 76% of the stomachs empty. However, it is likely that a significant proportion of the empty stomachs were regurgitated in the process of catching. Krill constituted about 44% of the overall average diet, and fish about 44%, for all individuals examined (Figure 9.11). *C. aceratus* fed primarily on krill and mysids (*Antarctomysis maxima*; 8%) when they were small (< 30cm). Mysids were likely taken close to the bottom. When *C. aceratus* change to a more sedentary life and sit and wait for prey on the bottom (ambush feeding) they alter their prey to fish (*C. gunnari*, *L. larseni*, etc.) with a smaller proportion of krill taken. This was also observed during the 2002/03 AMLR Survey of the South Shetland Islands (Flores et al., 2004).

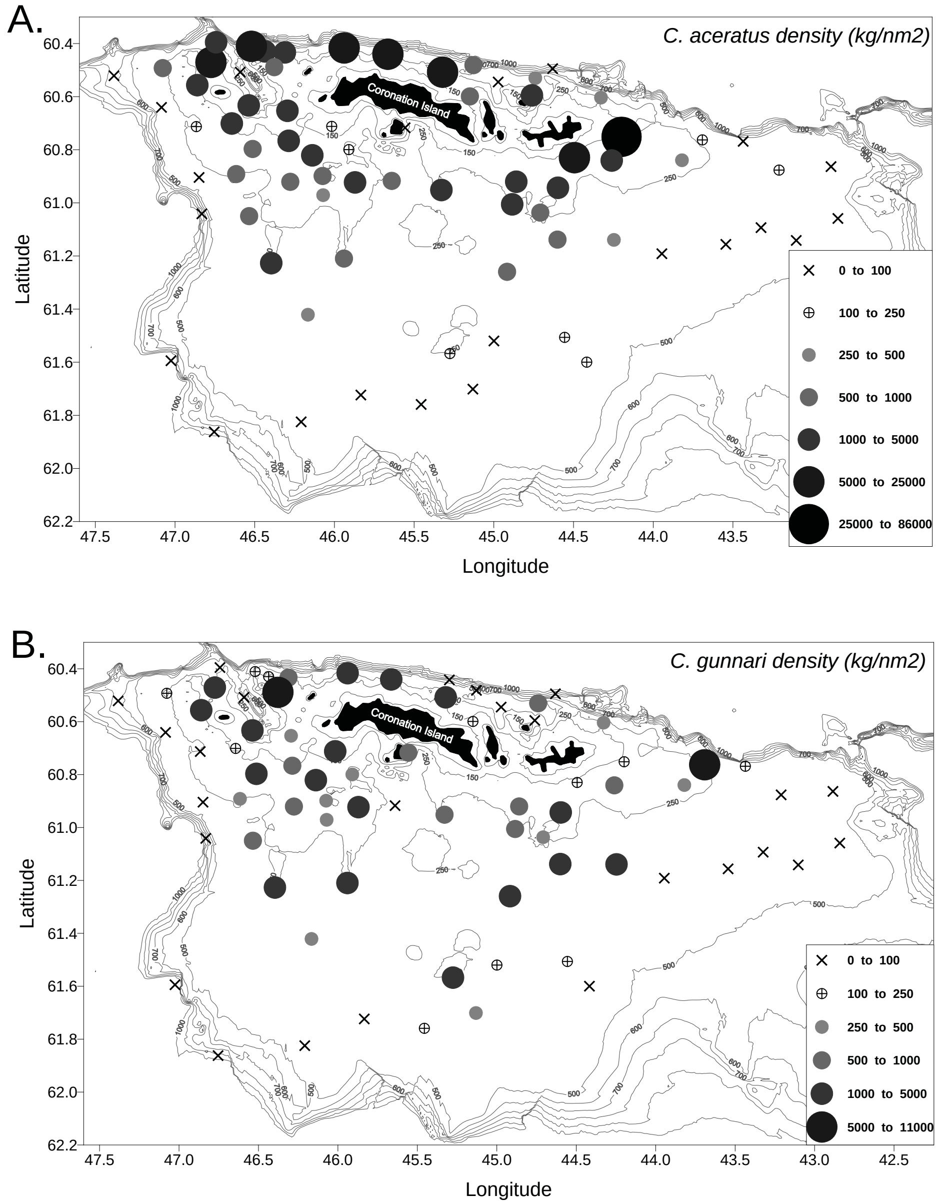


Figure 9.3. Standardized density (kg/nmi^2) for *C. aceratus* and *C. gunnari*.

Champsocephalus gunnari: The active bentho-pelag-

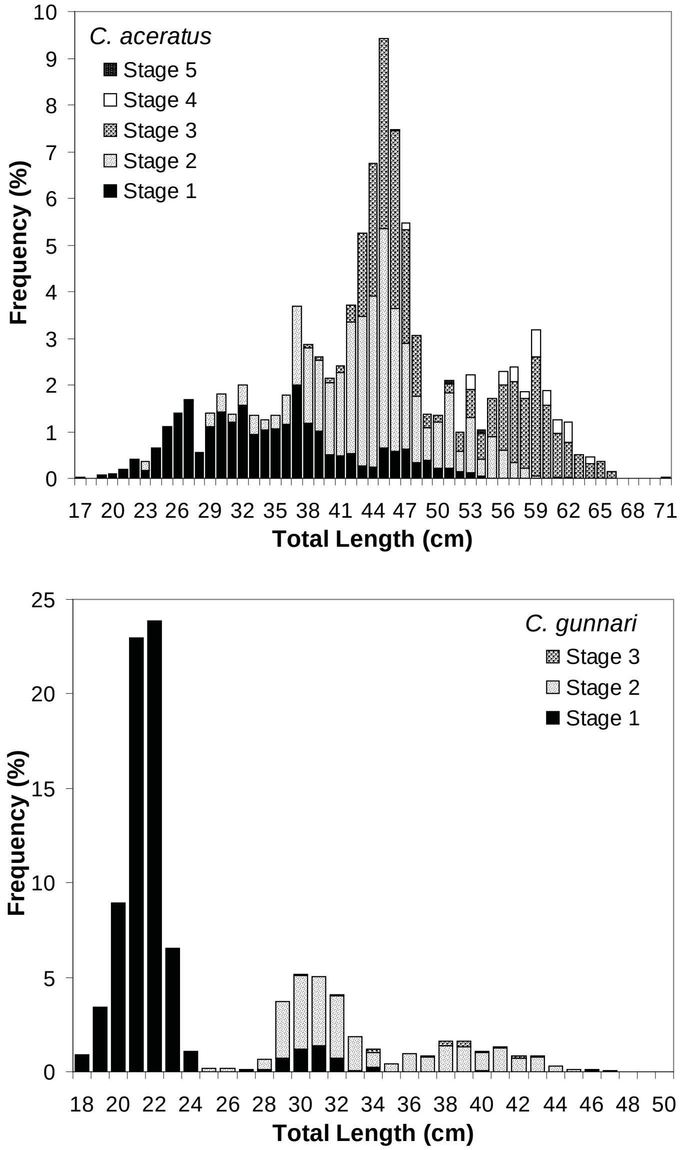


Figure 9.4. Catch-weighted length-frequency distribution for *C. aceratus* and *C. gunnari*.

ic channichthyid *C. gunnari* (mackerel icefish) was the most important commercially exploited finfish species in the South Orkney Islands (Jones et al., 2000), and the recovery of this species from depletion is of considerable interest to interest to CCAMLR.

We regularly encountered small numbers of *C. gunnari* across much of the surveyed area of the South Orkney Islands. A total of 575 kg (2,259 individuals) were encountered at 55 stations (Table 9.2), with an overall average standardized density of 833 kg/nmi^2. The highest densities of *C. gunnari* were observed in the western shelf regions (Figure 9.3), with the highest average densities occurring within the 50-150 m depth strata (Table 9.3). The spatial distribution of *C. gunnari* demonstrated relatively patchy concentrations across the shelf.

The size distribution ranged from 18 to 49 cm, with strong year-class modes at 22 cm, 30 cm, likely representing the age two and three year classes, respectively, and 38 cm, probably representing a mix of four-and-older year classes (Figure 9.4). Most fish (72%) were immature, from the large age two year class, with the remaining 26% and 1% at maturity stages two and three, respectively. C. gunnari is a winter spawner. Its egg diameter ranges from 2.0 – 3.5 mm

A total of 946 *C. gunnari* stomachs were sampled for dietary compostion. Of these, 754 (80%) had at least 25% full stomachs. Results from the diet analysis indicated that *C. gunnari* fed on about 99% krill (Figure 9.11). A few specimens had fish (primarily myctophids) in their stomachs. *C. gunnari* smaller than 25 cm also had a small proportion of *Thysanoessa macrura* and occasionally *Themisto gaudichaudii* and *Euphausia frigida* in their diet. The amount of food taken and the degree of digestion varied considerably between stations and even between individuals caught on one station. Stomach content weight varied from < 1 to 10% of the body weight.

Chionodraco rastrospinosus: The channichthyid *C. rastrospinosus* (Ocellated icefish) is a true high-Antarctic species that occurs regularly throughout the deeper shelf regions of Subarea 48.2 and other regions of the Southern Scotia Arc. A total of 618 kg (2,679 individuals) were captured, with an overall average standardized density of 783 kg/nmi^2. This species was among the most ubiquitous finfish species, occurring in all depth strata sampled (Table 9.3) at 62 stations (Table 9.2). The highest densities were encountered in the southernmost shelf deep stations (Figure 9.5) within 250-500 m depth strata (Table 9.3).

The size distribution of *C. rastrospinosus* ranged from 12 to 47 cm (Figure 9.6), with two strong year class modes appearing at 25 cm and 31 cm. Most fish (67%) were immature (maturity stage 1) with 30% and 2% observed at maturity stages 2 and 3, respectively (Figure 9.6). A very small percentage of post spawners were observed, which suggests the species was near the end of the spawning season.

Of the 547 stomachs examined for diet, only 173 (32%) contained material. The proximity of the spawning season likely prevented many *C. rastrospinosus* from feeding. The average diet composition consisted mainly of krill (76%) and both mesopelagic and benthic fish (21%; Figure 9.11).

Gobionotothen gibberifrons: The ubiquitous demersal nototheniid species *G. gibberifrons* (yellow notothenia) has been observed in relatively high abundance through the Southern Scotia Arc Islands, and was a substantial retained bycatch species when the South Orkney Islands were fished commercially for finfish (CCAMLR, 1990a; 1990b). As in the previous AMLR bottom trawl survey of Subarea 48.2 (Jones et. al, 2000), *G. gibberifrons* was the most abundant demersal finfish species, as well as the species most frequently encountered. A total of 2,628 kg (11,178 individuals) was captured from 72 stations (Table 9.2), and the overall average standardized density in the surveyed area was 3,733 kg/nmi^2. Fish were encountered in all depth strata, including slope stations (Table 9.3), with highest standardized densities occurring in the 150-250 m strata. The majority of catches occurred along an east-west band across the northern shelf areas of the islands, with highest concentration in the northwestern shelf sector (Figure 9.5).

The size distribution ranged from 9 to 44 cm, with an overall mode around 26-29 cm and no clearly defined year class modes (Figure 9.6). Most fish had immature or resting stage gonads, with 44% immature (stage 1), 48% maturing virgin or resting (stage 2) and 8% developing (Stage 3). Gonads of *G. gibberifrons* in resting stage confirm observations from other areas in the southern Scotia Arc that the species spawns in late austral winter. Egg diameters were less than 2 mm.

Of the 285 *G. gibberifrons* stomachs analyzed, 275 (96%) had at least 25% full stomachs. *G. gibberifrons* exhibits a high degree of variability in diet composition; it is primarily an opportunistic benthic browser (Figure 9.11). Most of the stomach contents (59%) were highly digested benthic invertebrates and not identifiable in the field. Polychaetes accounted for one of the most abundant identifiable prey items in their stomachs (14%), followed by salps (7), ophiuroids (7%), krill (4%), amphipods (4%), and isopods, echinoderms, pycnogonids, and fish equally making up the remainder (4%) of the average diet.

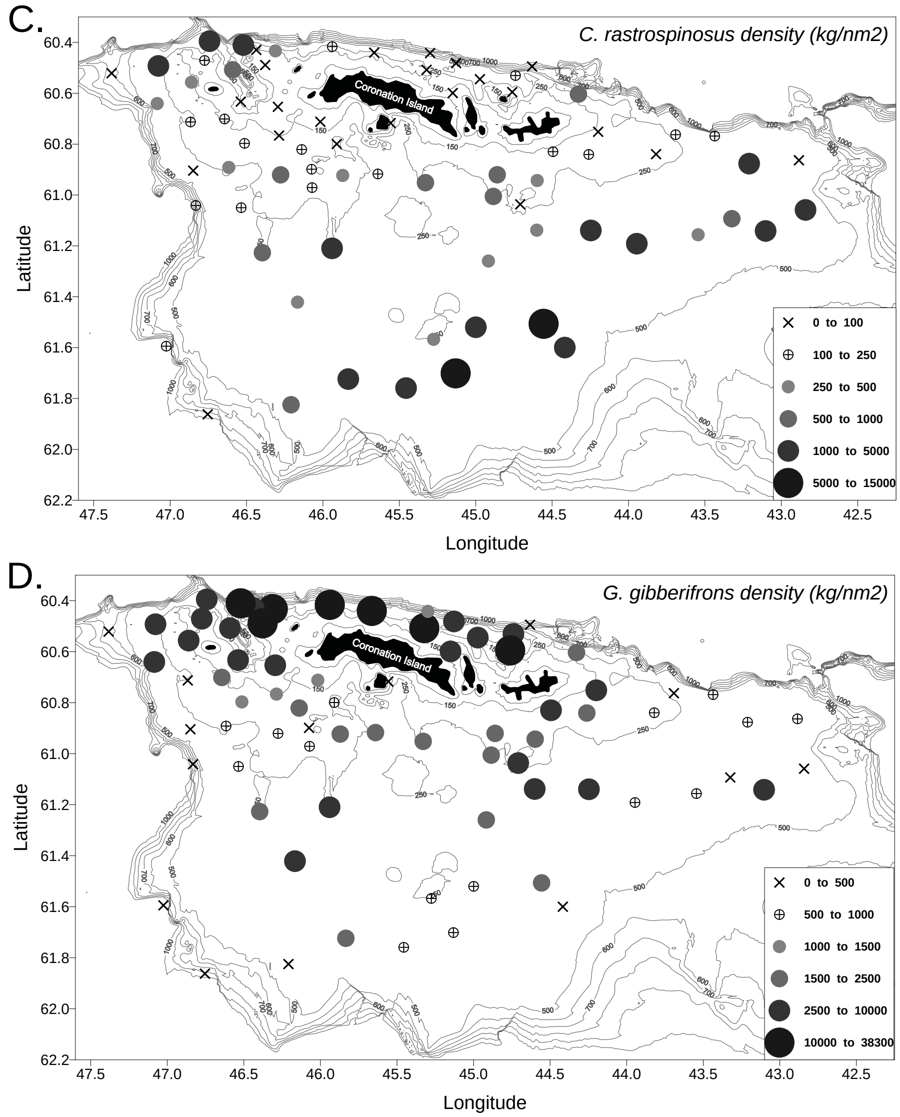


Figure 9.5. Standardized density (kg/nmi^2) for *C. rastrospinosus* and *G. gibberifrons*.

Lepidonotothen squamifrons: A relatively large number of the nototheniid *L. squamifrons* (grey rockcod) was encountered during this survey. A total of 505 kg (892 individuals) was captured at 44 stations (Table 9.2), and the average standardized density was 679 kg/nmi^2. Catches occurred in mid- to deep-water stations, with highest densities near the northwestern shelf break (Figure 9.7) north of the Inaccessible Islands. Highest average densities were encountered in the 150-250 m stratum (Table 9.3), which is somewhat unusual, as *L. squamifrons* has occurred in highest densities in deeper waters during previous AMLR Surveys

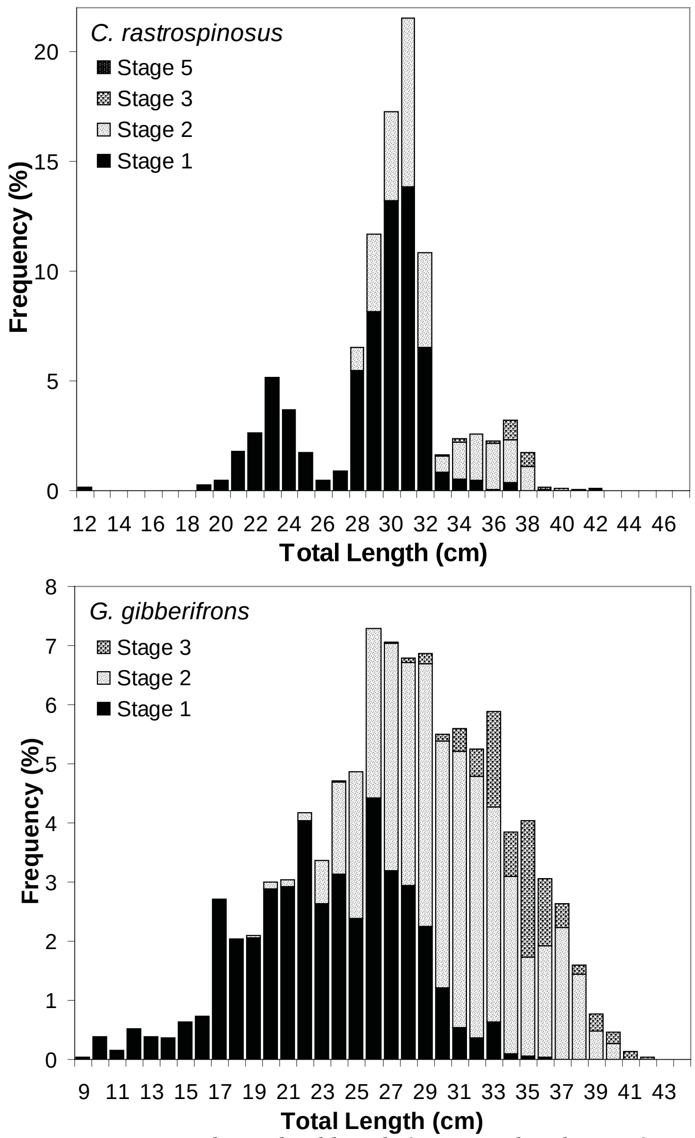


Figure 9.6. Catch-weighted length-frequency distribution for *C. rastrospinosus* and *G. gibberifrons.*

around the South Orkney Islands and northern Antarctic Peninsula regions.

The length-frequency distribution of *L. squamifrons* ranged from 6 to 49 cm, with a broad mode of likely mixed year classes from 32 to 42 cm (Figure 9.8). Fish were found at all five stages of maturity, with most (43%) in maturity stage 2 (resting), and 17%, 11%, .5%, and 27% observed at maturity stages 1, 3, 4, and 5, respectively. The relatively large fraction of spent individuals indicates *L. squamifrons* was well into their spawning season.

A total of 222 stomachs from *L. squamifrons* were analyzed for diet composition. Of these, 196 (88%) had at least 25% full stomachs. The diet of *L. squamifrons* was complex, though comprised mainly of salps (49%; Figure 9.11). Also observed in the diet were unidentified, highly digested benthic invertebrates (26%), krill (10%), fish (7%), and amphipods (4%); isopods, pycnogonids, polychaetes, and echinoderms comprised the remainder of their diet.

Notothenia coriiceps: The nototheniid *N. coriiceps* (black rockcod) is an important representative of the demersal finfish community found throughout shallow shelf areas of the Scotia Sea. A total of 109 kg (81 individuals) was captured at 22 stations (Table 9.2), and the average standardized density was 170 kg/nmi^2. Fish were found in most shallow stations within the survey area, with the highest densities in the eastern and western shallow shelf areas (Figure 9.7). Concentrations of *N. coriiceps* were found primarily within the 50-150 m strata (Table 9.3).

The length-frequency distribution ranged from 34 to 59 cm, with a broad mode appearing at around 36-39 cm (Figure 9.8). Most individuals (77%) encountered were maturity stage 3 (sexually mature), with 22% and 1% at maturity stages 2 and 1, respectively. Maturation of most gonads appears to be synchronized. This species likely spawns over a comparatively short period of time, probably commencing about 3 – 6 weeks after this survey.

A total of 51 stomachs from *N. coriiceps* were analyzed for dietary composition, 45 of which had at least 25% full stomachs. The diverse diet that *N. coriiceps* has demonstrated from previous AMLR Surveys was confirmed (Figure 9.11), though the diversity was substantially less relative to diet in the South Shetland Islands and northern Antarctic Peninsula. In the South Orkney Islands, diet was dominated by krill (68%) as well as fish (25%). Other components included salps, highly digested unidentified benthic invertebrates, amphipods, and ophiuroids.

Pseudochaenichthys georgianus: A total of 656 kg (769 individuals) of the channichthyid *P. georgianus* (South Georgia icefish) was captured from 42 stations (Table 9.2). The majority of catches occurred at stations off the northeastern tip of Coronation Island, as well as at several stations on the southern shelf area (Figure 9.9). Fish were encountered in all shelf strata, with the highest average densities found in the 250-500 m strata (Table 9.4); the average standardized density was 906 kg/nmi^2.

The size distribution of *P. georgianus* ranged from 13 to 55 cm (Figure 9.10), with very well defined modes at

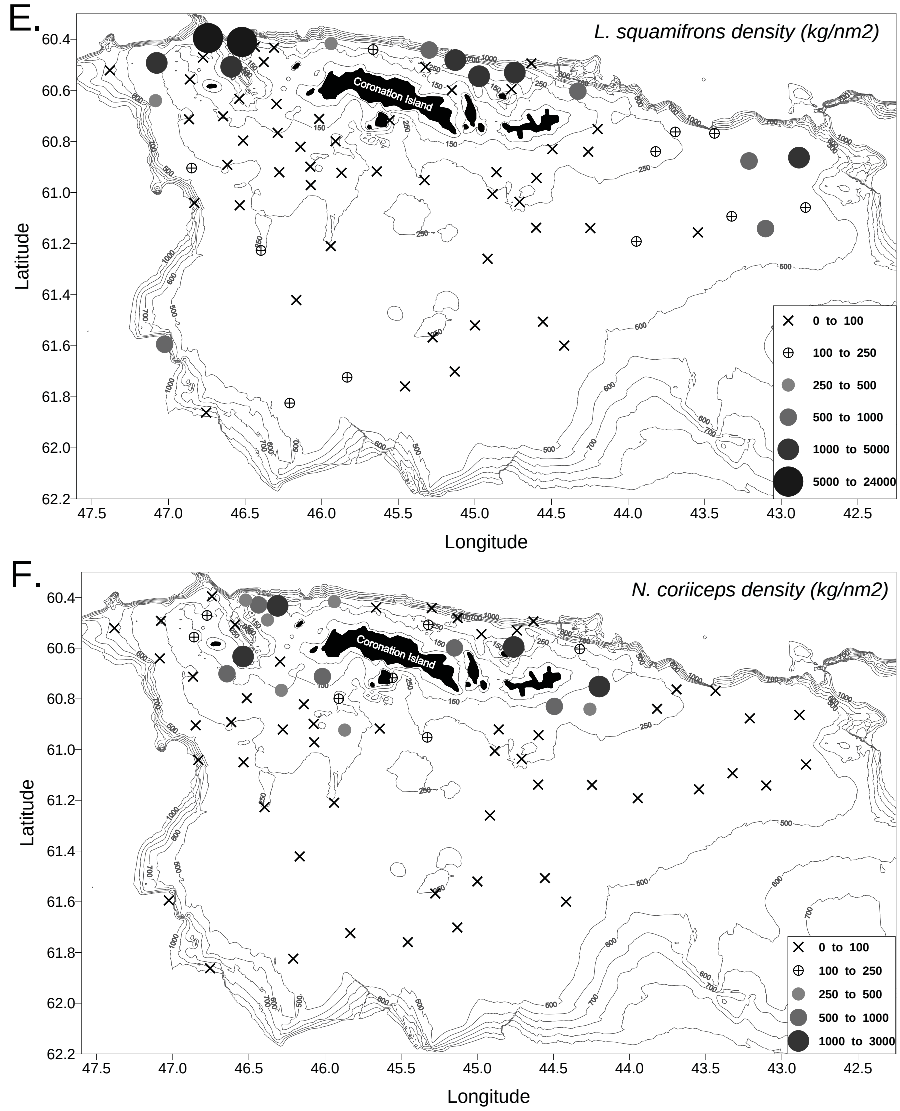


Figure 9.7. Standardized density (kg/nmi^2) for *L. squamifrons* and *N. coriiceps*.

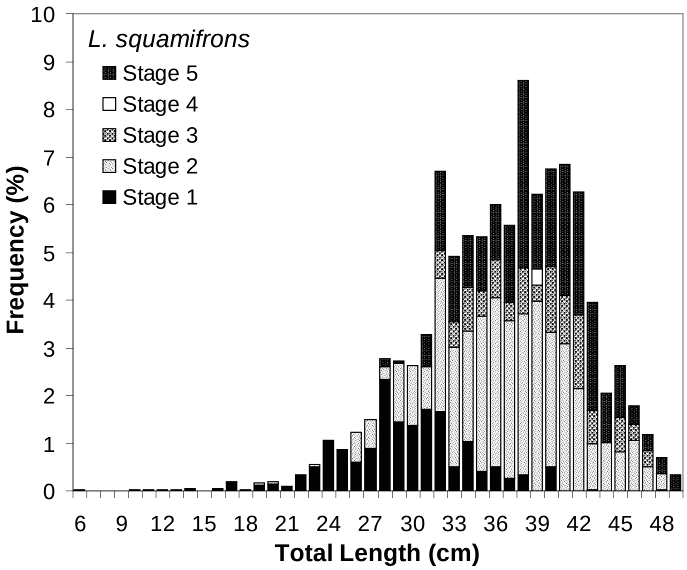
30, 38 and 47 cm. Most fish (41%) were maturity stage 2 (developing virgin), with 31%, 27% and 0.01% observed at maturity stages 1, 2 and 5, respectively. Fish with gonads in pre-spawning state, detected along the northern shelf area, will likely spawn in two months. This is consistent with observations of *P. georgianus* during the 1998/99 AMLR Survey of the South Orkney Islands, when a large spawning aggregation was detected north of Coronation Island in late March.

A total of 259 stomachs from *P. georgianus* were analyzed for diet composition. About 65% (169) of these had at least 25% full stomachs. The average diet comprised mainly krill (68%) and fish (26%); the remaining remaining percentage was composed of mysids and unidentified invertebrates (Figure 9.11).

Trematomous eulepidotus: There were a surprisingly large number of encounters of the nototheniid *T. eulepidotus* (Antarctic rockcod). This species had been targeted in the commercial fishery by the Soviet Union in the high-Antarctic in the 1980s (CCAMLR, 1990a; 1990b), and occurs on the shelf of the South Orkney Islands and other high-latitude Antarctic shelf areas. A total of 92 kg (413 individuals) was collected from 56 stations (Table 9.2), and the average standardized density was 92 kg/nmi^2. The species was present in all depth strata, with the highest standardized densities on the shelf occurring in the 350-500 m stratum, and considerably more on the slope sets (Table 9.3). The spatial pattern of *T. eulepidotus* density demonstrated the preference of this species toward deeper regions of the South Orkney Island shelf, with a relatively consistent distribution of densities at depths greater than 250 m (Figure 9.9).

The lenth-frequency distribution ranged from 9 to 36 cm, with broad modes at 23-25 cm and 32-34 cm (Figure 9.10). Most fish (67%) were maturity stage 3, along with 26% and 7%, observed at maturity stages 1 and 2, respectively. Pre-spawning *T. eulepidotus* were caught in larger numbers (38 and 126 specimens) at Stations 103 and 101, respectively, which were positioned in the outflow of the western Weddell Sea from 620 to 745 m depth. The first, shallower, haul contained 126 individuals, of which more than 90% were males. The second haul, about 120 m deeper, contained only females. The two hauls seem to suggest that males occupy a habitat different than females prior to spawning. Whether they occupy territories, as a number of other notothenioids do, is still speculative.

A total of 189 stomachs were analyzed for diet composition; about 59% (111) of these had stomachs at least 25% full. Results from the diet analysis indicated that *T. eulepidotus* have a variable diet, though feed primarily on krill (47%) as well as miscellaneous benthic and pelagic invertebrates, including jellyfish (29%), salps (8%), fish (7%), and mysids (5%), with amphipods, polycheates, and echinoderms composing the re-



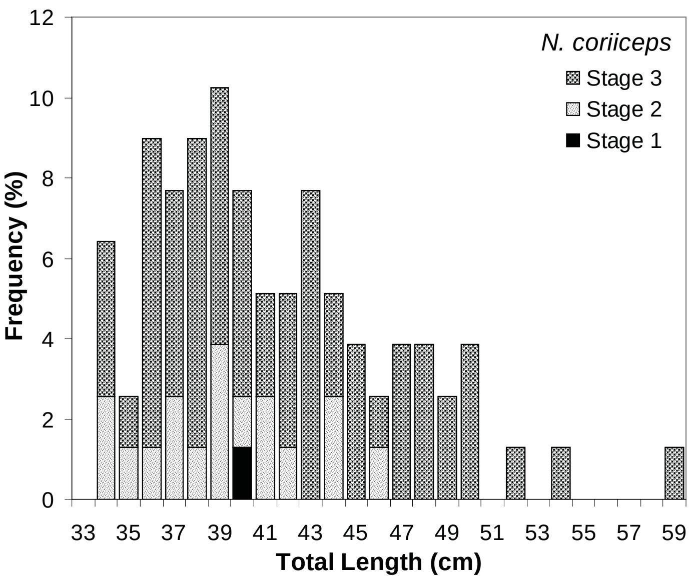


Figure 9.8. Catch-weighted length-frequency distribution for *L. squamifrons* and *N. coriiceps*.

mainder of the diet (Figure 9.11).

Other Species

Notothenia Rossii: The nototheniid *N. rossii* (Marbled rockcod) was an important commercially targeted species in the South Orkney Islands in the late 1970's and early 1980's (CCAMLR, 1990a; 1990b), and the recovery of this species from depletion is of considerable interest to CCAMLR. Jones et al. (2000) noted that there appeared to be some signals of recovery from the results of the 1998/99 AMLR Survey of the South Orkney Islands. Results from this survey suggest that the species still has not recovered to the level of biomass during the 1970s-1980s. A total of only 49 kg (23 individuals) was captured from 17 stations (Table 9.2). Catches occurred in all depth strata, with the highest average densities encountered within 250-500 meters (Table 9.3).

The size distribution ranged from 38 to 69 cm, with no well defined mode. About half of the individuals staged for sexual maturity were maturity stage 3 (developing), with maturity stages 1 and 2 equally represented in the remaining half. Diet composition was collected from 21 individuals, 18 of which (86%) had at least 25% full stomachs. Their diet consisted mainly of fish (41%), krill (35%), and salps (13%), with the remaining composed of unidentified digested benthic invertebrates and amphipods (Figure 9.11).

Lepidonotothen larseni: The ubiquitous nototheniid *L. larseni* (Painted rockcod) is small, relatively abundant throughout the Southern Scotia Arc region, and is an important prey item to fish-eating demersal finfish. A total of 38 kg (888 individuals) were captured from 61 stations (Table 9.2).

The greatest densities of this species were encountered in the 150 and 250 m strata (Table 9.3). The size distribution of *L. larseni* ranged from 6 to 22 cm. Gonads were in an early stage of maturation, with most fish in either maturity stage 2 (69%) or maturity stage 1 (29%), and a few specimens starting to develop. This suggests that spawning will likely not commence before June.

A total of 167 stomachs from *L. larseni* were analyzed for diet composition, 140 (84%) of which had at least 25% full stomachs. Their diet (Figure 9.11) largely comprised krill (40%) and miscellaneous digested benthic invertebrate material (49%). In addition, their diet consisted of salps (7%), mysids (3%), amphipods and polychaetes (2%).

Dissostichus mawsoni: The nototheniid *D. mawsoni* (Antarctic toothfish) is currently one of the most important commercially harvested species several in other regions of the high Antarctic Southern Ocean. The closely related *D. eleginiodes* was commercially harvested in small numbers around the South Orkney Islands during the late 1970s and early 1980s (CCAMLR, 1990a; 1990b), though there is some speculation that the species may have been misreported, and may have been *D. mawsoni*. During this survey, as well as during AMLR 1998/99 Survey, only representatives of *D. mawsoni* were encountered.

A total of 21 kg (12 individuals) was captured from five stations (Table 9.2). The size distribution ranged

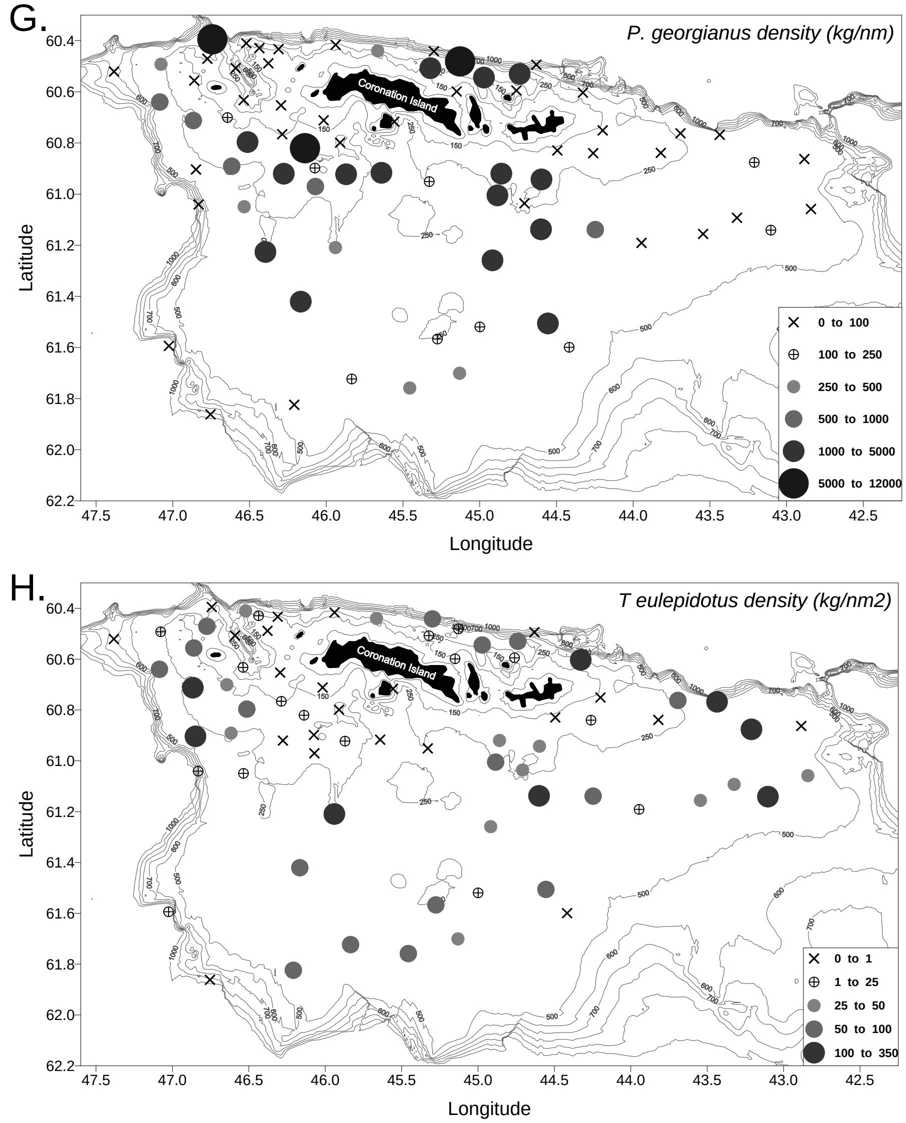


Figure 9.9. Standardized density (kg/nmi^2) for *P. georgianus* and *T. eulepidotus*.

from 33 to 88 cm. Ten of the 12 specimens were immature (maturity stage 1), with the remaining two maturing virgins (maturity stage 2). Stomach contents from 10 individuals were examined, six of which had at least 25% full stomachs. The composition of the diet for those fish with stomach contents consisted mostly of fish (67%), the remaining percentage was highly digested unidentified material (Figure 9.11).

Pleurogramma antarcticum: A surprisingly large number of the mesopelagic species *P. antarcticum* (Antarctic silverfish) was captured opportunistically during course of the survey. This species, along with *G. nicholsi* and Electrona Antarctica, is an important prey item for several species of finfish, seabirds and mammals, and thus one of the most important finfish species of the Antarctic ecosystem. We captured 94 kg (6,156 individuals) at 22 stations (Table 9.2), by far the most *P. antarcticum* captured during an AMLR bottom trawl survey. In contrast, The 1998/99 AMLR Survey of the South Orkney Islands (using a similar sampling design on the shelf), captured only 12 specimens.

Catches occurred at stations deeper than 250 m along the survey area (Table 9.3). The length-frequency distribution of *P. antarcticum* ranged from 71 to 263 mm, with a mode around 115-125 mm. A limited number of specimens were staged for maturity (n=89); measured fish were primarily immature (85%) or developing gonads (15%). A total of 18 *P. antarcticum* stomachs were sampled for dietary composition, six of which had at least 25% full stomachs. Of this limited sample, the diet was 83% krill, with the remaining percentage consisting of miscellaneous digested pelagic invertebrates (Figure 9.11).

Gymnoscopelus nicholsi: The pelagic myctophid *G. nicholsi* was captured opportunistically during the course of the survey. This species, along with *Electrona antarctica* and *P. antarcticum*, constitutes an important prey item for several species of finfish, land-based birds and mammals. Other myctophid species occasionally encountered included *G. braueri*, *G. opisthopterus*, and *K. anderssoni* (Table 9.2)

A total of 77 kg (2,188 individuals) of *G. nicholsi* were captured from 27 stations. Catches occurred at offshore stations in waters deeper than 250 meters. The size distribution of *G. nicholsi* ranged from 122 to 168 mm. A total of 91 *G. nicholsi* were staged for maturity, 93% of which were immature.

Other finfish families: The other two families of the suborder Notothenioidei, the Bathydraconidae (dragon fish) and the Artedidraconidae (plunderfish), were less represented in samples during the course of the survey. The bathydraconids encountered were *Bathydraco marri*, *Gymnodraco acuticeps*, *Parachaenichthys charcoti*, *Prionodraco evansii* and *Racovitzia glacialus*. Artedi-

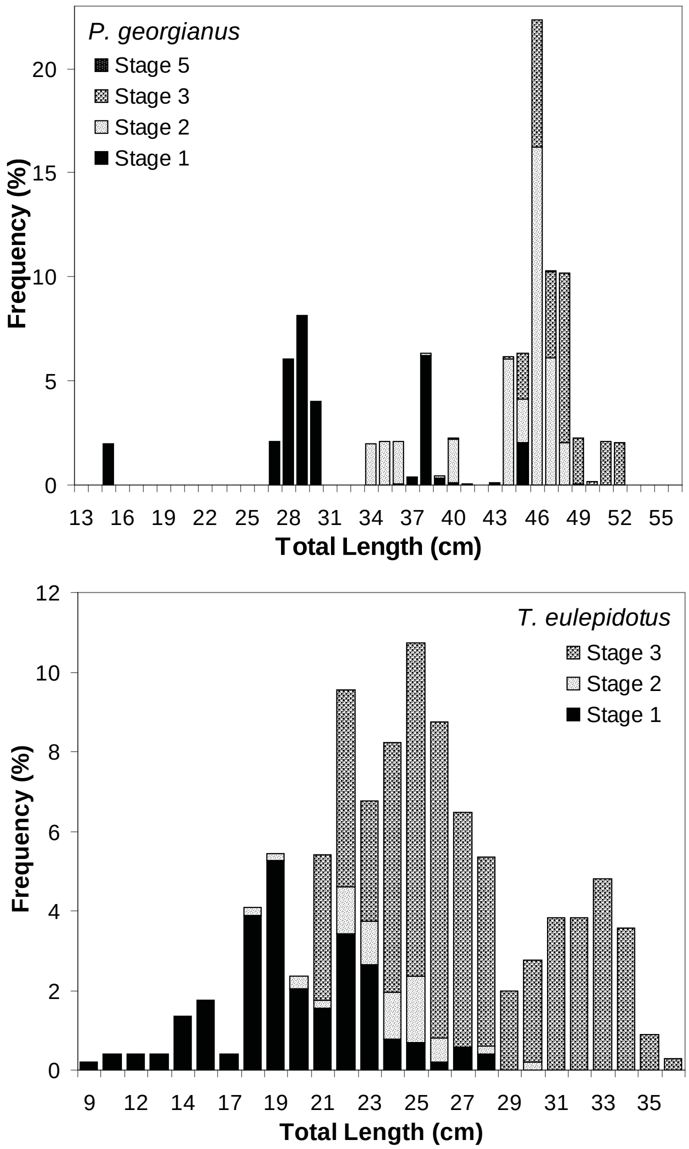


Figure 9.10. Catch-weighted length-frequency distribution for *P. georgianus* and *T. eulepidotus*.

draconids were represented by *Artedidraco skottsbergi* and members of the genus *Pogonophryne*, including *P. barsukovi*, *P. macropodon*, and *P. scotti*.

One of the more interesting Artedidraconid species is *Pogonophryne scotti*, usually encountered in small numbers in a typical survey, with the exception of the 1998/99 AMLR Survey of the South Orkney Islands, during which 100 individuals were captured. During the course of this year's survey, 52 individuals were captured.

We have made additional important observations on diet, reproductive condition, and buoyancy on several rare notothenioid species, including *Bathydraco marri*, *Prionodraco evansii*, *Aethotaxis mitopteryx*, *Pogonophryne barsukovi*, *Artedidraco skottsburgi*, and *Trematomus tokarevi*. In addition, we have confirmed the presence of *Trematomus nicolai* in the South Orkney Islands. The occurrence of this species in the South Orkney Islands had only been recorded once, in the 1960s, and this record was considered erroneous.

Other faunal elements encountered during the course of the survey included the zoarcids (*Pachycara brachycephalum*, *Ophthalmolycus amberensis*), skates (*Bathyraja eatonii*, *B. maccaini*, *Bathydraco sp. 2*) and several snailfishes (Liparididae) of the genus *Paraliparis*. They are either of non-Antarctic origin or form separate species in the Southern Ocean.

Enrionmetal Observations

Information on several characteristics of the pelagic and seafloor components of shelf areas around South Orkney Islands were collected in an effort to elucidate the role of mesohabitat ecological features on demersal fish assemblages. Shelf areas of the South Orkney Islands are widely varied in their bathymetry, water mass characteristics, pelagic prey distribution, seabed composition, and benthic invertebrate communities. These features likely play a significant role in the spatial distribution, density, demography, and dietary composition of demersal finfish across the South Orkney Island shelf area.

Data collections during Leg II of the AMLR Survey that complement the demersal finfish survey results included physical oceanographic measurements (Chapter 1), characterization of krill density (Chapters 3 and 12), benthic invertebrate megafauna distribution and composition (Chapter 10) and direct video observation of habitat features (Chapter 11).

Biodiversity, buoyancy variation, and systematics

Sixty-five species of notothenioid demersal fish were encountered during the course of the 2008/09 AMLR Survey finfish trawl, which was by far the largest tally for any AMLR Survey bottom trawl. Of these species, 835 finfish specimens and tissue biopsies were collected from 62 species. Tissue biopsies were collected for ongoing phylogenetic and population genetic studies of notothenioid fishes. Whole specimens collected were fixed in formalin for deposition in the fish collection at the Peabody Museum of Natural History, Yale University. Included in the collections are several rare notothenioid species including *Aethotaxis mitopteryx*, *Trematomus tokarevi*, *Vomeridens infuscipinnis*, and *Neopagetopsis ionah*. Specimens of *Notothenia* *coriiceps* and *Trematomus hansoni* have been collected by the Peabody Museum in order to investigate long standing unresolved questions in the taxonomy and systematics of these species.

Work on buoyancy variation is demonstrating that closely related notothenioid species can have significantly different buoyancy measurements. This is hypothesized to reflect water column habitat use, with more buoyant species being less benthic. Most species of teleost fishes use a swim bladder to regulate buoyancy. All notothenioid fishes lack a swim bladder; however, there has been substantial variation in buoyancy detected among notothenioid species (Near et al. 2009). The buoyancy of a specimen, considered as the percent of the weight in air of the weight in water, was measured from all notothenioid species along with other measurements taken for functional morphological characters. To determine the weight in water, specimens were suspended completely in seawater by a silk suture attached to a triple beam balance.

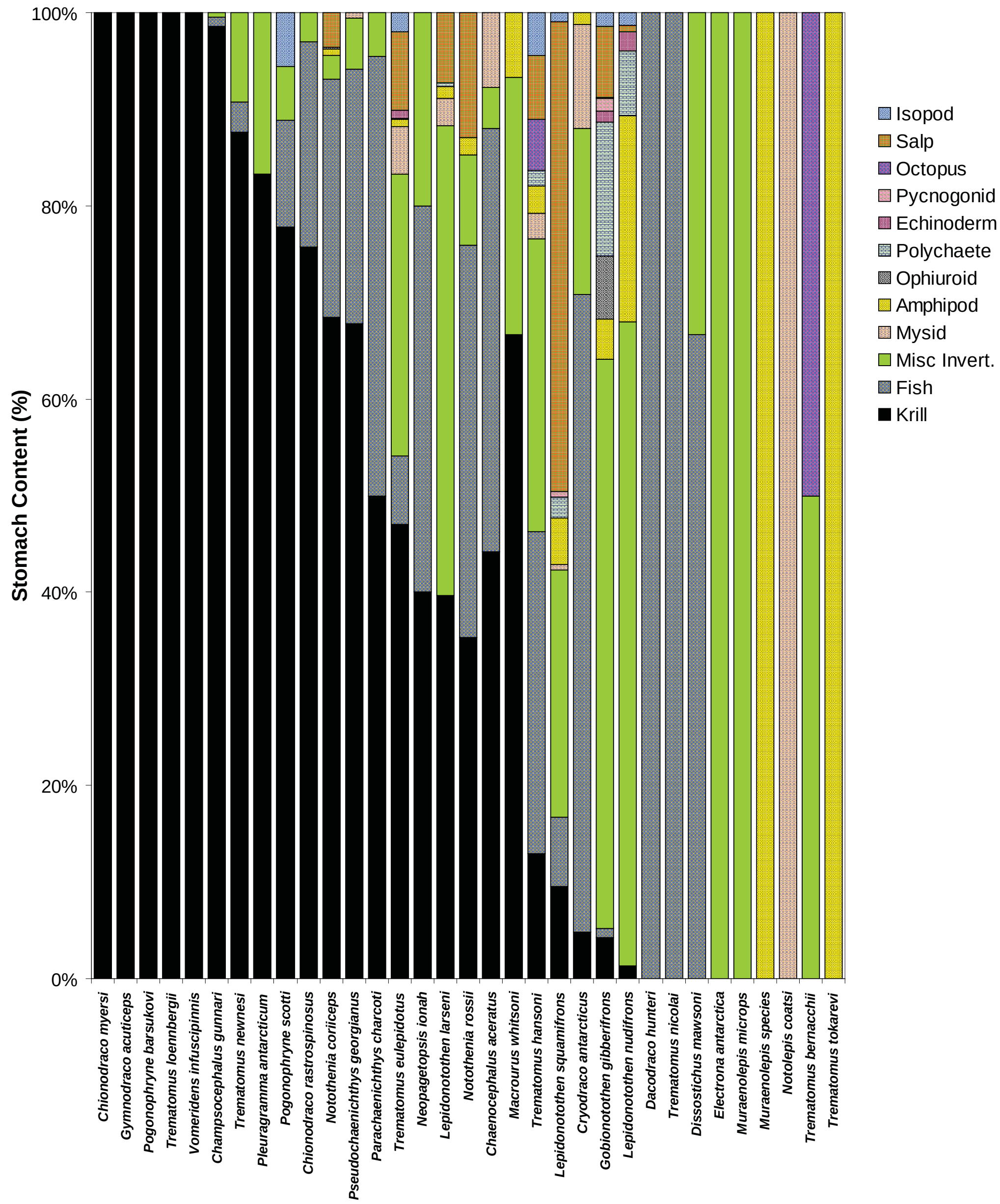


Figure 9.11. Summary of diet composition of 33 species of finfish, based on mean stomach content scores and sorted by % krill, from the 2008/09 AMLR Survey of finfish in the South Orkney Islands.

Sampling during the course of Leg II resulted in collection of specimens of at least two undescribed species: an unknown muaenolepid and a *Bathyraja* species that has been known to scientists for at least 20 years. Investigation and possible species description will take place at Yale University.

Finfish Age and Growth

A total of 2,583 otoliths from 21 finfish species were collected. These otoliths are to be used in age estimation and population structure studies based at the Center for Quantitative Fisheries Ecology (CQFE), Old Dominion University (ODU), Norfolk, Virginia. In addition, otoliths and gonads for *C. aceratus* were collected for examining age and growth, reproductive biology, and population structure of this species. Otoliths of *P. antarcticum*, *D. eleginoides*, *D. maswoni*, and *N. coriiceps* are being targeted for the fulfillment of connectivity and population structure projects based at the CQFE. A total of 130 gonads (male and female, maturity stages 1-3) were collected from *C. aceratus*. Gonads have also been collected from *C. gunnari*, *N. coriiceps*, *T. hansoni*, *P. antarcticum*, *L. larseni*, *T. newnesi*, *C. rastrospinosus*, *N. rossii*, and *L. squamifrons*. Total gonad collection for all species was 187 gonads. These gonads will be used in histological studies based at the CQFE and the Consiglio Nazionale delle Ricerche (CNR) in Ancona, Italy.

Discussion

Leg II of the 2008/09 AMLR Survey represented the first comprehensive demersal finfish survey in the South Orkney Islands since 1999. Analysis of the results of this survey will prove critical in terms of understanding the present status of South Orkney Islands shelf finfish populations and other ecosystem components. Results from further analysis will be used to develop management advice for the CCAMLR Scientific Committee and potentially develop or revise harvest policy or spatial management initiatives. There has been a moratorium imposed by CCAMLR on all finfish fishing in Subarea 48.2, which includes the South Orkney Island shelf, since the 1990/91 season (CCAMLR CM 32-03). This moratorium was set in place due to a major depletion of finfish, primarily of *C. gunnari* and *N. rossii*, as a result of overfishing that took place primarily prior to the inception of the CCAMLR Convention, and a lack of precautionary management and harvest policy.

Results of Leg II provide the information necessary to estimate standing stock biomass for several finfish species, compare these estimates to historical information, and provide advice as to whether a sustainable fishery for any of the finfish resources could be implemented at this time. Further, the collection of data for several other ecosystem components during the course of Leg II, such as pelagic prey and benthic invertebrate density and distribution, allows the demersal finfish results to be integrated in a more ecosystem context, potentially providing information that could be used toward spatial management initiatives.

Protocol Deviations

The demersal survey sampling design of the South Orkney Islands shelf area did not deviate significantly from the protocol outlined during the 1998/99 AMLR Survey of this region. The timing of the survey, though, was about one month earlier than the 1998/99 AMLR Survey. The realized locations of almost all hauls varied from the initially planned coordinates due to sea, wind, bottom, and ice conditions. Several initially planned stations were inaccessible due to heavy ice concentrations. However, these were successfully relocated in the same general shelf region within the same targeted depth strata. Further, there were a number of other research projects that were not undertaken during the previous survey. With respect to sampling off the shelf, another strata with stations set on the slope region was added (these will not impact the estimate of biomass for the shelf survey). There was substantially greater sampling and preservation of finfish specimens and tissue as well.

Other differences from the previous survey of the South Orkney Islands included detailed benthic invertebrate megafauna characterization from the trawling stations, photo/video transects using the skiing camera configuration to characterize seafloor habitat, benthic communities, and to provide direct evidence of Vulnerable Marine Ecosystem (VME) indicator taxa that will be used toward potentially registering VME risk areas in the CCAMLR Convention Area. The survey also included IKMT net tows for krill and zooplankton composition, which will help elucidate spatial relationships between finfish krill predators and prey on the shelf area.

Acknowledgments

We greatly appreciate the hard work and skill of the captain, Alexandr Shtakhov, and crew of the R/V *Yuzhmorgeologiya*, especially with respect to the determination they demonstrated in allowing us to complete our survey design in full. We thank the trawlmaster, Capt. Peter Njardvik, for his mastery of the art of trawling in remote regions with numerous obstacles and often difficult conditions. We also thank the all other participants of Leg II who assisted in the processing of samples in their spare time.

Disposition of Data

Data collected from the trawl survey were documented on hardcopy datasheets and entered into an MS-ACCESS computer database. The U.S. AMLR program maintains these hardcopies and computer databases. Data are available from Christopher Jones, Antarctic Ecosystem Research Division, Southwest Fisheries Science Center, 3333 North Torrey Pines Court, La Jolla, CA 92037; phone/fax – (858) 546-5605/546-5608; e-mail: Chris.D.Jones@noaa.gov.

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Benthic Invertebrate Composition and Characterization of the South Orkney Islands
Susanne Lockhart, Nerida Wilson, Eric Lazo-Wasem, and Christopher Jones

Abstract The epi-benthic megafaunal invertebrate community density and composition of the South Orkney Islands was sampled during Leg II of the 2008/09 AMLR Survey and analyzed to the level of phyla. The benthic invertebrate megafaunal component of 75 bottom trawls completed around the South Orkney Islands, and an additional three off the Antarctic Peninsula, was analyzed by weight and by sorting into 61 operational taxonomic units (OTUs), including the 18 provisionally recognized by CCAMLR as indicators of the presence of a Vulnerable Marine Ecosystem (VME). The results from this year's survey include:

- Around the South Orkney Islands, total megafaunal invertebrate densities show a geographic pattern whereby the highest densities are clustered at the western and eastern tips of the island chain, while benthic community densities decrease toward the outer limits of the shelf.
- Densities of the VME indicator taxon (VME-IT) Porifera in general follow the same pattern as the total benthic community, while densities of Other VME-IT are greatest along the northern shelf.
- On the western shelf, Porifera dominate the community composition in the region closest to Coronation Island while on the outer limits of the shelf the benthos is dominated by Echinoderms.
- Large assemblages of tunicates (Chordata) are often found near narrow sections of shelf between islands that presumably experience higher currents and water flow than broader regions of the shelf.
- Well-established sponge communities dominate the benthos closest to Laurie Island on the eastern shelf, which give way to communities dominated by Pterobranchia and Echinodermata at the eastern most shelf limits and to the south and southeast of the South Orkney Islands.
- The southern shelf of the South Orkney Islands supports benthic communities mostly dominated by Echinodermata.
- Additional oceanographic factors in further analyses are required to explain the geographic patterns in density and composition described herein.
- Of the 18 provisionally recognized VME-IT, 15 were encountered during the course of this expedition.

Introduction

Benthic invertebrate catch composition and habitat characterization was conducted concurrent with the bottom trawl survey and demersal finfish research (Chapter 9). In order to better understand the Antarctic finfish ecosystem and the relationships of its components it is vital to conjointly investigate the characteristics of the benthic invertebrate communities with which these fish are associated. Moreover, the relevance and value of benthic community research has been elevated, and the need to identify, define and designate Vulnerable Marine Ecosystems (VME) has been recognized by the Commision for the Conservations of Antarctic Marine Living Resources, or CCAMLR (CM 22-06 and 22-07) and the United Nations General Assembly (RES. 61/105) with the aim of minimizing risk to VMEs, and ultimately the successful monitoring and sustainable management of the Antarctic ecosystem and its resources.

With this intent, the objectives for Leg II included composition analysis (identification and quantification) of the benthic invertebrate component of bottom trawl catches in order to characterize the seafloor habitats encountered with intent to gather data necessary for VME identification and designation and work toward the benthic bioregionalization of the area. In addition, extensive sampling of the benthic invertebrate species encountered was conducted by the current authors for their own continued research and also on behalf of other specialists in the U.S. and around the world with the aim of augmenting current, inadequate, knowledge of the region's biodiversity.

Methods

Bottom trawling was conducted primarily along the South Orkney Islands shelf. Seventy successful hauls were accomplished at shelf depths between

Table 10.1. Operational taxonomic units (OTUs) utilized in the characterization of the benthic invertebrate component of the bottom trawl catch. ✓ denotes those currently classified by CCAMLR as indicator taxa of vulnerable marine ecosystems (VME-IT). NB: The genera *Flabellum* and *Gorganocephalus* are not treated as separate VME-IT by Parker et al. (2008), but are instead included under the high taxonomic ranks of Scleractinia and Pharynophiurida, respectively. Likewise, bryozoans and ascideans (each separated herein into two groups: filamentous/foliose and hard/reef building; and solitary and compound, respectively) are each treated as one VME-IT by Parker et al. (2008). † denotes OTUs not encountered during the course of the current field season. *Harpovoluta weights, including symbiotic anemone, were attributed to Mollusca except in the few cases where anemones were detached and easily included within Actiniaria.

Phylum	Taxon	Genus or Common Name	VME-IT	CCAMLR Code
Porifera (PFR)	Hexactinellida	Glass Sponge	✓	PFR
Porifera	Demospongiae	Siliceous/Demo Sponge	✓	PFR
Cnidaria (CNI)	Hydrozoa	Hydroid	✓	CNI
Cnidaria	Hydrozoa/Stylasterida	Hydrocoral	✓	CNI
Cnidaria	Anthozoa/Actiniaria	Anemone	✓	ATX
Cnidaria	Anthozoa/Alcyonacea	Soft Coral	✓	AJH
Cnidaria	Anthozoa/Scleractinia	Stony Coral (Miscellaneous)	✓	CSS
Cnidaria	Anthozoa/Scleractinia	*Flabellum*	✓	CSS
Cnidaria	Anthozoa/Pennatulacea	Sea Pen	✓	CNI
Cnidaria	Anthozoa/Antipatharia	Black Coral†	✓	AQZ
Cnidaria	Gorgonacea/Isididae	Bamboo Coral	✓	GGW
Cnidaria	Gorgonacea/Coralliidae	Red/Precious Coral†	✓	GGW
Cnidaria	Gorgonacea/Primnoidae	Bottle Brush, Sea Fan/Whip	✓	GGW
Cnidaria	Gorgonacea/Paragorgiidae	Bubblegum Coral	✓	GGW
Cnidaria	Gorgonacea/Chrysogorgiidae	Golden Coral	✓	GGW
Brachiopoda		Lamp Shell		BRC
Bryozoa		Filamentous/Foliose	✓	-
Bryozoa		Hard/Reef Building	✓	-
Platyhelminthes		Flat Worm†		-
Nemertina		Ribbon Worm		-
Cephalorhyncha	Priapulida	Penis Worm		-
Mollusca (MOL)	Aplacophora	Aplacophoran		-
Mollusca	Polyplacophora	Chiton		-
Mollusca	Gastropoda	Sea Snails (Miscellaneous)		GAS
Mollusca (Cnidaria)	Gastropoda-Actiniaria	*Harpovoluta* (with obligate symbiotic anemone) *		GAS
Mollusca	Gastropod/Lamellaria	Lamellarian		GAS
Mollusca	Gastropoda/Opisthobranchia	Sea Slugs (Miscellaneous)		GAS
Mollusca	Gastropoda/Opisthobranchia	*Bathyberthella*		GAS
Mollusca	Scaphopoda	Tusk Shell		-
Mollusca	Bivalvia	Clam Shell		CLX
Mollusca	Cephalopoda/Octopodiformes	Octopus		OCT
Mollusca	Cephalopoda/Decapodiformes	Squid		SQQ
Sipuncula		Peanut Worm		-
Annelida	Echiura	Spoon Worm		-
Annelida	Polychaeta	Bristle Worm (Miscellaneous)		WOR
Annelida	Polychaeta/Aphroditidae	Sea Mouse		WOR
Arthropoda	Pycnogonida	Sea Spider		PWJ
Arthropoda	Cirripedia	Barnacle		-
Arthropoda	Amphipoda	Sand Hopper		AQM
Arthropoda	Isopoda	Sea Slater (Miscellaneous)		ISH
Arthropoda	Isopoda/Serolidae	Serolid		ISH
Arthropoda	Isopoda/Chaetiliidae	*Glyptonotus*		ISH
Arthropoda	Decapoda	Shrimp, Prawn		DCP
Echinodermata (ECH)	Crinoidea (Stalked)	Sea Lily †	✓	CWD
Echinodermata	Crinoidea/Comatulida	Feather Star (Miscellaneous)		CWD
Echinodermata	Crinoidea/Comatulida	*Promachocrinus*		CWD
Echinodermata	Asteroidea	Sea Star (Miscellaneous)		STF
Echinodermata	Asteroidea/Forcipuladitda	*Labidiaster*		STF
Echinodermata	Ophiuroidea	Brittle Star (Miscellaneous)		OWP
Echinodermata	Ophiuroidea/Ophiuridae	*Ophionotus*		OWP
Echinodermata	Ophiuroidea/Pharynophiurida	Snake Star, Basket Star (Miscellaneous)	✓	OWP
Echinodermata	Ophiuroidea/Pharynophiurida	*Gorganocephalus*†	✓	OWP
Echinodermata	Holothuroidea	Sea Cucumber (Miscellaneous)		CUX
Echinodermata	Holothuroidea/Aspidochirotida	*Bathyplotes*		CUX
Echinodermata	Holothuroidea/Psolidae	Psolid Cucumber		CUX
Echinodermata	Echinoidea/Cidaroida	Pencil Spine Sea Urchin		URX
Echinodermata	Echinoidea/Echinidae	*Sterechinus*		URX
Echinodermata	Echinoidea/Spatangoida	Irregular Sea Urchin		URX
Hemichordata	Pterobranchia	Pterobranchs		-
Chordata	Tunicata/Ascidiacea	Solitary Tunicate/Sea Squirt	✓	SSX
Chordata	Tunicata/Ascidiacea	Compound Ascidian	✓	SSX

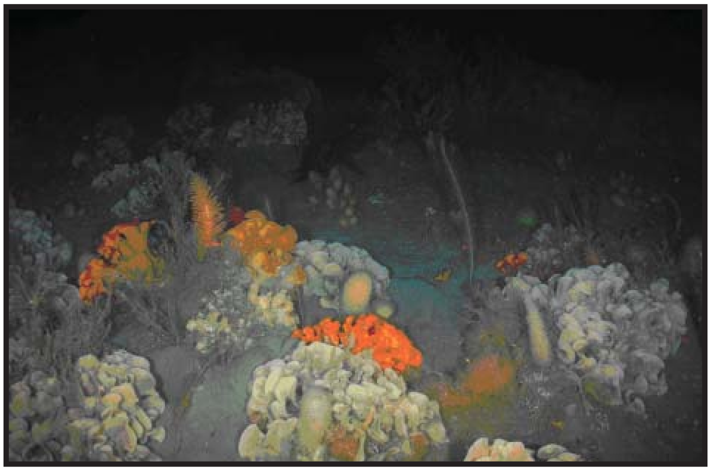

Figure 10.1. A number of different hard bryozoan species can form reef-like structures as complex as coral reefs in tropical waters. This particular example is located at station 63 (mean depth: 142 m) south of Inaccessible Islands, South Orkney Islands.

63-497 m (mean trawl depth). Five more hauls were completed at slope depths around the South Orkney Islands (mean trawl depth range: 629-798 m) and an additional three slope hauls were taken off the Antarctic Peninsula (mean trawl depth range: 623-759 m). Specifics on trawling activities and techniques are described in Chapter 9 of this report, which includes details of each haul (Table 9.1) and a map illustrating station locations (Chapter 9, Figure 9.1).

Once the trawl catch was secured on deck it was shoveled into fish baskets and moved to the sorting tables. For catches that required sub-sampling, the fish were separated on the back deck and for those that did not the fish were usually separated from the benthos on the sorting tables. At a few locations the biomass of the hauls was so great that only a portion of the invertebrate component could feasibly be put into baskets for weighing. In these cases up to 20 baskets of invertebrates were moved to the sorting area for weighing, while any additional baskets were counted and discarded. In this way, an average weight per basket could be calculated for extrapolation. In cases where it was not feasible to sort all baskets of benthic invertebrates that made it to the sorting area, a subsample was randomly chosen (minimum 6 baskets) and the remainder weighed.

Density of megafaunal invertebrates by sampling station was standardized by prorating nominal pooled catch of the station's swept area to one square nautical mile (nmi^2). The area of seabed sampled at each station was determined by GPS latitude/longitude coordinates, taken at the start and the end of bottom trawling (seabed contact), and the average trawl mouth width during this time. Calculations of total benthic invertebrate density excluded only inorganic matter, pelagics and algae. VME-Indicator Taxa (VME-IT; Table 10.1) biomass data were separated into two categories - Porifera and Other VME-IT – to avoid the density of the latter from being swamped by the significantly heavier sponges.

The benthic invertebrate catch was compositionally analyzed by sorting into 61 feasible taxonomic groupings, or operational taxonomic units (OTUs) (Table 10.1). This number of OTUs represents a significant increase in complexity and resolution since the 2006 survey (44 OTUs) in order to incorporate those taxa recently put forward by CCAMLR as taxonomic indicators of VMEs (Parker et al., 2008). As per current opinion, echiurans are not treated as a distinct phylum, but rather are included within Annelida (Rousset et al., 2007). The phylum Bryozoa was divided into two functional groupings: those that do and those that do not form reef-like structures utilized by other organisms. That hard bryozoans can be reef-forming is well illustrated in Figure 10.1. Thus, the bryozoans were split into: a) filamentous or foliose forms and; b) hard or reef-building forms. Likewise, the class Tunicata was split into: a) solitary forms and; b) colonial forms. The VME-IT Ascidiacea is a class-level taxon (CCAMLR Code, SSX) of the subphylum Tunicata rather than Urochordata, which is no longer recognized as a distinct phylum from Chordata (World Register of Marine Species (WoRMS); www.marinespecies.org). The *On-deck classification guide for potentially vulnerable invertebrate taxa in the Ross Sea long-line fishery* (Parker et al., 2008) includes the order Euryalinida (phylum: Echinodermata) which, according to the WoRMS (www.marinespecies.org), is no longer a valid taxon; the appropriate order is Pharynophiurida. Whether this designated VME-IT should be further refined to the family level - that which encompasses the three species depicted on the *On-deck Classification guide* (Parker et al., 2008), i.e. Gorgonocephalidae, - remains to be determined.

Weights of each OTU were recorded and individuals counted where appropriate. Any dead or non-sortable organic matter was also weighed and, for the latter, characterized (e.g. 60% demosponge, 30% irregular echinoid fragments, 10% organic matter). Algae were also weighed and recorded, but the data is not presented here. Incidentally caught pelagic invertebrates such as jellyfish and salps (excluding decapods and squid) and inorganic matter were weighed only in the cases where subsampling was necessary. When excessive biomass prevented complete analysis of a haul, weighed baskets of benthos were numbered and a subset (maximum feasible) randomly chosen for characterization.

For the purpose of meso-scale comparisons of benthic invertebrate composition between stations, weights were pooled within each phylum to calculate the proportion each contributed to the total. These calculations excluded the dead non-characterizable portion of the non-sortable organic matter as described above, as well as inorganic matter, pelagics and algae. In past field seasons, stations within the same stratum and in close vicinity were pooled and averaged for visual simplicity. However, with the current focus on VMEs, and how CCAMLR is to define and designate them, it was deemed essential to treat each station separately so that an idea of the size of various benthic ecosystem types could be gained.

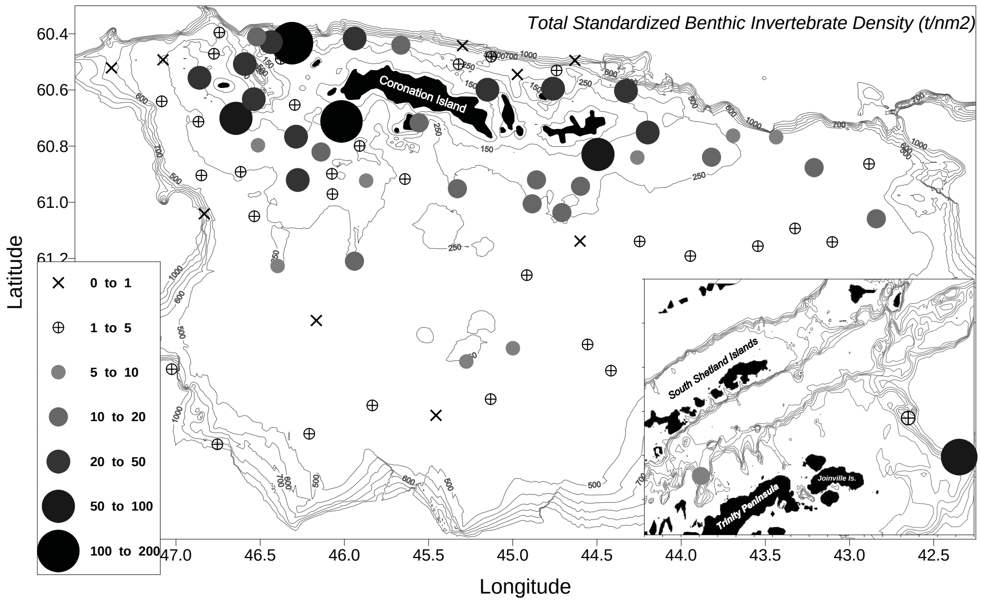

Figure 10.2. Total standardized benthic invertebrate density (t/nmi^2) at each station sampled during the 2009 bottom trawl finfish survey of the South Orkney Islands and the Antarctic Peninsula (inset).

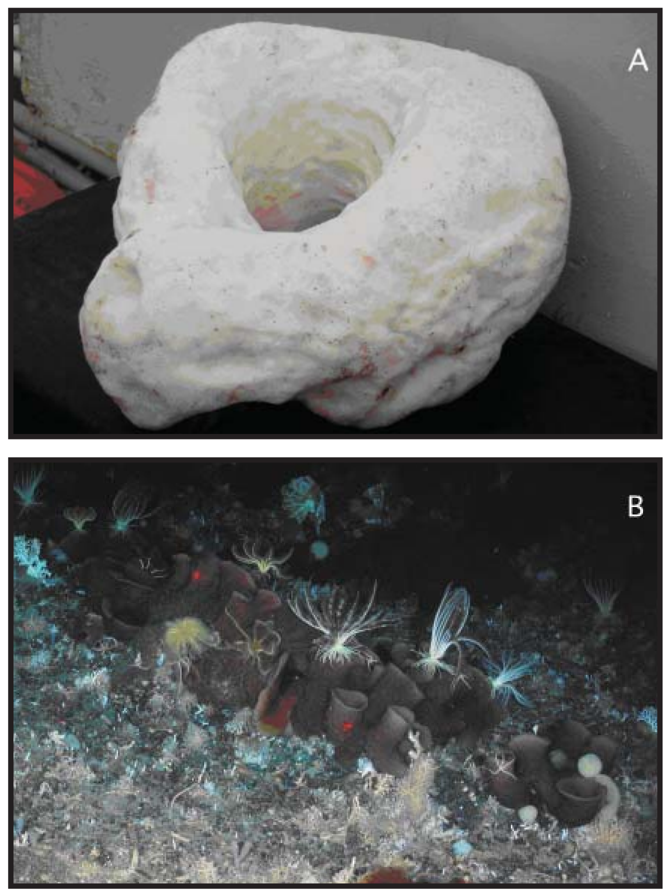

Figure 10.3. Two unidentified hexactinellid sponge species collected at station 101 east of Joinville Island (mean depth 623 m). A) a trumpet-lipped glass sponge approx. 1 m in diameter. B) a brown glass sponge that did not retain its form in the trawl. N.B. Distance between red laser dots is 50 cm.

Results

The distributional density of benthic fauna in the South Orkney Islands is illustrated in Figure 10.2. The invertebrate community with the greatest density encountered at the South Orkney Islands, just over 183 t/nmi^2, was at station 82 off the southwest tip of Coronation Island, at a mean depth of 96 m. In contrast, no benthic invertebrates were collected at Station 87, at a mean depth of 657 m, at the far western edge of the shelf. Even though a relationship between density and depth generally exists (Lockhart and Jones, 2006), the fact that no fish were caught may indicate a failed haul. Station 32, south of Laurie Island, yielded the next lowest benthic invertebrate density, 0.36 t/nmi^2, at a mean depth of 314 m. At the Antarctic Peninsula, stations 103 and 104

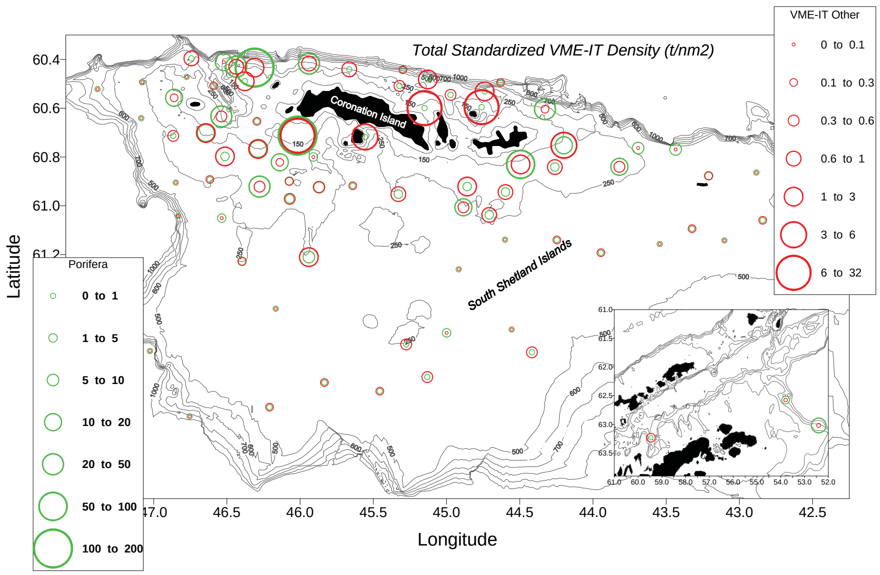

Figure 10.4. Standardized VME-IT densities (t/nmi^2). Green – Porifera. Red – other VME-IT (refer to Table 10.1 for a list of taxa). Note the differing scales.

(mean depth: 731 m and 759 m respectively) had a relatively low community density, following the depth trend apparent during the 2006 survey of that region (Lockhart & Jones, 2006). However, an interesting outlier to the rule was uncovered at a mean depth of 623 m east of Joinville Island (station 101). Although demosponges make up most of the almost 84 t/nmi^2 of invertebrate density found at this station, hexactinellid sponges also contribute significantly and included two unidentified species never before encountered by the authors: an impressive trumpet-lipped species (Figure 10.3A) and a beautiful, at least *in situ*, brown species (Figure

Figure 10.5. Sea pen (VME-IT), *Umbellula sp.* (Cnidaria: Pennatulacea), collected from station 13 (mean depth: 350 m) north of Powell Island, South Orkney Islands.

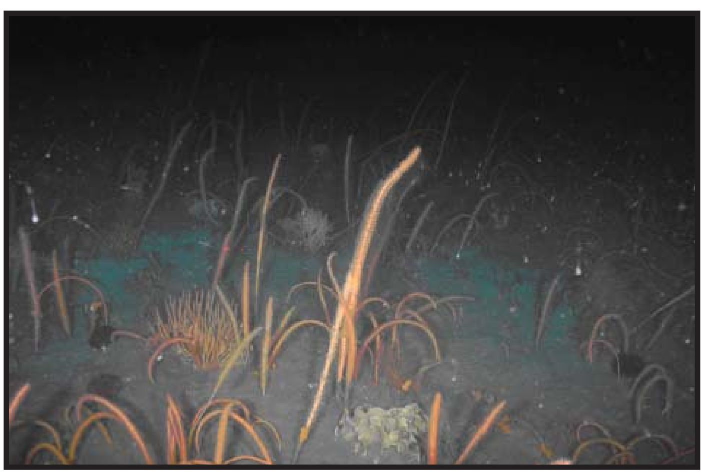

Figure 10.6. Diverse primnoid gorgonians at station 82 (mean depth: 96 m) off the southwest tip of Coronation Island, South Orkney Islands.

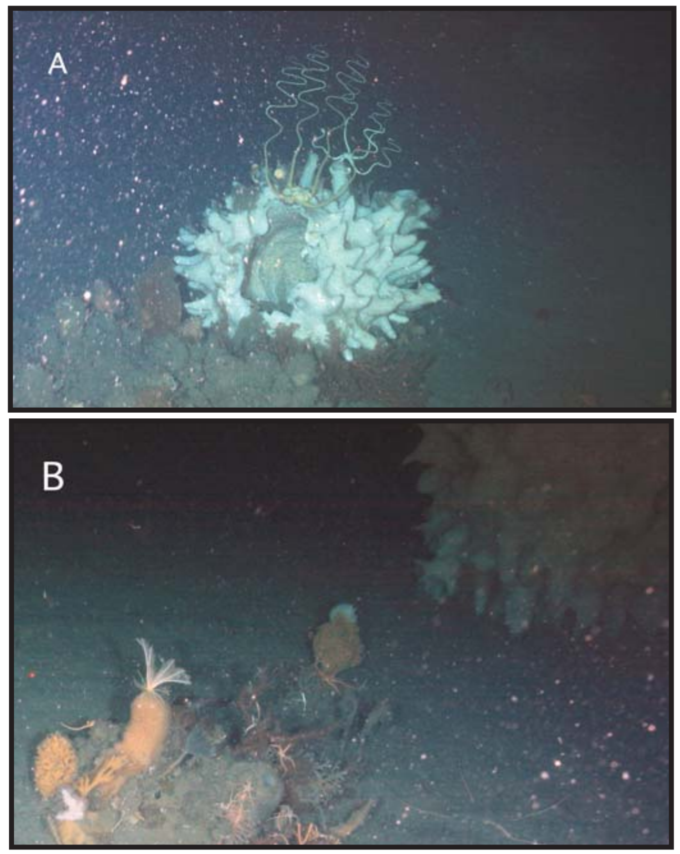

Figure 10.7. Volcano glass sponges (Porifera: Hexactinellida) near the 2005/06 AMLR Survey station 12 (max. depth: 398 m) off the Trinity Peninsula, Antarctic Peninsula. A) Specimen measures more than 50 cm in diameter. Two brittle stars of the VME-IT, Astrotoma agassizi, can also be seen. B) The portion of glass sponge in the top right corner is substantially greater than 50 cm wide, making the true diameter of this impressive specimen extremely large. In the foreground, VME-IT include several species of demosponges, hexactinellid sponge, numerous bryozoan species and some primnoid gorgonians.

10.3B). Also contributing significantly to the high biomass at this station were three specimens of a giant octopus, one of which weighed over 37 kg. Lastly, of note at this location, which shows great potential for designation as a VME, was a substantial biomass of stylasterid hard corals (or hydrocorals: Figure 10.3B) and a lovely delicate bamboo coral species not observed by us previously

As those taxa deemed indicators of VME risk areas (VME-IT) were of paramount interest, the standardized density of sponges (Porifera) and all other VME-IT (see Table 10.1) are mapped in Figure 10.4. Due to their greater weight the pattern of standardized sponge density is for the most part a reflection of the total benthic community density seen in Figure 10.2. Over 139 t/nmi^2 of sponges were encountered at Station 82. There were a number of stations that yielded no sponge community: stations 32, 34, 67, 85, 88 (mean depths: 314 m, 426 m, 299 m, 371 m, and 764 m, respectively) and, of course, the previously mentioned station 87.

The distribution of non-sponge VME-IT densities around the South Orkney Islands is somewhat different. The greatest densities are found along the narrow northern shelf. The densest community of non-sponge VME-IT, 31.90 t/nmi^2 , was encountered at Station 97 (mean depth: 118 m) north of Laurie Island, 98% of which was compound ascidians. Thirteen other stations support non-sponge VME-IT densities greater than one t/nmi^2. For all of these, it is the biomass of ascidians and anemones that dominate the non-sponge VME-IT densities, and if these are to remain VME-IT it may prove more informative to treat these 'heavy' taxa separately along with sponges. Aside from station 87, only one station, station 46 (mean depth: 352 m), had no VME-IT other than sponges and tunicates.

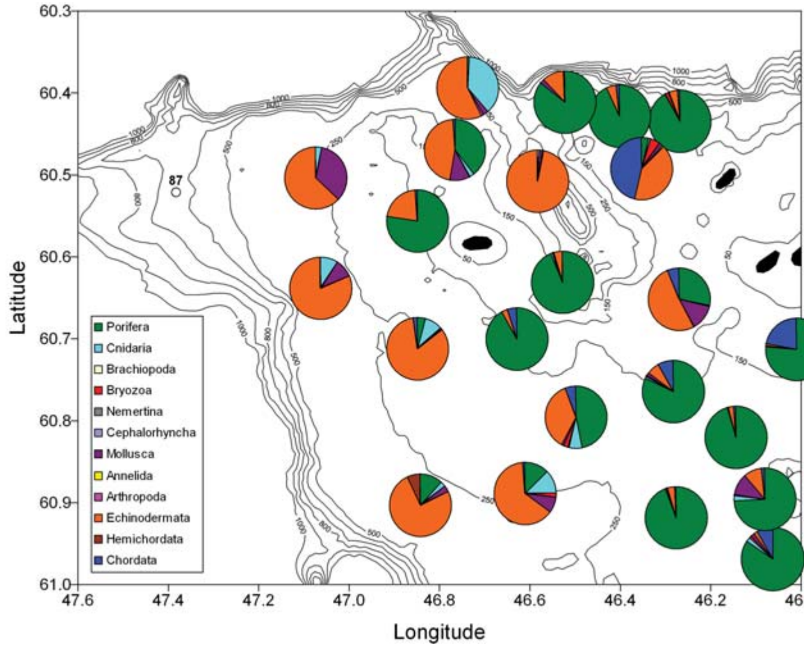

Figure 10.8. Relative contributions of invertebrate phyla to the benthic community composition at the South Orkney Islands, western shelf.

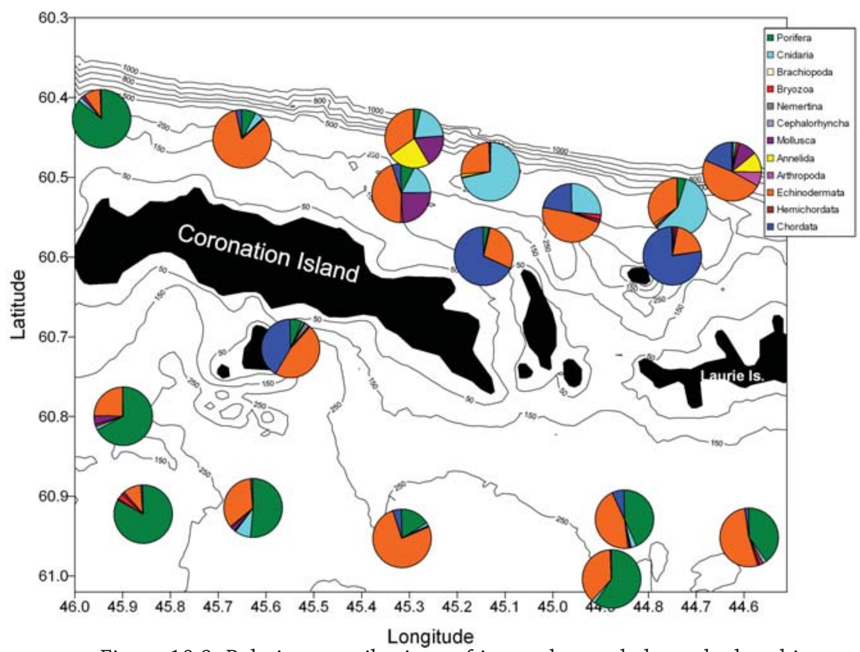

Figure 10.9. Relative contributions of invertebrate phyla to the benthic community composition at the South Orkney Islands, main island shelves.

The sea pen, *Umbellula sp*. (Figure 10.5), would be particularly vulnerable to commercial bottom fishing activities. The large disc shaped heads (up to12 cm in diameter) are attached to very long and very thin stalks (up to 3.5 m long) lending this location (Station 13) great potential for designation as a VME. Another exceptional local with considerable potential for VME designation is Station 82, already mentioned as having the greatest invertebrate density due to an extensive demosponge community and diverse prim-

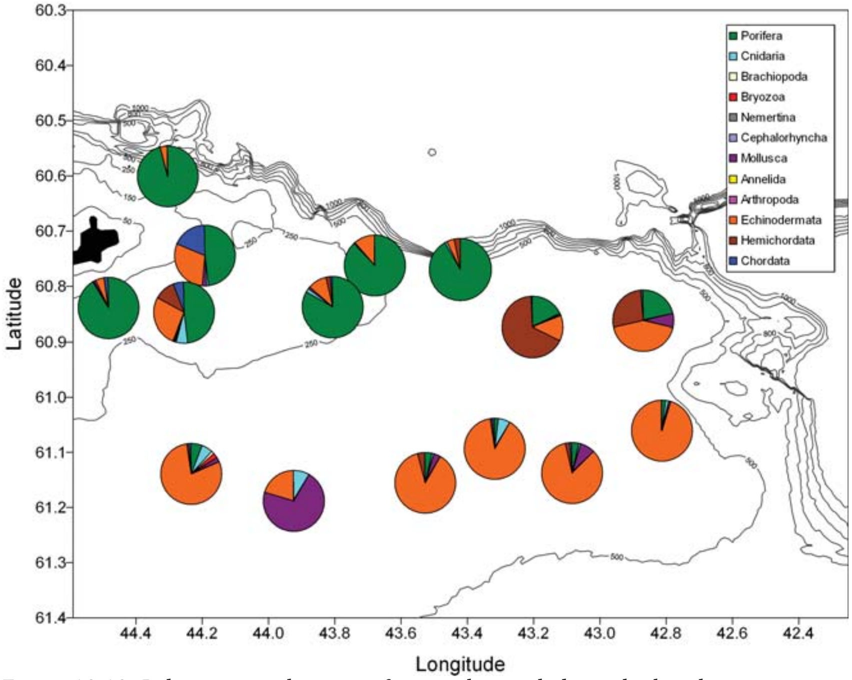

Figure 10.10. Relative contributions of invertebrate phyla to the benthic community composition at the South Orkney Islands, eastern shelf.

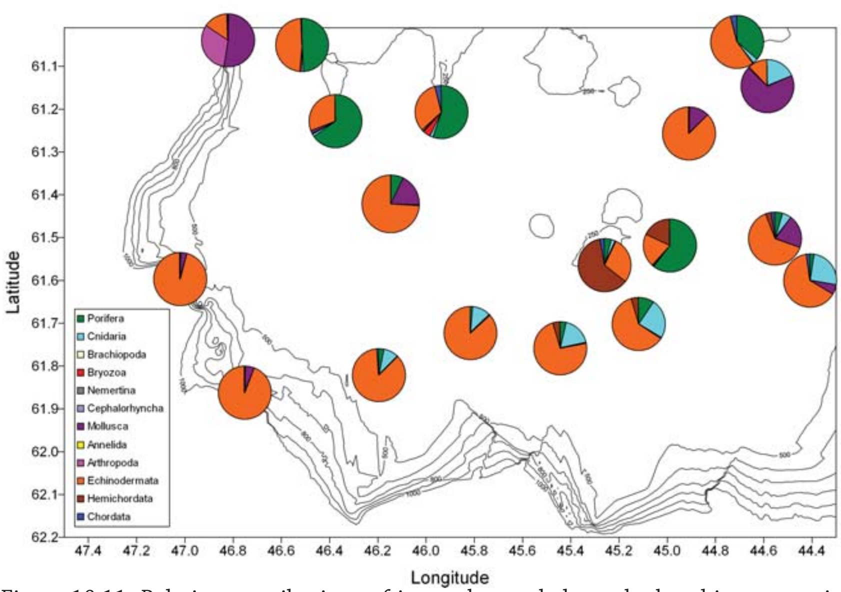

Figure 10.11. Relative contributions of invertebrate phyla to the benthic community composition at the South Orkney Islands, southern shelf.

noid gorgonian assemblage (Figure 10.6).

Additionally, although the location was not trawled, a photographic and video transect (Chapter 11) was conducted in the Bransfield Strait where, during the 2006 survey (Lockhart & Jones, 2006; Lockhart & Jones, 2008), 1.5 metric tons of extremely large hexactinellid sponges considered to be of ancient age (at least many hundreds of years) were recorded (Figure 10.7). Images like those in Figure 10.7 serve as direct evidence in support of designating and registering VME risk areas.

A broad geographic pattern in is apparent, with megafaunal invertebrate dominance on the western shelf of the South Orkney Islands (Figure 10.8). Echinodermata dominates the outermost shelf areas while Porifera dominates the benthic communities between Inaccessible Island and the largest of the South Orkney Islands, Coronation Island, a pattern reflected in the total standardized invertebrate densities (Figure 10.2).

The well-established sponge assemblages extend north and south of the western tip of Coronation Island (Figure 10.9). Further east, echinoderms begin to become more important components of the benthic community. However, between Coronation and Signy Islands, between Coronation and Powell Islands, and also between Powell and Laurie Islands, tunicates, both solitary and colonial, contribute significantly to the total community biomass. This association of high ascidian biomass at locales with presumably high water flow, also observed between the islands of the South Shetland Island chain and between the Trinity Peninsula and Joinville Island (Lockhart & Jones, 2008: Figure 4), appears to be quite robust and predictable over a large geographic range. Cnidaria make up a significant portion of the megafaunal assemblage on the northern edge of this shelf system. The Cnidaria biomass here is attributed, for the most part, to anemones and the large *Umbellula sp.* sea pens (Figure 10.5).

East of Laurie Island (Figure 10.10), Porifera once again dominates the benthic assemblage. On the outer northeastern shelf, particularly at stations 22 and 23 (mean depths: 359 m and 336 m, respectively), vast communities of Pterobranchia, a little known phylum of worm-like colonial organisms, were encountered. The stations sampled further south on the eastern shelf reveal a return to echinoderm-dominated benthos; a trend that covers the majority of the outer south shelf of the South Orkney Islands (Figure 10.11).

In the Bransfield Strait (Figure 10.12), station 104 (mean depth: 759 m) follows the bathymetric pattern seen in the 2006 survey data (Lockhart & Jones, 2006). Stations 101 and 103 (mean depth: 731 and 623 m, respectively), on the other hand, reveal surprisingly complex sponge-dominated benthic assemblages that, perhaps due to their depth, have escaped iceberg scour.

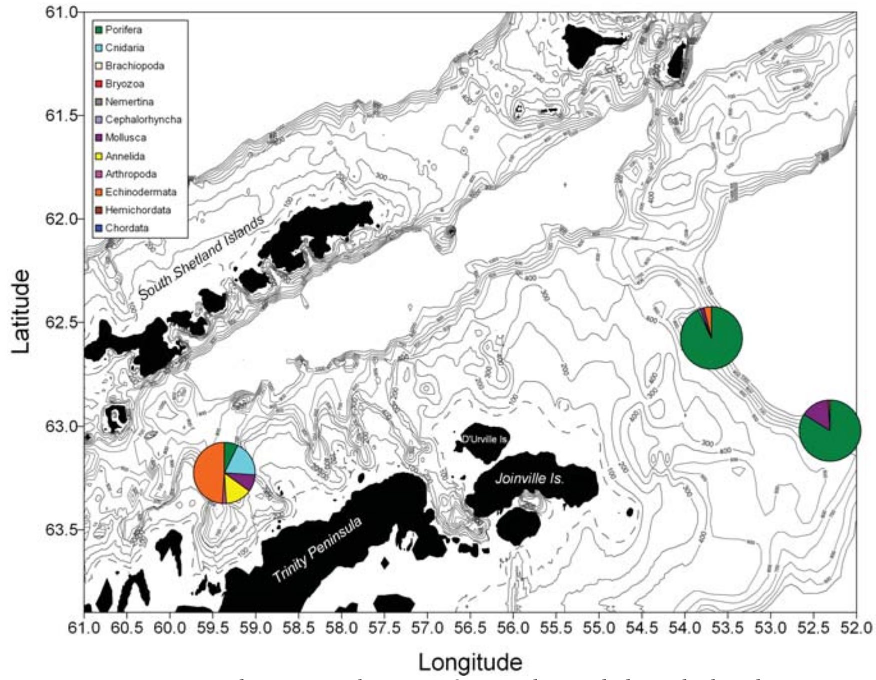

Figure 10.12. Relative contributions of invertebrate phyla to the benthic community composition off the Antarctic Peninsula and east of Joinville Island.

Bioiversity, in terms of OTUs, was greatest at station 41 (mean depth: 240 m), south of the western tip of Coronation Island, where 38 OTUs were represented despite supporting a relatively low community density (12.69 t/nmi^2). Biodiversity was lowest (with the exception of station 87) at Station 32, where only six OTUs were encountered. Biodiversity, in terms of the VME-IT, was again greatest at Station 41 and also at Station 60 (mean depth: 150 m), southwest of the western tip of Coronation Island, where 12 of the 20 accepted VME-IT (with bryozoans and ascidians each split into two categories) were represented. Both these stations support reasonably high, but not the highest, densities of non-sponge VME-IT (0.80 t/nmi^2 and 0.50 t/nmi^2, respectively). This raises the question of whether or not diversity should factor into required criteria for VME risk area designation. Again. with the exception of Station 87, VME-IT diversity was lowest at Station 32 as it was for overall biodiversity. Interestingly, the one VME-IT encountered in abundance here was the sea pen, *Umbellula sp.*, which, as explained above, would be a species highly vulnerable to damage by bottom fishing gear.

Discussion

At the South Orkney Islands a pattern is revealed when the total standardized benthic invertebrate density (t/nmi^2) at each station is mapped (Figure 10.2). The benthic invertebrate communities with the greatest densities are clustered at both the western and eastern limits of the island chain. In general, the communities are sparser on the outer shelves. This is particularly so to the south, where the wide shelf extends into the Weddell Sea. Although this may be due in part to scouring by icebergs carried in the Weddell Sea currents, there appears to be other factors at work here. Further research into oceanographic conditions such as bottom water temperature may elucidate additional causal elements.

It is thought that benthic community structure and distribution is largely determined by glacial scouring. Based on the results of this survey, the biogeographic patterns in benthic invertebrate community density and composition described above can not be explained simply in terms of iceberg scour, which was believed to play an important role in the patterns detected off the Trinity Peninsula in 2006 (Lockhart & Jones, 2006). However, the driving forces behind these patterns may be elucidated with further analysis, concurrent with analyses of additional oceanographic conditions, such as bottom water temperature, which Lockhart & Jones (2008) suggested had a significant effect on distribution patterns seen in community composition around the South Shetland Islands and the Antarctic Peninsula. The South Orkney Islands appear to present a complexity that is reminiscent of the composition and water temperature distribution seen around Elephant Island (Lockhart & Jones, 2008).

Protocol Deviations

There were no signification deviations from the standard benthic sampling protocol during the course of the 2008/09 AMLR Survey.

Acknowledgements

This research could not have been conducted without the assistance of many on board, whose cheerful and untiring assistance in sorting the large amounts of invertebrate catch is gratefully acknowledged. In particular, many thanks go to John Moore, Ryan Driscoll and Kim Dietrich.

Disposition of Data

Benthic invertebrate data collected during the trawl survey are available from Christopher Jones, Antarctic Ecosystem Research Division, Southwest Fisheries Science Center, 3333 North Torrey Pines Court, La Jolla, CA 92037; phone/fax – (858) 546-5605/546-5608; e-mail: Chris.D.Jones@noaa.gov. Invertebrate samples collected for taxonomic and genetic analyses will be deposited and housed at Yale's Peabody Museum. Tissue samples will be housed at Scripps Oceanographic Institute. Additional samples collected by request for taxonomic and genetic research will be sent to the University of California, Fullerton, the California Academy of Sciences (San Francisco) and the Museum of Victoria (Australia).

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Deployment of an Underwater Photographic/Video Imaging System to Characterize Seafloor Habitats and Benthic Invertebrate Megafauna and Detect Vulnerable Marine Ecosystems

André Hoek, Christopher Jones, Anthony Cossio, Susanne Lockhart and Derek Needham

Abstract A high resolution underwater photographic/video imaging system was designed and constructed prior to the 2008/09 AMLR field season. The system was tested during Leg I, and modified and deployed during Leg II of the AMLR Survey to collect images and video of seabed habitats, in situ benthic invertebrate megafauna, and Vulnerable Marine Ecosystem (VME) indicator taxa. In addition, acoustic transects were completed in the South Orkney Islands and northern Antarctic Peninsula to characterize seabed type and bottom topography. Results from the 2008/09 AMLR Survey include:

- Twenty-one video/photographic tows completed at depths up to 637 m;
- A total of 2,865 still photographs and 17 hours of high resolution video recorded;
- Identification of several potential VME risk areas.

Introduction

The AMLR Program began characterizing the seabed habitat features and benthic invertebrate communities of the South Shetland Islands during the 2002/03 AMLR Survey using a combination of acoustic, video, and sediment sampling methods. During the 2008/09 AMLR Survey, this program was continued in the South Orkney Islands and northern Antarctic Peninsula, with a combination of acoustic, video and still imagery transects. The objectives of this research are to map seabed characteristics, collect information on benthic and demersal habitats and invertebrate epibenthic megafauna, groundtruth benthic invertebrate results from trawl sampling (Chapter 10) and identify potential Vulnerable Marine Ecosystems (VME), as defined in Conservation Measure 22-06 (2008) by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR).

Methods

Digital imagery was obtained using a custom-built high resolution photographic/video imaging system on an open-frame, towed sled with individual pressure casings, developed by Sea Technology Services (Figure 11.1). The system used a Canon EOS 450D, 12.2 MP SLR with 16 GB memory for still images and a Canon Vixia HF11 HD with 32 GB memory for video images (Table 11.1). Data was transferred from the camera via an ethernet connection and processed using a PC running Windows Vista with remote camera and custom control and monitoring software. The system was shipped from Cape Town, South Africa to Punta Arenas, Chile on 20 December 2008 and delivered to the R/V *Yuzhmorgeologiya* prior to Leg I of the 2008/09 AMLR Survey.

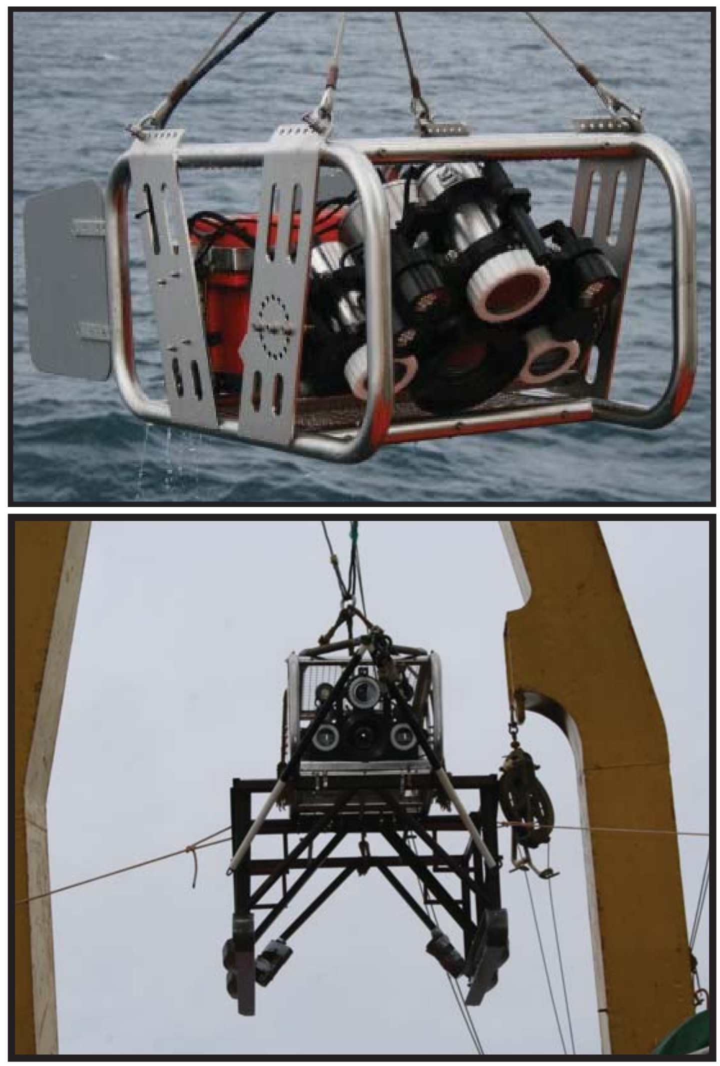

Figure 11.1. (A) The photographic/video imaging system, and (B) the addition of skis and supports to the body of the system that enabled consistency of altitude off the seabed (see Protocol Deviations section for more information).

Table 11.1. Specifications for the towed-body photographic/video imaging system built for seabed and benthic habitat characterization during the 2008/09 AMLR Survey of the South Orkney and northern Antarctic Peninsula.

System Characteristic	Technical Specification
Depth rating:	Casings 1000 m, camera dome port 750 m
Towing speed:	1.5 to 2.5 knots
Towing cable:	Steel armoured, two copper cores, 7000 m long
Construction materials:	Stainless steel, nylon, acrylic
Casing types:	O-ring sealed, quick release, nitrogen purged
Power:	12 V 80 Ah AGM lead acid battery
Camera:	Canon EOS 450D, 12.2 MP SLR, 16GB memory
Camera lens:	Canon EF 24mm f/1.4L II USM, wide angle
Camera flashes:	Canon Speedlite 580EX II (x2), E-TTL controlled
Camera domed port:	Acrylic, optically matched to lens
Camera live feed:	Streamed TTL video (5fps) to deck PC
Camera control:	Full control from deck PC software
Video camera:	Canon Vixia HF11 HD, 32 GB memory with bulk battery
Video lighting:	ROS LED SmartLIGHT II (x3), continuous level control
Laser pointers:	Deep Sea Power & Light, SeaLaser 100 (x3), remote controlled
Laser spacing:	Triangle with 500 mm base and 400 mm sides
Depth sensor:	Sea-Bird SBE-50, 1000 m, accuracy 0.1 %, resolution 0.002 %
Acoustic altimeter:	PSA-916D, 100 m bottom detection, resolution 1 cm
Software:	Deck PC running Windows Vista, Remote Camera & STS custom control and monitoring software
Deployment duration:	2-3 hours before recharge

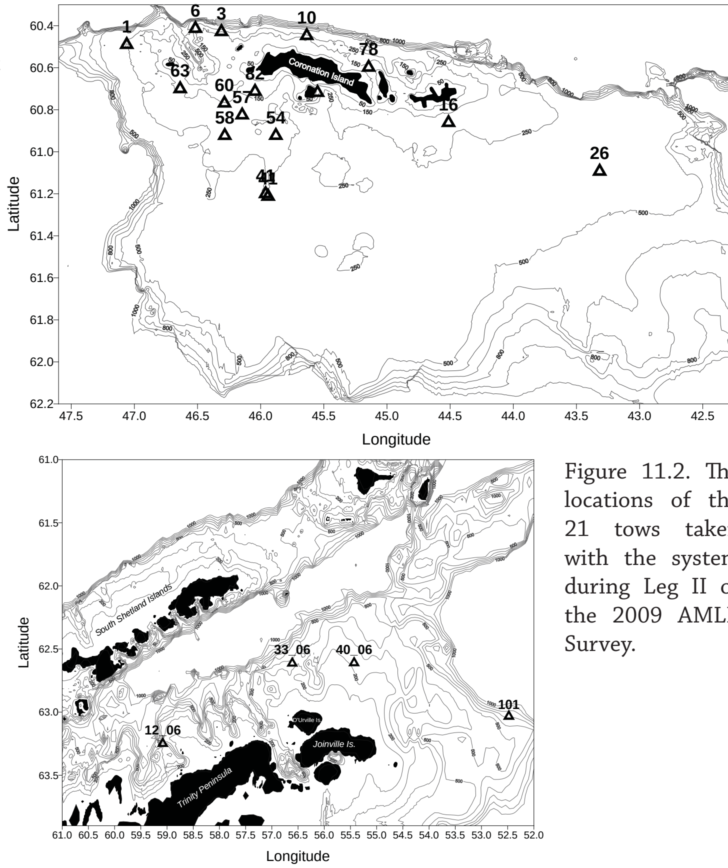

Figure 11.2. The locations of the 21 tows taken with the system during Leg II of the 2009 AMLR Survey.

Figure 11.3. A large field of stylasterid hydrocorals were captured on images taken at station 101, east of Joinville Island (max. depth: 637 m). Isidid bamboo coral can also be seen amongst the exceptional diversity of primnoid gorgonians.

The system was tested at the end of Leg I before beginning Leg II deployments. A single tow was completed to a depth of 720 m in order check the watertight integrity and functionality of the system and to practice flight procedure above the seabed. This was followed by two shallower test tows to adjust photographic settings, ballast weights, and towing procedures.

During Leg II, the system was deployed in the South Orkney Islands where bottom trawl transects were taken; additional deployments were completed where trawls were taken off the the northern Antarctic Peninsula. This allowed collection of high-resolution imagery of undisturbed seafloor characteristics and in situ fauna to compare with results from trawl sampling. Transects ranged from 20 min to 1 hr.

Results

The photographic/video imaging system was deployed a total of 21 times during Leg II of the 2008/09 AMLR Survey. There were 17 deployments in the South Orkney

Table. 11.2. Summary of trackline information for all deployments of the video/camera system during Leg II of the AMLR Survey.

Dip No.	Date Time (CMT)	Station Number	Depth (m)	Latitude, Longitude	Bottom Time	Photos Taken	Video Taken
1	02/10/09 12:18:27	3	157	6025.722742 S, 4618.637114 W	00:59:04	88	1
2	02/10/09 00:00:00	4	0		0	0	1
3	02/10/09 00:04:51	10	240	6026.855278 S, 4538.111853 W	00:57:08	153	1
4	02/11/09 00:38:44	78	98	6035.887761 S, 4508.710197 W	00:59:43	324	1
5	02/15/09 23:18:39	26	444	6105.588168 S, 4318.985752 W	00:58:24	92	1
6	02/17/09 20:01:36	16	197	6051.682711 S, 4430.767283 W	00:39:58	228	1
7	02/22/09 19:25:33	41	236	6112.739356 S, 4556.467641 W	00:20:26	26	1
8	02/22/09 22:54:54	41	246	6111.994422 S, 4557.634055 W	00:48:51	105	1
9	02/23/09 23:15:04	81	74	6043.096904 S, 4532.987015 W	00:39:51	69	0
10	02/25/09 11:26:05	57	198	6049.519407 S, 4608.789014 W	01:01:15	105	1
11	02/26/09 14:26:50	54	208	6055.363646 S, 4552.795036 W	00:43:09	1	1
12	02/27/09 01:33:05	58	225	6055.382368 S, 4617.057202 W	00:45:14	132	1
13	02/28/09 12:16:02	1	252	6029.397923 S, 4703.626674 W	00:41:47	135	1
14	03/01/09 16:22:00	6	218	6024.824533 S, 4630.997397 W	00:40:00	121	1
15	03/02/09 00:41:43	63	150	6042.018712 S, 4638.246711 W	00:48:35	176	1
16	03/02/09 20:09:51	82	104	6042.767771 S, 4602.667768 W	00:55:10	193	1
17	03/02/09 23:13:25	60	154	6046.132526 S, 4617.197827 W	00:53:09	184	1
18	03/05/09 03:12:58	101	637	6300.947414 S, 5222.802771 W	00:57:28	213	1
19	03/05/09 18:51:08	40_06	153	6236.578555 S, 5525.728743 W	00:53:45	189	1
20	03/05/09 00:06:49	33_06	229	6236.949076 S, 5636.032592 W	00:47:14	101	1
21	03/08/09 00:16:12	12_06	398	6314.926776 S, 5904.897490 W	01:00:38	230	1

Islands (Table 11.2) and four off the northern Antarctic Peninsula. The camera completed 17 hours of total bottom time; 2865 still photographs were taken, and video was recorded on 20 of the 21 tows (Table 11.2).

The images collected revealed several shelf and slope regions with high densities of Vulnerable Marine Ecosystem Indicator Taxa (VME-IT), including stylasterid hydracorals (Figure 11.3), demosponges and pimniod gorgonians (Figure 11.4A&B), scleractinian stony corals (Figure 11.5), reef-forming bryozoans (Figure 11.6A), and filiose bryozoans (Figure 11.7). Also of note are hexactinellid sponges (Figure 11.4B) and bamboo corals (Figre 11.3). The data will be

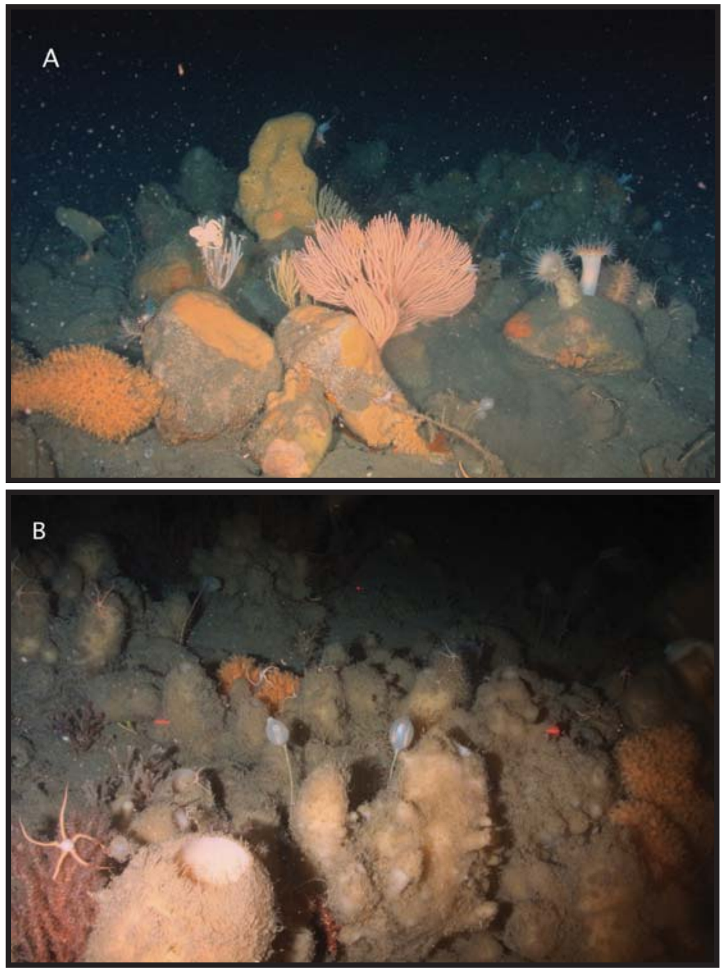

Figure 11.4. Northern Trinity Peninsula shelf, station 12_06 max. depth 398 m. (A) Vulnerable Marine Ecosystem indicator taxa (VME-IT; see Chapter 10) include several species of demosponge, a diversity of primnoid gorgonians (sea fan and bottle brush) and anemones. (B) Clusters of hexactinellid (glass) sponges like these were common along this transect. Hiding is a channichthyid fish, possibly Chionodraco rastaospinosus.

Figure 11.5. Tens of thousands of these scleractinian stony corals, Flabellum, were captured in images taken along this transect at station 6, north of the Inaccessible Islands (max. depth: 218 m).

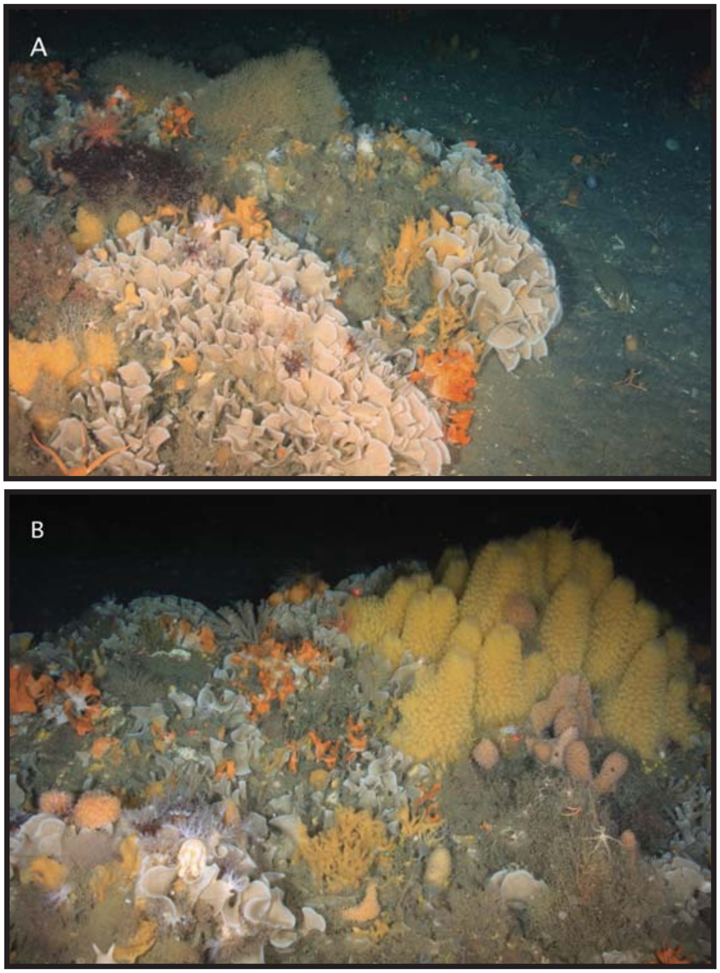

Figure 11.6. Station 33_06, north of D'Urville Island, Antarctic Peninsula, max. depth: 229 m. (A) Several hard bryozoans form complex reefs. (B) Demosponges and mats of filamentous bryozoans and hydroids add to the complexity of these reef systems.

Figure 11.7. A large biomass of foliose bryozoans can be seen in this image taken at station 40_06, north of Joinville Island (max. depth: 153 m), along with butterfly and other demosponges, a diversity of primnoid gorgonians and hydroids. The fish in the center is Lepidonotothen nudifrons.

used to identify areas with high diversity, complex community structure or vulnerable taxa.

Several potential VME risk areas were identified in the South Orkney Islands and the Antarctic Peninsula region using a combination of still images and trawl samples (Chapter 10). These sites are primarily characterized by dense communities of demosponges, hexactinelid glass sponges, bamboo corals and bryozoan reefs. Further analysis is required to confirm the characterization of these sites and appropriateness of notifications of potential VME risk areas. VME risk areas will be proposed to CCAMLR for inclusion in the CCAMLR VME registry.

Discussion

The photographic/video imaging system that was designed and engineered for use during the AMLR Survey was successfully deployed during Leg II of the 2008/09 AMLR Survey. This system has great potential to collect seabed still imagery and video during future AMLR Surveys. Video and photographic data collected during Leg II of the 2008/09 AMLR Survey are in the process of being analyzed by the Antarctic Ecosystem Research Division. The preliminary detection of several possible Vulnerable Marine Ecosystems in both the South Orkney Islands and northern Antarctic Peninsula region indicates the need for continued monitoring of the Antarctic benthic environment.

Protocol Deviations

There were considerable difficulties encountered during initial deployments in keeping the system flying consistently at an altitude of 2 to 3m off the seabed due to:

- the stern of the ship heaving in unpredictable surface swells
- inconsistent towing speeds
- changing cable angles
- the drag of the heavy towing cable without hair faired attachments
- the delay in the feedback loop from the live video view and altimeter, via the winch operator, to the response of the Traction Winch operation

Collaboration between the operator, scientists and a very resourceful Russian deck crew resulted in the design, construction and deployment of a towed-ski configuration to keep the cameras at a fixed altitude off the seabed. This was achieved by attaching two skis to additional supports under the camera sled. The towed-ski/camera configuration (a.k.a "Ski-Monkey") allowed the camera system to be deployed at a fixed altitude off the seabed and resulted in a substantial increase in the quality and quantity of the still images and video footage.

This "Ski-Monkey" configuration was used for the last 15 tows of the cruise. Besides the improved quality of the photography, ongoing improvements were made to the software and the operating and handling procedure.

Disposition of Data

Data, imagery and video collected during Leg II of the 2008/09 AMLR Survey are available from Christopher Jones, Antarctic Ecosystem Research Division, Southwest Fisheries Science Center, 3333 North Torrey Pines Court, La Jolla, CA 92037; phone/fax – (858) 546-5605/546-5608; e-mail: Chris.D.Jones@noaa.gov.

Acknowledgements

The co-operation, resourcefulness and assistance of the Russian technical support and deck staff was outstanding. Their deployments and retrievals, as well as their suggestions and assistance in building the skis, were greatly appreciated.

Distribution and Abundance of Krill in the South Orkney Islands

Anthony Cossio, Kimberly Dietrich, Ryan Driscoll and Christopher Jones

Abstract Net tows were completed during Leg II of the 2008/09 AMLR Survey in the South Shetland Islands to complement data collected the previous year, as well as finfish data collected during the same cruise. During this survey:

- Nineteen tows were completed at randomly selected stations throughout the South Orkney Islands;
- A total of 5,204 krill were caught, the majority of which were found to the northwest of Coronation Island; and
- Krill caught exhibited a unimodal length-frequency distribution around 44-48 mm.

Introduction

During Leg II of the 2008/09 AMLR Survey, net-tow samples were taken in the South Orkney Islands to aid in measuring the meso-scale distribution of Antarctic krill (*Euphausia superba*) and support acoustic biomass estimates of krill. This is the second survey conducted in the South Orkney Islands during the International Polar Year. The data collected during this year's survey will complement last year's data to map zooplankton distribution, abundance and demography in the South Orkney Islands.

Methods

Net tows were completed using a 1.8 m Isaacs-Kidd Midwater Trawl (IKMT) fitted with a 505 μm mesh plankton net. All tows were fished to 170 m, or to within 10 m of the bottom where shallower. Real-time tow depths were measured using a depth recorder mounted on the trawl bridle. Flow volumes were measured using a calibrated General Oceanics flow meter mounted on the frame in front of the net. Tow speeds were maintained at two knots.

Postlarval krill were removed from the sample counted, measured, and sexed. If the krill catch was greater than 100, a subset of 100 individuals were randomly selected and measured. Measurements were made of total length (mm) from the rostrum to the tip of the telson. After the krill were measured, they were returned to the remaining sample, which was preserved in formalin and stored at the Southwest Fisheries Science Center.

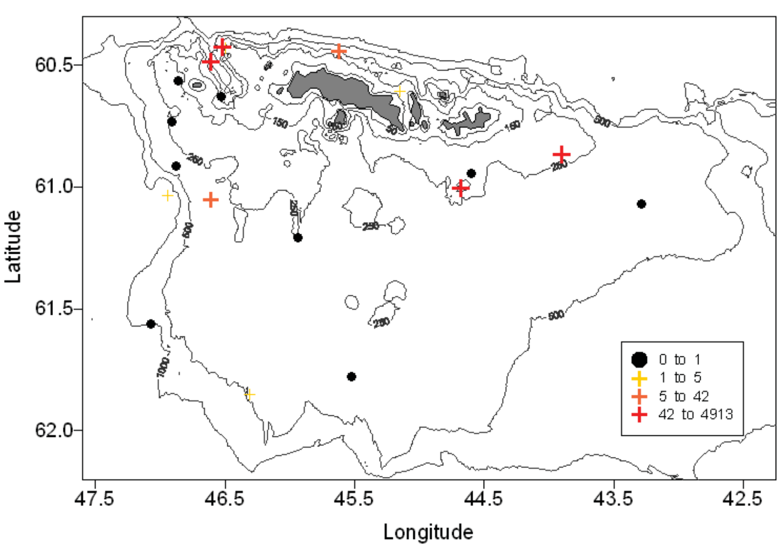

Figure 12.1. Geographic distribution and abundance of krill caught during Leg II of the 2008/09 AMLR Survey.

Results

A total of 19 IKMT tows were completed at stations associated with the stratified random trawl survey stations (Chapter 9). Krill were found in 10 of the 19 tows, yielding a total of 5,204 krill. The largest catch of krill was northwest of Coronation Island, where 4,912 krill were caught in a single tow (Figure 12.1). Several smaller catches were encountered to the southeast of the South Orkney Islands shelf, near the 250 m isobath.

Of the total krill catch, 865 krill were measured and sexed. The length-frequency distribution of krill in the

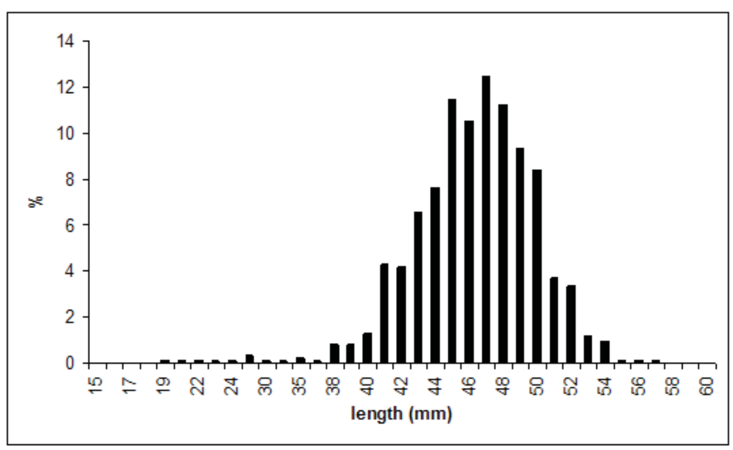

Figure 12.2. Length-frequency distribution of krill caught during Leg II of the 2008/09 AMLR Survey.

South Orkney Islands was unimodal and centered between 44-48 mm (Figure 12.2).

Discussion

The length-frequency distribution of krill in the South Orkney Islands (Figure 12.2) was similar to that in the West Area of the South Shetland Islands during Leg I of the 2008/09 AMLR Survey (Figure 4.3). The majority of the krill measured were larger than 45 mm (> 3 yrs old), indicating a lack of recruitment of krill to the South Orkney Islands for at least three years. The results from the 2007/08 survey of the South Orkney Islands indicated a bimodal length-frequency distribution with modes at 29 mm (one-year-old krill) and 42-47 mm (two-year-old and older krill). Comparing the results from the two years, it seems likely that while last year's krill continued to grow, there was very little recruitment to the krill population from last year's breeding season.

The geographic distribution of krill around the South Orkney Islands shifted from last year, when the overall abundance of krill was greater to the south of the South Orkney Islands. This year very few krill were found on the southern shelf of the South Orkney Islands, and most of those were located near the 250 m isobath. However, last year's results were similar to this year's in that the greatest concentration of krill was found over the 1,000 m isobath to the northwest of Coronation Island; historically this area is the site of an active krill fishery (Jones and Ramm, 2004). The presence of commercial krill trawlers in this region was also noted during Leg II. Interestingly, the highest density of demersal finfish was also located to the northwest of the South Orkney Islands during Leg II of the 2008/09 AMLR Survey (Chapter 9, Fig 9.2a). The association of these ecosystem components and potential effects of the commercial krill fishery on the dynamics of finfish populations in this region are topics of further research.

Protocol Deviations

There were no major deviations from the standard net-tow sampling protocol.

Disposition of Data

Data and samples are available from Christian Reiss, NOAA Fisheries, Antarctic Ecosystem Research Division, 3333 Torrey Pines Court, Room 412, La Jolla, CA 92037. Ph: 858-546-7127, Fax: 858-546-5608

Acknowledgements

We thank the crew of the R/V *Yuzhmorgeologiya* for their continued support throughout the field season.

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Appendix A: Suggestions for Improvement

The following suggestions are made in an effort to continuously improve the nature of the AMLR Survey and the quality of data produced.

Shipboard Suggestions

- The oceanographic equipment owned by the Antarctic Ecosystem Research Division is reliable and regularly calibrated; it should see the AMLR Survey into the future. The preventative maintenance strategy used while onboard seems to increase the CTD deployment success rate. However, it is suggested that gradual equipment upgrading/replacement programs be implemented to phase in new equipment.
- To complement the ongoing pre- and post-cruise calibration routines of the CTD, TSG and SCS systems it is suggested that a similar calibration routine, in a controlled environment, be set up for all five PAR sensors used on the ship (two submersible and three mast-mounted). The two LI-COR 2 pi PAR sensors already have a pre- and post-cruise calibration routine; they are calibrated along with the WEATHERPAK system. A calibration routine should also be implemented for the three Biospherical PAR sensors.
- The SCS/CTD PC needs to be replaced with a new unit and a second "hot standby" PC, dedicated to the SCS/CTD operation, should also be purchased. PCs and PC components had to be replaced due to numerous PC problems, and software had to be reinstalled. Most of this was achieved between stations; there were minimal gaps in the SCS data and only one CTD upcast lost.
- The Guildline Portasal salinometer needs to be sent back to Guildline for a thorough service. The whole mechanical clutch assembly needs to be replaced. The unit is not that old; it just needs a service at the Guildline factory, rather than at a center that specializes in calibration.
- The ongoing process of replacing the existing carousel sampling bottles and building up a stock of spares should be continued.
- There is an ongoing problem with the ship's clean seawater supply and the TSG debubbler plumbing system that was partially resolved during the cruise. The pump is too powerful and cavitates, causing excessive bubbles that the debubbler cannot clear fast enough. This causes spiking on the salinity trace. Continual cleaning and monitoring of the pump by the ship's staff was required to reduce the amount of bubbling. A bypass plumbing system was added to relieve some of the pressure from the system. This seemed to improve the situation, but there is still room for improvement. A new gravity-fed pump and debubbler system was designed, in collaboration with the crew of the R/V *Yuzhmorgelogiya*, and a plan implemented to get this installed on the ship, if the ship is used for future contracts.
- It would be useful to link the data flow from the underway array to the CTD in order to measure both time and incident PAR during downcasts. In this manner, euphotic zone depth could be measured directly during a station cast, rather than through its mathematical estimation as currently employed. A dedicated clean water system for analytical work (Alpha-Q or Milli-Q) would be an appropriate acquisition in the future, since trace-metal chemistry and salinity measurements require a higher level of purity than otherwise available from the regular water supply of the R/V *Yuzhmorgeologiya*.
- The ski assembly used to support the photographic/video system could be rebuilt out of stainless steel, or the existing steel assembly could be neatened up and galvanized. It is suggested that funding be allocated for a selection of spare parts, such as underwater connectors, domed ports etc. If called for, the operating software can be upgraded to read in GPS and SCS data and stamp these to every photograph. A mini CTD or other sensors could also be added.

Landbased Suggestions

- The monitoring program at Cape Shirreff is confined to measuring parameters during the first three months of fur seal pup rearing. Only a few of the summer-measured parameters (e.g. adult female over-winter survival, pregnancy rates, and cohort survival) reflect ecological processes over a broader temporal spatial scale. Yet these data suggest that post-weaning environments are important for survival, recruitment, and sustainability of the Cape Shirreff fur seal population. The dominance of the 1999/00 cohort in tag return data and differential cohort strength offer one of the best examples of this. Recent technology in miniaturization and programmability of satellite-linked transmitters provide the means by which to develop an understanding of post-weaning environments as well as dispersal of females and pups post-weaning. These instruments cannot only provide information on dispersal, but they can measure the physical environment encountered by individuals. Future studies should use this technology to measure dispersal, survival and various parameters of the physical environment in order to identify factors leading to increased survival and recruitment of juvenile pinnipeds and seabirds.

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