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AMLR 2010-2011 FIELD SEASON REPORT

Editor, Jennifer G. Walsh,

National Marine Fisheries Service
Southwest Fisheries Science Center
8901 La Jolla Shores Dr.
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U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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Introduction

The 2010/11 U.S. Antarctic Marine Living Resources (U.S. AMLR) field season continues a long-term series of studies of the Antarctic Peninsula ecosystem, designed to provide scientific support for the conservation and management of Antarctic marine fisheries as outlined by the Convention on 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 form the basis of research conducted by the U.S. AMLR Program: 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 inception of the U.S. AMLR Program in 1986, 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. Historically, these field studies include land-based observations of pinniped and seabird ecology at Cape Shirreff on Livingston Island and Admiralty Bay on King George Island (Figure 1), and two identical pelagic surveys of the waters surrounding the South Shetland Islands (Figure 2), completed in January and again in February.

During the austral summer of 2010/11, the traditional AMLR survey grid was completed on Leg I (January/February). During Leg II (February/March), a comparison study was undertaken in the Elephant Island Area in order to pursue the replacement of the historical IKMT net with a new Tucker Trawl, which would allow for the addition of pelagic fish research to the survey. Storms in February and March prevented the completion of the second survey on the grid; however, three areas (Elephant Island, Joinville Island and the South Area) were successfully sampled, and an additional survey was undertaken in the Gerlache Strait.

Field-based activities were successfully completed during the 2010/11 AMLR field season; field stations were opened in October of 2010 and closed in March of 2011. During that time, researchers conducted studies on the foraging ecology, breeding biology, and abundance of three penguin and four pinniped species. In addition to their routine effort, AMLR scientists implemented the second year of an overwinter study on the movement patterns of these predators. A total of 51 animals were tagged and monitored through the austral winter of 2011.

This is the 23rd issue in the series of U.S. AMLR Field Season Reports, documenting the 25th year of Antarctic research. Logistical support for this field season was provided by the U.S. National Science Foundation through the U.S. Antarctic Program.

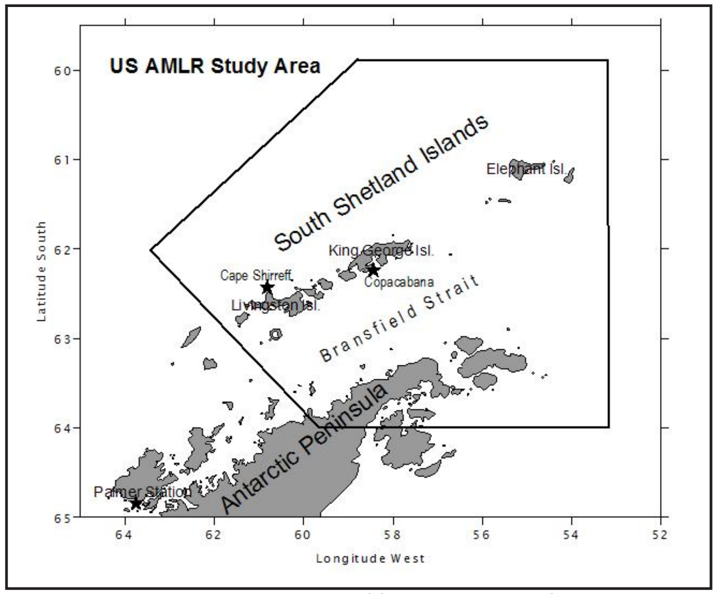


Figure 1. Locations of U.S. AMLR Field Stations: Cape Shirreff, Livingston Island; Admiralty Bay (Copacabana), King George Island.

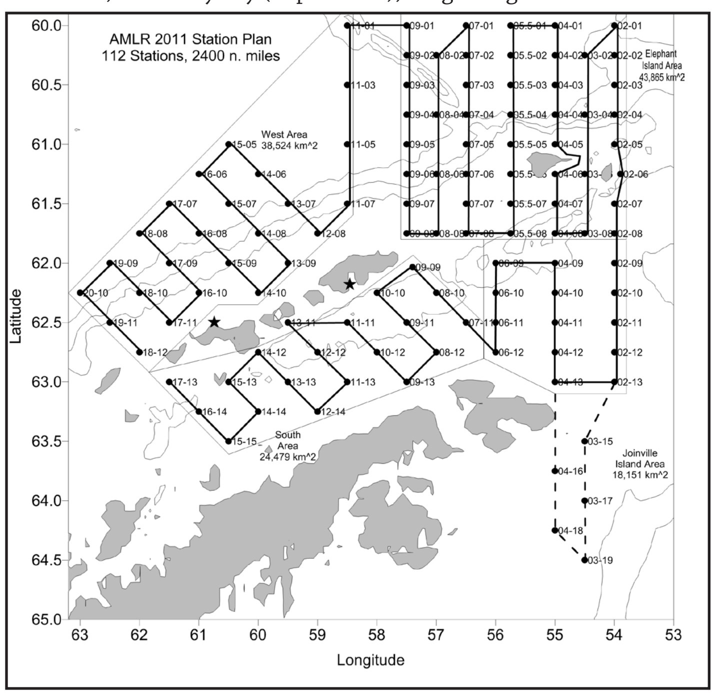


Figure 2. Survey design for AMLR 2010/11 (Leg I/Survey A), in the vicinity of the South Shetland Islands, Elephant Island, and the Antarctic Peninsula. Stars indicate field camp locations. Survey strata are divided into four areas: the West, South, Joinville Island, and Elephant Island Areas. Depth contours are 500 m and 2000 m. Black dots indicate locations of planned oceanographic/biological sampling stations; heavy lines indicate planned transects between stations.

Summary of 2010/11 Results

Hydrographic results characterizing the water masses around the South Shetland Islands indicate that several water masses converge in the area, forming a front along the shelf break north of the archipelago. This front is associated with high densities of phytoplankton and Antarctic krill, although there is considerable variability in the seasonal abundance and reproductive success of krill, which are strongly correlated with multi-year trends in the physical environment. Predator foraging patterns and breeding success are tied to the annual availability of krill, which is the primary prey item in the Antarctic ecosystem during the austral summer. The following summarizes the results of the ecosystem-wide studies conducted during the 2010/11 U.S. AMLR Field Season.

Oceanography

A total of 97 CTD stations were sampled during Leg I, and 69 sampled during Leg II simultaneously with the Tucker Trawl, which had its own CTD mounted to the frame. Sampling indicated that the warm Antarctic Circumpolar Current (ACC) remained offshore during the 2010/11 AMLR Field Season, found only in the western part of the South Shetland Islands, and that Weddell Sea outflow extended through the Bransfield Strait.

Phytoplankton

During Leg I, Chl-*a* concentrations in the upper 5 m were similar to those recorded in 2010, with high Chl-*a* concentrations present around the shallow waters of the South Shetland Islands, especially in the Bransfield Strait and the southwestern region of the Elephant Island Area. During Leg II, Chl-*a* in surface waters was higher on this leg than during Leg I, but was also highly variable. Comparisons of nutrient data collected during 2010 and 2011 showed that there was considerably more variability in the data from 2010.

Acoustics

Acoustic data indicated that krill densities increased slightly in the Elephant Island, West, and South Areas from the previous season. Krill densities have historically been the highest in the Elephant Island Area, and the same was true during the 2010/11 AMLR field season.

Zooplankton

Net sampling of zooplankton indicated that mean krill abundance during Leg I was less than half of the long-term average. The highest numbers of krill were caught in the Elephant Island Area and to the north of the South Shetland Islands, and length-frequency data indicated a large influx of juveniles into the population during this season. The abundances of Salpa thompsoni and Thysanoessa macrura also decreased this year to levels similar to the 2008-09 field season, but Antarctic krill larvae, copepods, and *T. macrura* larvae increased in abundance over the previous field season.

Pelagic Finfish

The U.S. AMLR Program conducted its first large-scale survey of pelagic fish community composition during the 2010/11 field season using a new Tucker Trawl. A total of 70 stations were completed during Leg II, showing considerable variability across the Antarctic shelf region. Greater numbers and a greater diversity of fish larvae were sampled with Tucker Trawl than postlarval fish. Most postlarval fish sampled belonged to the family Myctophidae.

Seabirds

On King George Island, populations of Adélie, gentoo, and chinstrap penguins increased significantly over the 2009-10 field season, which was an abnormally low year. Fledging mass and breeding success also rebounded from the previous season. Skua breeding pairs were also more successful this year compared to last year.

On Livingston Island, the chinstrap penguin population continued to decline, but fledging masses indicated that chicks fared better this season than during the 2009-10 breeding season. Skua breeding pairs were more successful during this breeding season than the last breeding season on this island as well.

Pinnipeds

The number of fur seal pups born at Cape Shirreff in 2010/11 declined over the previous year, and represented the fourth consecutive year of declining pup production. Additionally, more than half of all pups born in 2010/11 were lost to leopard seal predation by mid-February. Analysis of dietary components indicated that fish consumption by fur seals was the lowest it has been since monitoring began in 1997-98.

Unmanned Aerial Systems Survey

This year, a pilot study was conducted at Cape Shirreff to determine the feasibility of using unmanned aerial systems equipped with digital cameras to estimate the abundances of penguins and fur seals at U.S. AMLR study sites. Preliminary results indicate that counts of penguins estimated from aerial photographs were not significantly different from traditional ground counts of penguins in the same colonies. Additionally, fur seal tags were detectable in images taken from altitudes of over 23 m.

At-sea Marine Mammal and Seabird Distribution

This year, the seabird community exhibited a high level of diversity due to the intrusion of sub-Antarctic species. Fin whale concentrations were high along the shelf break north of King George Island, but humpback whale concentrations were lower in the Bransfield Strait than in previous surveys. Antarctic fur seals were abundant in the Bransfield Strait in January, earlier than in most years.

The Copacabana Field Station at Admiralty Bay, King George Island. Photo by Mattias Cape.

The R/V *Moana Wave*, anchored just off the Copacabana Field Station at Admiralty Bay, King George Island. Photo by Suzanne Romain.

The Cape Shirreff Field Station at Cape Shirreff, Livingston Island. Photo by Wayne Perryman.

2010/11 AMLR Field Season Objectives

Oceanographic Survey

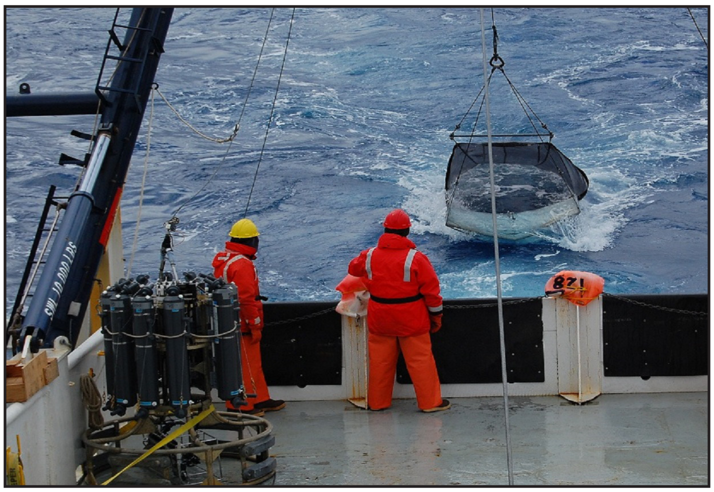
1. Conduct a bioacoustic, oceanographic, and net-based krill and pelagic fish survey in the vicinity of the South Shetland Islands (Legs I and II) to map meso-scale features of water mass structure, phytoplankton biomass and productivity, zooplankton constituents, and the dispersion and population demography of krill.
2. Calibrate shipboard acoustic system at Admiralty Bay at the beginning of Leg I and again near the end of Leg II.
3. Collect continuous measurements of ship's position, sea surface temperature, salinity, turbidity, fluorescence, air temperature, barometric pressure, relative humidity, and wind speed and direction.
4. Collect underway observations of seabirds and marine mammals.
5. Deploy 20 drifter buoys in cooperation with the NOAA/Atlantic Oceanographic and Meteorological Laboratory's Global Drifter Program.
6. Provide logistical support to field camps at Cape Shirreff, Livingston Island and Admiralty Bay (Copacabana), King George Island. Support will include transfer of personnel, equipment, building materials, supplies, and provisions.
7. Prepare fur seal milk for lipid analysis, process fur seal diet samples collected at field camps, collect fur seal and penguin prey (krill, fish, and squid) for lipid analysis and bomb calorimetry, and measure krill for validation of krill carapace to total length relationship.
8. Conduct a comparative investigation of krill and pelagic fish catch rates using the traditional Isaacs-Kidd Midwater Trawl (IKMT) and a new Tucker Trawl, to determine the feasibility of the permanent use of the Tucker Trawl and to incorporate a pelagic fish survey into the regular survey grid.

Cape Shirreff Field Station

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 dietary krill length/frequency distributions.
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 transmitters (PTTs).
10. Instrument gentoo and chinstrap penguins with PTTs for over-winter tracking studies.
11. Monitor female Antarctic fur seal attendance behavior.
12. Collaborate with Chilean researchers in collecting Antarctic fur seal pup mass for 100 pups every two weeks through the season.
13. Collect 10 Antarctic fur seal scat samples every week for diet studies.
14. Collect a milk sample at each female Antarctic fur seal capture for fatty acid signature analysis and diet studies.
15. Instrument female Antarctic fur seals with ARGOS satellite-linked transmitters (PTTs) and GPS units to record at-sea foraging locations, and with PTTs for over-winter tracking studies.
16. Deploy time-depth recorders (TDRs) on female Antarctic fur seals for diving studies.
17. Tag 500 Antarctic fur seal pups for future demographic studies.
18. Collect teeth from selected Antarctic fur seals for age determination and other demographic studies.
19. Deploy a weather station for continuous summer recording of wind speed, wind direction, ambient temperature, humidity, and barometric pressure.
20. Conduct an archipelago-wide survey of Antarctic fur seal pup production.
21. Instrument southern elephant seals with conductivity–temperature–depth satellite-relayed data loggers (CTD-SRDLs).
22. Capture and instrument leopard seals for studies of top-down control of South Shetland Island fur seal populations, and for over-winter tracking studies.
23. Explore the feasibility of using unmanned aerial systems to estimate abundances of penguins and fur seals at U.S. AMLR study sites at Cape Shirreff.

Copacabana Field Station

1. Estimate chinstrap and gentoo penguin breeding population size.
2. Band 250 chinstrap and 200 gentoo penguin chicks for demography studies.
3. Determine chinstrap and gentoo penguin foraging trip duration 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 dietary krill length/frequency distributions.
7. Determine chinstrap and gentoo penguin breeding chronologies.
8. Record at-sea foraging locations for female Adélie, gentoo and chinstrap penguins using Platform Terminal Transmitters (PTT).



Deployment of the IKMT Net from the R/V *Moana Wave*. Photo by Jen Walsh.

Deployment of the CTD from the R/V *Moana Wave*. Photo by Jen Walsh.

An Antarctic fur seal mother nursing her pup at Cape Shirreff, Livingston Island. Photo by Mike Goebel.

A chinstrap penguin with its chick at Cape Shirreff, Livingston Island. Photo by McKenzie Mudge.

Description of Operations

The 2010/11 AMLR field season took place between 9 October 2010 and 20 March 2011. The oceangraphic survey was carried out between 8 January and 15 March (Table 1).

Oceanographic Survey

1. South Shetland Survey, Legs I and II: Each leg consisted of a survey of approximately 112 planned CTD and net-sampling stations (time and weather permitting) along approximately 2,400 nm of historical survey grid. Operations were conducted 24 hours per day (about six stations per day); desired transect speed between stations was 10 knots, depending on sea state.
2. Acoustic transects: Active acoustic data were collected continuously along the survey grid using Simrad ES60 echosounder and hull-mounted transducers (38, 70, 120 and 200 kHz). Data were logged and processed by computers located on the ship.
3. CTD operations: CTD casts were conducted to 750 m or 10 m from the bottom. The CTD collected temperature and salinity profiles for the entire water column at each station.
4. Net sampling operations: During both legs of the survey, a standard two meter IKMT fitted with 505-micron mesh net was used to sample zooplankton and micronekton (including krill).

   During Leg II, the IKMT and a four-meter-squared effective mouth, multi-opening Tucker Trawl were fished simultaneously to compare catch composition between the two pieces of equipment.

   Primary sample processing for both legs was conducted in laboratory compartments within the ship. Antarctic krill (*Euphausia superba*) were separated from the catch and enumerated; a sub-sample of salps (*Salpa thompsoni*) were separated, counted and measured; other adult and larval euphausiids, ichthyoplankton, and zooplankton material was identified, counted, and preserved. Sub-samples of *E. superba* from each tow were processed in the on-board laboratory space to determine the distribution of krill length, maturity stage, sex ratio, and reproductive condition. Myctophid fish were processed to determine sex, morphometric measurements, species, stomach contents, etc.
5. Phytoplankton operations: At every CTD station, water was sampled for Chl-*a* concentration at all depths in which Niskin bottles were fired, between five and 200 meters. A deck cell for the collection of PAR was installed on the ship super structure.

Table 1. Planned itinerary for the 2010/11 AMLR field season.

Vessel	R/V *Moana Wave*		
Itinerary			
Event	**Dates**	**Sea Days**	**Port Days**
Port call in Punta Arenas	08 - 10 Jan		3
Leg I	11 Jan - 10 Feb	31	
Port call in Punta Arenas	11 - 12 Feb		2
Leg II	13 Feb - 15 Mar	31	
Port call in Punta Arenas	16 - 18 Mar		3
Total Days		62	8
Schedule of Events			
Leg I Event	**No. of Days**	**Dates**	
Transit to Copacabana field camp	4	11 - 14 Jan	
Transfer personnel/ gear to Copa and Calibrate in Admiralty Bay	1	15 Jan	
Transfer personnel/ gear to Cape Shirreff	1	16 Jan	
Conduct Large-area Survey	20	17 Jan – 05 Feb	
Transfer personnel and trash from Cape Shirreff	1	06 Feb	
Transit to Punta Arenas	4	07 - 10 Feb	
Total days	31		
Leg II Event	**No. Of Days**	**Dates**	
Transit to South Shetland Islands	4	13 - 16 Feb	
Conduct gear comparison survey in large area	21	17 Feb – 09 Mar	
Close Cape Shirreff Field Camp	1	10 Mar	
Calibrate in Admiralty Bay, close Copacabana field camp	1	11 Mar	
Transit to Punta Arenas	4	12 - 15 Mar	
Total Days	31		

6. XBT operations: XBT probes were deployed to collect temperature data to depths of up to 750 m during Drake Passage transits.
7. Acoustic system calibration, Legs I and II: At the beginning of Leg I and again at the end of Leg II, the ship anchored in approximately 25 fathoms of water in Admiralty Bay (Ezcurra Inlet) and the ship's acoustic system was calibrated.
8. Continuous environmental data collection, Legs I and II: A meteorological instrument package was mounted on the ship's forward mast to collect continuous measurements of sea surface temperature and salinity, air temperature, barometric pressure, relative humidity, wind speed, wind direction, scalar and cosine PAR, and shortwave radiation. A thermosalinograph was also set up to collect continuous measurements of surface salinity.
9. Drifter deployment: Drifters were deployed from the ship on three of the four transits between the South Shetland Islands region and Punta Arenas, Chile, south of 58°S. Additional drifters were deployed in the Elephant Island Area.
10. Seabird and marine mammal observation: Seabird and marine mammal observations were collected from inside the pilot house along transects between stations and during the transits to and from Punta Arenas.
11. Field camp logistical support and garbage removal: At the beginning of Leg I, personnel, food, and equipment were dropped off at the Copacabana and Cape Shirreff Field Stations. At the end of Leg I, equipment and trash were recovered from Cape Shirreff, and Jefferson Hinke was transferred from the R/V *Moana Wave* to Cape Shirreff. At the end of Leg II, personnel, equipment, and trash were recovered from both the Cape Shirreff and Copacabana Field Stations to close the stations for the season. Daily radio communications were maintained between the various field sites and the ship. At every opportunity when visiting camps, and at the end of Legs I and II, we collected garbage from Cape Shirreff and Copacabana.

Cape Shirreff Field Station

1. A five-person field team (N. Pussini, R. Buchheit, K. Pietrzak, M. Mudge, and A. Larned) arrived at Cape Shirreff, Livingston Island, on 27 October 2010 via the R/V *Laurence M. Gould*. Equipment and provisions were also transferred from the R/V *Laurence M. Gould* to Cape Shirreff.
2. A four-person quadrocopter team (W. Perryman, N. Ash, S. Gardner, and D. Leroi), along with supplies and equipment, arrived at Cape Shirreff via the R/V *Moana Wave* on 16 January 2011.
3. J. Hinke arrived at Cape Shirreff on 5 February 2011, with additional supplies and equipment. The quadrocopter team (W. Perryman, N. Ash, S. Gardner, D. Leroi) left at that time.
4. Weather data recorders (Davis Instruments, Inc.) were set up at Cape Shirreff for wind speed, wind direction, barometric pressure, temperature, humidity, precipitation, and solar radiation on 6 November 2010 and continued to collect data through 5 March 2011.
5. Censuses of breeding elephant seals began 5 November and continued through 24 November 2010.
6. Weekly censuses of phocids began 10 November 2010 and continued through 15 January 2011.
7. Antarctic fur seal pups were counted at four main breeding beaches every other day from 30 November through 31 December 2010.
8. Attendance behavior of 30 lactating Antarctic fur seals was measured using radio transmitters. Females and their pups were captured, weighed, and measured from 1 – 17 December 2010.
9. CCAMLR Antarctic fur seal pup growth protocols were 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 (6 December 2010) and continued every two weeks until 19 February 2011.
10. Information on Antarctic fur seal diet was collected using scat (random collection of 10 per week for 11 weeks) and fatty-acid signature analyses of milk (84 samples) collected at every capture of an adult lactating female.
11. Eleven Antarctic fur seals were instrumented with time-depth recorders (TDRs) for studies of dive behavior.
12. Ten Antarctic fur seal females were instrumented with GPS satellite-linked time depth recorders for studies of at-sea foraging location and diving from 4 December 2009 to 26 February 2010.
13. A total of 500 Antarctic fur seal pups were tagged at Cape Shirreff by U.S. researchers for future demography studies. An additional 23 new adult females were tagged.
14. Three leopard seals were captured and instrumented with Mark 9 time depth recorders (TDR). Two TDRs

were successfully retrieved after collecting dive and temperature data for over a month.

15. Fourteen adult female fur seals and seven leopard seals were instrumented in late-February with ARGOS satellite-linked instruments after molting to record 2011 over-winter dispersal and foraging locations.
16. Censuses of active gentoo and chinstrap penguin nests were conducted on 18 November and 27 November 2010, 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.
17. A sample of adult chinstrap penguins were weighed on 19 November 2010, during peak clutch initiation, and first eggs were measured. Gentoo penguin eggs were weighed on 22 and 28 November 2010.
18. Radio transmitters were attached to gentoo penguins on 28 December 2010 and to chinstrap penguins on 2 January 2011 and remained on until 24 February 2011. These instruments were used to determine foraging trip duration during the chick-rearing phase.
19. Satellite-linked transmitters (PTTs) were deployed on adult chinstrap and gentoo penguins twice for eight to ten days at a time to collect geographic data on adult foraging locations. Six gentoos and six chinstraps were tagged in late December and mid-January, and another six penguins of each species were tagged in late January and early February. The first deployment coincided with the chick-brooding 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.
20. Diet studies of chinstrap and gentoo penguins during the chick-rearing phase were initiated on 3 January 2011 and continued through 8 February 2011. Forty chinstrap and 20 gentoo adult penguins were captured upon returning from foraging trips, and their stomach contents were removed by stomach lavage.
21. Counts of all gentoo and chinstrap penguin chicks were conducted on 25 January and 8 February 2011, respectively.
22. Two-hundred and fifty chinstrap penguin chicks and 200 gentoo penguin chicks were banded for future demographic studies.
23. Reproductive studies of brown skuas and kelp gulls were conducted throughout the season at all nesting sites around Cape Shirreff.
24. Three time-depth recorders (TDRs) were deployed on gentoo penguins in late December, and then retrieved in early January and deployed on chinstrap penguins. In late January, one TDR was deployed on a gentoo penguin, and in early February two TDRs were deployed on chinstrap penguins. The first deployment coincided with the chick-brooding 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.
25. PTTs were deployed on 15 gentoo and 15 chinstrap penguins after the molt for over-winter tracking studies.
26. The Cape Shirreff field camp was closed for the season on 10 March 2011. All personnel, garbage and equipment were retrieved by the R/V *Moana Wave*.

Copacabana Field Station

1. A four-person field team (S. Trivelpiece, A. Will, P. Chilton, and K. Boysen) arrived at the Copacabana field station on Admiralty Bay, King George Island on 9 October 2010 via the R/V *Laurence M. Gould*. Equipment and provisions were also transferred from the R/V *Laurence M. Gould* to Copacabana.
2. S. Trivelpiece left via the tour vessel Orlova on 17 December 2010.
3. W. Trivelpiece arrived at the field station via the R/V *Moana Wave* on 15 January 2011.
4. PTTs were deployed between 27 October and 2 November 2010 on five female Adélie penguins prior to their first departures to sea following clutch completion.
5. Censuses of active Adélie, gentoo and chinstrap penguin nests were conducted on 5 November, 1 November, and 29 November 2010, respectively. Reproductive success was studied by following a sample of 100 Adélie penguin pairs and 100 gentoo penguin pairs from egg laying to crèche formation.
6. A sample of adult chinstrap penguins were weighed on 18 November, during peak clutch initiation, and first eggs were measured.
7. Diet studies of chinstrap and gentoo penguins during the chick-rearing phase were initiated on 20 December 2010 and continued through 3 February 2011. Thirty gentoo and 10 chinstrap adult penguins were captured upon returning from foraging trips, and their stomach contents were removed by stomach lavage.
8. Counts of all Adélie, gentoo and chinstrap penguin chicks were conducted on 5 January, between 5 and 12

January, and 3 February 2011; respectively.

9. Two-hundred and fifty Adélie penguin chicks and 250 gentoo penguin chicks were banded for future demographic studies.
10. Fledging weights were collected from Adélie and gentoo penguin chicks as a measure of chick condition.
11. Radio transmitters were deployed on 13 Adélie and 20 gentoo penguins during the chick-rearing phase in order to determine their foraging trip durations. Colony attendance was logged between 24 December 2010 and 8 February 2011 using a remote receiver and data collection logger.
12. Fourteen PTTs were applied to gentoo penguins during three separate deployments between 4 January and 15 February, one during the brood stage and two during the crèche phase. Five PTTs were deployed on chinstrap penguins on 26 January 2011, during their chick crèche stage.
13. Reproductive success of brown skuas, south polar skuas, hybridizing skua pairs, and southern giant petrels was followed over the course of the summer season.
14. The Copacabana field station was closed for the season on 9 March 2011. All personnel, garbage and equipment were retrieved by the R/V *Moana Wave*.

Scientific Personnel

Chief Scientist:
Christian Reiss (Legs I and II)

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

Phytoplankton:
Guido Bordignon (Leg I)
Stephanie Sexton (Leg I)
Amy Van Cise (Leg II)

Bioacoustic Survey:
Anthony Cossio (Legs I and II)

Krill and Zooplankton Sampling:
Kim Dietrich (Legs I and II)
Ryan Driscoll (Leg I)
Ian Bystrom (Legs I and II)
Nissa Ferm (Legs I and II)
Suzanne Romain (Legs I and II)
Amy Van Cise (Leg II)
Cassandra Brooks (Leg II)
Michael Janssen (Legs I and II)
Lars Thoresen (Legs I and II)
Darci Lombard (Leg I)
Jefferson Hinke (Leg I)
Raul Vasquez del Mercado (Legs I and II)
Andrea Pesce (Leg I)

Pelagic Fish Sampling:
Phillipe Koubbi
Barbara Catalano

Fur Seal Energetic Studies:
Jen Walsh (Leg I)
Amy Van Cise (Leg II)

Seabird and Marine Mammal Observation Studies:
Jarrod A. Santora (Leg I)
Michael Force (Legs I and II)

Cape Shirreff Personnel:
Nicola Pussini
Ray Buchheit
Jefferson Hinke
McKenzie Mudge
Kevin Pietrzak
Allyson Larned
Wayne Perryman
Nancy Ash
Steve Gardner
Don LeRoi

Copacabana Personnel:
Sue Trivelpiece
Alexis Will
Penelope Chilton
Kristen Boysen
Wayne Trivelpiece

Physical Oceanographic Measurements and Underway Environmental Observations

Derek Needham and André Hoek

Abstract

Oceanographic data were collected at fixed stations around the South Shetland Islands during two legs of the 2010/11 AMLR Survey. A total of 97 CTD/carousel casts were completed on Leg I and 69 CTD deployments were done simultaneously with the Tucker Trawl on Leg II. Results indicated that:

- Antarctic Circumpolar Current (ACC) water remained mainly offshore, and was found primarily in the western part of the South Shetland Islands;
- Waters were mixed between Elephant Island and the Shackleton Fracture Zone, giving way to the colder, saltier waters of the Bransfield Strait south of Elephant Island and around Joinville Island;
- A number of instrument problems with dated equipment suggest the need for replacement of these instruments; and
- The new Tucker Trawl system provided the ability to better quantify biological and physical relationships at smaller space scales.

Introduction

Oceanographic variability has been shown to influence the Antarctic Peninsula ecosystem at a variety of temporal and spatial scales. These influences include impacting primary productivity in the region, the strength of currents, and the amount of snow and ice impacting the success of land-breeding birds and mammals. The objectives of this study were to:

1. Collect and process physical oceanographic data in order to identify hydrographic characteristics and map oceanographic frontal zones;
2. Collect and process underway environmental data in order to describe sea surface conditions during the surveys; and
3. Investigate the use of the Sea-Bird SBE19plus CTD mounted on the new Tucker Trawl system.

Together these data may be used to describe the physical conditions associated with various biological observations, as well as provide a detailed record of the ship's movements and the environmental conditions encountered.

Methods

CTD/Carousel Stations

A total of 97 CTD/carousel casts were completed on Leg I, using a Sea-Bird SBE 911plus CTD system together with a SBE 32 carousel carrying 11 ten-liter General Oceanics sample bottles. A Sea-Bird SBE 43 Dissolved Oxygen (DO) sensor, WetLabs C-Star red transmissometer, three Biospherical PAR sensors, and a Teledyne Benthos bottom detection altimeter were also interfaced to the CTD. All the above equipment was new, except for two of the PAR sensors, which were installed alongside a new PAR sensor on the carousel frame, for historical cross calibration purposes. A new Biospherical masthead 4pi PAR sensor was installed as a surface PAR reference, and cabled directly into a new SBE 11plus CTD deck unit to be recorded simultaneously with the CTD profile data.

The CTD, carousel, and auxiliary sensors were set up as per Table 1.1 and operated from the portside winch, which was fitted with a calibrated winch monitoring system (cable load, wire out, and wire speed). Deck sheets were generated for every station and CTD data were logged and bottles 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 were processed using SBE Data Processing Version 5.30a software, averaged over 1 m bins, and saved separately as up and down traces during post processing. Downcast data were reformatted using a SAS script and then imported into Ocean Data View (ODV) format for further "in-field" checking and presentation.

The CTD and its auxiliary sensors were calibrated by the manufacturers prior to the cruise and all calibration certificates have been stored in a central filing system, along with the calibration sheets from previous AMLR cruises.

The new Chelsea Instruments Aquatracka submersible

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

SCS Sensor Installation Summary				
SENSOR	MANUFACTURER	MODEL	SERIAL NO.	CALIBRATED
Leg I				
Weather Station	Ocean Environmental Systems	WeatherPak WP2000	797	7-Jul-10
PAR sensor (2pi)	Licor	Quantum LI-190SZ	Q40069	17-Aug-09
Pyranometer	Licor	LI-200	PY66797	25-Aug-09
PAR sensor (4pi)	Biospherical Instruments	QSR-2100	10281	23-Jun-10
Thermosalinograph	Sea-Bird Electronics	SBE-21	2971	2-Jul-10
Remote TSG probe	Sea-Bird Electronics	SBE-03-01/S	1310	2-Jul-10
GPS navigator	Ship's GPS		Ship supply	
Gyro compass	Furuno Marine		Ship supply	
Leg II				
Weather Station	Ocean Environmental Systems	WeatherPak WP2000	798	7-Jul-10
PAR sensor (2pi)	Licor	Quantum LI-190	Q28168	20-Jul-10
Pyranometer	Licor	LI-200	PY67458	25-Aug-09
PAR sensor (4pi)	Biospherical Instruments	QSR-2100	10281	23-Jun-10
Thermosalinograph	Sea-Bird Electronics	SBE-21	2971	2-Jul-10
Remote TSG probe	Sea-Bird Electronics	SBE-03-01/S	1310	2-Jul-10
GPS navigator	Ship's GPS		Ship supply	
Gyro compass	Furuno Marine		Ship supply	

CTD Sensor Installation Summary					
DESCRIPTION	MANUFACTURER	MODEL	SERIAL NO.	CHANNEL	CALIBRATED
Leg I					
Deck Unit	Sea-Bird Electronics	SBE 11plus V2	11P-60321-0844		7-Aug-10
Underwater Unit	Sea-Bird Electronics	SBE 9plus	09P60321-0995		7-Aug-10
Temperature Sensor	Sea-Bird Electronics	SBE 3plus	5339	Freq 1	7-Aug-10
Conductivity Sensor	Sea-Bird Electronics	SBE 4C	3769	Freq 2	3-Aug-10
Pressure Sensor	DigiQuartz with TC	Internal	995	Freq 3	5-Aug-10
Circulation Pump	Sea-Bird Electronics	SBE 5T	90543		Aug-10
SBE Carousel	Sea-Bird Electronics	SBE 32	3260321-0800		Aug-10
DO Sensor	Sea-Bird Electronics	SBE 43	1916	Voltage 0	31-Jul-10
PAR (new 2011)	Biospherical	QCP-2300	70320	Voltage 2	18-Oct-11
PAR (new 2005?)	Biospherical	QCP-2300	4744	Voltage 3	23-Jun-10
PAR (old)	Biospherical	QCP-200L	4264	Voltage 4	23-Jun-10
Altimeter	Teledyne Benthos	PSA-916	50481	Voltage 5	2010
Transmissometer	Wetlabs	C-Star Red	CST-1332DR	Voltage 6	19-Aug-10
Masthead PAR sensor 4pi	Biospherical	QSR-2200	70386	Into SBE 11p	2010
Leg II					
Underwater Unit	Sea-Bird Electronics	SBE 19plus V2	19p53746-6645		2010
Circulation Pump	Sea-Bird Electronics	SBE 5T	55722		2010
DO Sensor	Sea-Bird Electronics	SBE 43	431917	Voltage 0	2010

fluorometer failed on first power-up and was not used until spare parts were obtained before Leg II. The CTD, auxiliary sensors, and carousel equipment functioned reliably with the usual amount of pre-emptive servicing of underwater connectors required. The enclosing of the R/V Moana Wave transom greatly improved the safety of working on the aft-deck and reduced the amount of deployment damage to the equipment. With the deck being dry, maintaining and servicing the CTD system during the cruise was easier. The CTD system was stowed on the aft deck and secured to the ship's steelwork with ratchet straps during transits and between stations. A set of carousel water sampling bottles was broken when the CTD slammed the ship, but all these bottles were able to be repaired and put back into use.

Water samples were collected at 11 discrete depths on all casts for phytoplankton analysis during Leg I. 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 Teledyne Benthos altimeter was used to stop the CTD descent 5 to 15 m from the seabed on the shallow casts, depending on sea-state. Standard bottle sampling depths were 750 m, 200 m, 100 m, 75 m, 50 m, 40 m, 30 m, 20 m, 15 m, 10 m, and 5 m.

Salinity calibration checking was not done due to problems with the Guildline Portasal salinometer. Comparisons of dissolved oxygen levels in the carousel water samples with the levels measured during the casts (via the DO sensor) were not attempted during the survey.

CTD/Tucker Trawl Stations

During Leg II, a new Sea-Bird SBE 19plus V2 portable CTD system with a pumped SBE 43 DO sensor (see Table 1.1) was mounted on the Tucker Trawl and interfaced into the Tucker Trawl's electronics. CTD data were presented in real-time and logged by the Tucker Trawl software. A total of 69 Tucker Trawl stations were sampled during Leg II. The CTD performed well; only routine connector maintenance and battery changes were necessary. The SBE 19plus V2 CTD and SBE 43 DO sensor were calibrated by the manufacturers prior to the cruise and all calibration certificates have been stored in a central filing system, along with the calibration sheets from previous AMLR cruises. After an initial learning period, the Tucker Trawl electronics and software worked well. The deployment and retrieval procedures set in place by the deck operators resulted in the protection of the delicate electronics and no major damage resulted in any of the 69 trawl stations, even in bad weather. The only damage of note was to the oil-filled pressure casing cover of the net triggering motor. The cover was knocked against the ship on deployment and force jammed into the casing. Repairs were possible by heating the casing to release the jammed lid, rinsing the motor and refilling with oil. One of the flowmeters on the Tucker Trawl was replaced with a spare unit when it stopped functioning. Because the Tucker Trawl electronics, sensors, and CTD are complex and exposed to possible damage, a protective cage and spare parts should be considered for future cruises. Problems were experienced with both sea cables. The CTD (Leg I) and IKMT were deployed from the starboard side winch (Rochester .322" coax cable) and the Tucker Trawl on the port side winch (Rochester .450" coax cable).

Both cables displayed the tendency of having excess "spring" in them and wanting to coil back on themselves, unravel, and eventually kink. The .322" cable started unraveling and eventually kinked on three occasions during Leg I and twice on Leg II. This necessitated that the cable be cut back and the mechanical dead end and electrical underwater termination be redone each time. This also occurred on the .450" cable on the 13th tow using the Tucker Trawl (500 m deep tow). As soon as the tension was released from the cable on retrieval, it sprung back on itself and coiled and kinked on the winch drum. Various causes of these malfunctions were explored:

1. Exceeding working load of cables;
2. CTD or nets spinning underwater;
3. Dead ends not gripping both layers of armor;
4. Kinking due to pinching damage in A-frame moving parts;
5. Kinking due to hooking on ship protrusions when A-frame moving;
6. Cable not being layered smoothly on winch drum;
7. Exceeding minimum specified bending radius of cable (9"); and
8. Chaffing on blocks.

No definite solution has been found, but it is noted that both the hanging blocks on the aft A-frame are less than the minimum cable bending radius of 9".

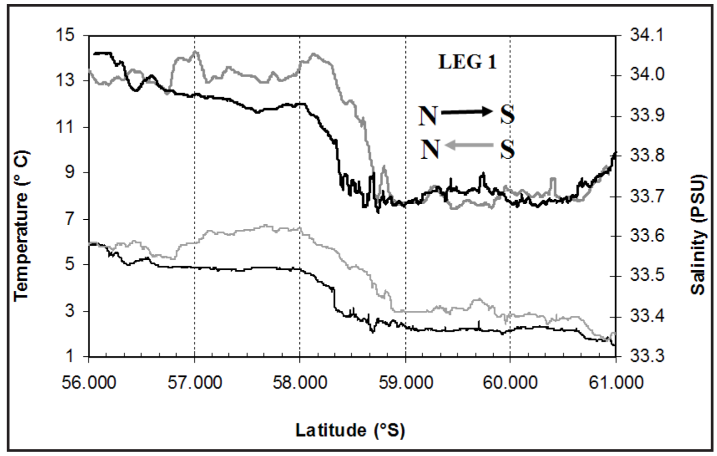
Underway Environmental Observations

Environmental and vessel position data were collected, logged, and displayed for a total of 59 days (30 days and 29 days during Legs I and II, respectively) via the Scientific Computer System (SCS) software package, which was run on a Windows XP based Dell PC with an internal 8-port RS232 expander card.

Environmental data were collected via a Coastal Environmental Company Weatherpak system, a Licor quantum PAR sensor, and a Biospherical 4PI QSR-2100 PAR sensor installed on the R/V *Moana Wave's* bridge-top mast. A Sea-Bird SBE-21 thermosalinograph (TSG) and debubbler system were installed in the zooplankton laboratory and fed into the SCS, with a remote Sea-Bird SBE-3 sea surface temperature probe in the suction line of the TSG pump, close to the hull intake. This system performed well, except during severe sea conditions when cavitation would require the pump to re-prime. The relative wind data were converted to true speed and true direction by the internally-derived functions of the SCS logging software. Vessel position data were recorded through the ship's GPS and gyro-compass, which were also fed into the SCS system.

All the above instruments were calibrated by the manufacturers prior to the cruise and all calibration certificates have been stored in a central filing system, along with the calibration sheets from previous AMLR cruises. See Table 1.1 for SCS installation summary.

The R/V *Moana Wave* does not have a deep echo sounder that can be used to record bottom soundings to the SCS or provide an indication of depth before deploying the CTD and nets. In shallow waters, soundings were obtained from the EK60 system; in deeper water, soundings obtained during the 2009 survey were used.



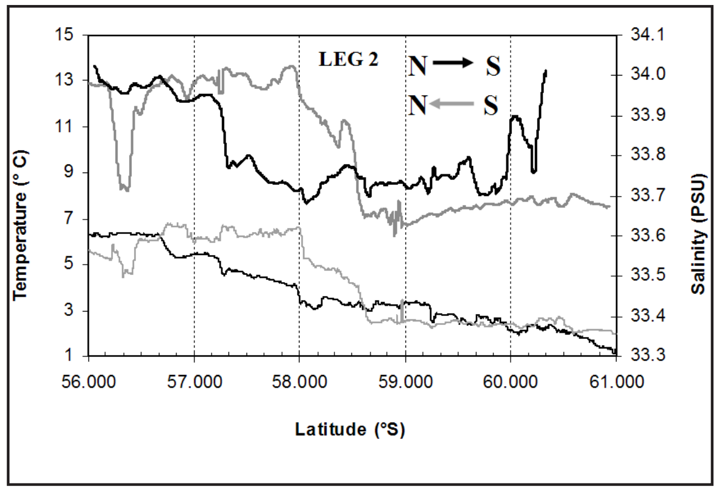


Figure 1.1. The position of the polar fronts as determined for AMLR 2011 Legs I (top) and II (bottom), from measurements of sea surface temperature and salinity for the south and north transits to and from the South Shetland Islands survey area.

Results

During Leg I, 97 CTD stations were successfully sampled across the survey grid. The position of the Antarctic Polar Front, identified by pronounced sea surface temperature and salinity change, was located from the logged SCS data during the four transits from and to Punta Arenas and the South Shetland Islands (See Figure 1.1). This frontal zone is normally situated between 57-58° S.

During both the south- and north-bound transits of Leg I, the Antarctic Polar Front was well defined with sharp salinity changes between 58° S and 58° 40' S, with accompanying sea surface temperature (SST) dropping from approximately 5°C to 2.5°C on the south-bound and increasing from 3.5°C to 6.5°C on the north-bound transit. Leg II saw less well-defined fronts, with the beginning of the front encountered around 57° 20' S on the southward transit and 58° 40' S to 58° S on the northward transit.

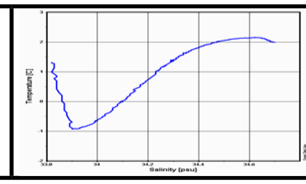
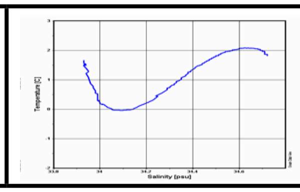
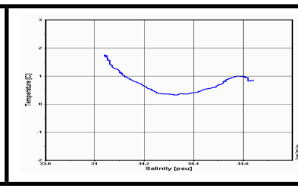
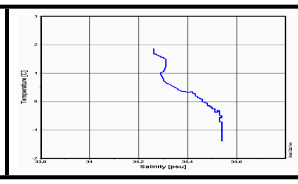
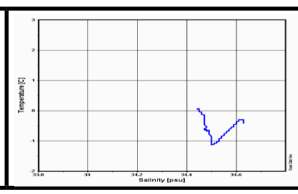
A comparison of the Sea-Bird SBE-21 thermosalinograph (TSG) system with CTD data showed that the TSG salinity readings were on average 0.005 ppt (n = 96) lower than the CTD, while the TSG sea temperature readings were on average 0.057°C (n = 96) higher than the CTD's 5 m temperature data.

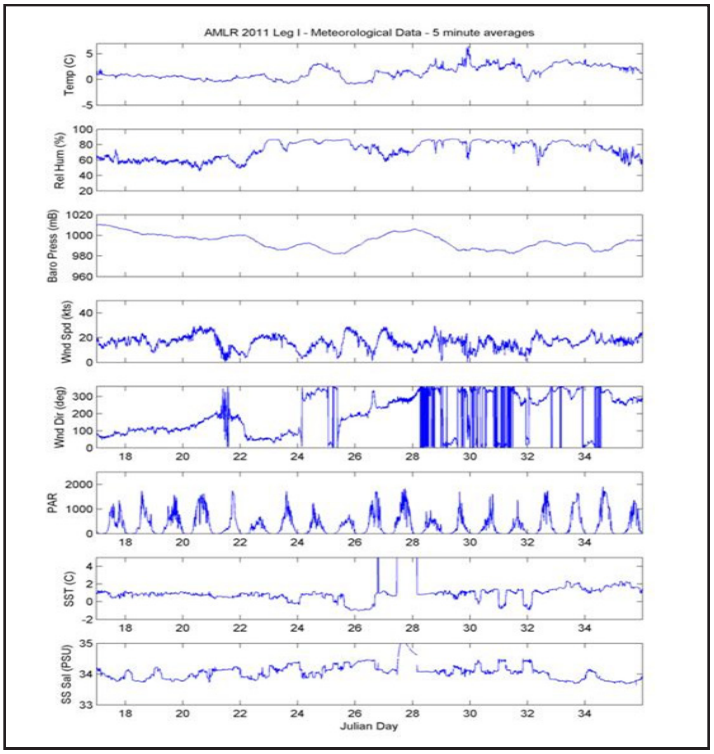
Environmental data were recorded for the duration of the surveys and for the transits between Punta Arenas and the survey area. Processed data were averaged and filtered over 1-minute and 5-minute intervals for Legs I and II (Figures 1.2 and 1.3, respectively).

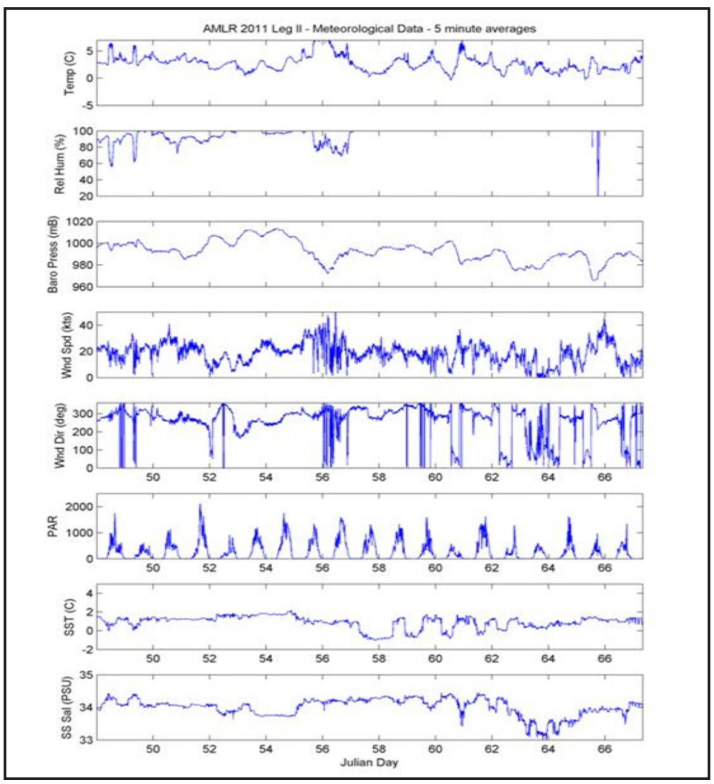
Discussion

All data were processed and a first attempt at water zone classification was undertaken to group stations with similar temperature and salinity profiles into five water zones as defined in Table 1.2 and presented in Figure 1.4. The tentative water zone classifications are sometimes prone to ambiguity, particularly in the coastal regions

Table 1.2. Water Zone definitions applied for AMLR 2011.

	T/S Relationship			
	Left	**Middle**	**Right**	**Typical TS Curve (from 2002)**
Water Zone I (ACW)	**Pronounced V shape with V at ≤0°C**			
Warm, low salinity water, with a strong subsurface temperature minimum, Winter Water, approx. -1°C, 34.0ppt salinity) and a temperature maximum at the core of the CDW near 500m.	2 to >3°C at 33.7 to 34.1ppt	≤0°C at 33.3 to 34.0 ppt	1 to 2°C at 34.4 to 34.7ppt (generally >34.6ppt)	
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 34.2ppt	-0.5 to 1°C at 34.0 to 34.5ppt (generally >0°C)	0.8 to 2°C at 34.6 to 34.7ppt	
Water Zone III (Transition)	**Backwards broad J-shape**			
Water with little evidence of a temperature minimum, mixing with Type 2 transition water, no CDW and temperature at depth generally >0°C	1 to >2°C at 33.7 to 34.0ppt	-0.5 to 0.5°C at 34.3 to 34.4ppt (note narrow salinity range)	≤ 1°C at 34.7ppt	
Water Zone IV (Bransfield Strait)	**Elongated S-shape**			
Water with deep temperature near -1°C, salinity 34.5ppt, cooler surface temperatures.	1.5 to >2°C at 33.7 to 34.2ppt	-0.5 to 0.5 °C at 34.3 to 34.45ppt (T/S curve may terminate here)	<0°C at 34.5ppt (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.	1°C (+/- some) at 34.1 to 34.4ppt	-0.5 to 0.5°C at 34.5ppt	<0°C at 34.6ppt	





Figures 1.2 and 1.3. Meteorological data (5-minute averages) recorded between 11 January and 10 February 2012 (Leg I, top) and between 13 February and 15 March 2012 (Leg II, bottom) of the AMLR 2010/11 Survey. PAR is photosynthetically available radiation.

around King George and Livingston Islands and south and southeast of Elephant Island. Classifications of Zone IV (Bransfield Strait) and Zone V (Weddell Sea) waters in these areas could 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. This was done to ensure consistency with past cruises and only serves as a "first attempt field classification." Stations that were too shallow, or where the water showed excessive mixing, were not classified for this report and are unlabelled on Table 1.2.

During Leg I, the most clearly defined Zone I (ACC) water was found on the two northern stations of Line 11 of the West Area, with the majority of the deep stations off the shelf break, north of the islands, tending towards Zone II (Transition) water and Zone III (Transition) water.

Zone IV (Bransfield Strait) water was found to the east and southeast of Elephant Island and in the South Area. Slight influences of Zone IV were also found north of the islands in the West Area, at the inshore stations 17-11, 16-10, and 14-10. Influences of Zone V (Weddell Sea) water were found east of Elephant Island, as well as in the Joinville Island Area and southern stations of the South Area.

For comparative purposes, vertical temperature profiles have been plotted for the same two station lines (EI03 and EI07) as last year. Figure 1.5 shows lines EI03 and EI07 for AMLR 2011 Leg I.

Protocol Deviations

There were no deviations from the standard protocol during the 2010/11 AMLR Survey.

Disposition of Data

Data are available from Christian Reiss, Southwest Fisheries Science Center, 8901 La Jolla Shores Drive, La Jolla, CA, 92037; phone/fax (858) 546-5603/(858) 546-7003; email: Christian.Reiss@noaa.gov.

Acknowledgments

The co-operation and assistance of the R/V *Moana Wave's* staff was excellent. All requests for assistance were dealt with effectively and in a professional manner.

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

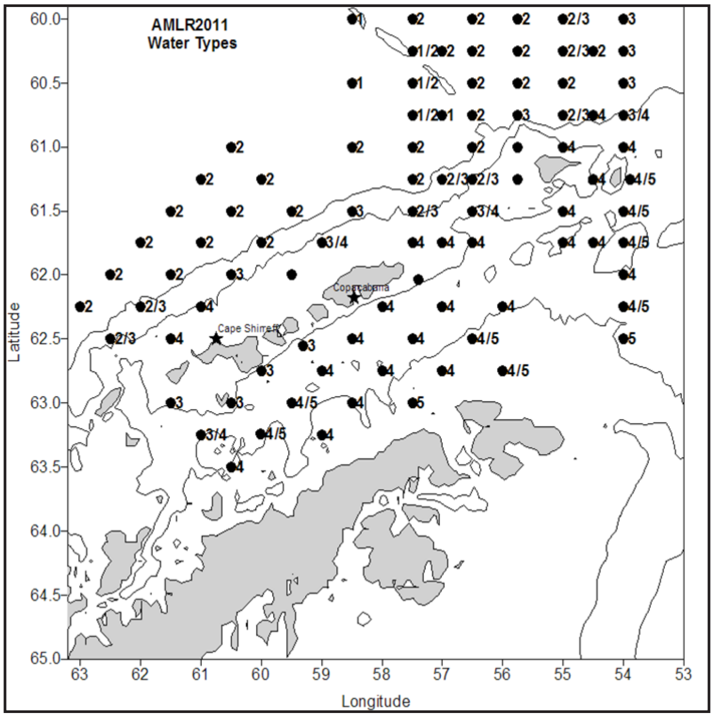


Figure 1.4. Leg I Water Zone classification for AMLR 2011, as defined in Table 1.2.

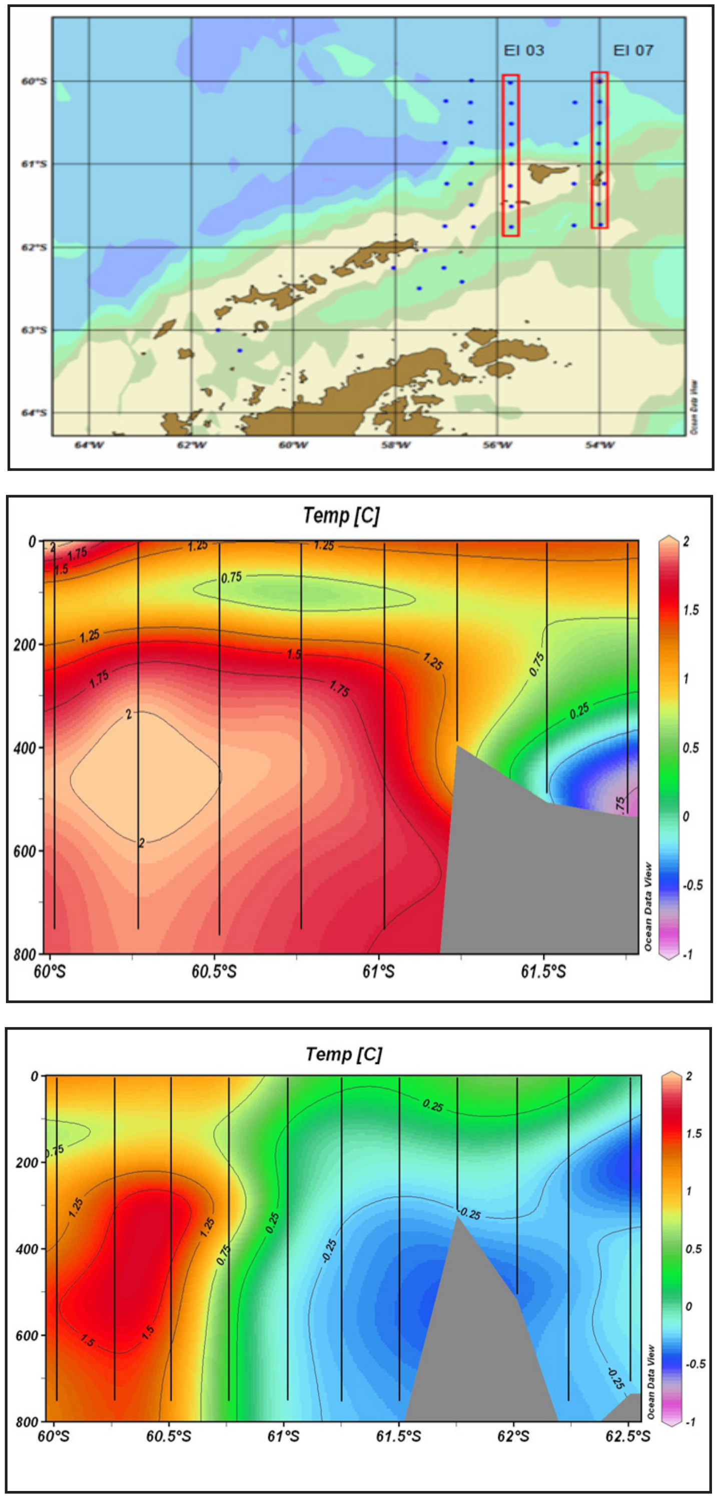


Figure 1.5. Vertical temperature profiles derived from CTD data recorded on two transects, EI 03 (middle) and EI 07 (bottom), during Leg I of AMLR 2011 South Shetland Island survey.

Phytoplankton Studies in the South Shetland Islands

Guido Bordignon, Stephanie Sexton, and Amy Van Cise

Abstract

Phytoplankton production was measured around the South Shetland Islands as part of the 25th U.S. AMLR field season. Depth discrete and surface water samples were collected for chlorophyll-a (Chl-*a*) biomass (mg m^{-3}), taxonomic determination, and macro-nutrient (NO^{-3}, PO^{-4}, and SiOH) concentrations in relation to water mass properties, including temperature and salinity. Results indicate that:

- During Leg I of the survey, a total of 95 full oceanographic and biological stations were occupied and water samples were collected from 0-200 m depth across the AMLR Survey grid;
- During Leg I, the Chl-*a* concentration averaged over the upper 15 m of the water column varied from 0.43 mg m^{-3} in the West Area to more than 1.3 mg m^{-3} in the South Area. Average Chl-a values for the Elephant Island and West Areas were close to their long term means;
- During the Leg II gear comparison study, only surface (~3 m) water samples were collected from the flow-through thermosalinograph at 59 stations, including stations within the Elephant Island (19), South (19) and Joinville Areas (9), but also within northeastern Gerlache Strait (12). These near-surface samples exhibited higher Chl-*a* concentration in all areas, and ranged from 1.3 mg m^{-3} in the Elephant Island Area to more than 3.2 mg m^{-3} in the South Area. In Gerlache Strait, outside the historical AMLR grid, the mean Chl-*a* concentration was 4.52 ± 3.53 mg $m^{-3\dagger}$; and
- New in situ and incident photosynthetically active radiation (PAR) sensors were calibrated with older sensors, and a high correlation (r^2 > 0.999) between the QCP-200L (sn 4264) sensor and a new QCP2300 (sn 70320) sensor was found. The older sensors, whose maximum operating depth is < 1000 m, will be retired.

Introduction

The U.S. Antarctic Marine Living Resources (AMLR) Program has collected phytoplankton, macro-nutrient, and chlorophyll data since 1990, to determine the factors affecting bottom-up control of krill and zooplankton productivity in the waters around the South Shetland Islands. The amount and quality of food available for zooplankton is fundamental to understanding krill abundance, distribution, and general web food dynamics, especially given the magnitude and rate of climate change in this region. In general, Chl-*a* biomass exhibits significant spatio-temporal variability, reflecting the low biomass within Drake Passage and higher biomass over the continental shelves and around islands. Low biomass is also found on the north side of the Peninsula, within the Bransfield Strait, indicating that mechanisms controlling production are complex. Temporally, Chl-*a* concentration is decreased during El Niño periods and elevated during La Niña periods. This suggests that there is a strong coupling between global scale climate patterns and productivity in this region. Given the impact of climate change on the Peninsula region, continued monitoring and examination of the factors controlling productivity of the system are important to understanding krill dynamics.

Methods

Sample collection

During Leg I, water samples for Chl-*a*, macro-nutrient, and fluoristic determination were collected at fixed stations on the AMLR Survey grid, which is divided into four areas around the South Shetland Islands: the Elephant Island, Joinville Island, West, and South Areas. At each station, water samples were collected with Niskin bottles attached to a conductivity-temperature-depth (CTD) sensor carousel. The depths sampled were 200, 100, 75, 50, 40, 30, 20, 15, 10, and 5 m, with occasional samples taken at 750 m. At shallow stations (< 200 m), samples were collected at standard depths and from 10 m off the bottom.

During Leg II, the CTD was not deployed, owing to a gear comparison study between the Tucker trawl and the IKMT net (see Chapter 4). To assess the Chl-*a* concentrations during Leg II, water samples for Chl-*a* were collected from the clean water outflow of the thermosalinograph (Sea-Bird SBE-21), which gets water from a pump placed in the hull at approximately 3 m depth (see Chapter 1 for thermosalinograph details).

Chlorophyll-a

To determine the concentration of Chl-*a* in the water, 100 ml of seawater was filtered through a glass fiber filter (Whatmann 2.5 cm GFF/0.7F) for each depth (between 5 and 200 m). Chl-*a* pigments were extracted from the filters using 9 ml of methanol over 24 hrs. Samples were then shaken, centrifuged, and the clear supernatant placed into a borosilicate tube. Fluorescence was determined using a calibrated Turner-designs model TD-700, fluorometer. After the initial reading, samples were treated with two drops of 1.0 N HCl solution and read again to quantify the phaeopigment concentration (Holm-Hansen et al. 1965; Holm-Hansen and Riemann, 1978).

Chl-*a* (mg m^{-3}) concentration was determined for each sample station using the following equation:

(1) $\text{Chl-}a = Fd\ t/(t-1) * (Rb-Ra)*1000/V_1*V_2$

Phaeopigment concentration (mg m^{-3}) was calculated with the following equation:

(2) $\text{Phaeo} = Fd*(t*Ra-Rb)*1000/V_1*V_2$

Where Fd (0.0000985) and t (2.802864) are calibration factors for the TD-700 fluorometer, Ra is the Chl-*a* fluorescence reading before addition of HCl, Rb is the phaeopigment fluorescence reading after addition of HCL, V_1 is the volume of water filtered, and V_2 is the volume of methanol used to extract the photosynthetic pigments.

Nutrients

Water samples for macro-nutrient determination were collected in the upper mixed layer from the 15 m water sample at 95 stations. Additionally, samples were collected from the surface to between 100 and 750 m at 5 stations (A18-08, A15-05, A11-01, 17-09, 9-13) during 2011. Further, owing to the earthquake during the AMLR 2010 survey, nutrient samples were not analyzed, and were instead left in a -80°C freezer in Punta Arenas until the end of the 2011 season. In 2010, eight full-cast stations were sampled for nutrients (NO_3, NO_2, SiO_4, PO_4), and 81 surface (10 – 15 m depth) samples were collected over the two legs of that survey. We present the results from both years' data here for comparison of potential quality issues. All samples were collected in acid-washed 100 ml Nalgene nutrient bottles, and immediately frozen until analysis by N. Silva (Universidad Catolica de Valparaiso, Valparaiso, Chile).

PAR

Three *in situ* PAR sensors were attached to the CTD and two mast-mounted incident PAR sensors were used during the 2011 U.S. AMLR field season. The mast-mounted PAR sensors were used to measure incident light continuously during the cruise and also used, in conjunction with the *in situ* sensors, to determine the euphotic zone depth (1%) light level across the survey area. These mast-mounted instruments (BSI model QSR2200) were deployed in two ways. In the first, a QSR2200 (S.N. 70386) was used to determine incident PAR and streamed into the SCS underway data string. In the second, the PAR values were fed directly to the SBE11 Underwater Unit to provide incident PAR for CTD cast data. The three *in situ* PAR sensors were all calibrated by BioSpherical Instruments (BSI Inc., San Diego, CA) prior to the cruise. Each sensor included a model QCP200L (S.N. 4262), which had been used since 1992 and will be retired because of its limited depth range, an early model of the QCP2300 (S.N. 4744) which consistently malfunctioned and will be retired, and a new QCP2300 (S.N. 70320), which had up-to-date electronics, an increased operating depth (2000 m), and will replace both the QCP200L and the older QCP2300. The goal of the comparison was to be able to ensure data continuity when switching to the new instrument. The new QCP2300 PAR is a log output quantum cosine profiling sensor; the single channel analog output voltage is proportional to the log of incident PAR (400-700 nm) irradiance to a depth up to 1500 m. Using BSI supplied calibrations, instrument voltages were converted to μE cm^{-2} sec^{-1}, and the QCP200L and the new QCP2300 were compared using linear regression analysis.

Fluorometry and Transmissometry

Owing to electronic failure on a voltage regulator on the Chelsea fluorometer (S.N. not available), no fluorometric data were collected during the cruise. A new transmissometer (Wetlabs C-Star Red, S.N. CST-1332DR) was used to provide data on optical characteristics of the water column at each station. These data is not reported here.

† Except where noted, variation is reported as standard deviation.

Results

Chlorophyll-a

Across the West Area, 24 of 25 stations were sampled for a total of 229 samples from various depths. Chl-*a* concentration at 10 m ranged from 0.044 to 1.49 mg m^{-3}. The

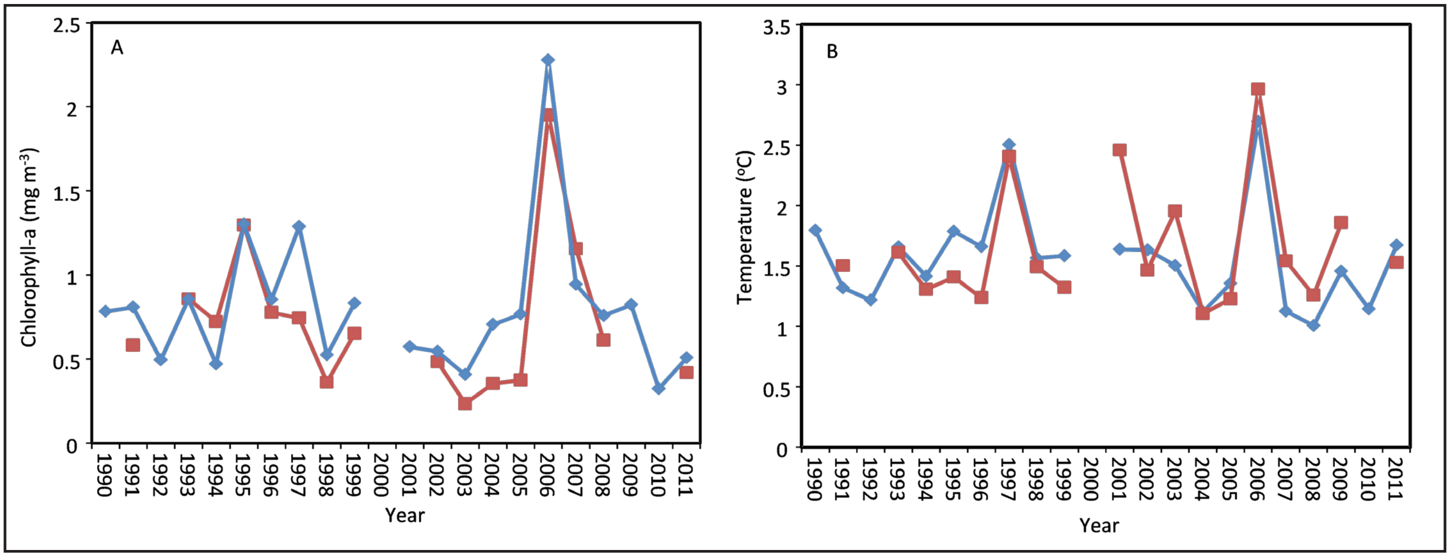


Figure 2.1. Time-series of the mean Chl-*a* (A) and temperature (B) in the West (red) and Elephant Island (blue) Areas of the South Shetland Islands averaged over the upper 15 m of the water column. West Area stations sampled prior to 1997 were not part of the fixed grid currently sampled, so care must be used to infer any differences between areas during that time period.

mean 10 m concentration was 0.48 ± 0.51 mg Chl-*a* m^{-3}. In the Elephant Island Area, 46 stations were sampled and 460 Chl-*a* samples were obtained. Chl-*a* concentrations at 10 m ranged from 0.069 to 2.20 mg Chl-*a* m^{-3}. The mean 10 m Chl-*a* concentration was 0.49 ± 0.43 mg Chl-*a* m^{-3}.

In the Joinville Island Area, only five stations were occupied (owing to ship breakdowns) and 50 Chl-*a* samples were collected. At 10 m, the Chl-*a* concentration ranged from 0.11 to 1.70 mg m^{-3}, with a mean concentration of 1.02 ± 0.75 mg m^{-3}. Finally, in the South Area, 20 stations were occupied and 258 Chl-*a* samples were collected. Chl-*a* concentration at 10 m ranged from 0.28 to 2.65 mg m^{-3}, and the mean concentration was 1.34 ± 0.66 mg m^{-3}, which was the highest among all areas sampled during Leg I.

Time series of Chl-*a* concentration and water temperature averaged over the upper 15 m from 1990 to 2011 for both the West and Elephant Island Areas showed that patterns were similar over time (Figure 2.1). After a peak in production associated with a very warm summer in 2006, both Chl-*a* and water temperature have declined to more average conditions.

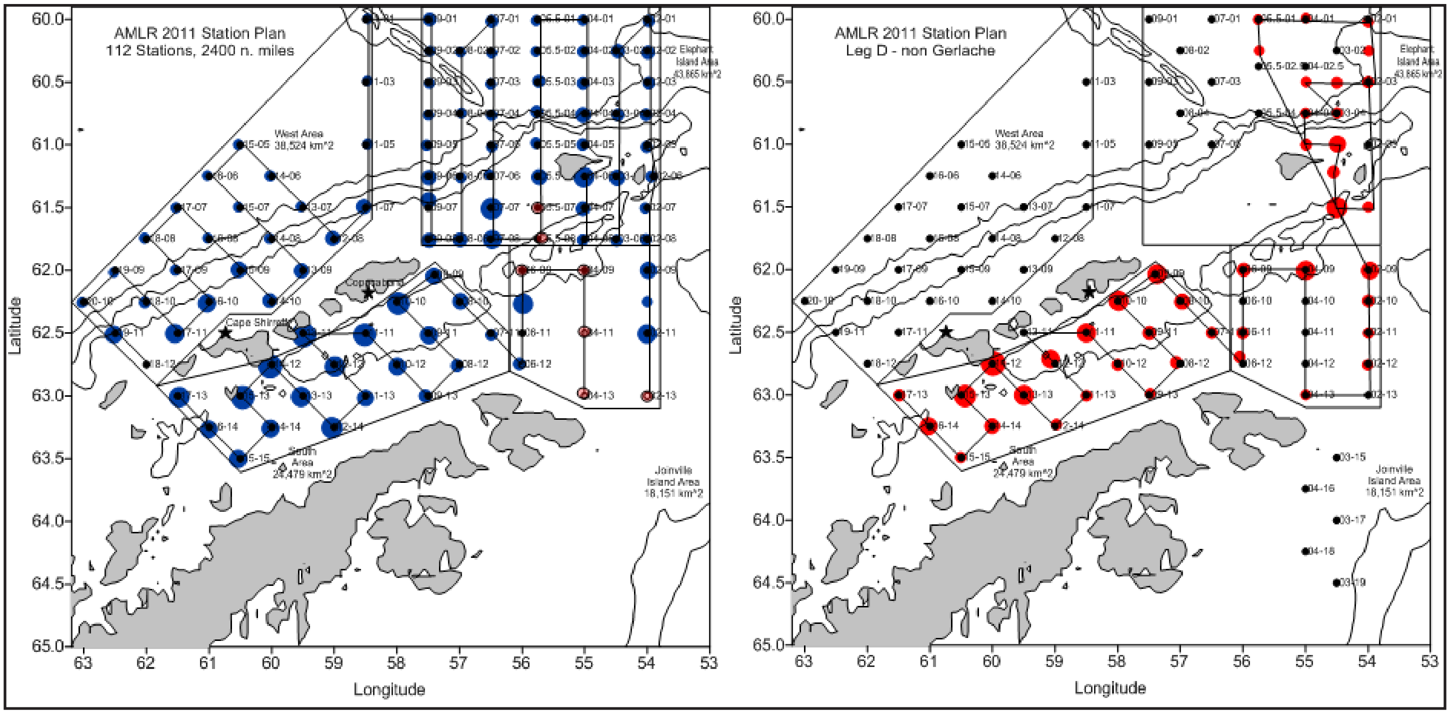
During Leg II, 47 water samples were collected from the clean water outflow of the thermosalinograph. These 47 samples were collected from the Elephant Island, Joinville Island, and South Areas, as well as within Gerlache Strait. The mean Chl-*a* concentration across all stations sampled during the leg was 2.21 ± 0.84 mg m^{-3} . The mean Chl-*a* concentration from the 12 samples collected from Gerlache Strait was much higher than the South and Joinville Island Areas, with a mean Chl-*a* concentration of 4.53 ± 1.02 mg m^{-3}.

Spatially, Chl-*a* concentration was highest near the shelves and coastal waters surrounding the islands during both legs (Figure 2.2). Consistently high concentrations of Chl-*a* were present on the north side of the Bransfield Strait. High Chl-*a* concentration was also associated with intermediate salinity waters (Figure 2.3a), and showed the clear unimodal relationship previously described for the region.

Nutrient concentrations

Concentrations of macro-nutrients were similar between 2010 and 2011, but some differences in the variability in macro-nutrient concentrations were observed (Figure 2.3). In 2010, the mean nitrate concentration was 26.9 ± 2.6 μMol kg^{-1} and ranged from 22.5 to 35.9 μMol kg^{-1}. In 2011, the mean nitrate concentration was 25.8 ± 1.4 μMol kg^{-1}, which was smaller and had a lower variance than the mean in 2010, and ranged from 23 to 35.7 μMol kg^{-1}, which was narrower than the range of values found in 2010.. Phosphate concentrations exhibited a similar pattern to nitrate, with mean concentrations of 1.96 ± 0.22 μMol kg^{-1} and 1.93 ± 0.18 μMol kg^{-1} in 2010 and 2011, respectively. Mean silicate concentrations, which are potentially more affected by long-term storage, were 43 ± 0.12 μMol kg^{-1} in 2010 and 45 ± 0.20 μMol kg^{-1} in 2011. Silicate concentrations in 2010 ranged from 19 to 80 μMol kg^{-1}, which was much narrower than the range of 12 to 84 μMol kg^{-1} observed during 2011.

Silicate and salinity were more strongly correlated in 2011 than in 2010, reflecting the overall range of sili-



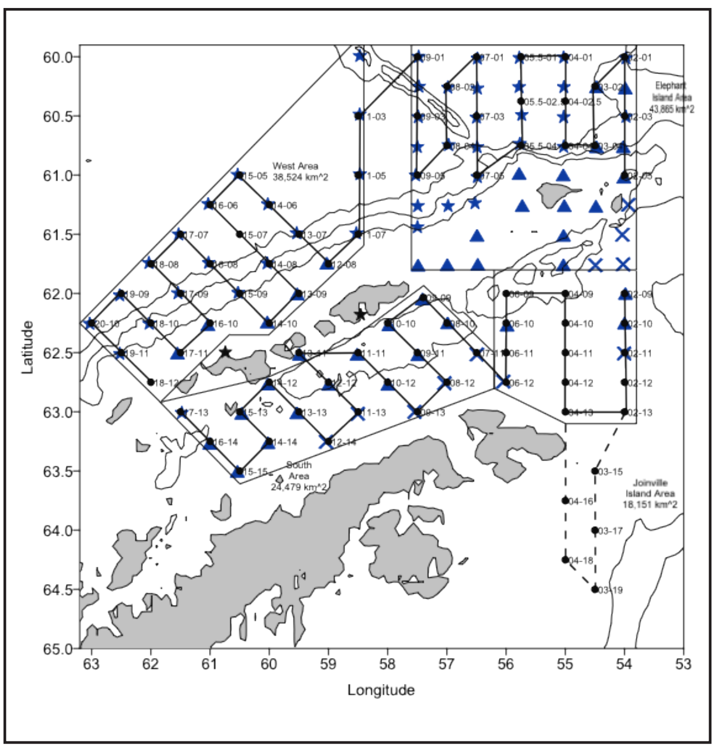


Figure 2.2. Top: Near-surface (5 m) Chl-*a* (mg m^{-3}) concentrations during Leg I (left panel) and Leg II (right panel) of the AMLR 2011 Survey. High concentrations of Chl-*a* are present near the islands and on the shelves. Bottom: Salinity during AMLR 2011 Leg I at 10 m depth. Stars indicate salinities ranging from 33.8 to 34; triangles indicate salinities ranging from 34 to 34.3; crosses indicate salinities ranging from 34.3 to 34.5. Black circles - historical stations not sampled on this survey.

cate observed in 2011, but also the lower variance. Patterns of correlation between salinity and both nitrate and phosphate concentrations were similar. Low but variable concentrations were present at salinities between approximately 33.7 and 34 , and then concentrations of both nutrients increased linearly with salinity.

Comparison of PAR Sensors

PAR measured by both the QCP200L and the QCP2300 were highly correlated (Figure 2.4). The intercept for all comparisons was not significantly different from 0, and the slopes of all relationships to the QCP200L were quite good over the range 0 to 0.05 μE cm^{-2} sec^{-1}. However, visual analysis of the residuals shows some deviation from a purely linear response over this range. Beginning at approximately 0.03 μE cm^{-2} sec^{-1}, the QCP2300 underestimated PAR by up to 0.004 μE cm^{-2} sec^{-1}. Inclusion of other data also showed similar deviations, and in some cases by much more than the equation described. However, detailed analysis of those data is beyond the scope of this Field Season Report.

Discussion

During Leg I of the AMLR 2010-11 field season, Chl-*a* samples were collected from various depths at 95 stations throughout all four areas of the survey grid. Chl-*a* concentrations in the upper 5 m were similar to those recorded in 2010, with high Chl-*a* concentrations present around the shallow water of the South Shetland Islands, especially in

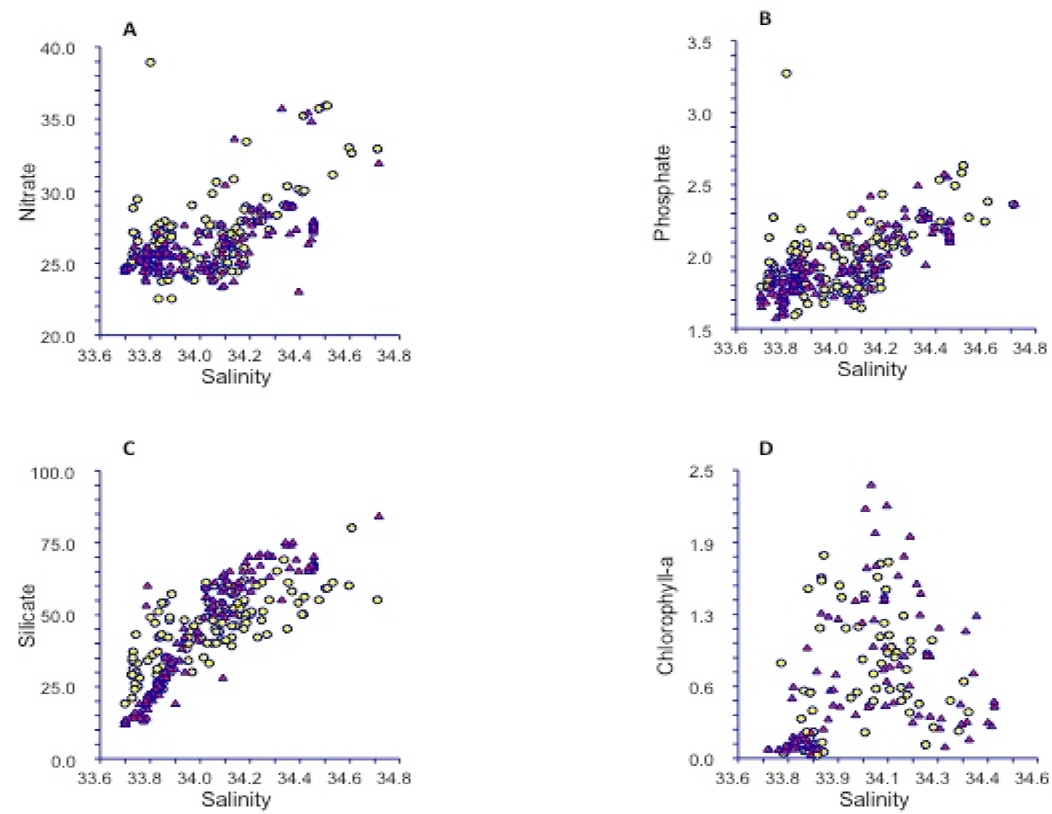


Figure 2.3. Nutrients and Chl-*a* versus salinity; comparison between AMLR 2010 and 2011.

the Bransfield Strait and the southwestern region of the Elephant Island Area. During Leg II, Chl-*a* sampling was restricted to the surface layer through the outflow of the thermosalinograph. Chl-*a* in these surface waters was higher on this leg than during Leg I, but was also highly variable. In the Gerlache Strait Area, extremely high Chl-*a* values (≥ 8 mg Chl-*a* m^{-3}) at stations GS04 and GS13 and very low Chl-*a* values (i.e., 0.08 mg Chl-*a* m^{-3} at station D05.501) were found.

Values in Gerlache Strait are not directly comparable to any AMLR historical data, and these values are higher than normally "high" values found in the AMLR study area. Previous research in southern Bransfield Strait near Gerlache Strait has shown that the area is often more productive than other areas (Holm-Hansen and Mitchell 1991). They found massive blooms in Gerlache Strait and in coastal waters of the Antarctica Peninsula region; typical conditions in these areas are close proximity to meltwater and reduced exposure to storm systems.

Comparisons of nutrient data collected during 2010 and 2011 showed that there was considerably more variability in the data from 2010. It is unclear whether the variability is a consequence of the unusual oceanographic and atmospheric conditions during 2009-10, or whether the variability is related to sample storage. Despite the variability, the overall patterns are similar between years, and suggest that the data quality is sufficient to include in the U.S. AMLR database.

New instruments for recording *in situ* PAR were compared to existing instruments that have long restricted the ability of the U.S. AMLR Program to sample the water column to depths greater than 750 m. Instruments were highly correlated; therefore, beginning in 2012, new PAR sensors with greater depth ranges will be used.

Protocol Deviations

During the AMLR 2011 field season, no fluorometric data was collected owing to an electronic failure on the Chelsea Aquatracka III fluorometer. Most stations were sampled on Leg I with the exception of stations in the Joinville Area.

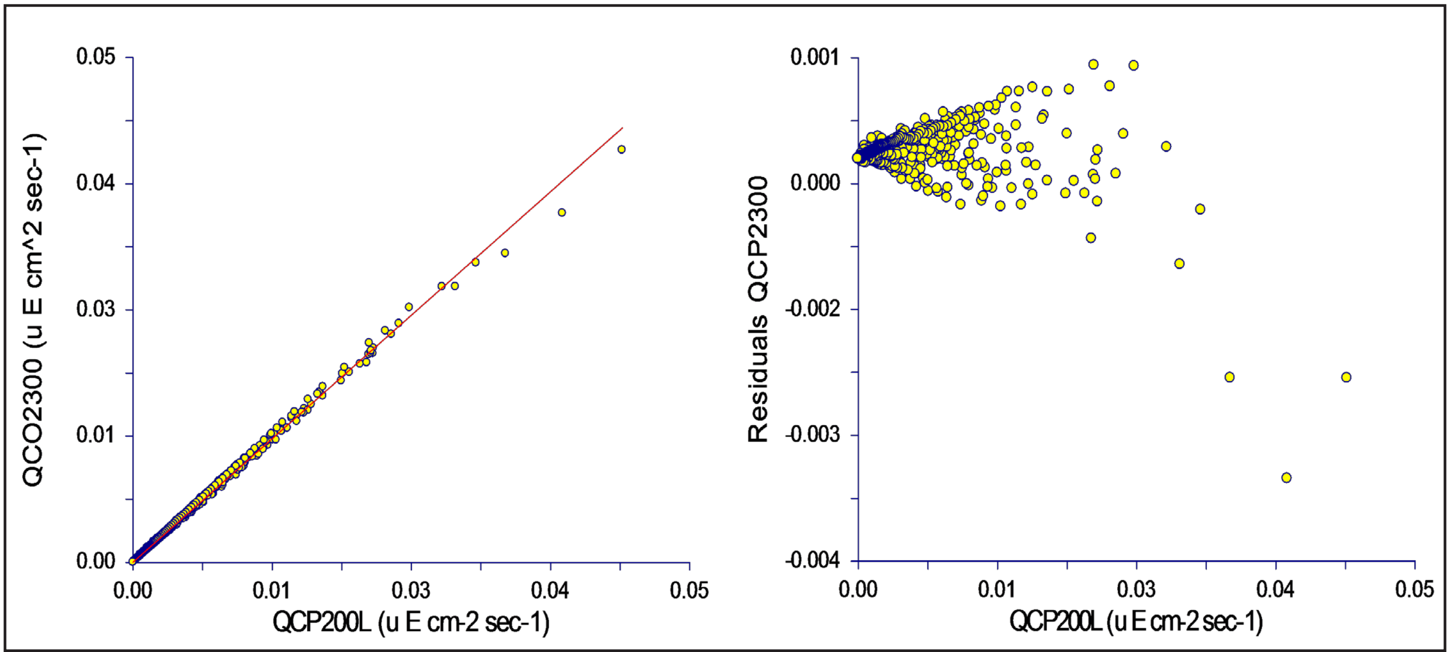


Figure 2.4. Correlations between *in situ* PAR sensors deployed during the 2011 U.S. AMLR Survey. From 1992 to 2011, a BSI QCP200L PAR sensor was used to measure PAR during the surveys. Lines are least squares fits to data collected over the upper 200 m of the water column, and between 0900 and 1600 hours UTC, during January 2011. The equation of relationship is 0.9787*QCP2300, $r^2 = 0.9995$ in microeinsteins cm^{-2} sec^{-1}.

Mechanical failure of the rudder required sampling to be halted and repairs made. This year, only 9 ml instead of 10 ml of methanol was used to extract Chl-*a* from the filters.

Disposition of Data

All Chl-*a*, primary productivity, and macro-nutrient data are available from Dr. Christian S. Reiss, NOAA Fisheries, Antarctic Ecosystem Research Division, 8901 La Jolla Shores Dr., La Jolla, CA 92037. Ph. 858-546-7127; Fax 858-546-7003.

Acknowledgements

We express our gratitude and appreciation to Captain John Seville and the crew of the R/V *Moana Wave*, whose support was fundamental in the success of the 2011 AMLR field season.

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Bioacoustic Survey

Anthony M. Cossio and Christian Reiss

Abstract

Multi-frequency acoustic data were collected around the South Shetland and Elephant Islands, Antarctica, from January to March 2011. Data were collected to determine the distribution and biomass of krill. Results indicate that:

- Around the South Shetland Islands in January through March, mean krill abundance was 49.5, 84.1 and 55 g m^{-2} for the West, Elephant Island, and South Areas, respectively; and
- Highest densities of krill were observed around Elephant Island.

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. In addition, efforts were made to map the distribution of myctophids and to determine their relationship with water mass boundaries and zooplankton distribution.

Methods

Data Collection

Acoustic data were collected using a multi-frequency echo sounder (Simrad EK60) configured with down-looking 38, 120, and 200 kilohertz (kHz) split-beam transducers mounted in the hull of the ship. System calibrations were conducted after the survey using standard sphere techniques 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 38, 120 and 200 kHz. 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 using Myriax Echoview software.

Acoustic surveys of the water surrounding the South Shetland Islands were divided into four areas during Leg I (Figure 2, Introduction): 1) a 43,865 km^2 area centered on Elephant Island (Elephant Island Area) was sampled with seven north-south transects; 2) a 29,031 km^2 area along the north side of the southwestern portion of the South Shetland Island 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) was sampled with one transect. During Leg II, acoustic data were collected during a net comparison study. Acoustic data were collected again for the South Area and three transects were collected for the Joinville Area. An auxiliary survey of 1,133 km^2 was performed around the Gerlache Strait.

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 during night time (Demer and Hewitt 1995).

Data Analysis

Krill are delineated from other scatters by use of a three-frequency ΔSv method (Hewitt et al. 2003; Reiss et al. 2008; SC-CAMLR 2005), using 95% of the total krill length-frequencies for each area. In 2010, the CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) held a working group for the SDWBA (stochastic distorted-wave Born approximation) model (Demer and Conti 2005; Conti and Demer 2006); those corrections are applied to the AMLR historical data used in this report (SC-CAMLR 2010) (Figure 3.1).

A ΔMVBS window of -5 to 2 dB was applied to a two-frequency (38 kHz and 120 kHz) method for the purpose of delineating myctophids. 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 (250 m) and averaged over 1,852 m (1 nautical mile) distance intervals.

Integrated krill nautical area scattering coefficient (NASC) (Maclennan and Fernandes 2002) 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) ($\sigma = 4\pi r 10^{TS/10}$ where r is the reference range of 1 m; Hewitt and Demer 1993). The length to weight relationship

(1) $W\text{ (g)} = 2.236 \cdot 10^{-3} \cdot TL^{3.314}$

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

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

where f_i = 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 each 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 Echoview software and then mapped across the South Shetland Islands using SURFER (Golden Software, Inc. Golden, CO).

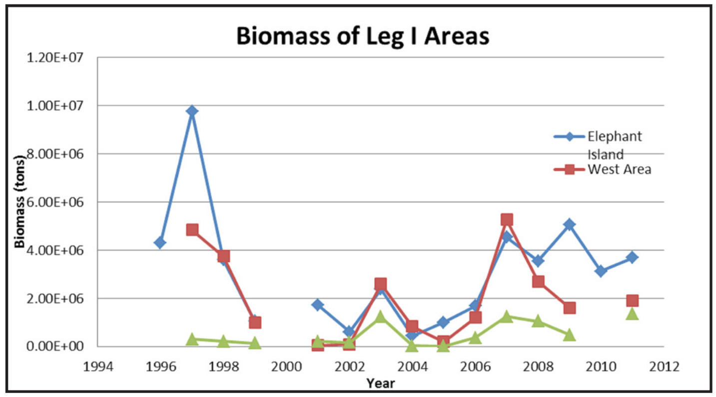

Figure 3.1. Krill biomass estimates for each area (revised to apply the corrected SDWBA method adopted in CCAMLR 2010). Biomass estimates are in tons and are only for Leg I.

Table 3.1. Daytime krill abundance estimates by area and transect the 2010/11 AMLR Survey, Leg I. n = 1 interval = 1 nautical mile. Transects are labeled numeric order from left to right in each area.

Area	Transect	n	Krill density (g/m²)
West Area			
	Transect 1	42	76.7
	Transect 2	42	64.5
	Transect 3	24	12.7
	Transect 4	61	50.5
	Transect 5	54	25.4
	Transect 6	33	10.3
	Transect 7	94	67.1
Elephant Island Area			
	Transect 1	79	71
	Transect 2	82	40.2
	Transect 3	87	175
	Transect 4	53	17.6
	Transect 5	106	77
	Transect 6	65	128
	Transect 7	79	60.2
South Area			
	Transect 1	28	94.2
	Transect 2	20	219
	Transect 3	20	17.6
	Transect 4	40	86.7
	Transect 5	46	41.6
	Transect 6	20	19.6
	Transect 7	65	0.05

Results

Mean krill abundance for each transect line in each area is presented in Table 3.1. Mean krill abundances during Leg I were 49.5, 84.1 and 55 g/m² for the West, Elephant Island, and South Areas, respectively. Leg II yielded mean krill abundances of 14.6, 76.7, and 76.1 g/m² for the South and Joinville Island Areas, and the Gerlache Strait, respectively. Highest densities were seen around Elephant Island during Leg I (Figure 3.2). Krill densities were lower in the Bransfield Strait during Leg II (Figure 3.3). The biomass estimates for this year are higher than the previous year. Myctophid NASC values are not significantly different from previous years (Figure 3.4).

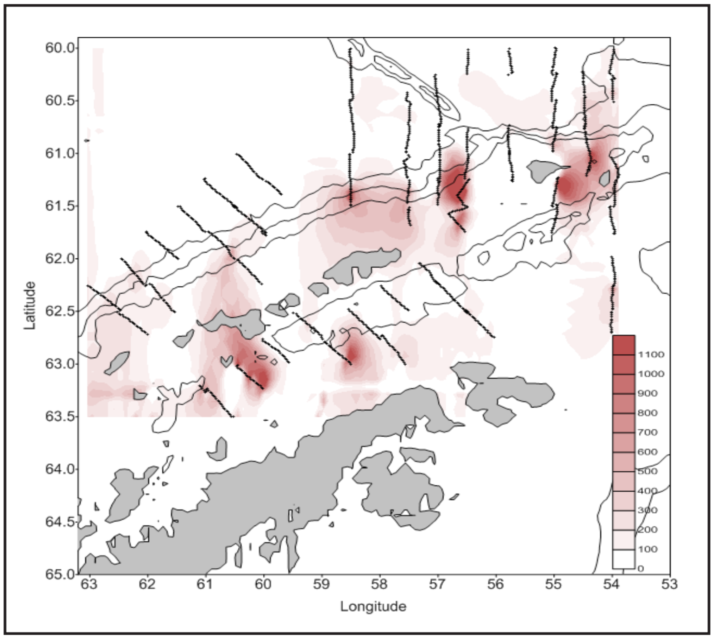

Figure 3.2 Kriged krill NASC values collected during Leg I at 120 kHz, using day data. (Latitude is south and longitude is west).

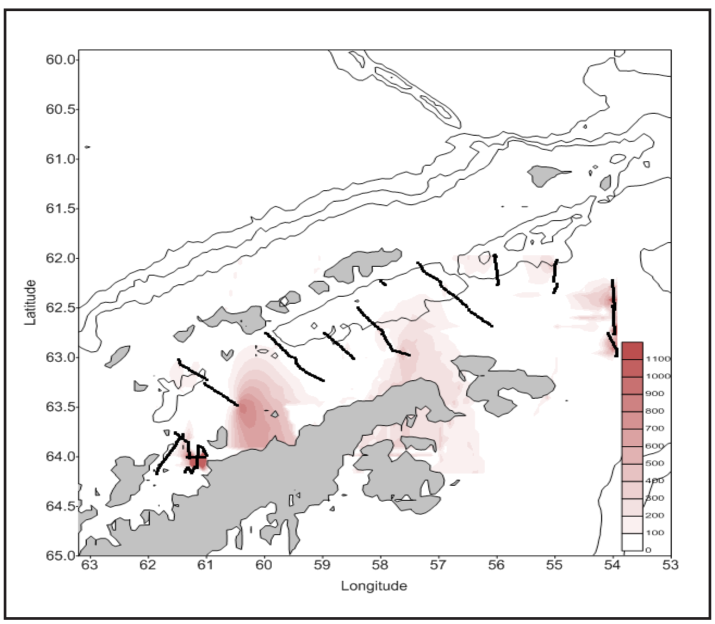

Figure 3.3. Kriged krill NASC values collected during Leg II at 120 kHz, using day data. (Latitude is south and longitude is west).

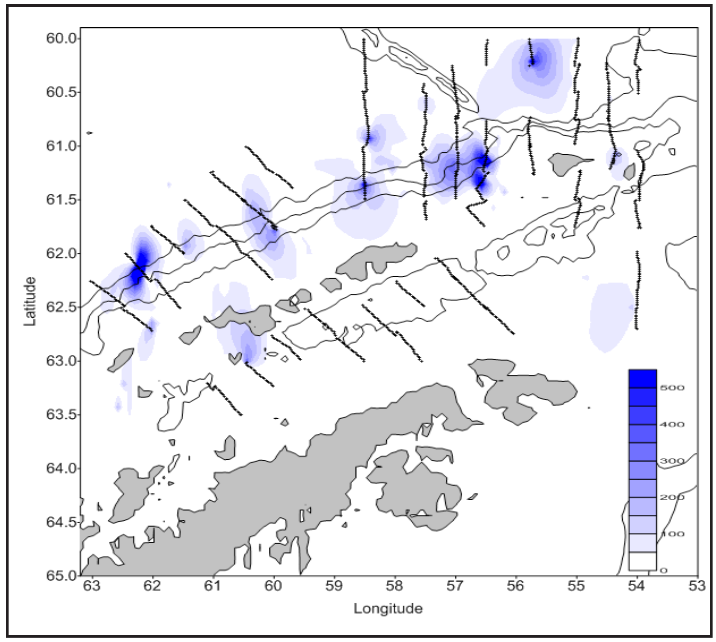

Figure 3.4. Kriged myctophid NASC values collected during Leg 1 at 120 kHz, using day data. (Latitude is south and longitude is west).

Discussion

Biomass estimates during Leg I for the Elephant Island and South Areas were at their highest levels since 1997. The West Area was higher than last year but not exceptionally high. Highest krill densities were seen around Elephant Island, where this has been historically true.

Leg II was more aimed at gear comparison than acoustic biomass estimates. Estimates for the South Area were average for the area during Leg II. The Gerlache Strait had a high krill density but still a low krill biomass. More analysis must be done in this area to understand its importance to the region.

Protocol Deviations

Due to high seas and strong winds, a survey was undertaken in the Gerlache Strait during Leg II instead of the West Area.

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 consume approximately 10 MB. The data are available from Anthony Cossio, Southwest Science Center, 8901 La Jolla Shores Dr., La Jolla, CA 92037; phone/fax – (858) 546-5609/546-7003; e-mail: Anthony.Cossio@noaa.gov.

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We would like to thank Captain Seville and the crew of the R/V *Moana Wave* for their support during the 2010-11 field season.

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Distribution and Catch Rates of Zooplankton around the South Shetland Islands, Antarctica

Kimberly Dietrich, Cassandra Brooks, Ian Bystrom, Ryan Driscoll, Nissa Ferm, Jefferson Hinke, Michael Janssen, Darci Lombard, Andrea Pesce, Suzanne Romain, Lars Thoresen, and Amy Van Cise

Abstract

Zooplankton abundance and Antarctic krill demographic patterns around the South Shetland Islands and Elephant Island, Antarctica, are described using data collected during the 2010/11 AMLR field season. Leg I focused on the standard AMLR survey grid and 96 (of 107) stations were completed. The results from Leg I included:

- Krill were present at 64% of the standard stations (11.2 ± 39.2 individuals per 1,000 m^3†‡);
- Larval krill were present at 43% of the stations and had an average catch rate of 167 ± 1058;
- Copepods were numerically dominant (6,784 ± 14,111). *Thysanoessa macrura* larvae, the tunicate *Salpa thompsoni*, and chaetognaths followed with average catch rates of 1,820 ± 4,522, 696 ± 1,054, and 221 ± 474, respectively; and
- Mean catch rate of *Limacina helicina* was 126 ± 221, which is six times higher than the long term mean.

During Leg II, krill "catchability" was compared between two net types, the IKMT net traditionally used by the AMLR Program, and a new opening/closing Tucker Trawl for collecting mesopelagic fish. Due to an unresolved problem with flow volume calculations from the Tucker Trawl, the net comparison analysis is not presented in this report.

Introduction

The zooplankton community plays a crucial role in the Antarctic ecosystem. Most of the upper trophic level predators, such as baleen whales, fur seals, and penguins, depend on Antarctic krill (*Euphausia superba*; hereafter referred to as krill) as their primary food source, implying a very short chain of trophic links from autotrophs to top predators. Additionally, the structure of the zooplankton community is sensitive to changes in the ecosystem, and can serve as an indicator of local response to global climate change (Hays et al. 2005).

Net sampling at a fixed suite of stations was used to provide data on the length frequency of krill, necessary for inclusion into the acoustic model for the determination of krill biomass (Chapter 3). Krill length distributions, krill demography, and zooplankton community composition are also compared to oceanographic and krill-dependent predator data (Chapters 6, 7 and 8), both spatially and temporally, to describe the dynamics of the South Shetland Islands ecosystem as a whole.

Our objectives were to:

1. Deploy an Isaacs-Kidd Midwater Trawl (IKMT) at standard survey stations to develop krill length-frequency distributions and to estimate relative zooplankton abundance (Leg I); and
2. Complete a gear comparison study using the IKMT and opening/closing Tucker Trawl (Leg II).

Methods

Zooplankton were collected using a 1.8 m IKMT net with an effective mouth opening of 2.53 m^2, and equipped with a 505 μm mesh net. A General Oceanics flowmeter (Model 2030R) was mounted to the net frame to calculate the volume of water filtered during each tow. All tows were fished obliquely to 170 m depth or to approximately 20 m from the bottom, measured using a hard-wired depth sensor mounted to the net's bridle. A Vemco Minilog-TD temperature-depth recorder (TDR) was placed on the net to verify the depth sounder accuracy for the first five tows. During each tow, the ship maintained a speed of approximately two knots; the speed of wire deployment was approximately 40 m min^{-1} and the wire was retrieved at a rate of 20 m min^{-1}. Each tow was assigned a categorical time of day. Day was defined as one hour after sunrise to one hour before sunset, night as one hour after sunset to one hour before sunrise, and transition as one hour before and after sunset and sunrise. Data are stored in GMT.

All samples were processed on board using the following generalized procedures for different taxa:

- Juvenile and adult krill were counted and retained separately (refrigerated or frozen) for demographic analysis. When the sample yielded fewer than 100 krill, all individuals were measured, sexed, and assessed for maturity stage. When a larger number of krill were encountered, a minimum subsample of 100 krill was randomly collected and analyzed. The total length (mm) of krill was measured as the distance from the rostrum to the posterior tip of the uropods (Standard 1 as described by Mauchline (1980)). Krill were sexed and staged based on the Makarov and Denys (1981) classification system.

- Adult fish (typically myctophids) were identified, counted, measured (standard length), and frozen for future fatty acid analysis (Chapter 5).
- Salps (*Salpa thomponsi* and I*hlea racovitzai*) were counted and measured (up to 100 individuals per sample) according to the methods presented by Foxton (1966).
- All other macrozooplankton (e.g., euphausiids, amphipods, pteropods, polychaetes) were identified and counted.
- A subsample of the remaining organisms was examined using a stereo microscope and smaller organisms (e.g., invertebrate larvae, copepods) were counted and identified to the lowest taxonomic level possible. This process was repeated at least twice, and the total of the subsamples was used to estimate the total species composition for the sample.
- For larger samples, a subset of the total sample was counted and the total sample value was extrapolated based on the subset.

The processed samples were preserved in 10% buffered formalin and sent to the Southwest Fisheries Science Center for long-term storage.

During Leg II, in addition to IKMT deployment, a 4.0 m^2 Open Seas Inc. opening/closing net (Tucker Trawl) was deployed for 67 tows at 50 unique stations. The Tucker Trawl was equipped with three nets: one 5000 µm net used to target pelagic fish and two 505 µm nets for zooplankton. For the net comparison study we initially deployed one 505 µm net to 170 m and the other from 170 m to the surface.

Analysis-Leg I

The catch of each zooplankton species was standardized for each station by dividing the counts by volume of water filtered (No. per 1,000 m^3). For each of the most common species, a distribution map was created using ArcGIS (ESRI), and historical catch estimates were plotted and compared for trends.

Average abundance (x) was calculated for Leg I stations using the following formula:

$$x = \sum_1^j (T_j / V_j) \div W \quad (1)$$

where T is the total number of individuals collected at tow *j*, V is the volume of water filtered (unit = 1,000 m^3) at tow *j*, and W is the number of tows completed.

Krill and salp length-frequency and krill maturity-stage distributions were combined by area for Leg I. The length-frequency distributions (LFD) of krill and salps were weighted using the following formula:

$$L_i = \sum_1^j ((n_{ij} * (T_j \div M_j)) * D_j) * V_j \quad (2)$$

where L is the estimated proportion of the catch at length *i*, n is the number of individuals at length *i* for tow *j*, T is the total individuals in tow *j*, M represents the number of measured individuals in tow *j*, D is depth, and V is the volume of water filtered (unit = 1,000 m^3) at tow *j*. For the krill distribution, only individuals that had a length, sex and maturity were included (e.g., if only gender was known, the individual was excluded from this calculation).

† Except where noted, variation is reported as standard deviation.

‡Except where noted, mean units are individuals per 1,000 m^3.

Results

Leg I

A total of 96 stations were sampled throughout the South Shetland Islands and more than 120 taxonomic categories were identified. Of these, the most abundant groups are listed in Table 4.1.

<u>Juvenile and Adult Krill</u>

A total of 4,668 krill were caught at 63 stations during Leg 1. The mean abundance of krill for Leg I was 11.2 ± 39.2, which was lower than the long-term average (37.4; Figure 4.1a). In general, krill catches were highest in the Elephant Island area (Table 4.1) and at night.

All 25 stations in the West Area (WA) were completed and krill occurred at 11 stations, mostly inshore (Figure 4.1b). The mean catch rate for the WA (8.3 ± 15.8) was less than half the long-term average for this area during Leg I (18.2; Table 4.1). The length-frequency distribution was bimodal with approximate medians at 34 and

Table 4.1. Frequency of occurrence (% tows with positive catch), mean, standard deviation, median and maximum catch (No. per 1,000 m^3), and rank of total catch percent among areas for the major taxonomic groups for the West and Elephant Island Areas.

	West Area (n = 25)						Elephant Islant (n = 46)					
	FO (%)	Mean	SD	Median	Max	Rank	FO (%)	Mean	SD	Median	Max	Rank
Amphipods												
Cyllopus spp.	76%	2.1	2	1.3	8	20	83%	7.8	9	3.6	31	20
Primno macropa	60%	8.9	22	2.4	108	12	59%	12.4	28	1.1	129	17
Themisto gaudichaudii	96%	6.5	6	5	25	16	91%	10.3	16	7.4	93	18
Vibilia antarctica	80%	7.1	11	2.8	54	14	93%	13.5	17	6.7	71	16
Amphipod Other	56%	4.1	13	0.7	64	17	67%	3.4	7	1.1	47	23
Chaetognaths	96%	294.4	504	27	1567	6	72%	267.1	560	12.2	2495	4
Copepods	100%	10536.7	20828	1418.5	76910	1	100%	7612.3	12770	1633.9	63382	1
Calanidae	100%	8301.2	18235	749.6	74018		100%	5981.1	11483	788.1	56231	
Metridia spp.	64%	274.7	586	18	2290		76%	605.8	1116	91.7	5178	
Paraeucheata spp.	68%	100.2	197	7.8	740		72%	96.1	151	20.3	650	
Rhincalanus spp.	60%	106.1	292	5	1366		50%	164.8	572	0.2	3688	
Copepod Other	100%	1754.5	4644	242.1	22258		91%	764.5	1290	221.3	5296	
Euphausiidae												
Euphausia frigida (Ad)	8%	1.1	5	0	25	25	48%	14.2	28	0	121	15
E. frigida (L)	16%	45.1	133	0	585	9	9%	23.1	93	0	506	9
Euphausia superba (Ad)	44%	8.3	16	0	66	13	72%	16	54	0.6	361	12
E. superba (C total)	52%	539.1	1989	1.5	9532	3	35%	17.4	49	0	281	10
E. superba (F total)	8%	17.7	68	0	322	10	17%	16.6	50	0	217	11
Thysanoessa macrura (Ad)	80%	70.3	125	14.2	510	8	85%	50.4	116	15.6	766	6
T. macrura (L)	100%	2193.7	2797	1506.9	10993	2	98%	2489.3	6074	385.4	37678	2
Fish (larvae)												
Electrona spp.	16%	0.4	2	0	9	26	22%	1.5	6	0	43	28
Lepidonotothen kempi	16%	0.1	0	0	1	31	13%	0.3	1	0	5	32
Lepidonotothen larseni	16%	0.3	1	0	3	27	20%	0.4	1	0	6	30
Fish larvae Other	20%	2.1	10	0	48	21	26%	2.2	9	0	56	26
Gastropoda												
Clione limacina	76%	3.7	4	3.1	18	18	61%	5	14	1.3	91	21
Limacina helicina	100%	187.5	178	124.6	726	7	89%	135.3	282	32.3	1273	5
Ostracod	8%	1.5	7	0	36	23	11%	15.4	63	0	338	14
Polychaetes												
Tomopteris spp.	80%	3.4	6	1.8	27	19	39%	10	35	0	177	19
Polychaetes Other	24%	6.6	23	0	95	15	24%	3	10	0	43	25
Radiolaria	60%	328.9	785	0.5	2452	5	30%	40.1	102	0	547	7
Tunicates												
Ihlea racovitzai	0%	0	0	0	0	35	7%	0.3	1	0	8	33
Salpa thompsoni	100%	453.9	608	187.6	2073	4	100%	1062.1	1360	485.3	6878	3

Table 4.1 continued. Frequency of occurrence (% tows with positive catch), mean, standard deviation, median and maximum catch (No. per 1,000 m^3), and rank of total catch percent among areas for the major taxonomic groups for the South and Joinville Island Areas.

	South Area (n = 20)						Joinville Island (n = 5)					
	FO (%)	Mean	SD	Median	Max	Rank	FO (%)	Mean	SD	Median	Max	Rank
Amphipods												
Cyllopus spp.	45%	0.7	1	0	5	27	0%	0	0	0	0	32
Primno macropa	30%	1.8	5	0	21	18	60%	1.2	1	0.7	3	18
Themisto gaudichaudii	80%	3.5	9	1	43	15	20%	0.3	1	0	2	26
Vibilia antarctica	95%	5.1	4	4.3	16	12	80%	4.7	9	1.1	20	15
Amphipod Other	55%	1.7	2	0.6	10	19	60%	0.8	1	0.5	3	21
Chaetognaths	95%	77.9	115	24.1	475	5	60%	7.1	14	0.8	32	11
Copepods	100%	1478.3	1932	499.8	6231	1	100%	1618.2	1927	1244.6	4947	1
Calanidae	100%	972.3	1488	131.2	5170		100%	1057.1	1517	402.4	3727	
Metridia spp.	55%	268	601	6.6	2483		60%	178.1	321	2.5	741	
Paraeucheata spp.	70%	32.3	61	3.4	220		100%	62.5	90	4.9	207	
Rhincalanus spp.	70%	28.3	71	2.7	302		40%	10.7	23	0	53	
Copepod Other	95%	177.6	233	50.5	761		100%	309.8	359	248.8	865	
Euphausiidae												
Euphausia frigida (Ad)	25%	1	2	0	9	24	20%	6.6	15	0	33	12
E. frigida (L)	0%	0	0	0	0	35	0%	0	0	0	0	32
Euphausia superba (Ad)	65%	4.8	15	0.6	66	13	80%	6.6	8	2.8	17	13
E. superba (C total)	30%	7.7	20	0	87	9	40%	32.8	65	0	148	5
E. superba (F total)	15%	10.1	37	0	165	7	20%	9.8	22	0	49	8
Thysanoessa macrura (Ad)	100%	167.8	212	85.5	817	4	80%	96.4	132	17.1	300	4
T. macrura (L)	100%	235.6	568	70.1	2603	3	100%	126	94	78.7	232	3
Fish (larvae)												
Electrona spp.	0%	0	0	0	0	35	0%	0	0	0	0	32
Lepidonotothen kempi	20%	0.4	1	0	6	28	40%	1.2	2	0	5	19
Lepidonotothen larseni	50%	2.8	7	0.1	24	16	20%	0	0	0	0	31
Fish larvae Other	45%	1.6	4	0	13	20	60%	0.7	1	0.8	2	22
Gastropoda												
Clione limacina	80%	1.5	3	0.8	11	22	40%	0.6	1	0	2	23
Limacina helicina	100%	53.6	57	33	173	6	100%	16.3	15	12.4	35	7
Ostracod	35%	8.1	21	0	87	8	40%	9	13	0	30	10
Polychaetes												
Tomopteris spp.	35%	1.9	5	0	21	17	80%	0.3	0	0.2	1	27
Polychaetes Other	55%	5.4	10	0.6	41	11	60%	31	65	0.9	148	6
Radiolaria	0%	0	0	0	0	35	20%	0.1	0	0	1	28
Tunicates												
Ihlea racovitzai	5%	0	0	0	1	32	20%	4	9	0	20	16
Salpa thompsoni	100%	261.4	177	256.5	554	2	80%	273.3	381	1.5	788	2

49 mm for juveniles and sub-adult/adults, respectively (Figure 4.2a). The WA consisted of 29% adult females, 48% adult males, 11% sub-adult males, and 12% juveniles, which was the lowest proportion of juveniles compared to the other areas. No sub-adult females were found.

Forty-six of 48 Elephant Island (EI) Area stations were completed. Krill occurred at 35 stations. The mean catch rate for EI (16.0 ± 54.4) was slightly less than half the long-term average for Leg I (38.4). Highest catches occurred at the shallower stations (Figure 4.1b). The length-frequency distribution was also bimodal with approximate medians at 35 and 47 mm for juvenile and sub-adult/adults, respectively (Figure 4.2b). Of the krill staged, 51% were juveniles, 2% sub-adult females, 17% adult females, 4% sub-adult males, 24% adult males, and 2% of unknown maturity.

All 20 South Area (SA) stations were completed. Krill occurred at 13 stations with the highest catches at the east end of Bransfield Strait (Figure 4.1b). The mean catch rate for the SA (4.8 ± 14.6) was an order of magnitude lower than the Leg I long-term average (46.2). The length-frequency distribution was bimodal with approximate medians at 30 and 47 mm for juvenile and sub-adult/adults, respectively (Figure 4.3c). Of the krill staged, 65% were juveniles, 2% sub-adult females, 7% adult females, 11% sub-adult males, and 15% adult males.

Krill occurred at four of five Joinville Island (JI) Area stations sampled. The mean catch rate for JI was 6.6 ± 7.7. The length-frequency distribution was bimodal (Figure 4.3d). Of the krill staged, 63% were juveniles, although the sample size was small.

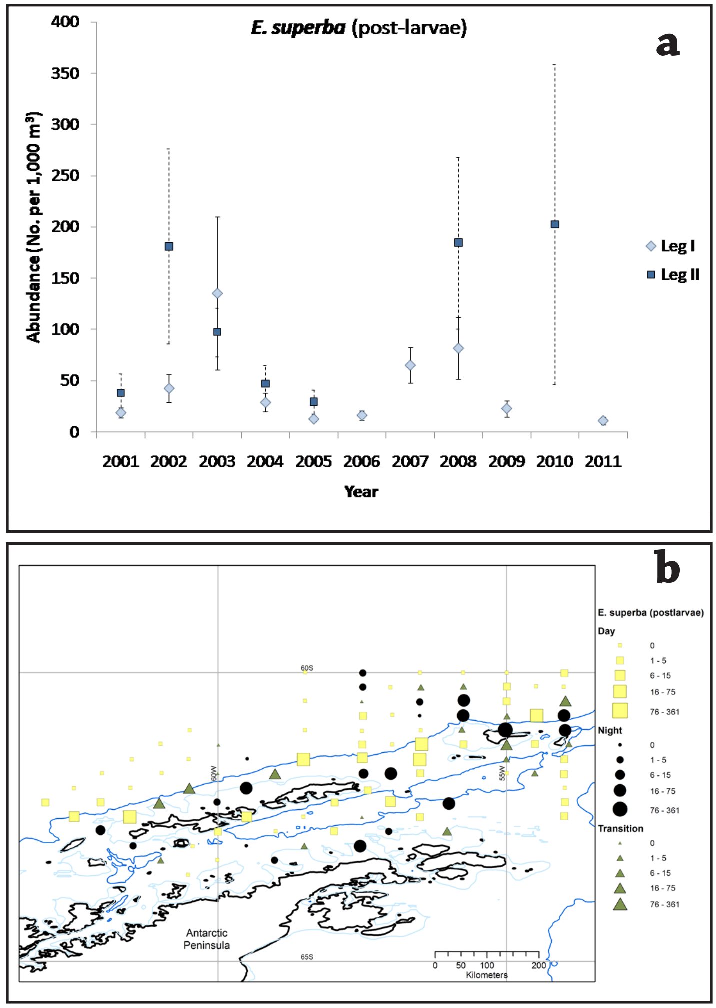

Figure 4.1. Historical catch rate (a) and 2011 Leg I distribution by time of day (b) of postlarval *E. superba*. Error bars are standard errors. The 200 m isobath is shown in light blue and 1000 m isobath in dark blue.

<u>Larval Krill</u>

The overall catch rate for Leg I was 167 ± 1058, which was substantially higher than the Leg I long-term average (78.3; Figure 4.3a); however, the overall mean was driven by extremely high catch rates in the WA (Table 4.1). Catch rates were also an order of magnitude higher during the day compared to the night and transition periods.

Krill larvae occurred at 56% of the WA stations (557 ± 2,048); the catch rate was more than seven times higher than the Leg I long-term average (73.1). Higher catches occurred at the offshore stations (Figure 4.3b). The larvae in the WA consisted primarily of stage 1 calyoptopsis.

Krill larvae occurred at 34% of the EI stations (34.0 ± 83.1) at a rate of one third the long-term average for Leg I EI stations (106). The highest catches occurred near the Shackleton Fracture Zone and consisted of both calyoptopsis and furcilia stages in equal proportions.

Krill larvae occurred at 35% of the SA stations (17.7 ± 55.9); the catch rate was similar to the long-term average (13.2). The highest catches occurred at the stations north and west of Joinville Island. Both calyoptopsis and furcilia stages were present.

<u>Other Zooplankton</u>

Copepods had the highest catch rates in all areas (6,784 ± 14,111), followed by *Thysanoessa macrura* larvae (1,820 ± 4,522), *Salpa thompsoni* (696 ± 1,054), chaetognaths (221 ± 474) and *Limacina helicina* (126 ± 221). Area specific catch rates are shown in Table 4.1.

Copepods had a ubiquitous distribution with the highest catch rates at the offshore stations in the WA and western stations in the EI Area (Figure 4.4b). Catch rates were also substantially higher than the Leg I long-

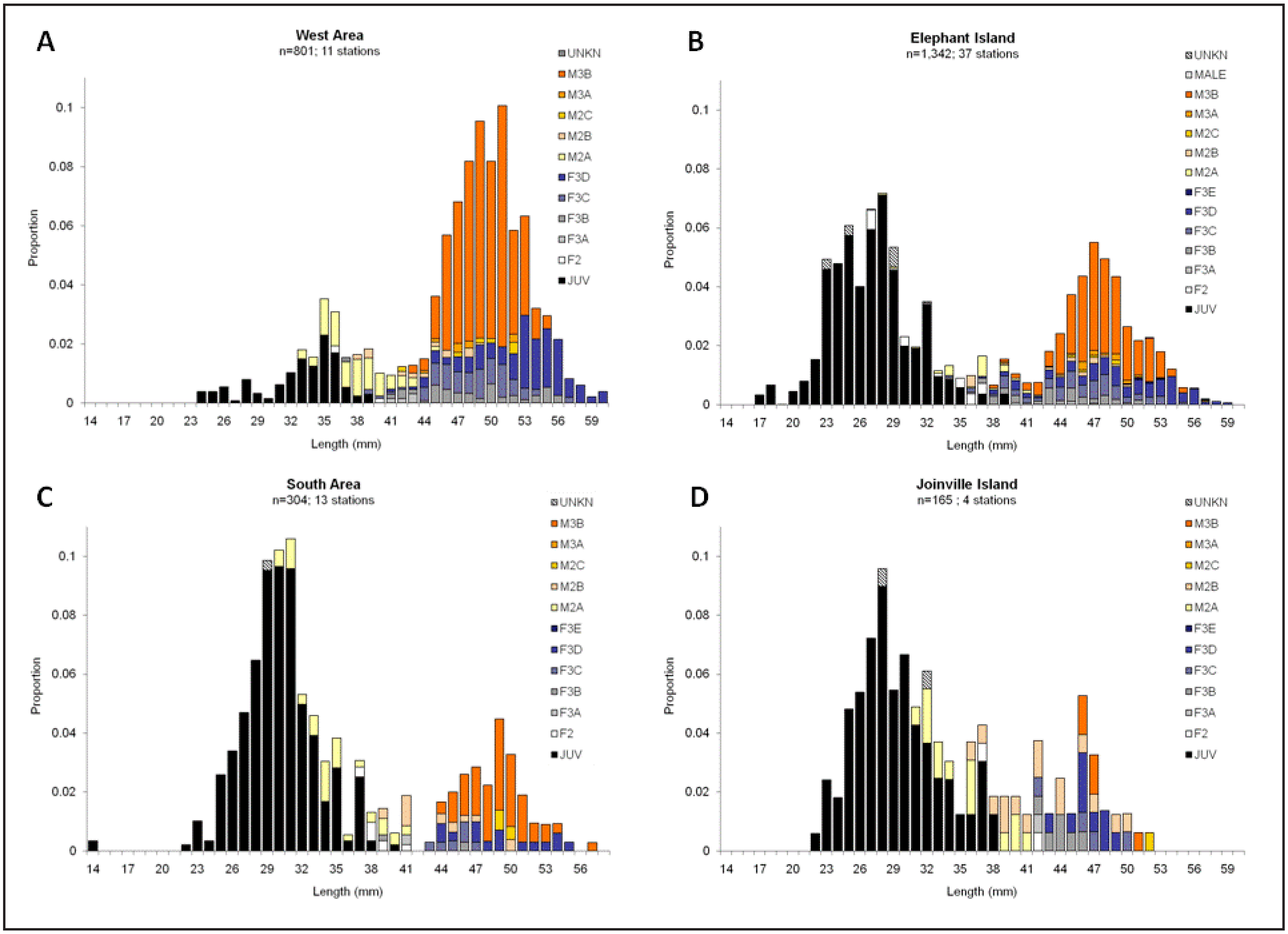

Figure 4.2. Length-frequency distribution of krill by gender, maturity stage and area. A) West Area; B) Elephant Island Area; C) South Area; and D) Joinville Island Area. M and F are Male and Female, respectively. Maturity stages according to Makarov and Denys (1981).

term average (1,840; Figure 4.4a). Although there were more than 15 species encountered during Leg I, the most common species included: *Calanus propinquus*, *Calanoides acutus*, *Rhinacalanus gigas*, *Metridia gerlachei*,and *Paraeuchaeta* spp. Mean copepod catch was higher during the day than night (7,996 vs. 4,166), driven by differences in the catch rates of Calanidae (*C. propinquus* and *C. acutus*).

Salpa thompsoni (hereafter salps) were also distributed throughout the South Shetland Island region (99% of Leg I stations), and were found in greatest density at the eastern stations of the EI Area and inshore stations in the WA (Figure 4.5). Unlike 2009-10, differences in abundance with time of day were not as apparent for salps. Salp catches were slightly higher than the Leg I long-term average (404). A very small proportion (< 0.5%) of solitary salps was encountered. Median salp lengths were smaller and similar in the WA and the JI and EI Areas (24 mm, 21 mm, and 24 mm, respectively) compared to the SA (30 mm; Figure 4.6).

T. macrura postlarvae were present at 86% of the stations and had the lowest catch rate since 2001 (82 ± 149; Figure 4.7). The highest catch rates were in the SA and the JI Area (Figure 4.7). *T. macrura* larvae, on the other hand, were present at more than 99% of the stations and the mean catch rate was more than six times higher than the Leg I long-term average (282; Figure 4.8). Larvae occurred in the highest catch rates in the WA and EI Area (Table 4.1; Figure 4.8). Both *T. macrura* postlarvae and larvae had the highest catch rates at night.

Limacina helicina catch rates were the highest recorded during a Leg I survey and were six times

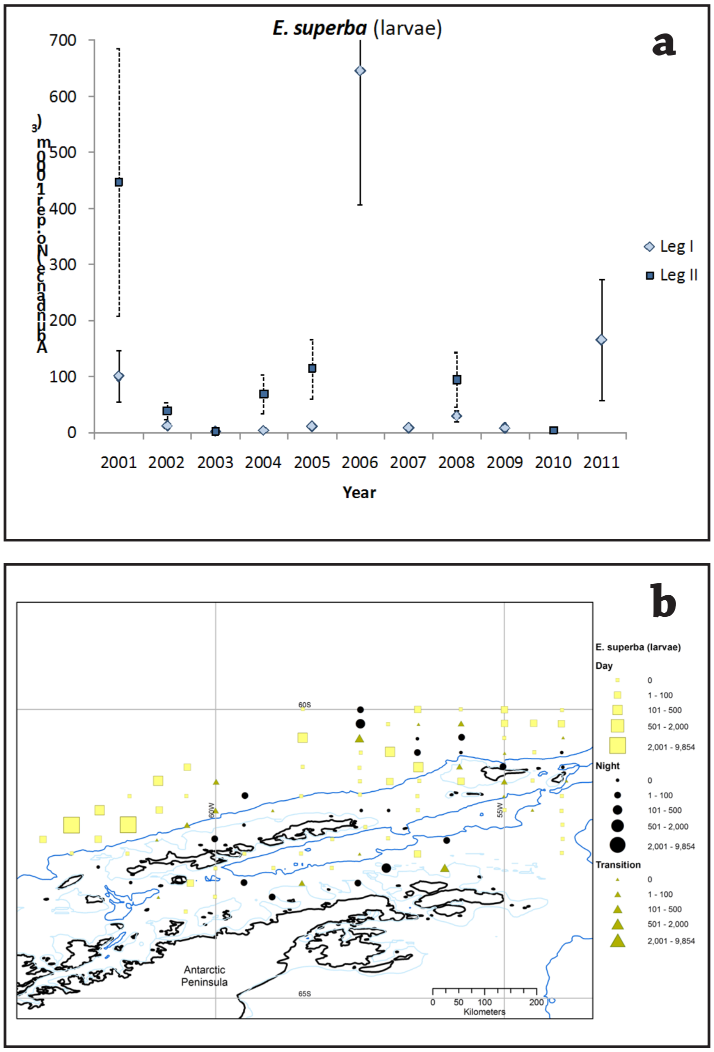

Figure 4.3. Historical catch rate (a) and 2011 Leg I distribution by time of day (b) of larval *E. superba*. Error bars are standard errors. Y-axis in (a) was limited to 700 in order to maintain resolution in other years; however, the full lower extent is shown.

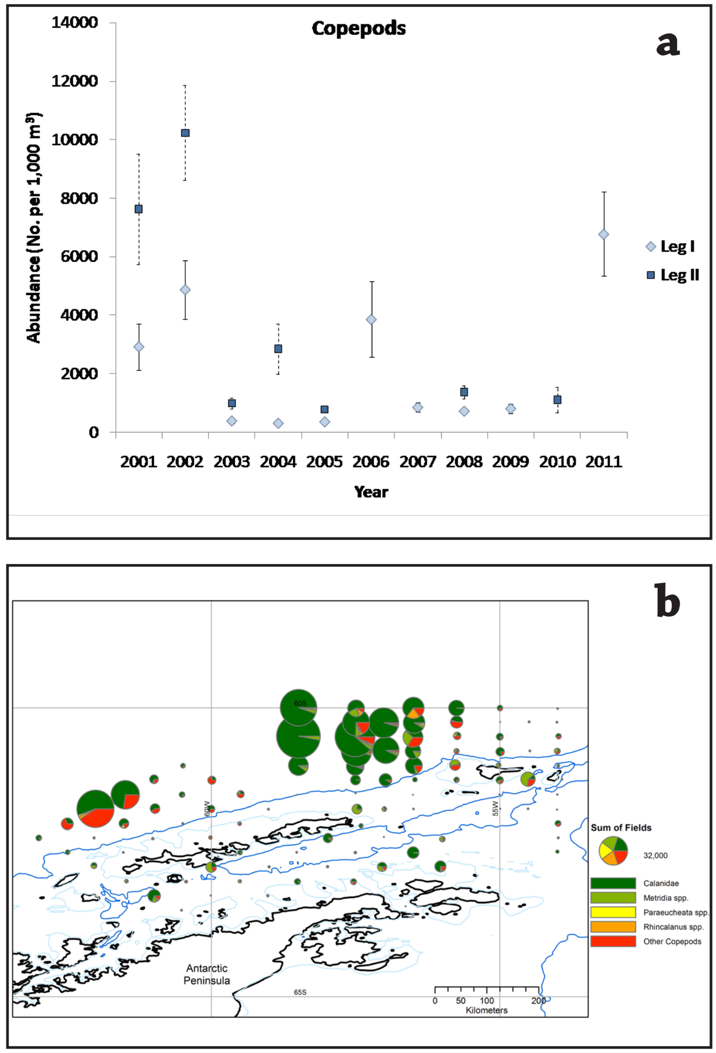

Figure 4.4. Historical catch rate (a) and 2011 Leg I distribution (b) of copepods. Error bars are standard errors. The size of the pie at each station is scaled to the sum of all five copepod categories; the symbol size in the legend represents 32,000 per 1000 m^3.

higher than the Leg I long-term average (20.4).

Discussion

Leg II – Gear Comparison Study

The AMLR program conducted this comparison in order to move sampling from the IKMT net to the more versatile Tucker Trawl in order to conduct broader ecosystem studies without compromising the long-term data. Once the data become available, standardized catch rates and demography of krill will be compared among the IKMT and Tucker Trawl tows. The initial deployment plan was to sample nine stations four times – twice during the day and twice at night – for a total of 36 net comparison stations. However, due to weather and other logistical limitations, we were unable to accomplish this plan and intend to include additional tows (from 170 m to the surface only) in the net comparison analysis in order to increase the sample size. Results will be used to inform decisions regarding the type of net used in future surveys.

A high diversity of fish larvae from a number of taxa was collected during Leg II (Chapter 5). And, although a dedicated person was tasked with identifying larval fish, the high number of taxa was not a result of this effort. A more detailed analysis of larval fish catch rates relative to past tow locations and the proximity to the Antarctic Peninsula is warranted.

Protocol Deviations

Krill demographic assessment was again performed

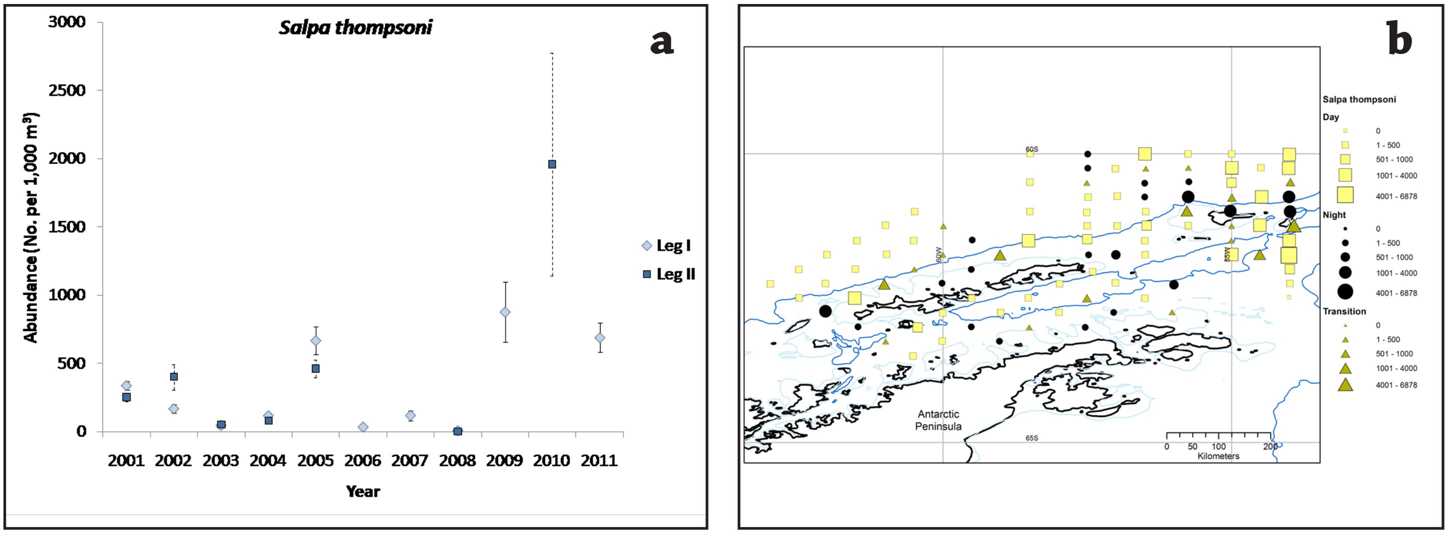

Figure 4.5. Historical catch rate (a) and 2011 Leg I distribution by time of day (b) of *Salpa thompsoni*. Error bars are standard errors.

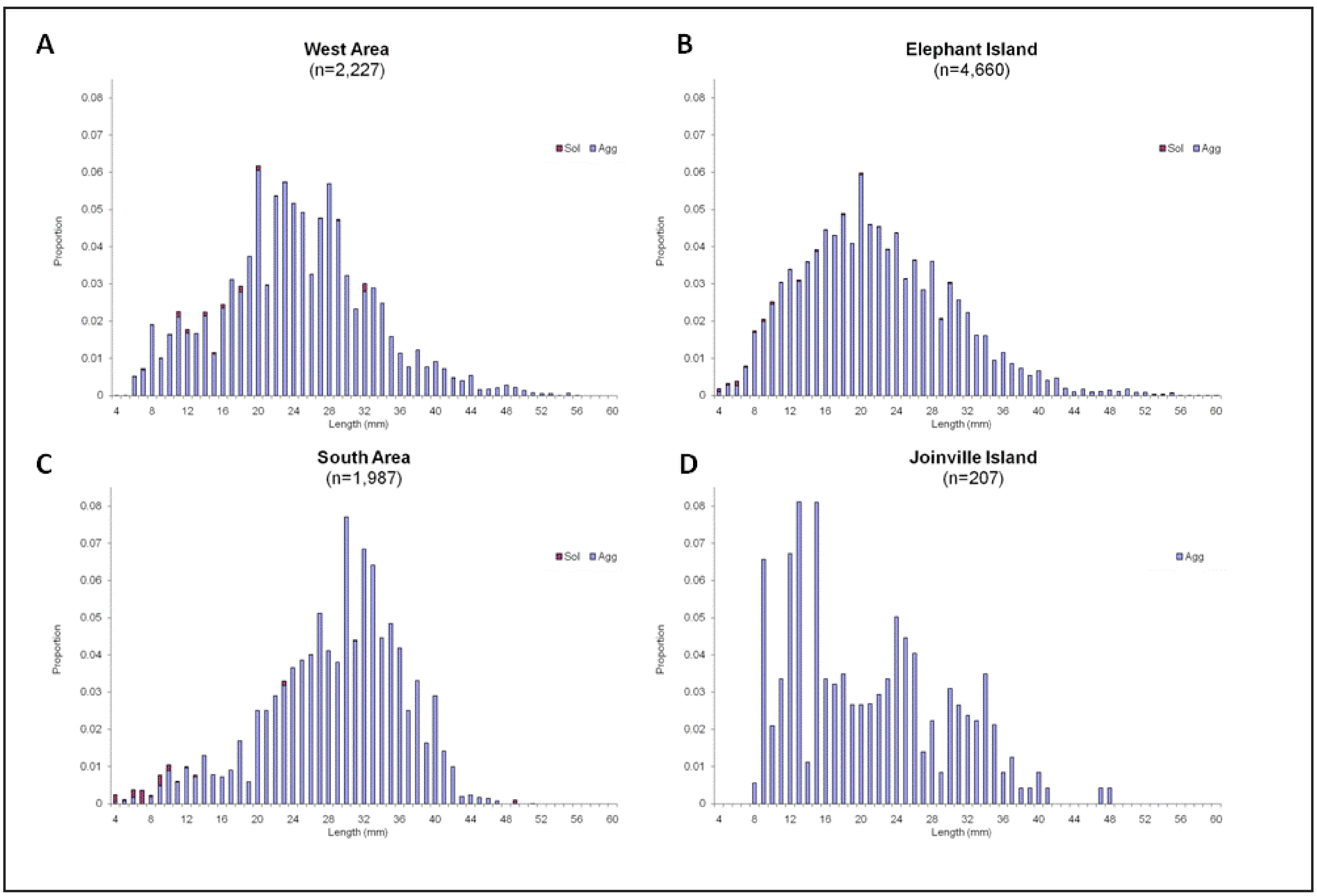

Figure 4.6. Salp length-frequency distribution by area: A) West Area; B) Elephant Island Area; C) South Area; and D) Joinville Island Area. Distribution was cropped at 60 mm as very few salps > 60 mm were encountered. Maximum length was 123 mm.

by multiple individuals. We calibrated our technique using blind comparisons of length and stage on the same krill. Individuals were allowed to stage krill until their length measurements agreed to within 1% of the length frequency derived by the lead zooplankton technician, and all staging was identical over multiple tests (up to three) of greater than 10 individuals. However, there remains some concern regarding staging of small krill due to the virtual absence of small (30-38 mm) females. We recommend continuing the blind comparisons at the start of each season and that the krill collected for cross-validation be examined by an expert in krill staging.

Database modifications caused substantial errors during data entry. This summary should be considered preliminary until database issues are resolved and data entry can be verified.

New decision rules were developed for copepod identification in order to minimize misidentification at the species level and to increase the consistency in identification among the technicians who vary widely in their experience.

- *Rhincalanus* was identified to the genus level unless the last three segments of the prosome and genital segment were inspected for the presence of spines. If absent, the individual was identified as *R. gigas* and if present, as *R. nasutus*.
- Only the adult females and occasionally stage 5 copepidites (C5) of *Calanus propinquus* and *Calanoides acutus* were identified to species level. Most were identified to the family level (Calanidae) due to the

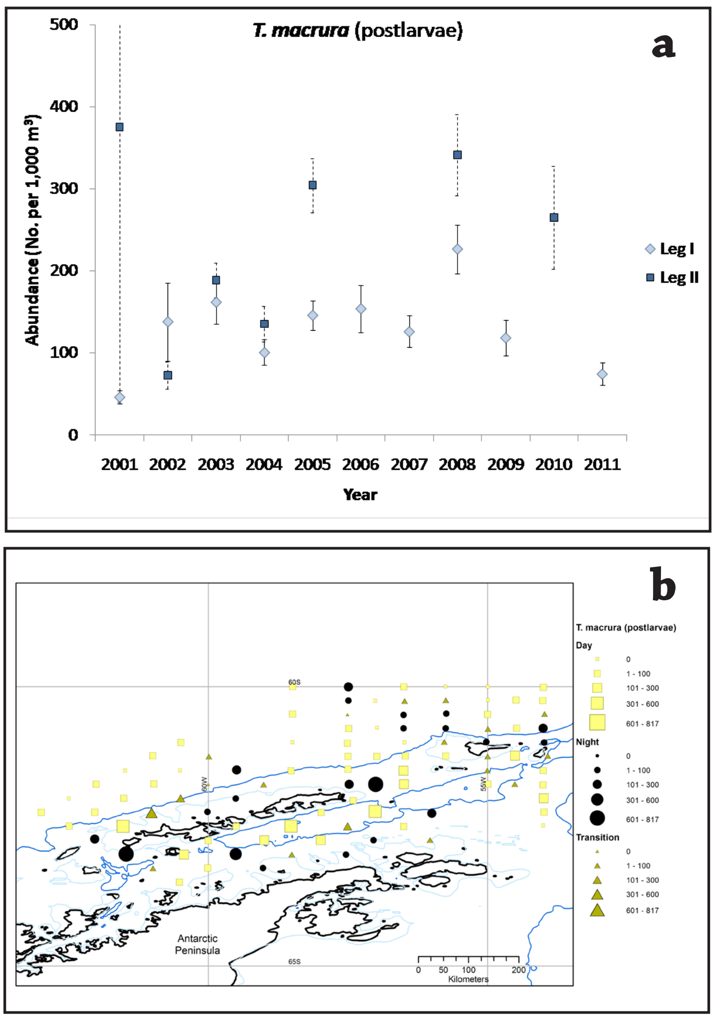

Figure 4.7. Historical catch rate (a) and 2011 Leg I distribution by time of day (b) of post-larval *T. macrura*. Error bars are standard errors. Y-axis in (a) was limited to 500 in order to maintain resolution in other years; however, the full lower extent is shown.

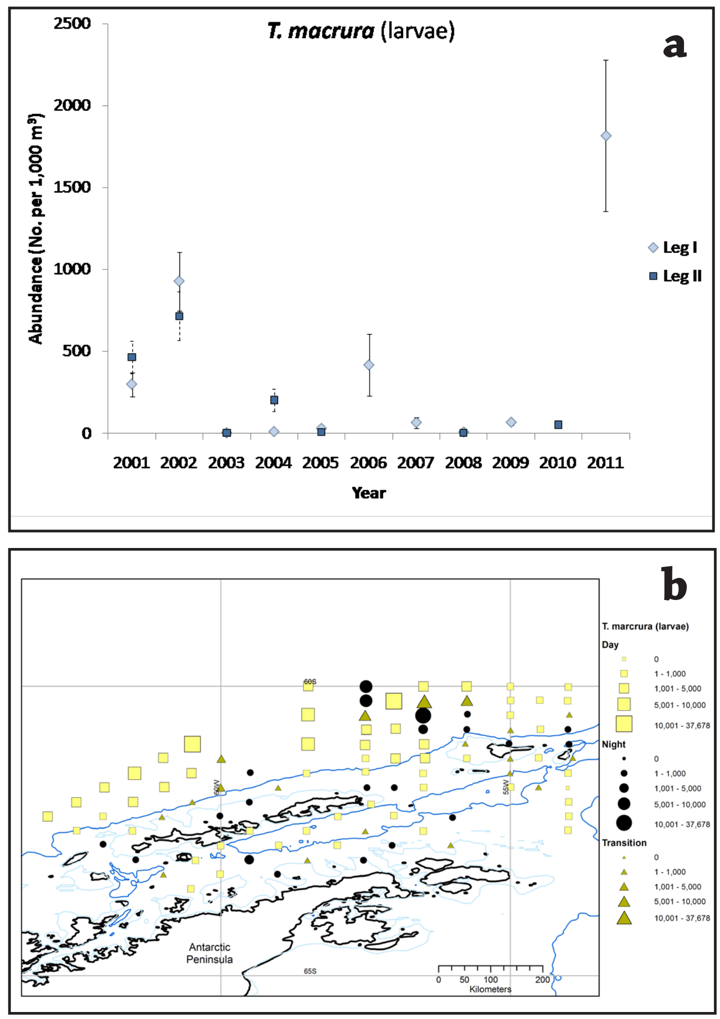

Figure 4.8. Historical catch rate (a) and Leg I distribution by time of day (a) of larval *T. macrura*. Error bars are standard errors. Y-axis in (a) was limited to 500 in order to maintain resolution in other years; however, the full lower extent is shown.

similarities of the males and earlier copepidite states.

- *Halioptilus* and *Paraeucheata* were identified to the genus level except for a few individuals identified to the species level by N. Ferm.
- For copepods we recommend stricter identification rules for *Metridia gerlachei* and *Pleuromamma robusta* due to the presence of known congeneric species in the samples.

N. Ferm finalized an identification key for identifying the dominant copepod families and species, which should assist in more consistent identification in the future. We recommend further testing and development in 2012.

Disposition of Data

Data and more detailed processing protocols are available from Christian Reiss, NOAA Fisheries, Antarctic Ecosystem Research Division, 8901 La Jolla Shores Dr., La Jolla Ca 92037. Ph: 858-546-7127, Fax: 858-546-7003.

Acknowledgments

We are extremely grateful to the Captain and crew of the R/V *Moana Wave*, whose continued support throughout the season made our work possible. Modifications to the ship for 2011 also increased our ability to deploy nets in a wider range of weather conditions. Thanks to the Physical Oceanography team for fixing a light source as well as setting up and coordinating the Tucker Trawl electronics and deployment.

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Mesopelagic and Larval Fish Survey

Christopher Jones, Philippe Koubbi, Barbara Catalano, Kimberly Dietrich, and Nissa Ferm.

Abstract

A survey of mesopelagic and larval fish was carried out during Leg II of the oceanographic survey using a three-panel net (Tucker Trawl). Finfish were also collected during IKMT deployments as part of a gear comparison experiment. Data collection included species identification, size composition, spatial and diel vertical distribution, diet composition, and otolith sampling of mesopelagic and larval finfish species around Elephant Island, near Joinville Island, and in the Bransfield Strait. Additional stations were sampled within the Gerlache Strait. The results from this field season include:

- 70 stations completed:
    - 26 in Elephant Island Area,
    - 14 in Joinville Island Area,
    - 22 in South Area (Bransfield Strait), and
    - 8 in Gerlache Strait;
- 148 individuals (1.479 kg) mesopelagic finfish of 10 species captured from all nets;
- 1,226 individual finfish larvae of 18 species captured from all nets;
- Spatial distribution of standardized finfish densities demonstrated substantial contrast across the shelf area;
- Length-frequency data presented for *Electrona antarctica* and *Gymnoscopelus braueri*; and
- Diet data presented for 82 specimens of 7 mesopelagic finfish species.

Introduction

It has been recognized that mesopelagic finfish species are among the most important predators of Antarctic krill and other important pelagic invertebrates in the South Shetland Islands and northern Antarctic Peninsula region. Further, pelagic finfish species serve as prey items, second only to Antarctic krill, for land-based predators such as fur seals and penguins. Although the importance of these finfish species in the Antarctic ecosystem is acknowledged, there are considerable uncertainties with respect to their population dynamics and their spatial distribution around the South Shetland Islands and northern Antarctic Peninsula, as well as the physical and biological factors that influence these.

The objective of the trawl survey conducted during Leg II was to elucidate the roles of mesopelagic and pelagic finfish in the pelagic trophic web; specific goals included data collection to be used for estimates of biomass, distribution, species and size composition, demographic structure, and diet composition of mesopelagic finfish species within the U.S. AMLR survey grid, as well as regions farther south. This survey represents the first comprehensive scientific characterization of these finfish in this area that the U.S. AMLR Program has undertaken, and the first survey of its kind in this region of the Southern Ocean.

Several other sampling efforts and biological experiments were conducted during the course of this survey, including otolith sampling for age and growth studies, voucher samples for land-based predator diet studies, and other specimen and tissue collections for biological, physiological, and phylogenetic studies. These data will be used to better understand the relationships of mesopelagic finfish to other components of the Antarctic ecosystem, including the physical oceanography in the region, and the density and distribution of Antarctic krill.

Methods

Pelagic Tucker Trawl Sampling

The primary fishing gear type employed was a four square meter effective mouth multiple opening/closing (three panel) Tucker Trawl net system (Open Seas Instrumentation Inc., Musquodoboit Harbour, NS). Additional finfish specimens were sampled with the IKMT net during gear comparison trials. The first and third panels of the Tucker Trawl were fitted with 505 µm nitex mesh net, and the second net (specifically targeting mesopelagic finfish) was fitted with a five millimeter knotless nylon mesh net. The cod-ends for all three nets consisted of six inch nominal OD, PVC, with four liter capacity and 250 µm window mesh. The trawl was instrumented with pitch and roll sensors, two GO (Model 2031H) electronic flow me-

Table 5.1. Deployment, station and nominal finfish catch information for the 2010/11 AMLR mesopelagic trawl survey. EI = Elephant Island; JI = Joinville Island; SA = Bransfield Strait (South Area); GS = Gerlache Strait.

AMLR Station	Deployment Type	Date	Region	Latitude Midpoint	Longitude Mid-point	Time First De-ployment	Number Finfish	Number Species
D0203A	Net Comp.	2/17/2011	EI	-60.489	-54.070	1:50 AM	8	3
D0206A	Net Comp.	2/17/2011	EI	-61.25	-53.904	11:52 AM	0	0
D0207A	Net Comp.	2/17/2011	EI	-61.498	-53.975	03:16 PM	0	0
D0307A	Net Comp.	2/17/2011	EI	-61.497	-54.525	06:31 PM	0	0
D0306A	Net Comp.	2/17/2011	EI	-61.225	-54.490	09:45 PM	0	0
D0307B	Net Comp.	2/18/2011	EI	-61.492	-54.484	1:17 AM	7	3
D0207B	Net Comp.	2/18/2011	EI	-61.501	-54.576	4:32 AM	1	1
D0206B	Net Comp.	2/18/2011	EI	-61.250	-53.877	8:25 AM	0	0
D02051	Net Comp.	2/18/2011	EI	-61.006	-53.983	11:45 AM	0	0
D0305A	Net Comp.	2/18/2011	EI	-60.988	-54.335	02:25 PM	0	0
D0405A	Net Comp.	2/18/2011	EI	-60.981	-54.787	06:06 PM	0	0
D0306B	Net Comp.	2/19/2011	EI	-61.217	-54.767	1:20 AM	4	2
D0307C	All Tucker	2/19/2011	EI	-61.529	-54.571	5:30 AM	9	5
D0305B	Net Comp.	2/21/2011	EI	-60.988	-54.556	12:48 AM	0	0
D0405B	Net Comp.	2/21/2011	EI	-60.991	-54.826	3:42 AM	0	0
D0404A	All Tucker	2/21/2011	EI	-60.735	-55.047	7:19 AM	2	1
D0403A	All Tucker	2/21/2011	EI	-60.479	-55.050	10:54 AM	6	1
D0303A	All Tucker	2/21/2011	EI	-60.478	-54.695	02:45 PM	0	0
D0304A	Net Comp.	2/21/2011	EI	-60.742	-54.521	06:56 PM	0	0
D0203B	Net Comp.	2/21/2011	EI	-60.495	-54.236	010:46 PM	0	0
D0202	All Tucker	2/22/2011	EI	-60.247	-54.060	1:33 AM	13	3
D0201A	All Tucker	2/22/2011	EI	-60.038	-54.072	5:41 AM	5	2
D0201	All Tucker	2/22/2011	EI	-60.000	-53.972	7:08 AM	13	3
D0402	Tucker 1 & 3	2/22/2011	EI	-40.131	-43.595	07:23 PM	0	0
D0401	Tucker 1 & 3	2/23/2011	EI	-59.990	-33.014	04:12 PM	0	0
D05501	Tucker 1 & 3	2/23/2011	EI	-59.998	-55.479	08:11 PM	0	0
D0209	All Tucker	2/26/2011	JI	-61.983	-54.599	3:35 AM	2	2
D0210	Tucker 1 & 3	2/26/2011	JI	-62.041	-54.017	8:08 AM	0	0
D0211	Tucker 1 & 3	2/26/2011	JI	-62.493	-54.009	11:52 AM	0	0
D0212	Tucker 1 & 3	2/26/2011	JI	-62.755	-54.054	03:20 PM	0	0
D0213	Net Comp.	2/26/2011	JI	-62.980	-54.079	06:38 PM	0	0
D0413	All Tucker	2/26/2011	JI	-62.987	-54.721	011:49 PM	2	1
D0412	Net Comp.	2/27/2011	JI	-62.735	-55.044	3:23 AM	0	0
D0411	All Tucker	2/27/2011	JI	-62.483	-55.046	6:51 AM	0	0
D0410	Net Comp.	2/27/2011	JI	-62.240	-55.044	10:24 AM	0	0
D0409	Net Comp.	2/27/2011	JI	-62.015	-54.996	02:36 PM	0	0

Table 5.1 continued. Deployment, station and nominal finfish catch information for the 2010/11 AMLR mesopelagic trawl survey. EI = Elephant Island; JI = Joinville Island; SA = Bransfield Strait (South Area); GS = Gerlache Strait.

AMLR Station	Deployment Type	Date	Region	Latitude Midpoint	Longitude Mid-point	Time First De-ployment	Number Finfish	Number Species
D0609	Net Comp.	2/27/2011	JI	-61.987	-55.600	07:30 PM	1	1
D0610	Net Comp.	2/27/2011	JI	-62.241	-56.029	011:05 PM	1	1
D0611	All Tucker	2/28/2011	JI	-62.486	-56.037	2:23 AM	0	0
D0612	All Tucker	2/28/2011	JI	-62.736	-56.021	7:07 AM	0	0
D0711	Net Comp.	2/28/2011	SA	-62.491	-56.320	12:07 PM	0	0
D0810	Net Comp.	2/28/2011	SA	-62.243	-56.791	03:17 PM	0	0
D0909	Net Comp.	2/28/2011	SA	-62.041	-57.215	06:47 PM	0	0
D1010	Net Comp.	2/28/2011	SA	-62.245	-57.584	010:27 PM	0	0
D0911	All Tucker	3/1/2011	SA	-62.369	-57.526	1:58 AM	12	5
D0812A	All Tucker	3/1/2011	SA	-62.757	-57.268	6:20 AM	0	0
D0913	Net Comp.	3/1/2011	SA	-62.980	-57.510	12:28 PM	0	0
D1012	Net Comp.	3/1/2011	SA	-62.757	-57.800	03:50 PM	0	0
D1111	Net Comp.	3/2/2011	SA	-62.481	-58.310	2:56 AM	5	1
D1212	All Tucker	3/2/2011	SA	-62.744	-58.855	7:00 AM	8	3
D1113	Net Comp.	3/2/2011	SA	-62.999	-58.728	12:15 PM	0	0
D1313	Net Comp.	3/2/2011	SA	-62.996	-59.129	07:31 PM	0	0
D1412	Net Comp.	3/2/2011	SA	-62.741	-59.824	010:52 PM	0	0
D1513	All Tucker	3/3/2011	SA	-63.029	-60.296	2:16 AM	6	2
D1414	All Tucker	3/3/2011	SA	-63.216	-60.152	6:37 AM	12	1
D1515	Net Comp.	3/3/2011	SA	-63.489	-60.298	11:02 AM	0	0
D1614	Net Comp.	3/3/2011	SA	-63.238	-60.651	02:27 PM	0	0
D1713	Tucker 1 & 3	3/3/2011	SA	-62.993	-61.506	05:58 PM	0	0
GS01A	All Tucker	3/3/2011	GS	-63.747	-61.457	011:55 PM	5	3
GS02A	All Tucker	3/4/2011	GS	-64.328	-61.697	5:46 AM	4	4
GS03A	All Tucker	3/4/2011	GS	-64.577	-62.344	10:41 AM	1	1
GS03B	All Tucker	3/5/2011	GS	-64.562	-62.590	1:18 AM	7	2
GS03C	Targeted	3/3/2011	GS	-64.562	-62.550	2:44 AM	0	0
GS02B	All Tucker	3/5/2011	GS	-64.305	-61.769	7:10 AM	0	0
GS01B	All Tucker	3/5/2011	GS	-63.764	-61.570	12:43 PM	3	2
GS13	IKMT Only	3/5/2011	GS	-64.109	-61.468	011:22 PM	1	1
D1110A	All Tucker	3/7/2011	SA	-62.315	-58.045	09:55 PM	3	2
D1110B	All Tucker	3/8/2011	SA	-62.301	-58.032	12:27 AM	2	2
D1110C	Tucker 1 & 3	3/8/2011	SA	-62.333	-58.011	3:09 AM	4	2
D1110D	All Tucker	3/8/2011	SA	-62.293	-57.995	6:41 AM	1	1

ters, a net drop sensor, and a Sea-Bird Seacat plus profiler.

Mesopelagic finfish sampling operations were conducted aboard the R/V *Moana Wave* 17 February through 8 March 2011 (Table 5.1). A total of 70 stations were completed (Figure 5.1). The survey targeted areas near Elephant Island, Joinville Island, the Bransfield Strait, and the Gerlache Strait. Of the 70 stations, 34 were sampled as part of the gear comparison between the IKMT and Tucker Trawl nets one and three (the 505 µm nitex nets for krill); 26 of the comparison tows used all three nets of the Tucker Trawl and eight comparison tows used Tucker Trawl nets one and three. In addition, there was one tow taken to ground truth a strong scattering layer of krill, and one tow only using the IKMT. The positions of these stations by deployment type are illustrated in Figure 5.1.

Sampling depths depended on the gear deployment type. In the case of the Tucker Trawl deployments, net one was fished from the surface to 170 m (descending), net two fished from 170 m to the maximum deployment depth, which ranged from 240 to 652 m, and net three fished from 170 m to the surface (ascending). The IKMT was deployed the standard 170 m. Sampling was conducted around the clock, with most Tucker Trawl net two deployments undertaken at night.

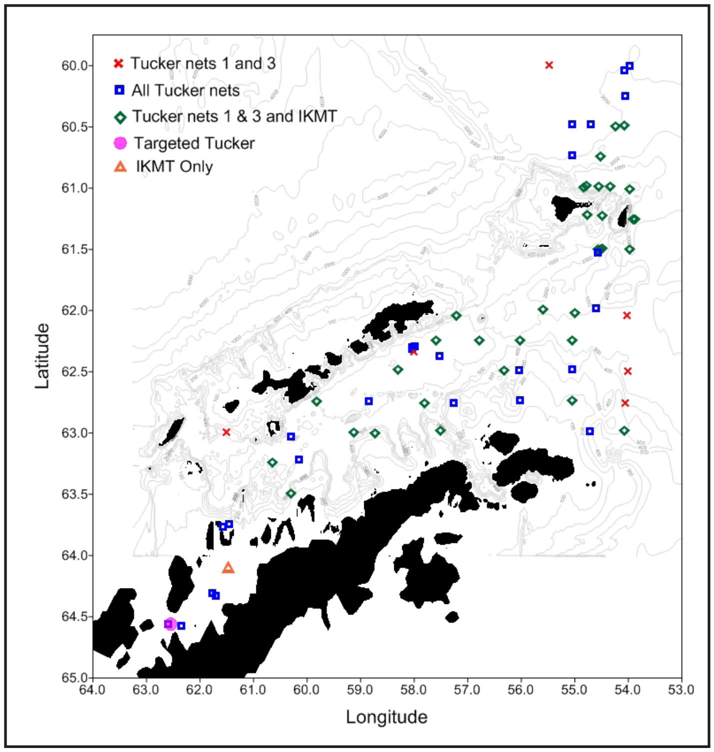


Figure 5.1. Station locations by gear deployment from the 2010/11 AMLR mesopelagic finfish survey of the Elephant Island, Joinville Island and South Areas.

Haul Processing

After a successful haul, the contents of the trawl were emptied and transferred to a sorting table, where fish were identified, separated into species, and placed into individual species trays. Pelagic fish were processed separately from krill and invertebrates. Trays were weighed to obtain total catch weights by species. Data collected in included length (mm), mass (g), sex, gonad maturity stage where possible, and diet composition. Length types were collected as standard length (length from tip of snout to end of caudal peduncle). All masses were measured as total fresh mass to nearest gram. For mesopelagic species, maturity was classified on a scale of I to V (immature, maturing virgin or resting, developing, gravid, spent) according to the method set out for *Electrona antarctica* in the CCAMLR manual for scientific observers (CCAMLR 1999). In addition, otoliths and tissue samples were taken from most specimens. Early life stages of fish species were classified on a scale of I to IV according to Koubbi et al. (1990) and measured in standard length to the nearest mm. Identification was done mainly using North and Kellerman (1990).

An examination of the diet composition of mesopelagic finfish was conducted across all regions of the survey for most species. Stomach content information included content weight (to the nearest g); a measure of the filling degree on a scale of 0 - 5 (empty, 25% full, 50% full, 75% full, 100% full, regurgitated); and a measure of the degree of digestion on a scale of 1-3 (fresh, moderately digested, fully digested). Dietary items were identified to general common taxonomic groupings, 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 adding to 10.

Results

Patterns of Distribution of Mesopelagic Finfish

A total of 148 individuals (1.48 kg) of 10 finfish species were processed from all hauls (Table 5.2). The family Myctophidae was the dominant element of the pelagic finfish fauna both in terms of biomass and numbers. The highest catches of all mesopelagic fish occurred at offshore stations (Figure 5.2). In general, there was an absence of fish at stations located on shallower shelf areas, though this is likely influenced by the specific gear deployment and time of day (Table 5.1, Figure 5.2). In the case of the latter, myctophids likely migrated deeper than the depth of gear deployment during daylight hauls. With regard to catch by gear type (Figure 5.3), the Tucker Trawl net two,

Table 5.2. Summary of catch data for mesopelagic finfish by species.

Family	Species	Total Numbers	Total Weight (g)	No. Stations Occurred	Stomachs Analyzed	Otoliths Collected
Myctophidae	*Electrona antarctica*	76	693	38	58	25
	Electrona carlsbergi	13	90	6	12	8
	Gymnoscopelus braueri	32	229	15	26	11
	Gymnoscopelus nicholsi	11	368	9	11	8
	Gymnoscopelus opisthopterus	1	16	1	1	
	Protomyctophum bolini	4	2	4	3	1
Bathylagidae	*Bathylagus antarcticus*	7	36	6	3	1
Nototheniidae	*Pleuragramma antarcticum*	2	16	1	-	-
	Chionodraco rastrospinosus	1	30	1	-	-
Gonostomatidae	*Cyclothone* spp.	1	-	1	-	
Total		148	1480		114	54

specifically designed and deployed to catch mesopelagic fish, caught the most fish (n = 62), followed by the Tucker Trawl net three (n = 42), Tucker Trawl net one (n = 24) and the IKMT (n = 21). For most species, the Tucker Trawl net one (505 µm mesh descending net) caught fewer fish than Tucker Trawl net three (505 µm mesh ascending net).

The two most prominent mesopelagic finfish species encountered during the course of the survey were *Electrona antarctica* and *Gymnoscopelus braueri* (Table 5.2), which were captured in all net types, followed by *Electrona carlsbergi* and *Gymnoscopelus nicholsi*. The remaining species only represented a few individuals. Average standard lengths of all specimens measured are listed in Table 5.3, and length-frequency distributions for *E. antarctica* and *G. braueri* are plotted in Figure 5.4. The spatial distribution of catches was driven primarily by the occurrence of *E. antarctica* (Figure 5.5), which was encountered at 38 stations, followed by *G. braueri* (Figure 5.6), which was encountered at 15 stations.

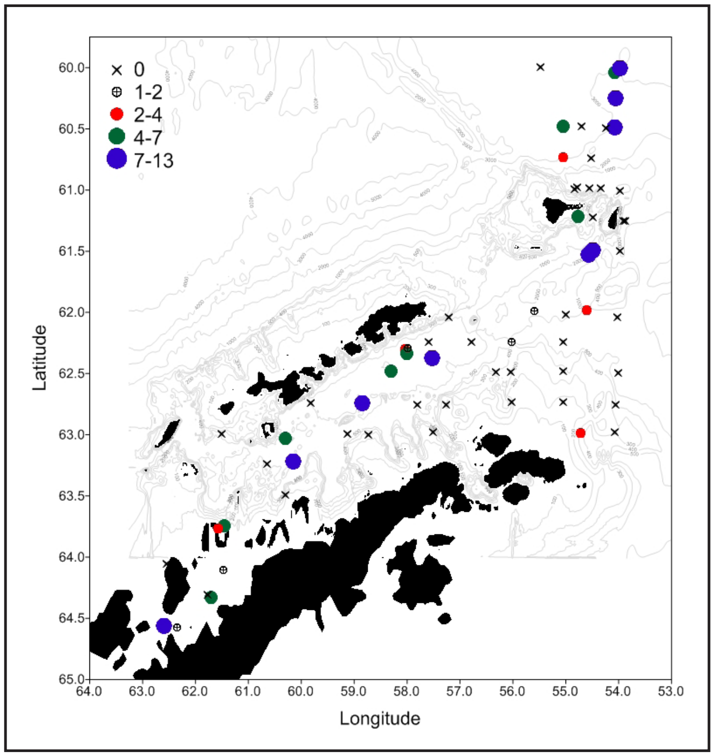


Figure 5.2. Nominal catch in numbers of mesopelagic finfish from all gear deployments.

Diet

Diet was characterized for 114 fish (Table 5.4). Of these, 82 (72%) had stomach contents. The frequency of occurrence of prey items (number of stomachs where the specific prey was found over the total number of stomachs with prey) for the four main myctophid species are illustrated in Figure 5.7. The x axis of each figure lists the major planktonic groups, while the y axis indicates the frequency of occurrence for some prey items identified to species. Caution should be noted with respect to interpreting the species-specific data with respect to euphausiids, as most of them were digested and could not be identified to species. Thus, the frequencies of occurrence of *Thysanoessa macrura* and *Euphausia superba* (identified to species) is underestimated, whereas the frequency of occurrence of total euphausiids

Table 5.3. Standard length (cm) of mesopelagic finfish by species.

Species	Total numbers	Mean SL (cm)	STD SL	SL Min	SL Max
Bathylagus antarcticus	4	10.5	1.2	9.1	11.9
Bathylagus spp. (juveniles)	3	3.6	1.1	2.9	4.9
Cyclothone spp.	1	3.4			
Electrona antarctica	76	8.4	1.6	3.2	10.6
Electrona carlsbergi	13	8	0.3	7.4	8.6
Gymnoscopelus braueri	32	9.2	1.8	6.4	13.1
Gymnoscopelus nicholsi	11	14.6	0.7	13.4	15.6
Gymnoscopelus opithopterus	1	12.5			
Protomyctophum bolini	4	4.825	0.4	4.4	5.3
Pleuragramma antarcticum	2	9.7		9.6	9.8
Chionodraco rastrospinosus	1	15.8			

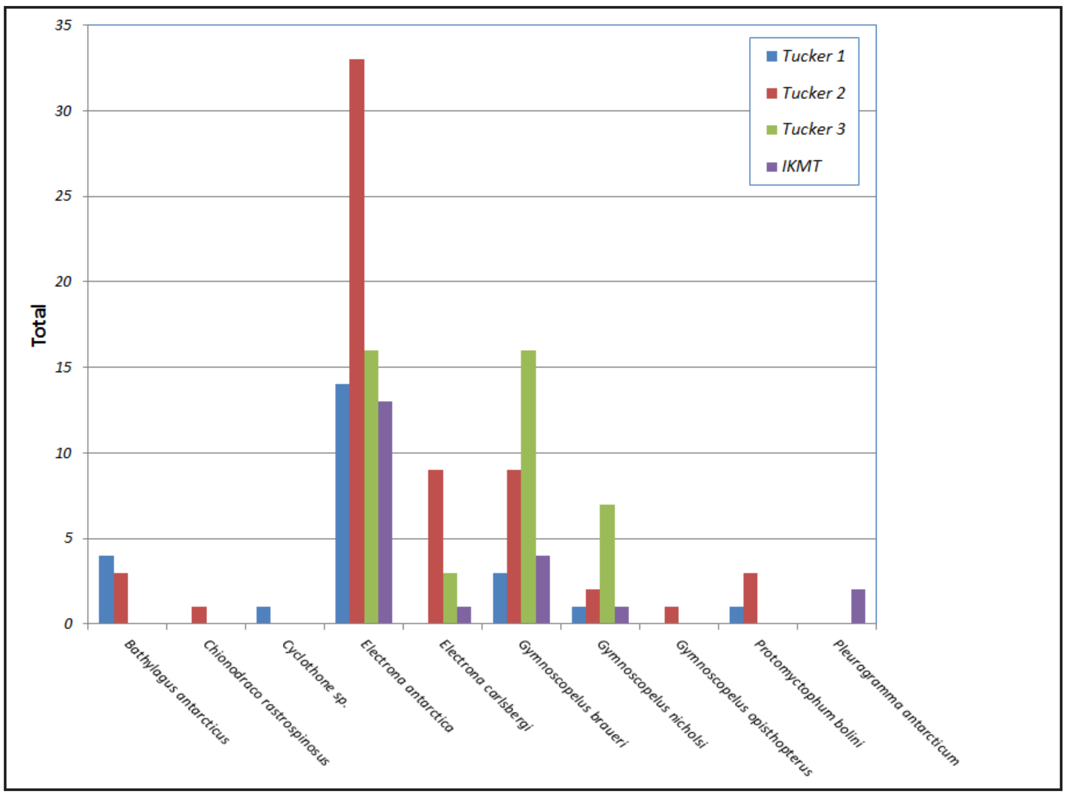


Figure 5.3. Nominal catch in numbers of mesopelagic finfish by gear type.

is more accurate. The issue of identification to species was less important for other prey species. In addition, it should be noted that sample sizes for species other than *E. antarctica* are very low, and thus the dietary composition should be treated as indicative.

The top prey items for all four myctophid species were euphausiids and copepods. The primary species within these major planktonic groups for *E. antarctica*, *G. braueri*, and *G. nicholsi* were the euphausiids *E. superba* and *T. macrura*, and the calanoid copepod *Metridia* spp. At the species level, the diet of *E. carlsbergi* was also dominated by *Metridia* spp., though the importance of the copepods *Oncea* spp. and *Rhincalanus gigas* were also apparent.

The spatial distribution of diet for *E. antarctica* and *G. braueri* across the surveyed area is illustrated in Figures 5.8 and 5.9, respectively. With respect to *E. antarctica*, there were no clear patterns, although interestingly, krill were particularly prominent in the stomachs of fish sampled just outside Admiralty Bay, where anecdotal evidence suggest the commercial krill fishery operated for a significant portion of the survey period. Also, the substantial proportion of *T. macrura* in the most southerly samples was noteworthy. Dietary composition of *G. braueri* demonstrated a somewhat stronger pattern particularly in the Bransfield Strait; *T. macrura* were particularly important in the stomachs of *G. braueri* collected south of King George Island, whereas the diets of the most southerly samples showed very similar compositions with respect to the proportions of *E. superba* and *T. macrura*.

Diel Vertical Distribution

During night tows, catches were taken primarily in the epipelagic zone. Bathypelagic species were rarely collected.

Estimates of the vertical distribution of *E. antarctica* were completed us-

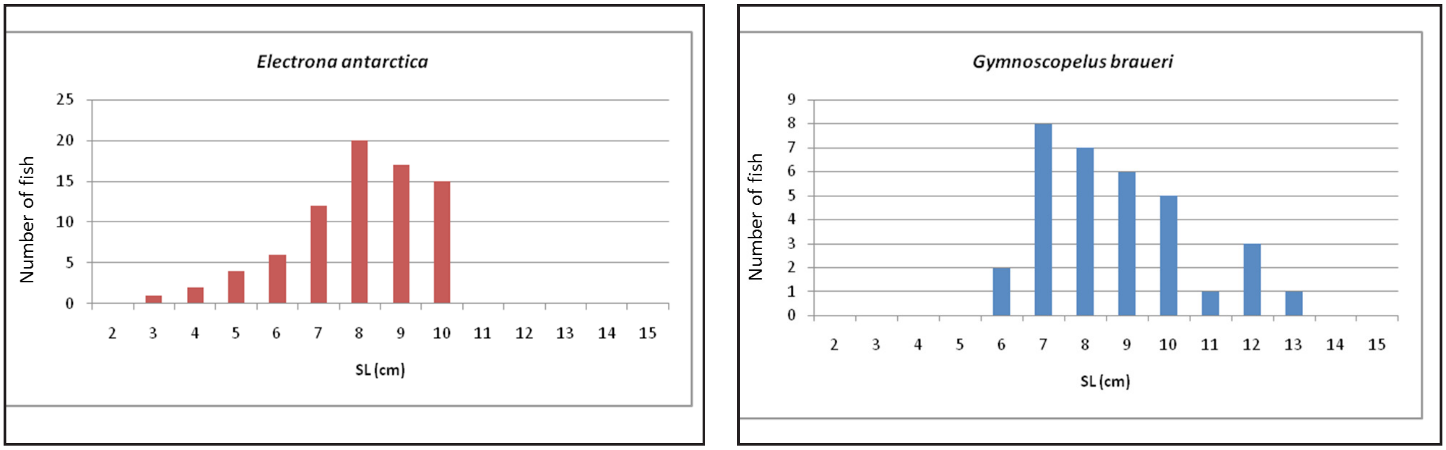


Figure 5.4. Length-frequency distributions for *E. antarctica* and *G. braueri* (SL = standard length).

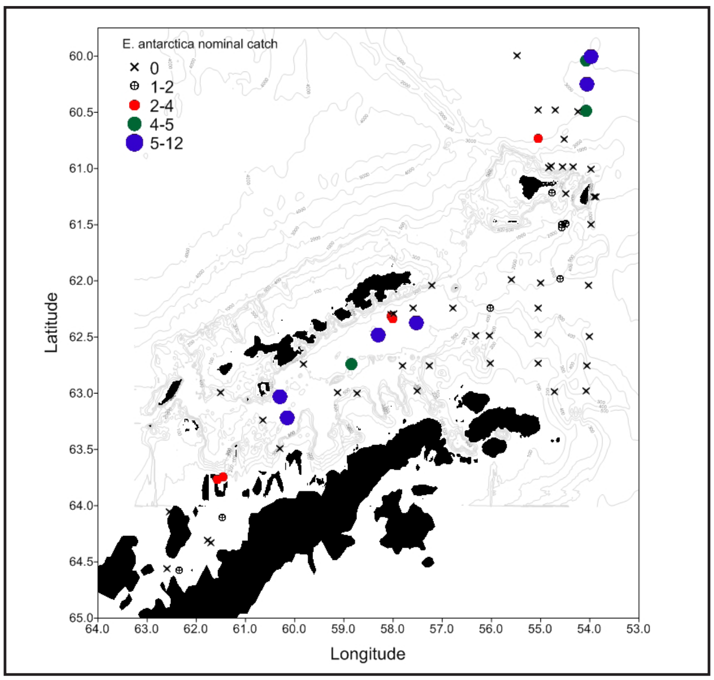


Figure 5.5. Nominal catch in numbers of *Electrona antarctica* from all gear deployments.

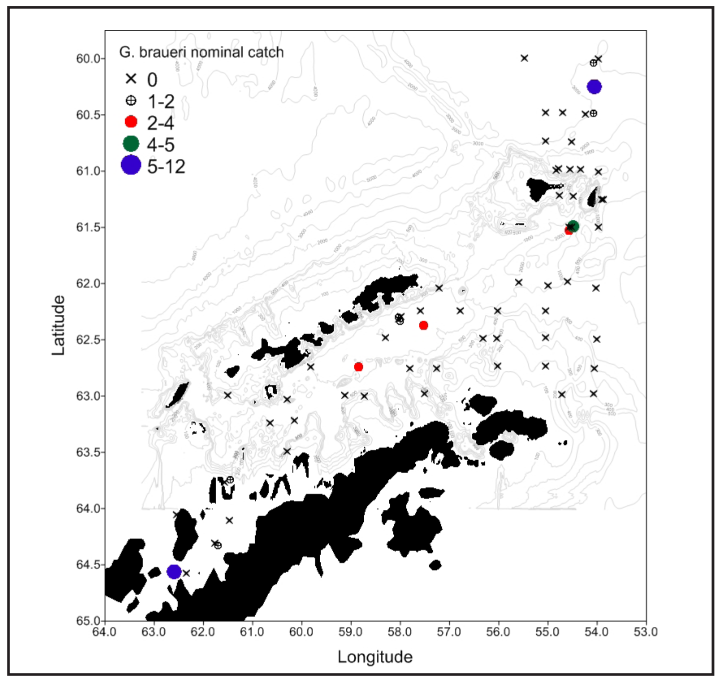


Figure 5.6. Nominal catch in numbers of *Gymnoscopelus braueri* from all gear deployments.

ing the maximum depth of each IKMT and Tucker Trawl sample and the local time at sampling. Figure 5.10 demonstrates the vertical migration at night of *E. antarctica*, which migrates to deep layers during the day. Bubble size corresponds to the number of fish collected (and is indicative of abundance), and the blue points correspond to each IKMT and Tucker Trawl. When information on flow rates of all trawls become available, it will worthwhile using this information to calculate the actual abundance.

As expected, the few specimens of Bathylagidae (many of them juveniles) were collected in the deeper layers, and *G. braueri* was only found at night in all layers.

Fish Larvae

A total of 1,226 fish larvae of 18 different species were collected from all nets. For samples with high numbers of salps, subsamples were sorted for fish larvae and the rest of the plankton sample was rapidly screened. Otherwise, all larvae were sorted. The majority of fish larvae collected were identified to species level, according to North and Kellerman (1990). On a few occasions, identifications were made at a higher taxonomical level, due mainly to damaged specimens. Due to the uncertainties of volume readings from the Tucker Trawl (at the time of this report), it was not possible to calculate accurate abundances for

Table 5.4. Numbers of species analyzed for diet composition with stomach filling degree. Filling degree categories are as follows: 0 = empty, 1 = 25% full, 2 = 50% full, 3 = 75% full, 4 = 100% full, and 5 = regurgitated.

Species	Filling Degree						Total Fish Analyzed	Fish with Stomach Contents
	0	1	2	3	4	5		
Bathylagus antarcticus		3					3	3
Electrona antarctica	20	15	12	9	2		58	37
Electrona carlsbergi	1	4	7				12	11
Gymnoscopelus braueri	11	6	3	6			26	15
Gymnoscopelus nicholsi	1	7	3				11	10
Gymnoscopelus opithopterus		1					1	1
Protomyctophum bolini		2	1				3	3
Total							114	82

fish larvae, so the term "abundance" as used here represents the number of collected specimens.

The most abundant species found was *Lepidonotothen larseni* (n = 558), which was collected at 28.95% of sampled stations. The species encountered most frequently was *Lepidonotothen kempi*, which was collected at more than 40% of the stations, although in low numbers (n = 98) (Table 5.5). Other frequently collected species were *Trematomus scotti* (FO 23.68%; n = 78); *Chionodraco rastrospinosus* (FO 21.05%, n = 29), *Pleuragramma antarcticum* (FO 17.11%, n = 111) and *Champ-*

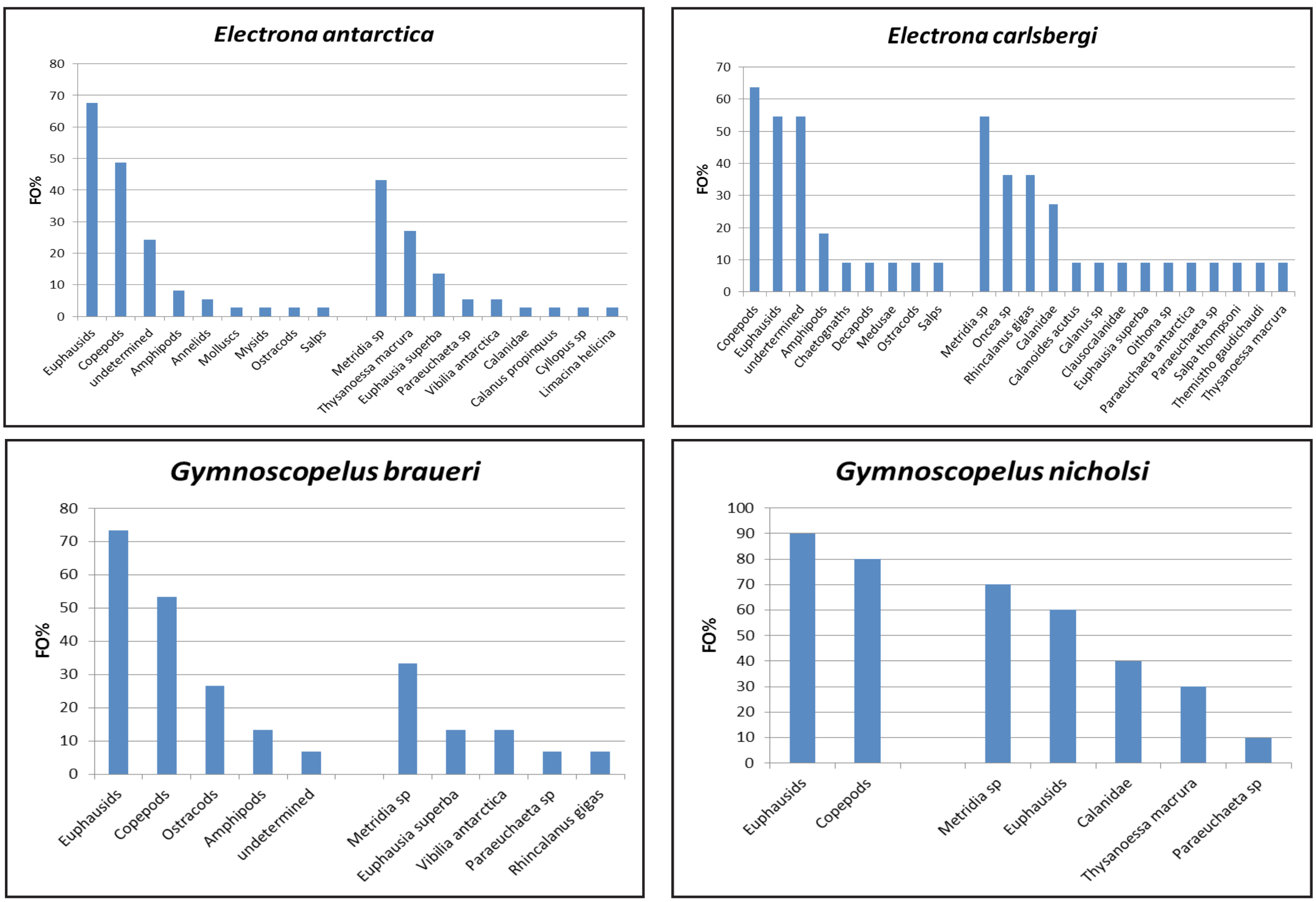


Figure 5.7. Frequency of occurrence for prey items found in the four prominent species of myctophids.

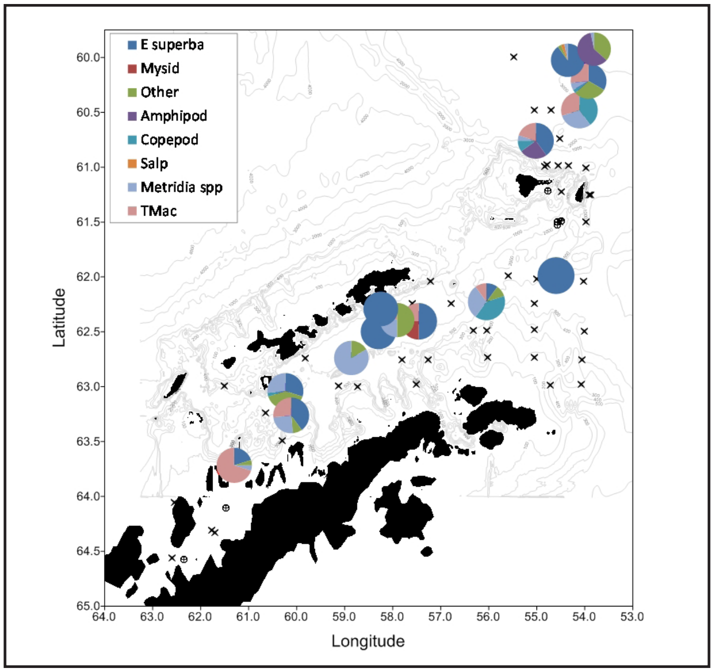


Figure 5.8. Spatial distribution of average dietary composition for the myctophid *E. antarctica*. TMac is the euphausiid *Thysanoessa macrura*.

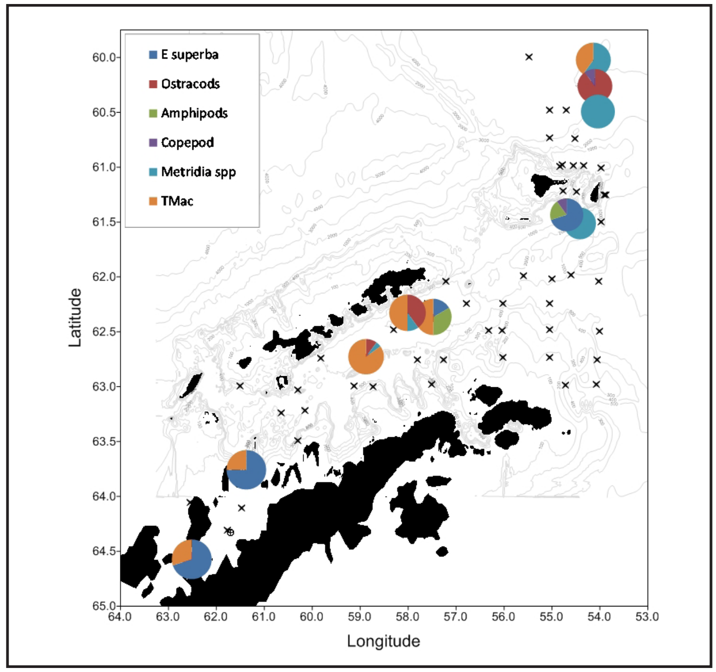


Figure 5.9. Spatial distribution of average dietary composition for the myctophid *G. braueri*. TMac is the euphausiid *Thysanoessa macrura*.

socephalus gunnari (FO 15.79%, n = 130).

The majority of fish larvae collected (97.4%) were of early life stages (stages 1 - 4, according to Koubbi et al. (1990)); the rest were juveniles or transforming larvae stages. For instance, all *Chaenodraco wilsoni*, *C. rastrospinosus*, *Cryodraco antarcticus*, *Parachaenichthys charcoti*, and *Pogonophryne marmorata* specimens collected were juveniles or transforming stages (Table 5.6). A few *P. antarcticum* juveniles were also collected.

Table 5.7 shows the minimum and maximum standard lengths found per species. Figure 5.11 illustrates length-frequency distributions for the most abundant fish larvae collected.

The capture comparison between the different nets was also evaluated according to stage of development. Fish larvae in stages 1 - 4 were mainly captured in the upper 170 m of the water column. Although the IKMT net caught the most larval fish, the Tucker Trawl, with a similar towing dynamic, collected a greater number of specimens when Tucker Trawl net one (towed from 0 – 170 m) and net three (towed from 170 – 0 m) data were combined (Figure 5.12). This is consistent with the greater dimension of the Tucker Trawl. Captures of juveniles and transforming larvae were greater in deeper layers, as emphasized by the greater number of specimens collected in Tucker Trawl net two, towed between 170 and 300 m (for most hauls,

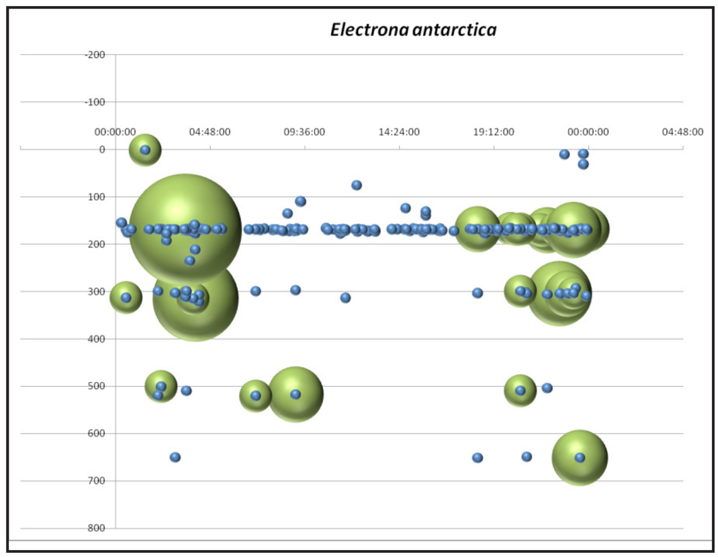


Figure 5.10. Catch of *E. antarctica* by time of deployment. Time of day is on the horizontal axis, and depth is on the vertical axis. Bubble size corresponds to the number of fish collected, and the blue points correspond to each IKMT and Tucker net deployment.

Figure 5.13). When the flow meter readings are resolved, catch/m^3 will clarify any differences in net efficiencies.

Discussion

Future mesopelagic finfish sampling efforts should endeavor to undertake deep net deployments during day-

Table 5.5. Number of fish larvae collected and % occurrence.

Species	Number Collected	% Occurrence
Bathylagus antarcticus	1	1.32
Bathylagus spp.	4	5.26
Chaenodraco wilsoni	2	1.32
Champsocephalus gunnari	130	15.79
Channichthydae spp.	2	2.63
Chionodraco rastrospinosus	29	21.05
Cryodraco antarcticus	4	5.26
Electrona antartica	9	10.53
Electrona sp.	115	7.89
Gobionothen gibberifrons	1	1.32
Lepidonotothen kempi	98	40.79
Lepidonotothen larseni	558	28.95
Myctophidae larvae	1	1.32
Notolepis coatsi	10	9.21
Notolepis spp.	3	2.63
Nototheniidae spp.	4	5.26
Nototheniops nudifrons	31	5.26
Pagetopsis maculatus	2	2.63
Pagetopsis spp.	2	2.63
Parachaenichthys charcoti	4	1.32
Pleuragramma antarcticum	111	17.11
Pogonophryne marmorata	1	1.32
Racovitzia glacialis	3	2.63
Trematomus newnesi	7	1.32
Trematomus scotti	74	23.68
Unident. fish larvae	20	2.63
Total	1,226	

light hours to better understand the vertical migratory patterns in the AMLR study region. During this field season, the Tucker Trawl was deployed to depths considerably more shallow than what was intended (approximately 600 m), primarily due to technical difficulties with the cable. Fishing at greater depths for all hauls will improve sampling of mesopelagic fish, and will enable collection of a broader range of mesopelagic species and better elucidation of their relationships to mesozooplankton.

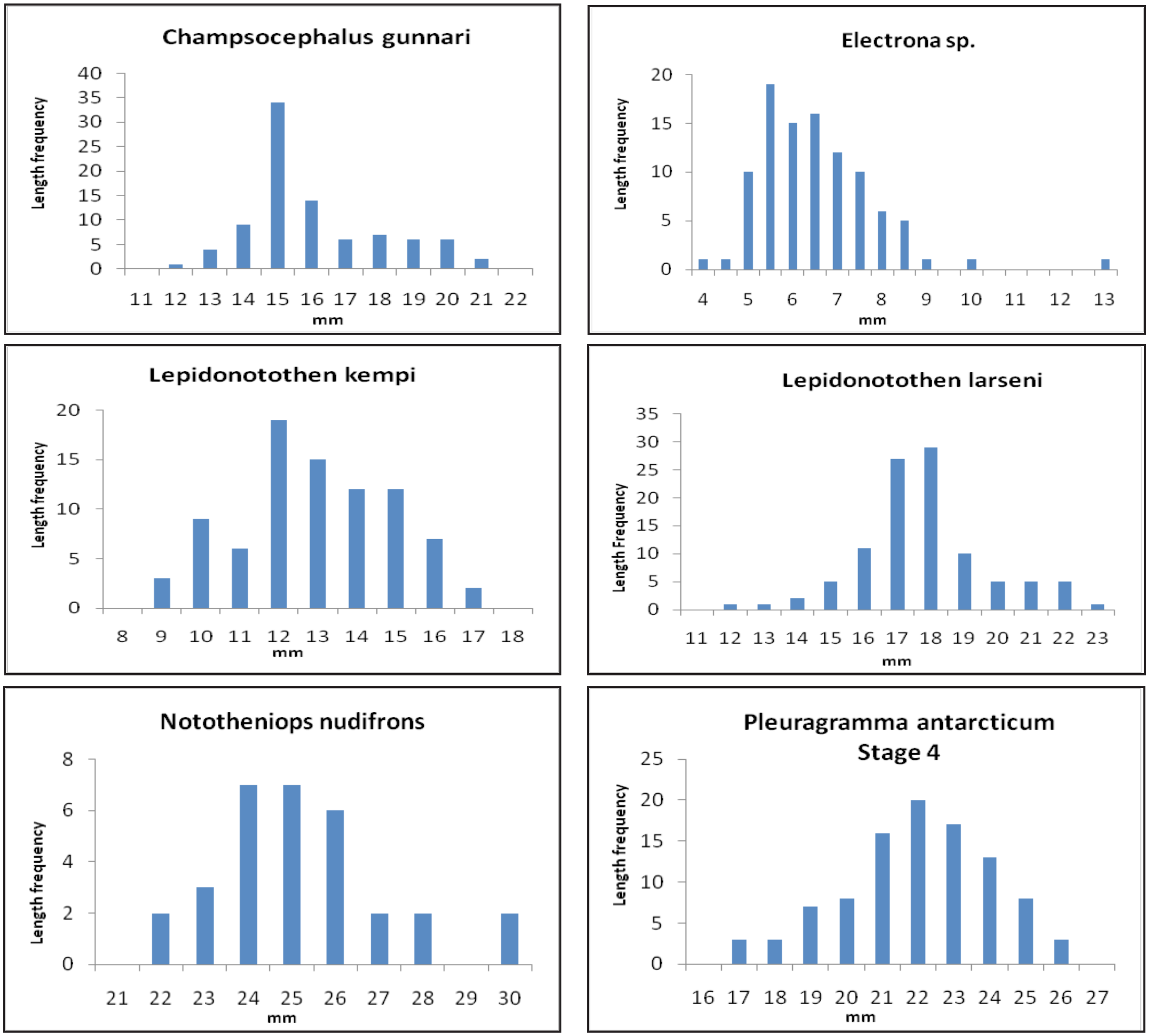
With respect to larval fish, some small changes to the

Table 5.6. Number of juveniles/transforming stages collected.

Species	Number collected
Bathylagus spp.	3
Chaenodraco wilsoni	2
Chionodraco rastrospinosus	7
Cryodraco antarcticus	4
Notolepis spp.	2
Nototheniidae spp.	1
Parachaenichthys charcoti	4
Pleuragramma antarcticum	8
Pogonophryne marmorata	1

Table 5.7. Minimum, maximum, and average standard lengths (with standard deviation) of fish larvae (SL = standard length).

Species	Min SL (mm)	Max SL (mm)	Average SL (mm)	St. dev SL (mm)
Bathylagus spp.	17	49	31.25	13.22
Bathylagus antarcticus	11.3	11.3		
Chaenodraco wilsoni	56	69	62.5	9.19
Champsocephalus gunnari	12	21.2	16.23	2.04
Chionodraco rastrospinosus	40	72	54.3	9.62
Cryodraco antarcticus	87	107	100.75	9.46
Electrona antarctica	8.6	15.3	11.35	2.89
Electrona spp.	4.44	13	6.82	1.21
Gobionothen gibberifrons	26.5	26.5		
Lepidonotothen kempi	9.4	17.2	13.16	1.89
Lepidonotothen larseni	12.4	23	17.86	1.92
Nothteniidae juv.	71	71		
Notolepis coatsi	12.3	42	26.89	10.17
Notolepis spp.	65	65		
Nototheniidae unid.	13.1	13.1		
Nototheniops nudifrons	22	30.2	25.23	1.99
Pagetopsis maculatus	17	17		
Pagetopsis spp.	19	22	20.5	2.12
Parachaenichthys charcoti	52.8	58.7	54.475	2.83
Pleuragramma antarcticum	17.7	72	25.07	10.87
Pogonophryne marmorata	31.2	31.2		
Racovitzia glacialis	20.6	24	22.27	1.7
Trematomus newnesi	34.5	39.7	37.27	2.14
Trematomus scotti	11.7	20	15.7	2.03



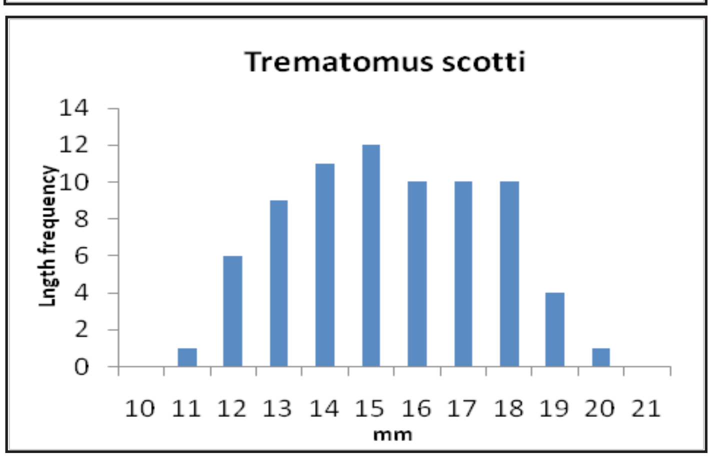


Figure 5.11. Length-frequency distributions for the most abundant fish larvae.

protocol of zooplankton sampling would reduce underestimation of fish larvae. As for krill, samples should be processed whole for fish larvae presence or an increased subsample volume should be considered. When there is a great abundance of *Salpa thompsoni* it could be tedious, but in some occasions species not found in the subsample were instead found in the rest of the sample, within the same net.

Protocol Deviations

This was the first year that a pelagic fish survey was

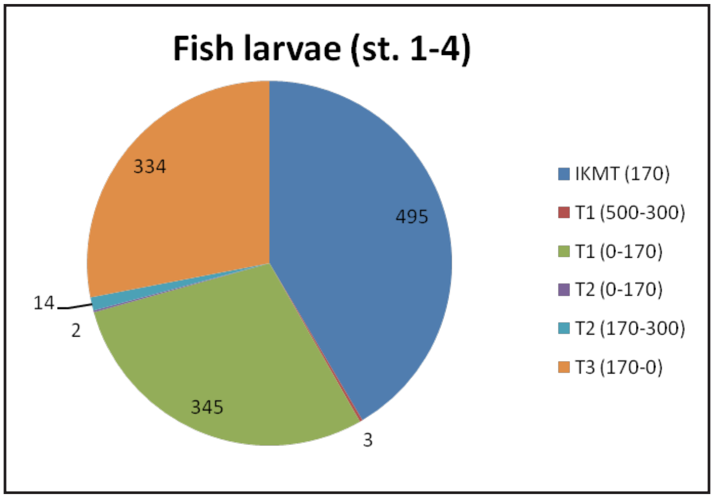


Figure 5.12. Catch comparison per net type of fish larvae stage of development 1-4. Numbers in parentheses indicate the depths in meters at which the nets were towed, and the numbers in the figure are the numbers of larvae caught.

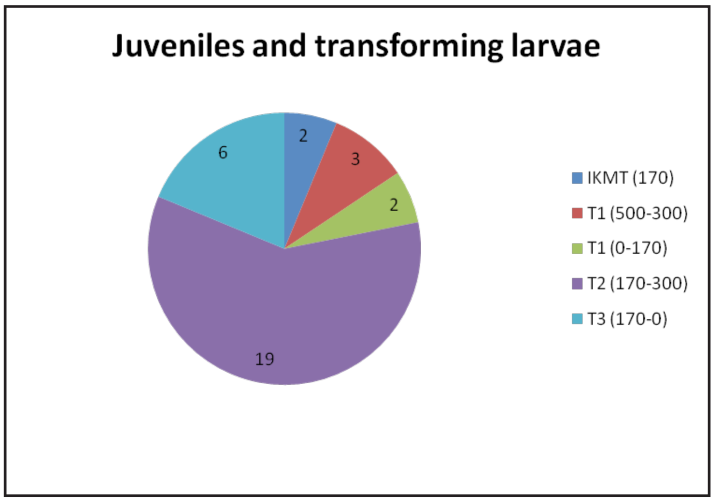


Figure 5.13. Catch comparison per net type of juvenile fish and transforming larvae. Numbers in parentheses indicate the depths in meters at which the nets were towed, and the numbers in the figure are the numbers of larvae caught.

completed by the U.S. AMLR Program. As such, the sampling protocol is still in development. However, this year the protocol was designed for sampling to approximately 600 m using the Tucker Trawl; poor weather conditions and a faulty cable prevented sampling to this depth. Most samples were collected in tows done at 300 m depth, with a few samples collected as deep as 500 m.

Disposition of Data

Data are available from Christopher Jones, NOAA Fisheries, Antarctic Ecosystem Research Division, 8901 La Jolla Shores Dr., La Jolla, CA 92037. Ph: 858-546-5605, Fax: 858-546-7003.

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Seabird Research at Admiralty Bay, King George Island, Antarctica

Susan G. Trivelpiece, Alexis Will, Kristen Boysen, Penelope Chilton, and Wayne Z. Trivelpiece

Abstract

Land-based seabird data were collected between October 2010 and March 2011 at the Admiralty Bay penguin colonies. Main results include:

- Populations of Adélie, gentoo, and chinstrap penguins experienced 20-32% increases in numbers relative to the 2009/10 season. However, these increases were largely a rebound from the abnormally low counts in the prior year, when heavy snowfall precluded breeding by all penguin species in our colonies;
- Mean fledgling masses of Adélie (3330 ± 284 g, n = 153) and gentoo (4989 ± 579 g, n = 100) penguins were the highest in 20 years; and
- All skua pairs had much higher breeding success in the 2010/11 season than their long-term means, with south polar and hybridizing pairs fledging about twice as many chicks per pair in 2010/11 as they fledged per year over the last decade of study.

Introduction

The U.S. Antarctic Marine Living Resources (AMLR) Program completed its 15th field season of joint NSF/AMLR land-based seabird research at the Copacabana (Copa) Field Camp on King George Island, Antarctica (62º 10'S, 58º 30'W), during the austral summer of 2010/11. The western shore of Admiralty Bay is an Antarctic Specially Protected Area (ASPA #128) and long-term monitoring of predator populations are conducted there in support of U.S. participation in the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR).

The objectives of the seabird research program for the 2010/11 season were to collect the following long-term monitoring data (CCAMLR 2004):

1. To estimate Adélie (*Pygoscelis adeliae*), chinstrap (*P. antarctica*), and gentoo (*P. papua*) penguin breeding population sizes (CCAMLR Ecosystem Monitoring Program (CEMP) Standard Method A3);
2. To band 250 Adélie and 250 gentoo penguin chicks for demography studies (CEMP Std. Method A4);
3. To determine Adélie and gentoo penguin foraging trip durations during the chick-rearing stage of the reproductive cycle (CEMP Std. Method A5);
4. To determine Adélie, chinstrap, and gentoo penguin breeding success (CEMP Std. Methods A6a, b, & c);
5. To determine Adélie and gentoo penguin chick weights at fledging (CEMP Std. Method A7c);
6. To determine gentoo and chinstrap penguin diet compositions, meal sizes, and krill length–frequency distributions (CEMP Std. Methods A8a, b, and c); and
7. To determine Adélie and gentoo penguin breeding chronologies (CEMP Std. Method A9).

Methods

We arrived at Admiralty Bay on 9 October 2010 via the National Science Foundation's ARSV *Laurence M. Gould*. We conducted research until we closed camp on 9 March 2011. The AMLR-chartered R/V *Moana Wave* provided logistical support and transit back to Punta Arenas, Chile, at the field season's conclusion.

Breeding Biology

We conducted nest censuses for Adélie penguins on 5 November 2010, for gentoo penguins on 1 November 2010, and for chinstrap penguins on 29 November 2010. Chick censuses were conducted for Adélie penguins on 5 January 2011, for gentoo penguins between 5 and 12 January 2011, and for chinstrap penguins on 3 February 2011. All chick census dates were approximately one week after mean crèche for each species. The range of dates for the counts for gentoo penguin chicks was due to the asynchrony in chick crèche dates among the different breeding groups within the colony.

Detailed reproductive success was measured by following 100 banded pairs of breeding Adélie penguins and 100 pairs of gentoo penguins that had one member of each pair banded. These nests were followed from clutch initiation through crèche formation (Std. Methods 6b). In addition, all known-age penguins that initiated clutches were also followed to crèche. Chick mortality is typically low after reaching crèche age, thus these numbers were also used to estimate fledging success.

A sample of 250 Adélie and 250 gentoo 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 weights were collected from Adélie and gentoo penguin chicks as a measure of chick condition. Banded Adélie penguin chicks from the demography study were captured on the beach as they were about to fledge and weighed to the nearest 25 g with hand-held Pesola scales. A non-banded Adélie chick was also captured and weighed at the same location and time to increase sample sizes. Gentoo penguin chicks are provisioned by their parents after they begin making trips to sea, so it is not possible to obtain definitive fledging weights by catching and weighing chicks prior to departure. Instead, gentoo penguin chicks were weighed 85 days after their mean clutch initiation date, at approximately the age when other *Pygoscelis* chicks fledge.

Foraging Ecology Studies

Diet samples were collected from 30 gentoo and ten chinstrap penguins between 20 December 2010 and 3 February 2011. Adults were captured at their nest sites upon returning from foraging trips, to assure they were feeding chicks, and the stomach contents were collected using the wet-offloading technique (Wilson 1984). Full stomach loads were collected from chinstrap penguins. However, for gentoo penguins, samples were confined to the fresh portion of the stomach samples only to avoid undue stress associated with handling these larger birds. A sub-sample of 50 individual Antarctic krill from each diet sample was measured and sexed to determine length and sex frequency distributions of the krill selected by foraging penguins.

Radio transmitters were deployed on 13 Adélie and 20 gentoo penguins during the chick-rearing phase in order to determine their foraging trip durations. Colony attendance was logged between 24 December 2010 and 8 February 2011 using a remote receiver and data collection logger.

Gentoo and chinstrap penguins were instrumented with satellite transmitters (PTTs) to provide geographic data on adult foraging locations during the chick-rearing period. A total of 14 PTTs were applied to gentoo penguins during three separate deployments between 4 January and 15 February; the first deployment was during the brood stage, the remaining two deployments during the crèche phase. Five PTTs were deployed on chinstrap penguins on 26 January 2011, during their chick crèche stage. Two of the instruments were recovered seven and ten days later, while the other three PTTs were not recovered and will continue to provide us with novel information about the foraging areas used by chinstrap penguins post-chick rearing, when they are at sea acquiring food in preparation for their annual molting fast in late February. The PTT data are awaiting analysis.

Other Seabirds

The reproductive success of brown (*Catharacta antarctica lonnbergi*), south polar (*C. maccormicki*), and hybridizing skua pairs breeding along the western shore of Admiralty Bay was followed over the course of the summer season via weekly surveys and nest checks. The reproductive performance of southern giant petrels (*Macronectes giganteus*) was also followed over the austral season via nest checks following egg laying and chick hatching, and a final nest check in late February when all surviving giant petrel chicks were banded in their natal colonies.

Diets of the at-sea foraging south polar and hybrid skua pairs were followed by collecting fecal samples, which will be sorted later for evidence of fish and other prey species. These samples were collected four times during the breeding season on the skuas nesting territories; once each during courtship and incubation and twice during the chick-rearing period. All skua reproductive data await analysis and the fecal samples have been sent to Pomona College, where they will be sorted and analyzed by Dr. N. Karnovsky as part of an ongoing collaboration.

Early Season Studies

Upon arrival at the field camp on 9 October, we found the Norwegian (Aker Marine) krill fishing vessel, *Saga Sea*, trawling for krill in Admiralty Bay and learned that they had been fishing in this vicinity for the past three weeks. The following day, the fishery was closed because the provisional krill catch-limit was reached. In response to this unanticipated event, we collected 10 early season diet samples from foraging, pre-breeding gentoo penguins and analyzed these samples as per the chick-phase samples: the samples were sorted for prey types and 50 krill were selected from the fresh contents of each stomach and sexed and measured to the nearest 1 mm in length. We also attached PTTs to five female Adélie penguins prior to their first departures to sea following clutch completion. The PTTs were deployed between 27 October and 2 November 2010 and retrieved in mid-November when the females returned to their respective nest sites to relieve the males that were incubating the eggs.

Results

Breeding Biology Studies

The penguin colony at Copa consists of a dozen Adélie and many loosely defined gentoo penguin sub-colonies. In addition, there are several nesting chinstrap penguin pairs that usually breed within one of the Adélie penguin sub-colonies. There are additional colonies of chinstrap penguins at three other locations along the western shore of Admiralty Bay: the DeMay, Uchatka, and Patelnia colonies. There were 2793 Adélie penguin breeding pairs at the Copa colony and 5330 pairs at the nearby Pt. Thomas colony in 2010/11. The Copa colony Adélie penguin count increased almost 700 pairs above the census figures from the 2009/10 season, a 32% increase from last year. Gentoo penguins at Copa began breeding in October, even before the Adélie penguins in some areas. A total of 4814 gentoo penguin nests were counted in 2010/11, an increase of 1325 nesting pairs from the previous year. Interestingly, in spite of the traditional beach colony nesting areas being snow-free in October 2010 when we arrived, gentoo penguins that moved to new, higher ground last season (2009/10) in response to the deep snow on the beach areas returned to these new, higher sub-colonies in 2010 and bred there. A total of 1017 chinstrap penguin nests were counted in the three colonies along the western shore of Admiralty Bay, an increase of nearly 200 pairs following the decline reported in the prior season. (Figure 6.1).

The Adélie penguin chick count was 2755 at Copa and 4982 at the Pt. Thomas colony, the gentoo penguin chick count was 5773, and the cumulative chinstrap penguin chick count from the three colonies we surveyed was 944. Based on census data, Adélie penguins fledged 0.99 chicks per breeding pair at Copa and 0.94 chicks per pair at Pt. Thomas. Gentoo penguins fledged 1.20 chicks per pair, while chinstrap penguins had a fledging success of 0.93 chicks per pair, similar to the overall Adélie penguin rate of 0.95 chicks per pair.

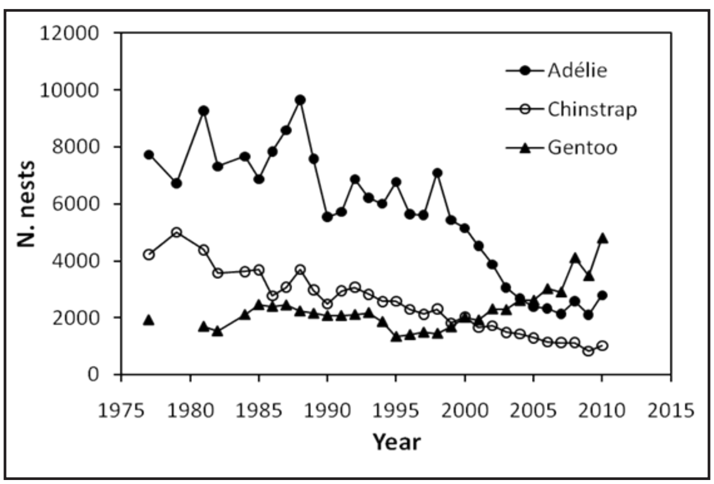

Figure 6.1. Long-term trends (1977-2011) in Adélie, gentoo and chinstrap penguin populations in Admiralty Bay, King George Island, South Shetland Islands, Antarctica.

Based on the banded sample of 100 nesting pairs in the reproductive study, Adélie penguins fledged 1.19 chicks per pair, 20% above the estimate derived from the census data and the highest reproductive success for Adélie penguins in the last decade of study. Gentoo penguins in the reproductive study fledged 1.27 chicks per pair (versus 1.20 from the census data). The high reproductive success observed, relative to the long-term mean for Adélie penguins, was most likely due to the low percentage of egg loss during the incubation period. Adélie penguins hatched 1.50 chicks per pair, suggesting they arrived in good condition and had favorable foraging success in the early spring following clutch completion. We do not follow chinstrap penguins on a daily basis, as their colonies are located 6-10 km from our primary study site.

Thirty-two known-age Adélie penguins (4 – 9 years of age), including 11 first-time breeding four-year-olds, fledged 0.71 chicks per pair this season, a vast improvement over the 0.17 chicks per pair produced by 23 similarly aged Adélie penguins in 2009/10. However, when data analysis was limited to just first-time, four-year-old breeders, reproductive success declined to only 0.45 chicks fledged per pair. This season, 87 known-age gentoo penguins were breeding in the colony, including 21 that bred for the first time. Breeding success among all known-age gentoo penguins was 1.17 chicks fledged per pair, slightly lower than the reproductive success of the banded population success rate of 1.27. This was primarily due to the lower reproductive success of the first-time breeding birds, which constituted approximately 25% of the known-age population and had a breeding success rate of only 0.52 chicks fledged per pair; similar to the success rate of the inexperienced Adélie penguins.

The mean fledging mass for Adélie penguin chicks in 2010/11 was 3330 ± 284 g (n = 153). This was 449 g (15.5%) heavier than last year's mean fledging mass of 2881 g and was the highest fledging mass for Adélie penguin chicks in the last 20 years A similar result was found in the fledging mass of gentoo penguin chicks this year. Gentoo penguin chicks were weighed on 20 February 2011 and had an average mass of 4989 ± 579 g (n = 100). This is the highest fledging mass since we began recording this parameter in 1997/98 and is more than 500 g above the previous 12-year mean (Figure 6.2).

Foraging Ecology Studies

Antarctic krill (*Euphausia superba*) was present in all

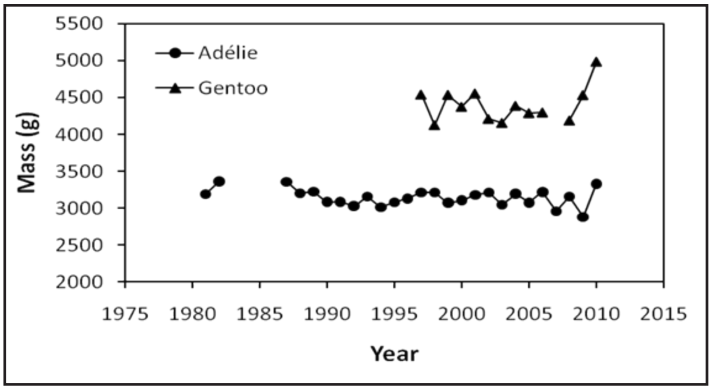

Figure 6.2. Annual mean fledgling weights (± 95% CI) for Adélie and gentoo penguin chicks at Admiralty Bay, King George Island, Antarctica 2010/11.

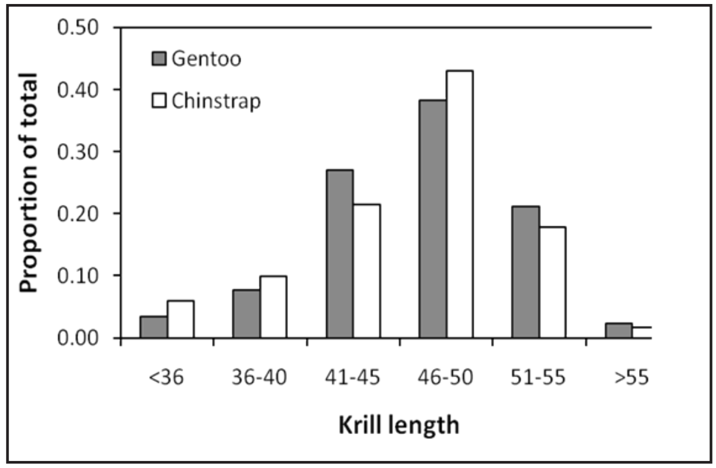

Figure 6.3. Krill length-frequency distribution from gentoo and chinstrap penguin diets at Admiralty Bay, King George Island, Antarctica in 2010/11.

stomach samples and comprised the majority of the diet in all 40 samples collected from gentoo and chinstrap penguins during their respective chick-rearing phases of the breeding cycle. *Thysanoessa macrura* was found in one of the 10 stomach samples collected from chinstrap penguins, but was not seen in any of the 30 gentoo penguin stomach samples. Gentoo penguins had evidence of fish in their diets (e.g., otoliths, scales, and hard parts) in five of the 30 samples, although only one of the five samples had more than trace amounts of fish. Chinstrap penguins also had evidence of fish in their diets in five of the 10 samples, but in each case, this was limited to just one to three otoliths per stomach sample, with no measureable amounts of fish tissue in any sample. Amphipods were also found in the stomach samples of gentoo penguins, but represented less than 0.1% of all prey items. Chinstrap penguin mean stomach mass was 638 g, 70 g greater than last season's mean stomach mass and nearly 50 g heavier than the long-term mean for this species.

The mean krill size in gentoo penguin stomach samples was 47.5 mm, slightly larger than the mean chinstrap penguin krill size of 46.2 mm. Of the krill eaten by the two species, 65% were between 41-50 mm in length, with 23% greater than 51 mm in length. Krill sex ratios in the diets of both gentoo and chinstrap penguins were similar; 55.2% of the krill were female, 40.4% were male, and 4.4% juvenile (Figure 6.3).

Due to an oversight in our ACA permit request, we reached the requested number of adult Adélie penguin "takes" prior to the beginning of the diets study and could not amend the permit request in time to collect diet samples in 2010/11. In addition, we also were unable to examine foraging trip locations in Adélie penguins using satellite tags (PTTs). However, we did put radio transmitters on 13 Adélie penguins feeding chicks shortly after chick hatching and were able to document foraging trip durations throughout the chick rearing period. Mean Adélie penguin foraging trip durations were 14.8 ± 2.3 hours (n = 13). This was less than the mean 17.5 hour foraging trips made by Adélie penguins in 2008/09 and 2009/10, but still an hour longer than the mean 13.6 hour trips made between 2005/06 and 2007/08. These results for Adélie trip lengths should be considered preliminary until we can check our daily logbooks to confirm these birds were not seen during several long (24 hours or longer) foraging trips during daily nest checks. In addition, we placed radio transmitters on gentoo penguins for the first time. Gentoo penguins spent an average of 12.4 ± 1.9 hours (n = 20) foraging at sea while provisioning chicks. This was two hours less than was spent by Adélie penguins foraging at this same time; however, this is the first year we have collected data on gentoo penguin foraging trip durations and thus have no historical data with which to compare this season for the gentoo penguin.

Other Seabirds

Brown skua pairs fledged a mean of 1.07 chicks per breeding pair, south polar skuas fledged 1.27 chicks per pair, and hybrid skua pairs had the highest reproductive success with a fledging rate of 1.3 chicks per pair. All skua pairs had much higher breeding success in the 2010/11 season than their long-term means, with south polar and hybridizing pairs fledging about twice as many chicks per pair in 2010/11 as they fledged per year over the last decade of study. This high productivity was likely due to an abundance of silverfish (*Pleuragramma antarcticum*) in Admiralty Bay and the nearby Bransfield Strait. We found large numbers of fresh silverfish lying around on many skua nesting territories in January and February 2011, meaning they had collected more than they or their chicks could eat. One territory had 240 fresh fish on the territory and another had 165 fish during a single weekly visit (Figure 6.4). We have rarely witnessed this phenomenon over the last three decades.

The southern giant petrel (*Macronectes giganteus*) population has been expanding recently at our study site and many known-age birds have returned to breed in the colonies. However, the 2010/11 season saw a decline of approximately 20% in the number of breeding pairs that laid an egg, relative to last season. In contrast to the decrease in breeding attempts, those pairs that did breed raised a mean 0.71 chicks fledged per pair in 2010/11, slightly above the long-term average of 0.67.

Early Season Studies

Upon discovering the krill fishing ship, *Saga Sea*, trawling in Admiralty Bay in early October, we collected diets samples from 10 pre-breeding gentoo penguins that were making daily feeding trips to sea at that time, and we placed satellite tags (PTTS) on five female Adélie penguins with completed clutches and tracked them during their first foraging trip to sea in late October. All stomach samples had 100% krill in them by mass, while two of the 10 individuals had trace amounts of fish. Measurements of individual krill consumed by the gentoo penguins found 75% of the krill in the 41-50 mm size range with approximately equal sex ratios. Examinations of the satellite-tagged Adélie penguin females' tracks are under analysis. However, preliminary examination of the PTT tracks revealed that only one penguin remained in the vicinity of King George Island, foraging in the mouth of Admiralty Bay and King George Bay to the NE, while the other four tagged birds went across the Bransfield Strait to the Western Antarctic Peninsula region or into the upper Weddell Sea. These latter trips are the normal patterns seen in earlier tracked birds at this time of year (Trivelpiece, unpublished data).

Figure 6.4. Regurgitated Antarctic silverfish (*Pleurogramma antarcticum*) remains on a south polar skua breeding territory. This phenomenon, which is rare and only documented a few times in the last 30 years, was seen on many territories in 2010/11, a year of high skua breeding success.

Discussion

This season marked the 35th anniversary of the onset of seabird studies in Admiralty Bay in 1976. This research has been focused at the Copacabana colony since 1984 and has allowed us to assess trends in penguin demography, breeding biology, and foraging ecology among the three sympatric *Pygoscelis* species.

Breeding population counts were significantly higher for all three penguin species in 2010/11. The increase in breeding numbers is largely a reflection of a rebound by breeders that abandoned breeding attempts due to unusually high snow deposition in the colonies in 2009/10. Reproductive success for Adélie penguins was well above their long-term mean and the highest success rate in more than 20 years. These results were likely due to a very high krill biomass in Admiralty Bay in the early season and to the warm snow-free spring that allowed Adélie penguins to begin breeding earlier than usual in October. The Adélie penguin population counts increased 32% over the number of breeding pairs in 2009/10; however, much of the increase can be attributed to a return to more normal conditions and breeding attempts following the very cold, snowy 2009/10 season when large numbers of Adélie penguins deserted their nesting attempts due to snow covering their nest sites well into December 2009.

Reproductive success among the banded sample of Adélie penguins was the highest in a decade and considerably higher than the estimate of breeding success derived from the census data. The higher estimates of chick production from the individually monitored nests may be due to selecting only breeding birds to follow in the reproductive study while the census data likely included young birds (pairs) that did not reproduce, yet were occupying nest sites at the time of the census in the colony. It is normal for many young pre-breeding-age Adelie penguins to migrate to their natal colonies in the spring when conditions are favorable (Trivelpiece et al. 2011). All indicators suggest this was such a season and the presence of these young penguins in the census data, but not in the breeding population, is the most likely explanation for the lower breeding success estimates derived from census counts.

Fledging weights of Adélie penguin chicks also reflected the abundance of krill in the local area, with chick fledging masses at the highest levels we have recorded in 20 years. These results are in sharp contrast to the fledging masses of chicks last season, when we recorded the lowest ever fledging weights since we began measuring this parameter in 1981. Moreover, this season reverses a trend in declining masses of chicks at fledging that has been evident since 2005.

Diet composition for gentoo and chinstrap penguins was comparable to previous seasons, with krill accounting for the majority of prey biomass. However, Adélie penguins were not sampled in 2010/11 and thus we have no corollary data on food loads, prey composition, or krill size for Adélie penguins in 2010/11. Gentoo and chinstrap penguin diets were similar to past years, with krill in the 41-50 mm size range accounting for 65% of all krill in the diets. Krill sex ratios among all penguin samples were similar and exhibited a familiar trend towards more female krill found in the samples than male krill (55.2% vs. 40.4%, respectively).

The mean foraging trip duration of Adélie penguins (14.4 h) was approximately the same as the long-term mean for this species, but about three hours less than the 17-plus hour trip lengths of the last two seasons. Gentoo penguin foraging trips were two hours less than the trips of Adélie penguins this season, but as this was the first season of data collected on this parameter for gentoo penguins, we have no reference point for comparisons to other years.

Protocol Deviations

Adélie penguin diet samples were not collected in 2010/11 due to permit restrictions. Likewise, we were not able to track Adélie penguin foraging trips to sea during the chick-rearing period. We added gentoo penguin foraging trip duration data collection to our normal suite of predator parameters in 2010/11 and plan to continue this in future years.

Disposition of Data

Land-based seabird data are available from Dr. Wayne Trivelpiece, NOAA Fisheries, Antarctic Ecosystem Research Division, 8901 La Jolla Shores Dr., La Jolla, CA 92037. Ph: 858-546-5607, Fax: 858-546-7003.

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Seabird Research at Cape Shirreff, Livingston Island, Antarctica

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Abstract

Land-based seabird data were collected during the 14th consecutive Antarctic breeding season at Cape Shirreff, Livingston Island. Main results include:

- The chinstrap population was estimated at 4127 nests, a 5% decrease from last year and 46% lower than the 15-year high of 7744 which occurred in the 1999/00 season;
- Mean fledgling masses of gentoo (4,971 ± 687.75 g, n = 175) and chinstrap penguins (3233 ± 313 g, n = 327) were higher than their respective long term means; and
- *Euphausia superba* was the main component of the penguin diet, but fish remains were identified in 90% of gentoo penguin diets and 33% of chinstrap penguin diets.

Introduction

The U.S. Antarctic Marine Living Resources (AMLR) Program conducted its fourteenth consecutive 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 2010/11. Cape Shirreff is a Site of Special Scientific Interest and long-term monitoring of predator populations are conducted in support of U.S. participation in the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR).

We arrived at Cape Shirreff on 3 November 2010 via the National Science Foundation vessel R/V *Laurence M. Gould* and conducted research until camp was closed on 10 March 2011. The AMLR chartered vessel R/V *Moana Wave* provided logistical support for camp closure and transit back to Punta Arenas, Chile. The objectives of the seabird research program for the 2010/11 season were to collect the following long-term monitoring data (CCAMLR 2004):

1. To estimate chinstrap (*Pygoscelis antarctica*) and gentoo penguin (*P. papua*) breeding population size (Standard Method A3);
2. To band 250 chinstrap and 200 gentoo penguin chicks for demography studies (Std. Method A4);
3. To determine chinstrap and gentoo 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 A6a, b, and c);
5. To determine chinstrap and gentoo penguin chick weights at fledging (Std. Method A7c);
6. To determine chinstrap and gentoo penguin diet composition, meal size, and krill length/frequency distributions (Std. Methods A8a,b&c); and
7. To determine chinstrap and gentoo penguin breeding chronologies (Std. Method A9).

Methods

Breeding biology studies

The penguin rookery at Cape Shirreff consisted of 19 sub-colonies of gentoo and chinstrap penguins during the 2010/11 breeding season. We conducted nest censuses for gentoo penguins on 18 November 2010 and for chinstrap penguins on 27 November 2010, approximately one week after mean clutch initiation for each species. Chick censuses were conducted for gentoo penguins on 25 January 2011 and for chinstrap penguins on 8 February 2011, approximately one week after mean crèche.

Mean reproductive success was estimated from the census data and 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. Nests of known-age penguins that initiated clutches were also monitored during the breeding season and reproductive success was estimated according to Standard Method A6b.

Two hundred gentoo and 250 chinstrap penguin chicks were banded for future demographic studies with uniquely numbered stainless steel flipper bands. The banded chicks that survive and return to the colony as adults will be observed for age-specific survival and reproductive success.

Fledging weights were collected from gentoo and chinstrap penguin chicks as a measure of chick condition prior to their first winter of independence. Chinstrap penguin fledglings were caught on the beaches just before fledging. Gentoo penguin chicks are still provisioned by their parents after they begin making trips to sea, so it is not possible to obtain definitive fledging weights by catching and weighing chicks prior to departure. Alternatively, gentoo penguin chicks are weighed 85 days after their mean clutch initiation date, which is approximately the age when other *Pygoscelis* chicks fledge.

Foraging ecology studies

We collected diet samples from gentoo and chinstrap penguins. Adults were captured at their nest sites after returning from foraging trips, but prior to chick provisioning, to assure they were feeding chicks. Once captured, stomach contents were collected using the wet-offloading technique (Wilson 1984). From each diet sample, a sub-sample of 50 individual Antarctic krill were measured and sexed to determine length and sex frequency distributions of the krill selected by foraging penguins.

To measure foraging trip durations, diving behaviors while foraging, and spatial distributions at sea of foraging penguins, we used three different external electronic tagging technologies. Colony attendance and foraging trip durations were measured with radio telemetry. Radio tags were attached to gentoo penguins on 28 December 2010 and on 2 January 2011 for chinstrap penguins. For both species, the radio signals were recorded through 24 February 2011 using a fixed position remote receiver. Due to a power loss for the remote receiver on 24 January 2011, the telemetry data were analyzed in two batches, one prior to the power loss, and one after the power loss. This method was necessary to eliminate foraging trips that might have been incorrectly classified as greater than 24 hours due to returns and subsequent departures of tagged individuals while the receiver was without power. Once both time periods were analyzed separately, the results were combined for calculation of mean foraging trip durations across the breeding season.

Time-depth recorders (TDRs) were also attached to chinstrap and gentoo penguins to collect penguin diving behavior data during the chick-rearing period. In late December, three TDRs were deployed on gentoo penguins that were brooding chicks. In early January the same three TDRs were retrieved and deployed on chinstrap penguins that were brooding chicks. In late January one TDR was deployed on a gentoo penguin, and in early February two TDRs were deployed on chinstrap penguins during the crèche phase when nests are unattended and both parents forage simultaneously.

We instrumented both species with satellite transmitters (PTTs) to collect geographic data on adult foraging locations during the chick rearing period. Twelve PTTs were deployed, six on gentoo penguins and six on chinstrap penguins in late December and mid-January during the chick brooding phase for each species. During the crèche phase in late January and early February, twelve PTTs were again deployed, six on gentoo penguins and six on chinstrap penguins. The PTTs deployed during the brooding and crèche phase were retrieved after 8-10 days of deployment. We also entered the second year of a study focused on identifying overwinter distributions of gentoo and chinstrap penguins. We therefore deployed 15 PTTs on each species at the end of February to track individual foraging patterns for the duration of winter. At the time of writing, the dive and spatial distribution data are awaiting analysis.

Other seabirds

Reproductive success of the population of brown skuas (*Catharacta lönnbergi*) was estimated using methods similar to those described above for penguins (St. Method A6b). We also measured reproductive success of kelp gulls (*Larus dominicanus*) by counting occupied nests during the incubation period and chicks during the fledging period (St. Methods A6c).

Results

Breeding biology studies

A total of 834 gentoo penguin nests were counted (Figure 1), a 4% increase from last year. This count is 2.2% higher than the previous 13-year average of 816. A total of 4127 chinstrap penguin nests were counted. This is a 5% decrease from last year's census and 46% lower than the 14-year high of 7744. This census continues the general trend of decline in the chinstrap penguin breeding population at Cape Shirreff, while the gentoo population has remained stable.

The census of gentoo penguin chicks was 906 (Figure 1), a 1.1% decrease from the 2009/10 count and 5% lower than the previous 13-year mean. The census of chinstrap penguin

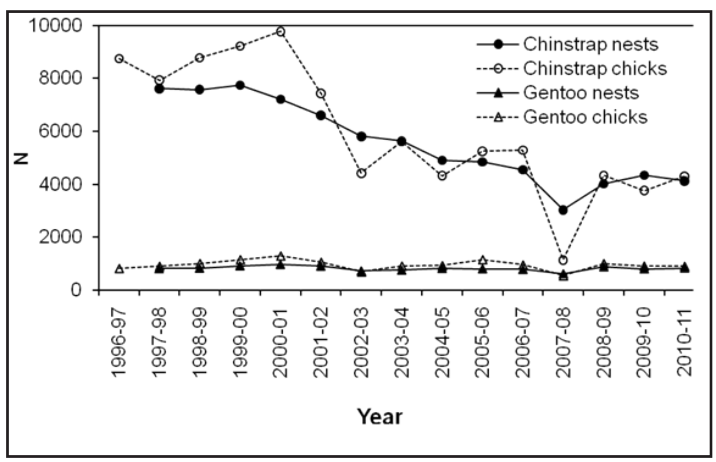

Figure 7. 1. Nest and chick census for gentoo and chinstrap penguins at Cape Shirreff, Livingston Island, Antarctica, 1996/97 to 2010/11.

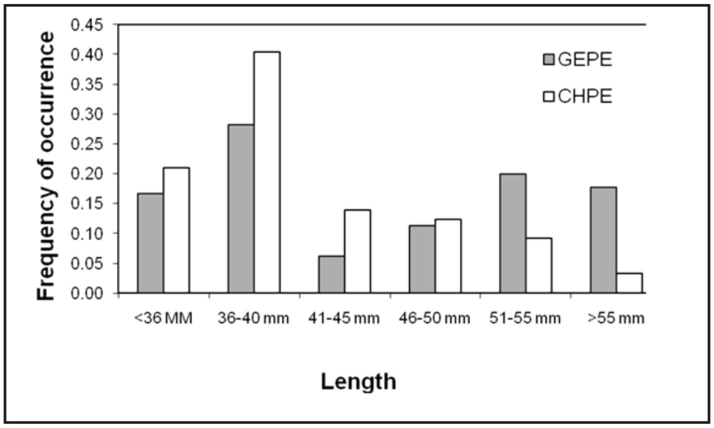

Figure 7.2. Krill length frequency distribution in gentoo and chinstrap penguin diet samples at Cape Shirreff, Livingston Island, Antarctica, 2010/11.

chicks was 4303 (Figure 2), 14% higher than the 2009/10 count and 30% lower than the previous 13-year mean of 6145.

Based on nest and chick census data, overall gentoo penguin reproductive success was 1.09 chicks•nest^{-1}. This is 7% lower than the previous 13-year mean of 1.17 chicks•nest^{-1}. Overall chinstrap penguin fledging success was 1.04 chicks•nest^{-1}. This is 3.4% higher than the previous 13-year mean of 1.01 chicks•nest^{-1}. Based on the reproductive study, gentoo penguins fledged 1.2 chicks•nest^{-1}, 2% lower than the long-term mean (1.22 chicks•nest^{-1}). Based on the reproductive study, chinstrap penguins fledged 1.0 chicks•nest^{-1}, 9% higher than the long-term mean (0.92 chicks•nest^{-1}).

Reproductive success of known-age gentoo penguins (where one member of the pair was of known age) was 0.74 chicks•nest^{-1} (n = 34 nests), while known-age chinstrap penguins also fledged 0.74 chicks•nest^{-1} (n = 61 known-age nests).

A sample of gentoo penguin chicks was weighed on 9 February 2011 and had an average mass of 4971 ± 687.75 g (n = 175). This is 18% higher than the previous 13-year mean. For chinstrap penguins, the fledging period occurred between 15 February and 22 February 2011. The fledglings had an average mass of 3233 ± 313 g (n = 327), 3% higher than the previous 13-year mean of 3144 g.

Foraging ecology studies

Diet samples were collected from 20 gentoo and 40 chinstrap penguins between 3 January and 8 February 2011. Antarctic krill (*Euphausia superba*) was present in all samples and comprised the majority of diet in 93% of samples. Fish remains (bones, otoliths, and flesh), present in 50% of all diets, represented the next largest component of the diet. Invertebrates other than *E. superba* represented <1% of penguin diets.

In gentoo penguin diet samples, 90% contained evidence of fish, higher than the 13-year average of 77% of gentoo diet samples with evidence of fish. Among chinstrap penguins, 33% of diet samples contained evidence of fish, which was also higher than the previous 13-year average of 30%. Identifiable remains of fish represented 22% of the gentoo penguin diet by mass and approximately 1% of the chinstrap penguin diet by mass.

The krill in gentoo penguin diet samples were slightly larger on average (47.6 ± 8.2 mm) than krill in chinstrap penguin samples (42.9 ± 6.3 mm). Large krill (> 50 mm) occurred more frequently in gentoo diets, while smaller krill (< 50 mm) occurred more frequently in chinstrap diets (Figure 2). Overall, penguin diets were composed of 20% juvenile krill (< 36 mm in length), 54% males and 26% females (Figure 3).

The average chick meal mass for chinstrap penguins was 541 g; this is 12% lower than the previous 13-year mean of 615 g. The ratio of fresh to digested portions in the chinstrap penguin diet samples was comparable to the previous 13 seasons. We only collected the fresh portion of diet samples from gentoo penguins, so chick meal mass was not evaluated.

Radio transmitters were deployed on 20 adult chinstrap and 19 adult gentoo penguins during the chick rearing phase. Mean foraging trip duration was 10.9 ± 2.2 hours (n = 20) for chinstraps and 12.1 ± 1.3 hours (n = 19) for gentoos. For chinstraps, mean foraging trip durations were over 2 hours shorter than the previous year.

Other seabirds

The breeding success of all skuas at Cape Shirreff and the adjacent Punta Oeste was monitored. In total, we counted 27 skua pairs holding territories, all of which were brown skuas (*Catharacta antarctica lonnbergi*) except one pair that was likely a pair of hybrid skuas (brown-South Polar skuas (*C. maccormicki*) mix). Clutches were initiated by 20 pairs and 15 chicks were fledged. The measure of

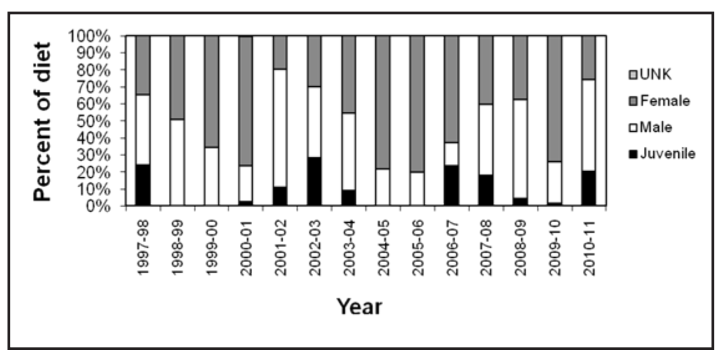

Figure 7. 3. Percent composition of Antarctic krill (*Euphausia superba*) in gentoo and chinstrap penguin diet samples at Cape Shirreff, Livingston Island, Antarctica, 1997/98 to 2010/11.

nest success (0.75 fledglings•pair^{-1}) was 12% higher than the previous 12-year average of 0.67 fledglings•pair^{-1}.

The reproductive performance of kelp gulls (*Larus dominicanus*) nesting on Cape Shirreff was also followed throughout the season. Fifty nests were initiated and overall fledging success was 0.68 fledglings•pair^{-1}.

Discussion

The 14th season of seabird research at Cape Shirreff allowed us to assess trends in penguin population size, as well as inter-annual variation in reproductive success, diet, and foraging behavior.

Breeding population counts of gentoo penguins have remained stable at Cape Shirreff over 14 years of study, while their reproductive success was lower than the long-term mean. Chinstrap penguin populations remain low relative to the long-term mean and, overall, the chinstrap breeding population at Cape Shirreff has declined by 47% from a high in 1999/00. Reproductive success of chinstrap penguins in 2010/11 was higher than the long-term mean and fledging weights for chinstrap and gentoo penguins were above average.

In general, diet composition of both species was dominated by Antarctic krill and was similar to previous seasons. Overall, the diet samples contained a relatively high proportion of male krill and there were similar amounts of juvenile and female krill seen this year. The interpretation of these diet patterns may be aided by analysis of foraging location and diving behavior data.

Acknowledgements

We sincerely thank Ray Buchheit, Kevin Pietrzak, and Nicola Pussini 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 transit to Cape Shirreff and for their help with camp opening, and to the crew of the AMLR chartered research vessel R/V *Moana Wave* 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

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Abstract

Field personnel conducted research on Antarctic fur seals and three species of phocid seals (elephant, leopard and Weddell) at Cape Shirreff, Livingston Island between 3 November 2010 and 9 March 2011. The results of this field season include:

- The estimated number of total fur seal pups born (live plus cumulative dead) for the U.S. AMLR study site in 2010/11 was 1,188 ± 20.1†. Our count this year represents a 14.2% reduction in pup production over last year and the fourth consecutive year of declines > 10.0 per annum;
- The mean foraging trip duration for lactating fur seals' first six trips to sea was 2.29 ± 0.93 days;
- 97.3% of the 110 fur seal scats collected contained krill. In addition, 310 otoliths were collected from 19.1% of scat samples. This represents the lowest number of otoliths collected since monitoring began in 1997/98. Mean krill length in fur seal diet was 47.7 ± 4.2 mm; and
- An estimated 57.7% of fur seal pups were lost to leopard seal predation by 22 Feb; and
- Fourteen adult female fur seals and seven leopard seals were instrumented with ARGOS satellite-linked transmitters for over-winter tracking studies.

Introduction

As upper trophic level predators, pinnipeds are a conspicuous component of the marine ecosystem of the Scotia Sea. They respond to spatio-temporal changes in physical and biological oceanography and, in the case of Antarctic fur seals (*Arctocephalus gazella*), 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 as important "krill-dependent" upper trophic level predators. 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 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, reproductive success, and population dynamics of this species. Southern elephant seals (*Mirounga leonina*) and Weddell seals (*Leptonychotes weddellii*) also use Cape Shirreff for reproduction and hauling out. A growing number of leopard seals (*Hydrurga leptonyx*) also use Cape Shirreff beaches as haul-out sites.

The 2010/11 field season began with the arrival at Cape Shirreff of a five-person field team via the R/V *Laurence M. Gould* on 3 November 2010. Research activities were initiated soon after and continued until closure of the camp on 9 March 2011. Our specific research objectives for the 2010/11 field season were to:

1. Monitor Antarctic fur seal female attendance behavior (time at sea foraging and time ashore attending a pup);
2. Monitor fur seal pup growth by collecting mass measures from a random sample of 100 pups every two weeks throughout the research period, beginning 30 days after the median date of births;
3. Document the phenology of fur seal pup production at designated rookeries and estimate total pup production at Cape Shirreff;
4. Collect and analyze fur seal scat contents on a weekly basis to document trophic interactions and the timing and incidence of prey switching;
5. 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;
6. Deploy time-depth recorders on adult female fur seals for diving and at-sea foraging studies;
7. Record at-sea foraging locations for adult female fur seals using GPS or ARGOS satellite-linked transmitters (with most deployments coinciding with the U.S. AMLR Oceanographic Survey cruises);
8. Tag 500 fur seal pups for future demographic studies;
9. Re-sight tagged known-aged animals

for population demography studies;

10. Monitor over-winter survival and natality of the tagged adult female population of fur seals;
11. Extract a lower post-canine tooth from tagged adult female fur seals for aging studies;
12. Deploy a weather station for continuous recording of wind speed, wind direction, ambient temperature, humidity and barometric pressure during the study period;
13. Record any pinnipeds carrying marine debris (i.e., entanglement);
14. Record any other tagged pinnipeds observed at Cape Shirreff;
15. Monitor pup production of southern elephant seals breeding at Cape Shirreff;
16. Retrieve over-winter CTD-PTT tags from any returning Weddell seals;
17. Deploy over-winter ARGOS PTT instruments on leopard seals for monitoring dispersal and home range; and
18. Deploy ARGOS PTTs and geolocation light sensors on adult female fur seals for over-winter tracking studies.

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 0-2 days postpartum (determined by the presence of a newborn with an umbilicus) from 1-17 December 2010 using VHF radio transmitters (Advanced Telemetry Systems, Inc., Model 7PN with a pulse rate of 40 ppm) according to CCAMLR Standard Method C1.2 Procedure A. Once instrumented, females 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 were 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 two remote VHF receiving stations with automated data collection and storage devices. 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. All mother-pup pairs were successful throughout the first six trips to sea (i.e., all pups survived to their mothers' completion of six trips).

Fur Seal Pup Growth

Measures of fur seal pup growth were collected according to CCAMLR Ecosystem Monitoring Program (CEMP) Standard Method C2.2 Procedure B, with the exception that weights were sampled every 15 days instead of every 30 days. At least 50 pups of each sex were weighed for each sample. The first sample of weights was initiated 30 days after the median date of pupping (6 December 2010) and the last sample was taken 19 February (four bi-weekly samples; collection dates: 6 January, 21 January, 4 February, and 19 February 2011).

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 Cape Shirreff, which comprise the U.S.AMLR study site. Censuses for pups (live and dead) were conducted every other day from 30 October through 31 December. From 3-13 December, live and dead pups were counted each day. Only recently dead pups are counted at each census.

Neonate mortality is defined as pup mortality occurring between the start of the breeding season (approximately 15 November) and up to one month after the median date of pupping (6 January). It occurs before most leopard seal predation, which begins once pups start entering the water at about one month of age (approximately late December/early January). It is measured by recording the number of new pup carcasses on census beaches at each count and calculating a cumulative mortality at each census from the start of births (this year 20 November) until the last births (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 and excluded female/pup pairs whose status was uncertain.

Diet Studies

Information on fur seal diet was collected using three different sampling methods: scat collection, stable isotope analysis of milk and vibrissae, and fatty acid signature analysis of milk. In addition to scats, 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 animals collected at capture, 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 110 scats from 18 December 2010 through 28 February 2011. Diet samples that could not be processed within 24 hours of collection were frozen. All samples were processed by 11 March. Up to 25 krill carapaces were measured from each sample that contained krill. A total of 2,635 krill carapaces were measured according to Goebel et al. 2007. Discriminant equations based on carapace measurements determined sex and age class of krill, after which independent regression equations for juvenile, male, and female lengths were applied (Goebel et al. 2007). Otoliths were sorted, dried, identified to species, and characterized as left or right. Squid beaks were counted, characterized as dorsal or ventral, and preserved in 70% alcohol for later identification.

Fatty Acid Signature Analysis (FASA) of Milk and Stable Isotope Analyses

In addition to scats, we collected 84 milk samples from 60 female fur seals. Each time a female was captured (either to instrument or to remove instruments), ≤ 30 mL of milk were collected by manual expression. Prior to milk collection, 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 each placed in solvent-rinsed glass tubes 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 transesterification of fatty acids.

Once lipid is extracted from milk, the remaining protein fraction is dried for stable isotope analysis. For additional stable isotope analyses, single vibrissae (n = 102) and blood samples (n = 86) were collected from individual female fur seals.

Diving Studies

Twelve of the 30 females outfitted with transmitters for attendance studies also received a time-depth recorder (TDR, Wildlife Computers, Inc., Mark 9: 66 x 18 x 18 mm, 31 g, n = 6; Mk-10-F: 90 x 55 x 29 mm, n = 6) on their first visit to shore. All females carried their TDRs for at least their first six trips to sea. Additionally, five more females were captured for studies of at-sea foraging locations after their first six trips, for a total of 17 females with TDRs. A total of 17 dive records for 120 trips to sea were collected from females in 2010/11. One TDR was lost this season.

Adult Female Foraging Locations

Of the 17 TDRs deployed, 11 were GPS (Global Positioning System) TDRs (Mk10-F; Wildlife Computers, Inc.) with fast-loc technology. A total of 76 trips to sea were recorded with GPS from 8 December 2010 through 23 February 2011. GPS foraging location data were analyzed for three sampling periods (December, January, and February).

Demography and Tagging

We tagged 500 fur seal pups (294 females, 201 males, and five unknown) from 4 February to 6 March 2011. All tags used at Cape Shirreff were Dalton Jumbo Roto tags with white tops and orange bottoms. Each pup was tagged on both fore-flippers with identical numbers. Series numbers for 2010/11 were 7000-7499 (the sex for tags 7150, 7284, 7301, 7462, and 7494 were recorded as unknown). Mother/pup tagged pairs were identified after tagging and 72 (14.4%) tagged pairs were recorded.

In addition to the 500 pups tagged, we also added 23 new tags to the adult female population (479-496; A00-A04).

Age Determination Studies

We began an effort of tooth extraction from adult female fur seals for age determination in 1999/2000. Tooth extractions are made using gas anesthesia (isoflurane, 2.5-5.0%), oxygen (4-10 liters/min), and midazolam hydrochloride (1 cc). A detailed description of the procedure was presented in the 1999/2000 U.S. AMLR Field Season Report. This year we did not take any teeth.

Weather at Cape Shirreff

A weather data recorder (Davis Weather Monitor II) was set up at the Cape Shirreff field camp from 6 November 2010 to 5 March 2011. 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 rope. The debris was successfully removed without capture using a boat hook.

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 2010/11, we instrumented three leopard seals with time depth recorders (TDR, Wildlife Computers; Mk9, 66 x 18 x 18 mm, 31 g). TDRs were attached to an Allflex tag and were deployed without capture. Two were successfully retrieved without recapture and had recorded 29.6 and 31.7 days of dive and haul out behavior. In addition to the dive recorders deployed, seven leopard seals were captured and instrumented with ARGOS-linked transmitters from 17-28 February for over-winter distribution and tracking studies. Vibrissae, nail clippings, blood, and a blubber sample were collected from each seal and mass and standard lengths were recorded.

Other Pinnipeds: Southern Elephant Seals

A daily census of elephant seals at breeding areas on Cape Shirreff was conducted from 7-25 November; thereafter a weekly census was conducted for the entire Cape. In addition, U.S. AMLR personnel captured and weighed 10 of 31 elephant seal pups born at Cape Shirreff. All pups were tagged (Dalton Jumbo Roto tag white/orange; series #: 323-353).

Other Pinnipeds: Weddell Seals

This was the second year of focal studies of Weddell seals by the U.S. AMLR program. Our primary objective for 2010/11 was to retrieve over-winter CTD-PTT instruments deployed on Weddell seals in March 2010. We captured two Weddell seals to retrieve instruments and recovered a third instrument on a beach at Cape Shirreff. A fourth instrument was retrieved from a beach by personnel at King Sejong base on the Barton Peninsula of King George Island.

Twenty-one Weddell seals were tagged without capture at Cape Shirreff in 2010/11 (seven adult females, six adult males, three juvenile males, three male pups and two female pups). All tags were Jumbo roto tags with white tops and yellow bottoms. Only one tag was placed on each animal. Tag series were 018-020, 022-030, and 034-042.

Other Pinnipeds: Weekly Phocid Census

A weekly census of the entire Cape for phocids was conducted beginning 10 November and ended on 15 January. A total of eight censuses were made (a census was not conducted the second and fourth weeks of December). Age class and sex were recorded when possible, without disturbance, for each of four species observed (Southern elephant, Weddell, leopard, and crabeater seals (*Lobodon carcinophagus*)).

†Except where noted, variation is reported as standard deviation.

Results

Female Fur Seal Attendance Behavior

The first female in our attendance study to depart to sea began her foraging cycles on 6 December. All females had completed six trips to sea by 20 January. Only one female lost her pup before completion of six trips to sea. The mean trip duration for the first six trips to sea was 2.29 ± 0.07 days ($n_{females}$ = 30, n_{trips} = 180, range: 0.35-5.94 days). There was no difference among females in duration for the first six trips (ANOVA: $F_{5,162}$ = 1.395, p = 0.004; Figure 8.1). We tested for the effect of carrying a TDR and found no difference (ANOVA: $F_{5,162}$ = 0.29, p = 0.917). Interactive effects were likewise not significant (ANOVA: $F_{10,162}$ = 0.58, p = 0.830).

The mean duration for the first six non-perinatal visits was 1.52 ± 0.12 days ($n_{females}$ = 30, n_{visits} = 150, range: 0.17-3.469 days; Figure 8.1).

An intra-seasonal comparison of foraging trip duration indicated a change in trip duration week seven after the median date of pupping (i.e., the week beginning 16 January). Prior to that week, the weekly mean trip duration was 2.7 ± 0.14 days, but thereafter the mean trip duration increased to 3.5 ± 0.13 days. Trip durations remained on average a day longer after mid-January (ANOVA: $F_{9,300}$ = 10.71, p < 0.001; Figure 8.2).

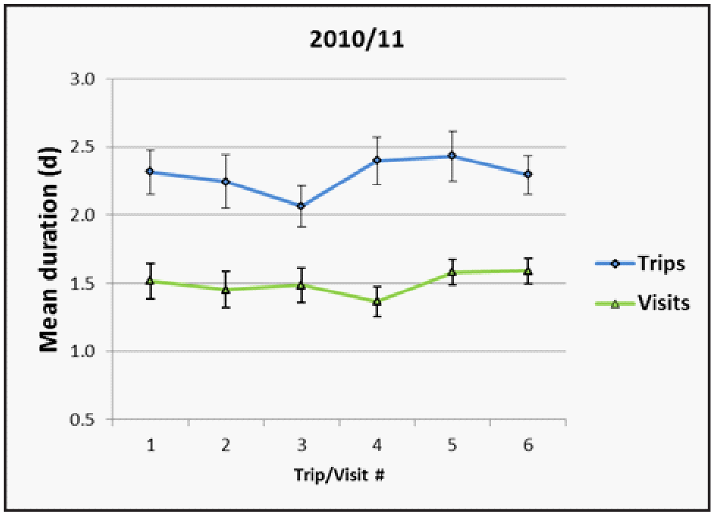

Figure 8.1. Antarctic fur seal mean trip and visit duration (with standard error) for 30 females rearing pups at Cape Shirreff, Livingston Island. Data plotted are for the first six trips to sea and the first six, non-perinatal visits following parturition.

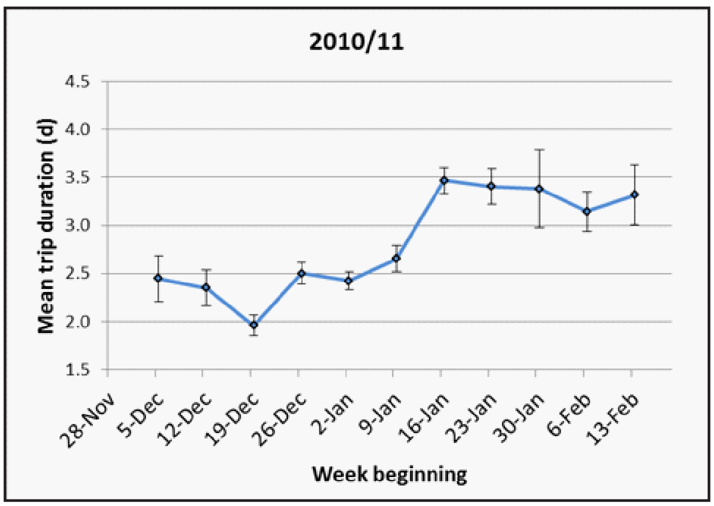

Figure 8.2. Antarctic fur seal weekly mean trip duration (with standard error) for 30 females rearing pups at Cape Shirreff, Livingston Island. Data plotted are all trips to sea for each week starting 7 December 2010.

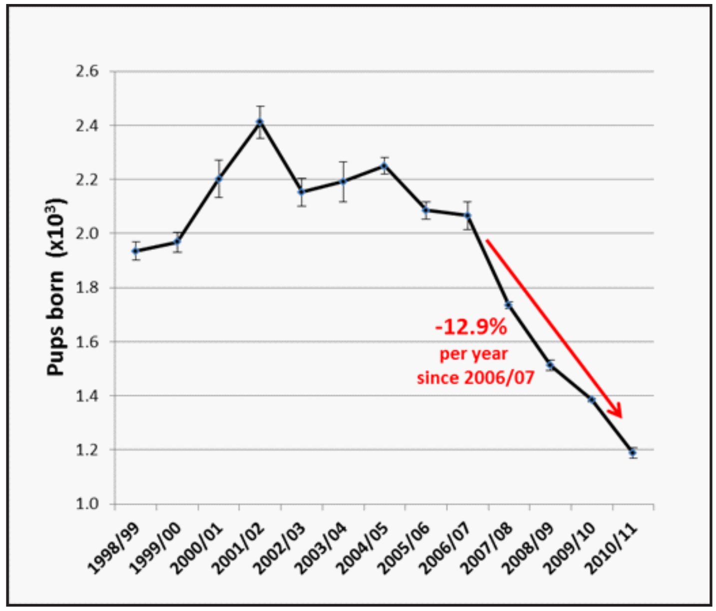

Figure 8.3. Antarctic fur seal pup production on the U.S. AMLR study site at Cape Shirreff from 1998/99 through 2010/11. Counts are a mean of three censuses for live pups taken the last week of December with an adjustment for the cumulative daily count of newly dead pups.

Pup Production and Phenology

The estimated number of pups born (live plus cumulative dead) for the combined four U.S. AMLR study beaches in 2010/11 was 1,188 ± 11.6, based on three counts the last week of December. Our count this year represents a 14.2% reduction in pup production over 2009/10 (Figure 8.3). The average rate of decline since 2006-07 is 12.9% per year. The median date of parturition based upon daily counts of pups was 6 December. The median date of parturition for our tagged female population was 4 December (n = 153).

Pup Growth and Mortality

Throughout the season male fur seal pups grew, on average, 104.7 g per day. Females grew 95.1 g per day (Figure 8.4). Neonate mortality was 3.3%, less than half that of last year (7.6 %). The long-term average (based on thirteen years of data, 1998-2010), is 4.4 ± 0.62%.

Our estimate of pup mortality due to leopard seal predation, calculated 22 February (78 days after the median date of pupping), was based on daily tag resights of mother/pup pairs (n = 147 tagged adult females with pups). By that date, 54.4% of pups were lost to leopard seals.

Fur Seal Diet

Of the 110 scats collected this season, 97.1% contained krill. Only 310 otoliths were collected from 19.1% of scats (Figure 8.5). Mean total length of krill in the diet, calculated from carapace measurements, was 47.7 ± 4.2 mm (n = 2635). Of all krill measured in scat, 4.4% were juveniles (Figure 8.5) and the male:female sex ratio was 2.35. Most otoliths were from *Gymnoscopelus nicholsi* (87.7%, n = 272). *Electrona antarctica* otoliths comprised 2.6% (n = 8), and *Electrona carlsbergi* otoliths comprised 7.1% (n = 22) of the total otoliths collected. An additional 2.6% of otoliths (n = 8) were eroded and unidentified. As in previous years, the incidence of fish in fur seal diet increased over the 10-week sampling period from 19 December to 1 March (Figure 8.6). Only one squid beak was collected (preliminary ID: *Brachioteuthis picta*).

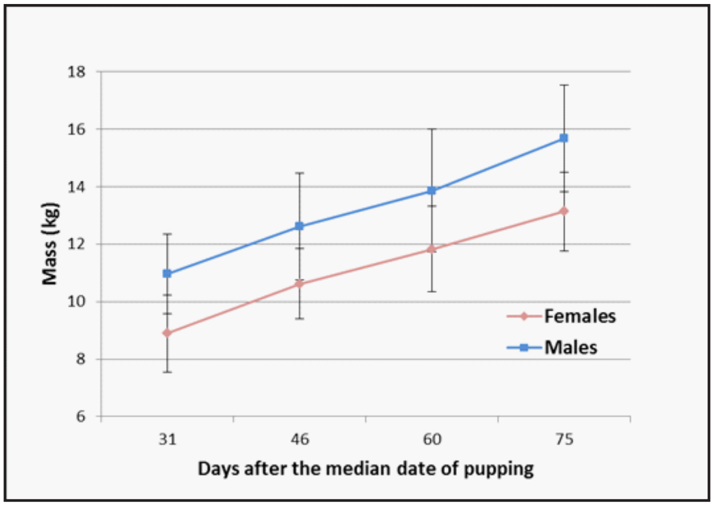

Figure 8.4. Antarctic fur seal pup growth. Four samples of pup weights were collected, every two weeks beginning 30 days after the median date of pupping (6 December 2010).

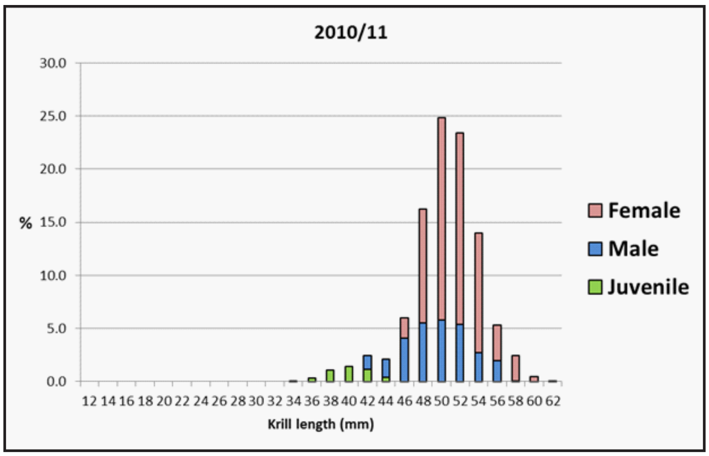

Figure 8.5. Krill length distribution in Antarctic fur seal diet from measures of 2,508 carapaces collected from fur seal scats. Data are derived by sampling 25 krill carapaces from each scat, measuring length and width, applying a discriminant function and independent regression equations for calculating total length of krill. A first order smoothing function is applied to two millimeter length bins.

Adult Female Fur Seal Over-Winter Survival and Natality

There were 192 adult tagged females with parturition sites on the U.S. AMLR study site in 2009/10. Of the 192, 156 (81.3%) returned this year. Of those 156 females, 125 (80.1%) returned pregnant and gave birth; 31 females (19.8%) did not give birth this year.

Adult Female Foraging Locations

A total of 5,039 GPS-derived locations were collected from 76 trips to sea by 11 females carrying Mark10-F TDRs with GPS fast-loc technology. Outliers and bad positions were filtered from the dataset prior to plotting, eliminating 1,399 locations (27.8%). Most of the outliers and bad positions were from six of the 11 female whose instruments appeared to develop problems mid-deployment. Foraging range changed from December through February with females foraging closer to the Cape in the continental shelf region as the season progressed (Figure 8.7).

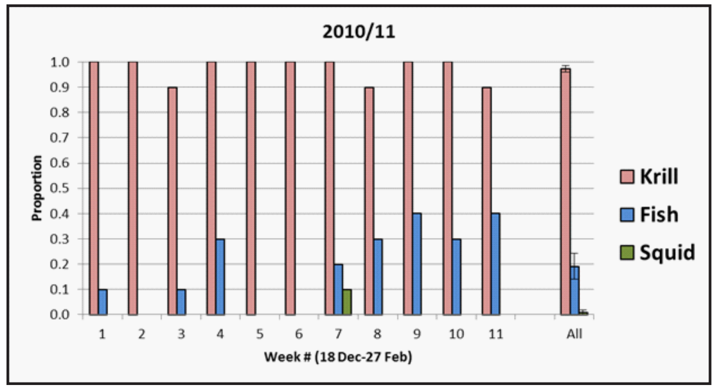

Figure 8.6. The weekly proportions of three types of prey in Antarctic fur seal diet 18 December 2010 – 28 February 2011. The last group of histogram bars is the season average plotted with standard error. Most fish otoliths (94.2%; 292/310) recovered from fur seal scats in 2010-11 were from three species of myctophid fish (*Electrona antarctica*, n = 8; *Electrona carlsbergi*, n = 22; and *Gymnoscopelus nicholsi*, n = 272).

Other Pinnipeds: Southern Elephant Seals

A total of 31 pups were born on Cape Shirreff (no mortalities were recorded) and no pups were born on the small sandy point between Cape Shirreff and Punta Oeste, where in past years some pup production has occurred All but two of the pups were born on Half Moon Bay above the beach. The other two were born on Marko Beach. Sixteen of the pups had already weaned at the time of the first census on 7 November.

Other Pinnipeds: Weekly Phocid Census

The maximum number of southern elephant seals counted in the weekly census of the entire Cape was 221, recorded on 28 December. For Weddell seals the maximum count was 48 on 24 November. The maximum count of leopard seals was 19 recorded on 7 January. Crabeater seals are rarely sighted at Cape Shirreff and the maximum counted at one census was only two.

Discussion

Fur seal pup production in 2010/11 at U.S. AMLR study beaches showed a decline (14%) over the previous year. This is the fourth year of double-digit decline in pup production. The decline suggests poor environmental conditions over-winter or soon after weaning in 2010, but also reflects changing demography as older females

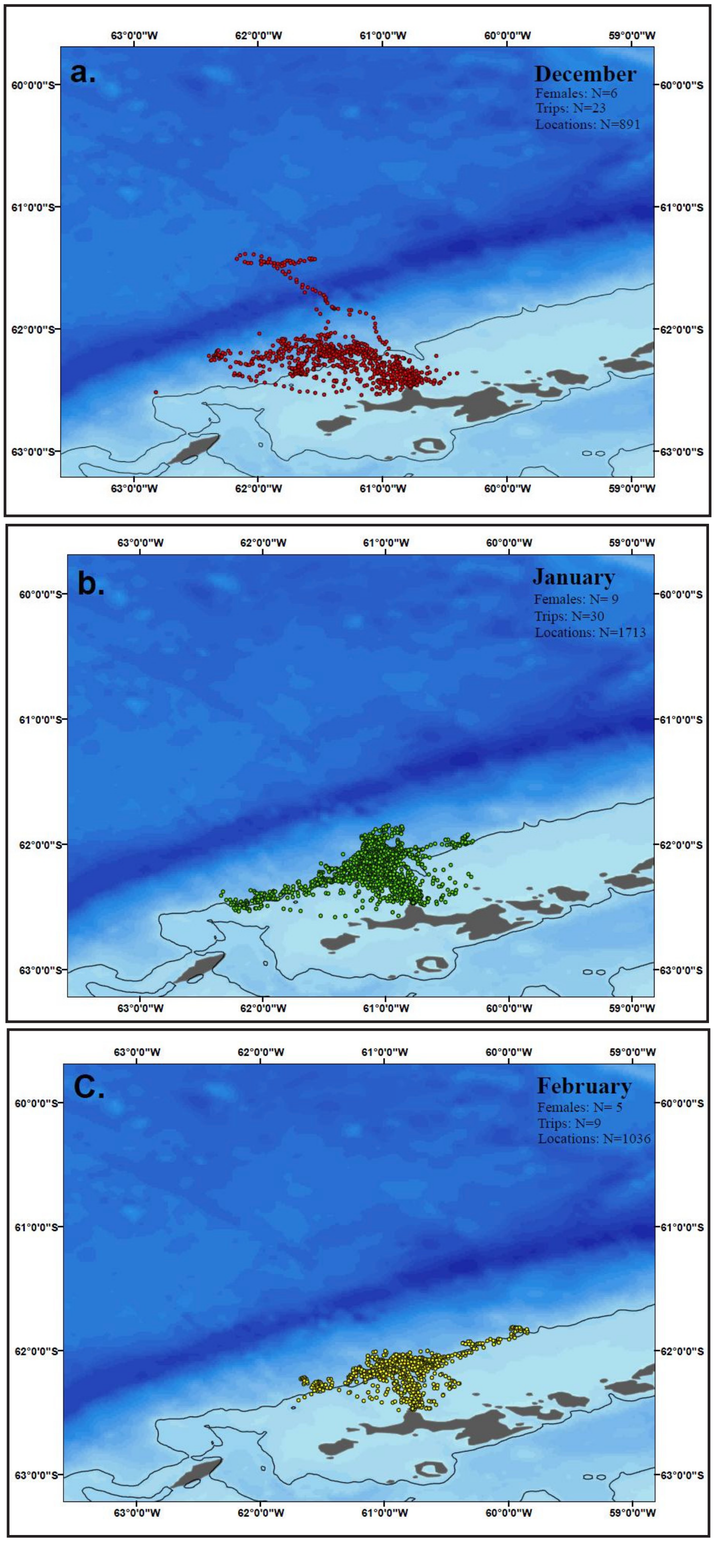

Figure 8.7. At-sea locations of lactating Antarctic fur seals carrying Mark10-F GPS time depth recorders in a) December (red); b) January (green); and c) February (yellow) foraging from Cape Shirreff, Livingston Island, South Shetland Islands, 2010/11. Sample size for the number of females, trips and GPS locations is in the inset for each plot. The 500 m bathymetry is outlined to show the location of the continental shelf edge.

from strong cohorts born in the early 90s senesce, have lower reproductive rates, and high mortality due to age. The summer environment, however, appeared to be one of the most favorable for female foraging, with mean trip duration for the first six trips being the lowest on record since our studies began at Cape Shirreff in 1997/98. Early season neonate mortality (3.3%) was lower than the long-term average of 4.5%. The median date of pupping, based on pup counts, was only one day earlier than last year. The mean foraging trip duration (2.9 ± 0.9 days) was similar to the long-term mean (3.7 ± 1.2 days; 1998/99 to 2009/10).

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 juvenile krill comprising most of the first mode and a second mode at 50 mm. We also recorded the lowest incidence of fish in the diet since 1997/98, with only 310 otoliths collected from 110 scats. Most (87.7%) were from one species of myctophid fish, *Gymnoscopelus nicholsi*. *Electrona carlsbergi* were recorded in fur seal diet this year for the first time since 2007/08.

In general, over-winter survival and natality were less favorable compared to previous years, but indices reflecting summer conditions were above average, resulting in better than average predator performance. Gains in performance and reproductive success were, however, offset by high leopard seal predation rates on fur seal pups.

During the summer months (November - February, 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 half or more of all fur seal pups born at Cape Shirreff. This year we recorded an increase in leopard seal numbers at the Cape and by mid-lactation for fur seals (22 February), we estimated 54% of all pups born were consumed by leopard seals. Leopard seal predation is a significant top-down factor controlling recovery of South Shetland populations of fur seals (Boveng et al. 1998).

Protocol deviations

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

Disposition of Data

All raw and summarized data are archived by the Antarctic Ecosystem Research Division of the National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA 92037.

Acknowledgments

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Distribution, Abundance, and Behavior of Seabirds and Mammals at Sea

Jarrod A. Santora and Michael P. Force

Abstract

The at-sea distribution and density of seabirds and marine mammals was measured through observation. A total of 5651 km (305 hrs) of survey effort was conducted on the U.S. AMLR grid, and four crossings of the Drake Passage (2500 km) were completed. This year's observations include:

- High concentrations of seabird, fur seal, and fin whale aggregations along the shelf break north of King George and Elephant Islands;
- Seabird community composition in the AMLR area reflected high diversity due to intrusion of sub-Antarctic species (e.g., shearwaters, prions, diving petrels), reflecting a signal previously detected in 2005 and 2009;
- During Leg I, Antarctic fur seals were abundant in Bransfield Strait, which is a pattern generally observed later in the season during Leg II;
- Humpback whales were less concentrated in Bransfield Strait compared to previous surveys. During Leg II, aggregations of humpback whales were clustered in Gerlache Strait; and
- In Drake Passage, numbers of Wandering and Royal Albatross were higher than in past AMLR surveys.

Introduction

This investigation focused on the at-sea distribution and density of seabirds and marine mammals during the 2010/11 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. Inter-annual spatial variability of foraging seabirds and mammals at sea;
2. Influence of krill abundance, patchiness and demography on foraging seabirds and mammals; and
3. Community structure and habitat selection by predator groups.

Methods

Observers collected data on predator abundance and distribution continuously during daylight hours between oceanographic stations along fixed transects distributed around the South Shetland Islands (Santora et al. 2009; Santora et al. 2010) (Figure 1). Ship speed during transits was 10 knots (~18.6 km/hr). Sighting data were entered into a computer using real-time mapping software, and positions were logged every 10 s while underway. Each record was assigned a time (to the nearest 0.1 s) and a spatial position from the ship's global positioning system (GPS). Sea surface state (Beaufort scale) and visibility (e.g., fog, glare) were monitored and effort during unfavorable conditions (e.g., Beaufort > 6, heavy fog) was excluded from the data set. Observers used hand-held binoculars and were located at a height of approximately 7 m above sea level.

Data on seabird distribution and abundance were collected during all four transits between the east end of the Strait of Magellan and the AMLR study area. Observations were conducted from the port side of the R/V *Moana Wave's* bridge. Counts of seabirds were made within an arc of 300 m directly ahead to one side of the ship while underway (Tasker et al. 1984). Individual birds, or flock of birds, were assigned a behavioral code. The behaviors were: flying, sitting on water or ice, feeding, porpoising (penguins), and ship-following. Ship-following birds were recorded when first encountered and ignored thereafter.

Surveys of whales were conducted using standard line transect theory by trained observers (Santora et al. 2010; Santora and Brown 2010). Weather conditions permitting, all cetacean sightings recorded were observed in a 180º arc forward of and up to 3 km away from the vessel. For each whale sighting, a best-estimate spatial position, bearing and a perpendicular distance estimate to the ship's trackline were logged. In addition, observations of seals were collected in a 180º arc forward of the vessel and included position and group size.

Data on survey coverage and the abundance and distribution of seabirds and marine mammals are presented in this report (Figures 1 and 2). Distribution maps were made using ArcView (ESRI 2007). Survey coverage in the AMLR area is presented in Figure 1 and represents the trackline where observations were collected during both legs. The relative abundances (per km) of seabirds and marine mammals observed during surveys in the AMLR area are presented in Tables 1 and 2 (see this table for scientific names). A summary of effort and species observed during Drake Passage surveys is presented in Tables 3-5.

Results and Discussion

AMLR Survey Grid

Seabirds

Observations were continuously collected during daylight hours whenever the R/V *Moana Wave* was underway (e.g., between stations, to/from field camps). The combined trackline (Legs I and II) depicted in Figure 1 represents the spatial coverage completed by the AMLR Program during January – March. A total of 5651 km trackline was sampled for 305 observation hours (208 h for Leg I and 97 h for Leg II). A summary of sightings and relative abundance of seabirds and marine mammals collected in the AMLR area is presented in Tables 1-2.

The seabird community consisted of (percentage-wise): cape petrel, southern fulmar, chinstrap penguin, Wilson's storm petrel, black-bellied storm petrel, prion spp., southern giant petrel, white-chinned petrel, blue petrel, black-browed albatross, soft-plumaged petrel, gentoo penguin, grey-headed albatross, south polar skua, wandering albatross, and light-mantled albatross (Table 1).

Feeding aggregations of cape petrels were found in the far West Area north of Livingston Island, northeast of King George Island near the shelf break, and along the northwestern edge of the Elephant Island Area (Figure 2a). These feeding aggregations coincided with high densities of chinstrap penguins, Antarctic fur seals, and groups of feeding fin whales. Chinstrap penguins were highly clustered in space in large foraging flocks of 30 to 100 or more individuals adjacent to breeding colonies near Livingston, King George, Elephant, and Clarence Islands (Figure 2b). Numbers of black-browed and grey-headed albatrosses observed this year were significantly lower than in past AMLR Surveys (Figure 2c). However, we encountered a high concentration of albatrosses at a location identified as an albatross hotspot during past AMLR Surveys in the southwestern Bransfield Strait. Numbers of wandering albatross and light-mantled Albatross were both present in higher numbers than in the past three AMLR Surveys. The abundance of prions, blue petrels (Figure 2d), and common diving petrels (species that breed in the Sub-Antarctic) were greater in number than the long-term average for Leg I, possibly indicating a response to the high concentrations of copepods and *Thysanoessa macrura* larvae found this year by the zooplankton team in waters far offshore in the West and Elephant Island Areas. These species have not been sighted in these numbers since 2009, and 2005 before that. In addition, soft-plumaged petrels and white-chinned petrels were highly conspicuous in offshore waters and were also present in higher numbers than the long-term average (Figure 2e). Two species, the sooty shearwater and parasitic jaeger, were sighted during this field season for first time since 2003.

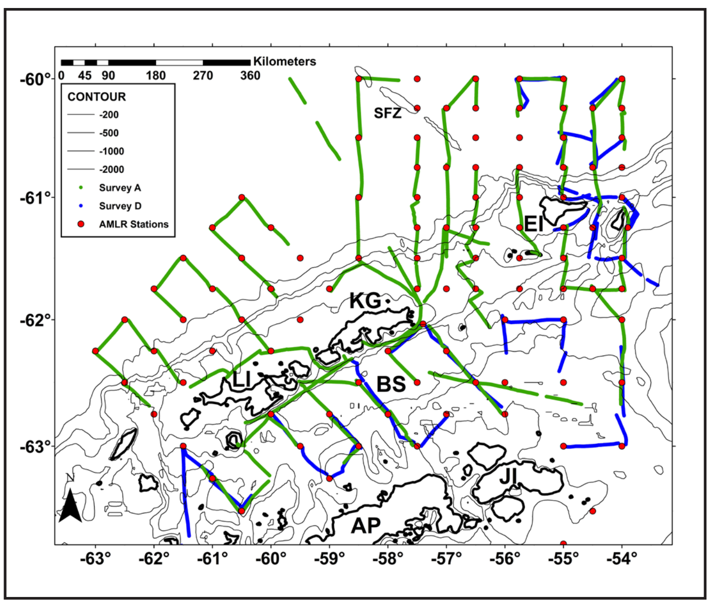


Figure 9.1. Survey trackline (daylight hours) sampled during AMLR 2011, January-March. Green trackline is Leg I (3857 km) and blue is Leg II (1794 km). Short survey conducted during Leg II in Gerlache Strait not shown. Locations: AP is Antarctic Peninsula, BS is Bransfield Strait, EI is Elephant Island, KG is King George Island, LI is Livingston Island, SFZ is Shackleton Fracture Zone. Red dots are AMLR station locations.

Marine Mammals

As in past AMLR Surveys (Santora et al. 2010), humpback whales were the numerically dominant baleen whale in Bransfield Strait, and 229 individuals were observed during 117 sightings (Figure 2e). However, the sightings and counts of humpback whales in the Bransfield Strait were slightly lower than average compared to past AMLR Surveys. Humpback whales were clustered throughout the Bransfield Strait over the deep basins, at the north and south ends of Nelson Strait, and within Hero Bay, north of Livingston Island (Figure 2f). During Leg I, the largest concentrations of humpback whales were observed east of King George Island near Cape Melville, at the north and south of Nelson Strait, and within Hero Bay en route to Cape Shirreff, Livingston Island. During Leg II, we observed fewer aggregations of humpback whales in Bransfield Strait, but sighted more individuals further south within Gerlache Strait.

Fin whales were common north of the South Shetland Islands, and 217 individuals were observed during 123 sightings (Figure 2f). Fin Whales were highly conspicuous in the shelf-break regions north of King George Island and to the west of Elephant Island during Legs I and II. The spatial distribution of their aggregations was highly clustered along the southern Antarctic Circumpolar Current front; for example, on three transects, 20 – 40 whales were sighted in groups of three to five individuals within a single hour (Figure 2f). At each of these locations, dense krill patches were detected on the acoustics system and net sampling revealed that the majority of krill captured were large mature females.

Table 9.1. Summary of seabirds observed in the AMLR area during Legs I and II.

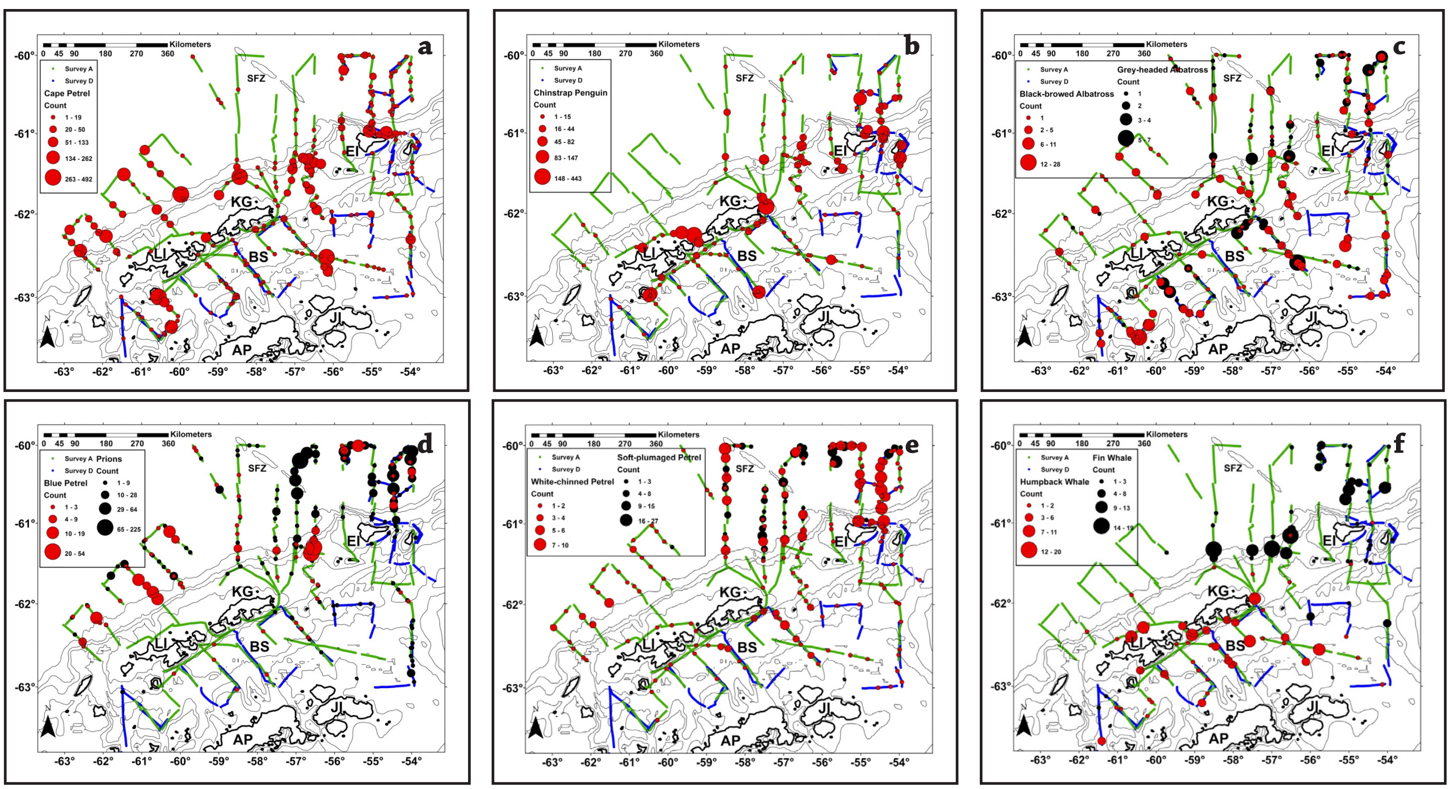
Species		Sightings	Individuals	Total/km
Adelie Penguin	*Pygoscelis adelie*	2	10	0.002
Gentoo Penguin	*Pygoscelis papua*	31	151	0.027
Chinstrap Penguin	*Pygoscelis antarctica*	481	3252	0.576
Macaroni Penguin	*Eudyptes chrysolohus*	5	7	0.001
Wandering Albatross	*Diomedea exulans*	31	31	0.006
Royal Albatross	*Diomedea epomophora*	1	1	0.000
Black-browed Albatross	*Thalassarche melanophrys*	225	252	0.045
Grey-headed Albatross	*Thalassarche chrysostoma*	119	120	0.021
Light-mantled Albatross	*Phoebetria palpebrata*	30	31	0.006
Southern Giant Petrel	*Macronectes giganteus*	339	433	0.077
Northern Giant Petrel	*Macronectes halli*	3	4	0.001
Southern Fulmar	*Fulamarus glacialoides*	1450	4272	0.756
Antarctic Petrel	*Thalassoica antarctica*	9	11	0.002
Cape Petrel	*Daption capense*	828	6274	1.110
White-chinned Petrel	*Procellaria aequinoctialis*	337	388	0.069
Sooty Shearwater	*Puffinus griesus*	7	7	0.001
Soft-plumaged Petrel	*Pterodroma mollis*	208	237	0.042
Kerguelen Petrel	*Lugensa brevirostris*	1	1	0.000
Snow Petrel	*Pagodroma nivea*	5	6	0.001
Antarctic Prion	*Pachyptilla desolata*	358	552	0.098
Prion spp.	*Pachyptilla spp.*	386	796	0.141
Slender-billed Prion	*Pachyptilla belcheri*	4	4	0.001
Fairy Prion	*Pachyptila turtur*	1	1	0.000
Blue Petrel	*Halobaena caerulea*	206	318	0.056
Wilson’s Storm Petrel	*Oceanites oceanicus*	1276	1666	0.295
Common Diving Petrel	*Pelecanoides urinatrix*	11	16	0.003
Black-bellied Storm Petrel	*Fregetta tropica*	1328	1662	0.294
Brown Skua	*Catharacta antarctica*	8	8	0.001
South Polar Skua	*Catharacta maccormicki*	81	96	0.017
Kelp Gull	*Larus dominicanus*	15	17	0.003
Parasitic Jaeger	*Stercorarius parasiticus*	1	1	0.000
Antarctic Shag	*Phalacocorax branfieldensis*	5	10	0.002
Antarctic Tern	*Sterna vittata*	59	10	0.002
Arctic Tern	*Sterna paradisaea*	8	21	0.004
Snowy Sheathbill	*Chionis alba*	2	2	0.000

Table 9.2. Summary of marine mammals observed in the AMLR area during Legs I and II.

Species		Sightings	Individuals	Total/km
Humpback Whale	*Megaptera novaeangliae*	117	229	0.041
Fin Whale	*Balaenoptera physalus*	123	217	0.038
Antarctic Minke Whale	*Balaenoptera bonaerensis*	10	10	0.002
Un-identified Baleen Whale	*Balaenoptera spp.*	30	36	0.006
Southern Bottlenose Whale	*Hyperoodon planifrons*	5	6	0.001
Killer Whale	*Orcinus orca*	2	8	0.001
Hourglass Dolphin	*Lagenorhynchus cruciger*	8	40	0.007
Antarctic Fur Seal	*Arctocephalus gazella*	195	249	0.044

Table 9.3. Summary of survey effort and relative abundance of total birds collected during Drake Passage crossings. Transects are defined as 30 minute intervals.

Transit	Total # of transects	Survey effort (min)	Trackline surveyed (km)	Total species	Individuals	Birds/km	Density (birds/km^2)	Average sea state (Beaufort)
1	79	2315	769.1	27	3449	4.5	1.1	5
2	70	2083	635.9	24	1397	2.2	0.77	4
3	60	1779	607.9	26	4632	7.6	1.03	5
4	62	1782	459	18	630	1.4	0.48	7
Total	271	7959	2471.9	33	10108	4.1		



Figures 2a-g. Abundance (#/hr) and distribution of (a) cape petrels, (b) chinstrap penguins, (c) black-browed and grey-headed albatross, (d) Blue Petrel and Prion species, (e) white-chinned and Soft-plumaged Petrels, (f) humpback and fin whales, and (g) fur seals (continued on next page).

There were 10 sightings of Antarctic minke whales that were distributed throughout the AMLR area. In the offshore waters of the Southern Drake Passage, there were five sightings of Southern bottlenose whales (six individuals) and eight sightings of Hourglass Dolphins (40 individuals). As in past AMLR Surveys, at-sea sightings of Antarctic fur seals were generally greater in proximity to breeding colonies near Livingston and Elephant Islands (Figure 2g); however, compared to previous Leg I AMLR Surveys, sightings of fur seals were much greater in the Bransfield Strait this year, a condition that usually occurs during Leg II (late February – early March).

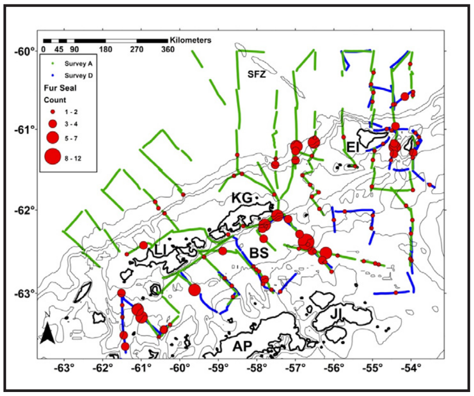


Figure 2g (fur seals) continued.

Drake Passage Crossings

Data on seabird distribution and abundance were collected during all four transits between the east end of the Strait of Magellan and the AMLR study area. Seabird observation effort employed a standardize 300 meter strip transect methodology using a series of continuous 30 minute transects conducted from the port side of the R/V *Moana Wave's* bridge (some transects were truncated due to weather and/or ship operational requirements). A brief summary of observation effort is presented in Table 3. A summary of all species seen and total individuals recorded while on effort arranged in descending order of relative abundance is presented in Table 4.

This year's survey effort approached last year's inten-

Table 9.4. Summary of seabird observations collected during Drake Passage surveys.

Species		Total Individuals
Black-browed Albatross	*Thalassarche melanophris*	2723
Sooty Shearwater	*Puffinus griseus*	2205
unidentified prion	*Pachyptila spp.*	1306
Slender-billed Prion	*Pachyptila belcheri*	791
South American Tern	*Sterna hirundinacea*	566
Great Shearwater	*Puffinus gravis*	441
Wilson's Storm-Petrel	*Oceanites oceanicus*	430
White-chinned Petrel	*Procellaria aequinoctialis*	414
Soft-plumaged Petrel	*Pterodroma mollis*	267
Southern Giant-Petrel	*Macronectes giganteus*	132
Manx Shearwater	*Puffinus puffinus*	112
Common Diving-Petrel	*Pelecanoides urinatrix*	77
Magellanic Penguin	*Spheniscus magellanicus*	75
Antarctic Prion	*Pachyptila desolata*	71
Cape Petrel	*Daption capense*	67
Black-bellied Storm-Petrel	*Fregetta tropica*	61
unidentified Sterna tern	*Sterna spp.*	48
Wandering Albatross	*Diomedea exulans*	43
Rockhopper Penguin	*Eudyptes chrysocome*	36
unidentified diving-petrel	*Pelecanoides spp.*	35
Royal Albatross	*Diomedea epomophora*	34
Gray-headed Albatross	*Thalassarche chrysostoma*	33

Species		Total Individuals
Chinstrap Penguin	*Pygoscelis antarcticus*	22
Chilean Skua	*Stercorarius chilensis*	20
unidentified Procellaria	*Procellaria spp.*	19
Blue Petrel	*Halobaena caerulea*	17
unidentified penguin	*Eudyptes spp.*	14
Imperial Cormorant	*Phalacrocorax atriceps*	10
Macaroni Penguin	*Eudyptes chrysolophus*	7
unidentified giant-petrel	*Macronectes spp.*	7
Westland Petrel	*Procellaria westlandica*	7
Magellanic Diving-Petrel	*Pelecanoides magellani*	7
Light-mantled Albatross	*Phoebetria palpebrata*	2
Northern Giant-Petrel	*Macronectes halli*	2
Great Grebe	*Podiceps major*	1
Southern Fulmar	*Fulmarus glacialoides*	1
Kerguelen Petrel	*Aphrodroma brevirostris*	1
Fairy Prion	*Pachyptila turtur*	1
Manx-type Shearwater	*Puffinus spp.*	1
South Polar Skua	*Stercorarius maccormicki*	1
unidentified skua	*Stercorarius spp.*	1
total individuals		10108
total species		33

Table 9.5. Summary of marine mammal observations collected during Drake Passage surveys

Species		Sightings	Individuals
Fin Whale	*Balaenoptera physalus*	14	41
Peale's Dolphin	*Lagenorhynchus australis*	10	41
Hourglass Dolphin	*Lagenorhynchus cruciger*	4	10
unidentified large whale	*Balaenoptera spp.*	3	4
unidentified dolphin	*Lagenorhynchus spp.*	2	3
Southern Bottlenose Whale	*Hyperoodon planifrons*	1	1
Minke Whale	*Balaenoptera acutorostrata*	1	1

sive coverage; 209 transects were completed, compared to 248 in 2010 (see Table 3). Mean number of transects based on comparable years (e.g., those with four transits, n = 8) is 145. Like last year, heavy weather was a factor, reducing the ship's speed and limiting navigable options with regard to heading, occasionally adding an additional day to the transit. This year was notable for the high numbers of White-chinned Petrels in the Drake Passage. Royal and Wandering Albatross numbers were also up over the last few years. A Wandering Albatross in fresh juvenile plumage on 15 February was only the second individual of this age class ever recorded on these surveys. Overall, abundance displayed widespread temporal and spatial variability. Diversity, on the other hand, was fairly consistent. Among the 10 most abundant species for 2010 and 2011, eight were common to both years: Black-browed Albatross, Sooty and Great Shearwaters, unidentified prion, Slender-billed Prion, Soft-plumaged and Southern Giant Petrels, and Wilson's Storm-Petrel.

Sightings of marine mammals were on an opportunistic basis and are summarized in Table 5. Marine mammal detection rates were inversely correlated with sea state. Fewer marine mammals were seen this year than last year, which is likely a direct result of poor weather on many transects. Furthermore, sightings were often clumped and patchy. For example, 88% of all fin whales, 13 of 14 detections, were concentrated along only a few kilometers of trackline just north of the AMLR study area.

Disposition of Data

All data are available from the NOAA/NMFS Antarctic Ecosystem Research Division, 8901 La Jolla Shores Dr., La Jolla, CA 92037. Ph: 858-546-7127; Fax: 858-546-7003.

Acknowledgments

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Small Unmanned Aerial Systems for Estimating Abundance of Krill-Dependent Predators: a Feasibility Study with Preliminary Results

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Abstract

Quantifying distribution and abundance of predators is an integral part of any ecosystem monitoring effort. Antarctica poses many challenges to doing so. Recent advances in the development of Unmanned Aerial Systems (UAS), particularly with vertical take-off and landing (VTOL) aircraft, have provided a new tool for addressing the challenges to estimating abundance of predators. We present preliminary results of a pilot study in the use of VTOLs for estimating abundance of krill-dependent predators. Studies in 2010/11 focused on operations, test flights, estimates of penguin abundance, comparisons to ground counts, and calculating colony area and density.

Introduction

Aerial photography has become a standard tool in wildlife assessments when scientists are faced with estimating the number of animals in large aggregations. Because manned aircraft support is not always available due to cost or logistical constraints, we investigated the applicability of small, unmanned aerial systems (UAS) as an alternative to manned platforms. We felt that there was an open niche for a platform that could be easily carried into the field, operated safely by a team of two people, and could collect images of adequate resolution to support accurate counts of small, aggregated targets in a low contrast environment. To provide the flexibility of operating in rugged terrain or from ships, we required that the aircraft be able to take off and land vertically. To reduce potential disturbance to the sampled populations and risks of pollution from fossil fuels, we restricted our search to platforms powered by batteries. We required that the UAS be capable of conducting missions under direct control of the operator or through a series of predetermined waypoints. Although our primary sampling system was to be single frame images, the aircraft would be required to transmit live video to a ground station to aid in target selection and mission planning. We envisioned these systems as tools for relatively short-range photographic missions requiring endurance on the order of 15 – 45 minutes.

After reviewing a wide range of military and commercial systems, we decided that the small, electric, multi-rotor copters were the best fit for our needs. These small UAS were designed to be photographic platforms and are exceptionally stable in flight. Their control systems incorporate input from 3-axis gyros, 3-axis accelerometers, barometric altimeters, and GPS units, making them relatively easy to fly. Because the rotors on these aircraft are directly driven by electric motors and aircraft movements are controlled by simply changing the rotation rate of one of the motors, these aircraft require none of the mechanical linkages and multiple moving parts associated with standard helicopters. In addition, the use of multiple rotors reduces the size and resultant kinetic energy in each blade, making the aircraft safer for both operators and wildlife in case of a mishap.

We selected Cape Shirreff, Livingston Island, South Shetland Islands for our field test because the habitat is rugged, remote, and scientists there work with large aggregations of penguins and fur seals. Our objectives were to:

1. Test operation of three independent vertical take-off and landing (VTOL) systems; one a large commercially-manufactured system, a second smaller custom-built quadro-copter system, and a third custom-built hexa-copter system;
2. Test range and duration for each system;
3. Monitor response of wildlife to aerial VTOL surveys;
4. Estimate abundance of gentoo penguins (*Pygoscelis papua*) and chinstrap penguins (*P. antarctica*) in colonies of various sizes and compare these to annually-collected standardized ground counts;
5. Photograph Antarctic fur seal rookery sites to determine whether image resolution is adequate to accurately count pups and to detect tags on adults;
6. Estimate areas of penguin colonies based on measurements from aerial photographs; and
7. Conduct a ship to shore sampling mission to demonstrate the feasibility of using this platform to sample otherwise inaccessible beaches.

We conclude with a discussion of the general feasibility of incorporating VTOLs as a standard monitoring tool, uses other than abundance estimation, future directions and recommendations.

Methods

Platform Selection

We took two approaches to acquisition of platforms for this project. First, we selected a new commercially available quadrocopter model (md4-1000) from Microdrones, GmbH (www.microdrones.com). Microdrones, GmbH, has been producing quadrocopters for aerial imaging since 2005. We found the md4-1000 especially appealing because it had the lift to carry heavier payloads and endurance that was advertised as up to 60 minutes.

Our second approach was to select a camera and then build an aircraft around that camera system. This process was conducted in collaboration with Aerial Imaging Solutions, Old Lyme, CT (www.aerialimagingsolutions.com). We structured this procurement of this platform in two steps. First, the contractor delivered a small, quadrocopter (APQ-16tr) that we could use for pilot training. In the second step, this same aircraft was upgraded to full sampling capabilities for field deployments at Cape Shirreff.

Training Missions and System Testing

The initial flight training took place at Microdrones, Siegen, Germany. The course included basic familiarization of the md4-100 system, including functionality and start-up, handling of the system, and handling of rechargeable batteries. Training also included academic and hands-on flight training; items covered were theoretical requirements, physical influences, choice of airfield/ flight area, downwash and ground effect, take-off, landing, influence of wind, temperature influence, practical flight exercises, post flight check, and safety instructions. An orientation of the flight control software was conducted. Training included flight time with the md4-200 and md4-1000 in INS and GPS modes, and in RC and pre-programmed flight modes. Weather conditions for training flights were 1.5-4.5°C with winds 4.5 – 6.5 m/s. The conditions were similar to those encountered at Cape Shirreff in January-February.

All training and testing missions in the U.S. were conducted at MacDill Air Force Base, Tampa, FL, under an agreement between NOAA and the U.S. Air Force that was facilitated through the support of NOAA's Aircraft Operations Center (AOC). Flights were conducted at a recreational field that had been reserved for VTOL testing ops and were limited to altitudes under 200'. Two intensive training and testing sessions are described below.

Efforts during this first session focused on flight training using the small APQ-16tr aircraft. During these tests the APQ-16tr proved to be very reliable, responsive, and nearly indestructible. We also experienced the periphery of a tropical storm, which forced us to push our work into winds in excess of 8 m/s. We learned from this experience that while we could safely operate the smaller platform in winds up to 8 m/s, the buffeting of the aircraft from the wind significantly degraded image quality even at high shutter speeds.

We tested ground and flight resolution for the Canon S90 camera with a medium contrast (8:1) resolution target (RST-704, series C) and a simulated wildlife cluster. Although the S90 is a highly reviewed "professional" point-and-shoot camera with a 10 megapixels sensor, the results of our initial field tests were less than ideal. One problem that has been reported for the high end point-and-shoot cameras is that the increasingly high pixel density chips were beginning to reveal the limitations of the lenses on these cameras.

In all of our resolution testing, we calculated image resolution and ground resolved distances as shown below:

$$R = h/f * X \quad \text{and} \quad G = h/R * f$$

where R = resolution (lines/mm); f = lens focal length (mm); X = combined width of bar and space of smallest target resolved; and G = ground resolved distance (mm) (Navy 1973).

The md4-1000 aircraft was delivered with an Olympus EP1 camera. This camera is one of several new "advanced compact or micro four thirds" cameras that support higher quality interchangeable lenses and chips that are nearly six times the size of the high end point-and-shoot cameras. We reviewed other "advanced compact" cameras and selected the Sony NEX-5 camera for testing. The Olympus and Sony cameras are significantly heavier than the Canon camera we had originally targeted for the AQ aircraft. Because added weight in mission components relates directly to power requirements and thus battery life, we began investigating ways to reduce the weight of these cameras without impacting their effectiveness for our missions. Eventually, the weight of the Olympus Pen-1 camera was reduced by 27% (from 460 g to 333 g) and the Sony NEX-5 by 12% (355 g to 314 g). Once we find a way to power the Sony camera with the aircraft battery we will be able to reduce the weight of that camera by another 60 g.

Between group sessions, several training flights with both the APQ-16 and md4-1000 were conducted at MacDill AFB. During these flights both aircraft performed well, but the landing struts on the md4-1000 showed cracks after only a few landings. These were reinforced, but the design of these landing struts appeared to be inadequate to handle the mass of this platform even when landing on a grass field.

The objectives for the second field session were to conduct side-by-side resolution testing for the two aircraft (using the Sony NEX-5 on the APQ-16 platform provided by Aerial

Imaging Solutions) and to test the ground station/video link for the md4-1000. We used the same resolution target and simulated wildlife cluster as described above.

During the field testing, we experienced significant problems linking the md4-1000 video transmitter and ground control station and there were also intermittent problems in aircraft control associated with loss of RC signal by aircraft. On the final flight of the md4-1000, the lid separated from the aircraft and sailed to the ground. Because the GPS antenna is mounted in the lid, we had to fly the aircraft without GPS assistance to the ground. The aircraft received some damage to the carbon fiber lid and landing gear.

Deployment Planning

Concerns over platform stability in winds typical of Cape Shirreff (e.g., mean summer wind speed: 6.1 ± 1.3 m/s) led to a decision to build a hexacopter as a third, back-up system. The hexacopter (APH-22) provides several advantages over the small AQ platforms. Adding two motors provides more stability in flight, increases power by about 50% for a 15% increase in weight, and makes even less noise in flight than the small quadrocopters. Otherwise, the electronics and control system are essentially the same as the APQ aircraft. The basic specs for the three platforms that we took to the Antarctic are presented in Table 10.1.

Antarctic Logistics

We embarked aboard the R/V *Moana Wave* in Punta Arenas, Chile, on 11 January 2011. During the transit we were able to inventory and check equipment, charge batteries, and work on the hexacopter before we encountered the rough seas of the Drake Passage. We were delivered to Cape Shirreff on 16 January. Field trials began soon after and continued weather permitting until shortly before pick up by the R/V *Moana Wave* on 6 February.

Table 10.1. Aircraft specifications for two quadrocopters (APQ-16 and md4-1000) and a hexacopter (APH-22) used at Cape Shirreff, Livingston Island, Antarctica, 2010/11. The APH-22 was owned and operated by Aerial Imaging Solutions, Old Lyme, CT.

Specification	APQ-16	md4-1000	APH-22
Wing span/total length (cm)	67.1	137.2	82.3
Dry weight (kg)	1.18	3.9	1.72
Gross weight (kg)	1.68	5.08	2.72
Engine1 (size/rating)	4X90 W	4X250 W	6X110W
Power1 (Type/qty)	22.75N	peak thrust 106N	peak thrust 48.24N
Payload capacity (kg)	0.499	1.179	0.998
Payload type2	Camera	Camera	Camera
Max speed (kts)	25	25	30
Cruise speed (kts)	10	10	10
Stall speed (kts)	n/a	n/a	n/a
Endurance (min)	30	50	25

Table 10.2. Comparison of specifications and tested resolution of images from mission cameras. All resolution testing was conducted at MacDill, AFB, Tampa, FL.

	Canon S90	Olympus EP1	Sony NEX5
Pixel Count (Mpix)	10	12	14.2
Sensor Size (mm)	7.6 x 5.7	18.0 x 13.5	23.4 x 15.6
Weight (grams)	197	460	355
Resolution (l/mm)	25	77	75

Image Analysis

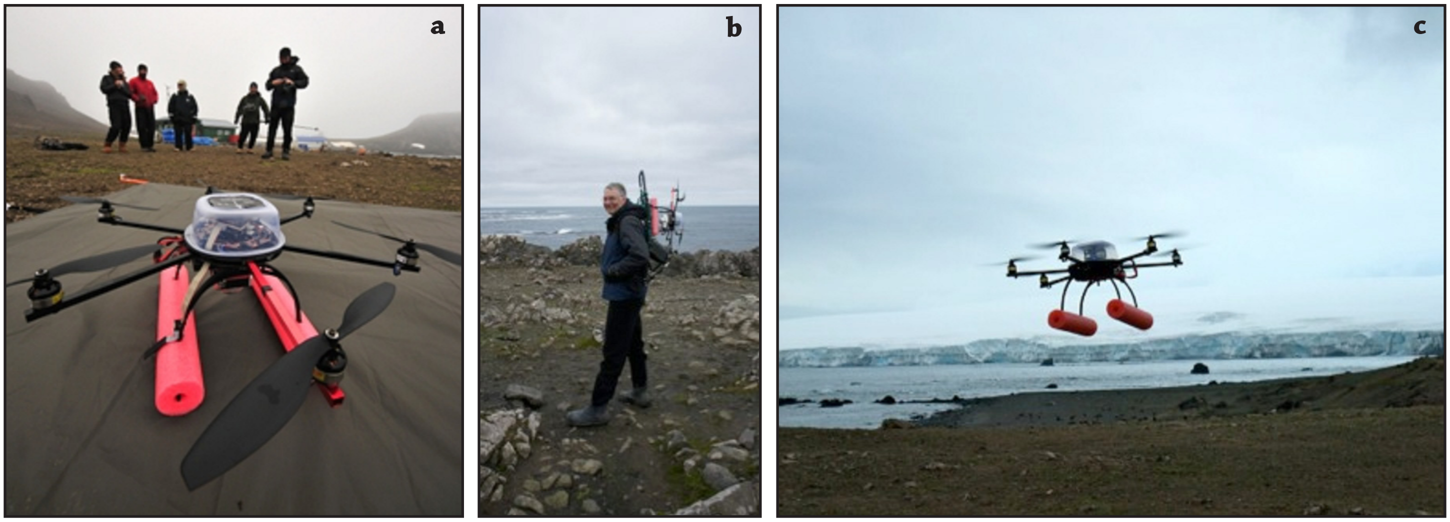
All mosaics, counts, and calculations of areas for penguin colonies were performed with basic tools included in Adobe Photoshop CS5 (ver. 12.04). We determined photographic scale based on calculated differences between pressure altimeter readings recorded on takeoff and as images were captured.

Results

Resolution and resulting ground resolved distances were excellent from all three systems (Table 10.2). Wildlife clusters were easily counted from 200' in altitude, and for high contrast features, objects approximately one square inch could be detected from over 150'. Both cameras outperformed the S90 camera even when this camera was tested on the ground.

Antarctic Field Experiment

On 18 January we worked through the prelaunch checklist for the md4-1000, calibrated the magnetic compass, and performed all the preflight checks. However, on lift-off the aircraft was not responding properly to the controls and it was quickly landed it. This problem had been experienced with the md4-1000 once before in Tampa, and we found that after shutting down the system and



Figures 10.1 a-c: a. A close up of the APH-22, a hexacopter built by Aerial Imaging Systems, Old Lyme, CT, showing the utility of simple construction tools; b. portability of the APH-22 carried on a frame pack; c. the APH-22 in flight at Cape Shirreff, Livingston Island.

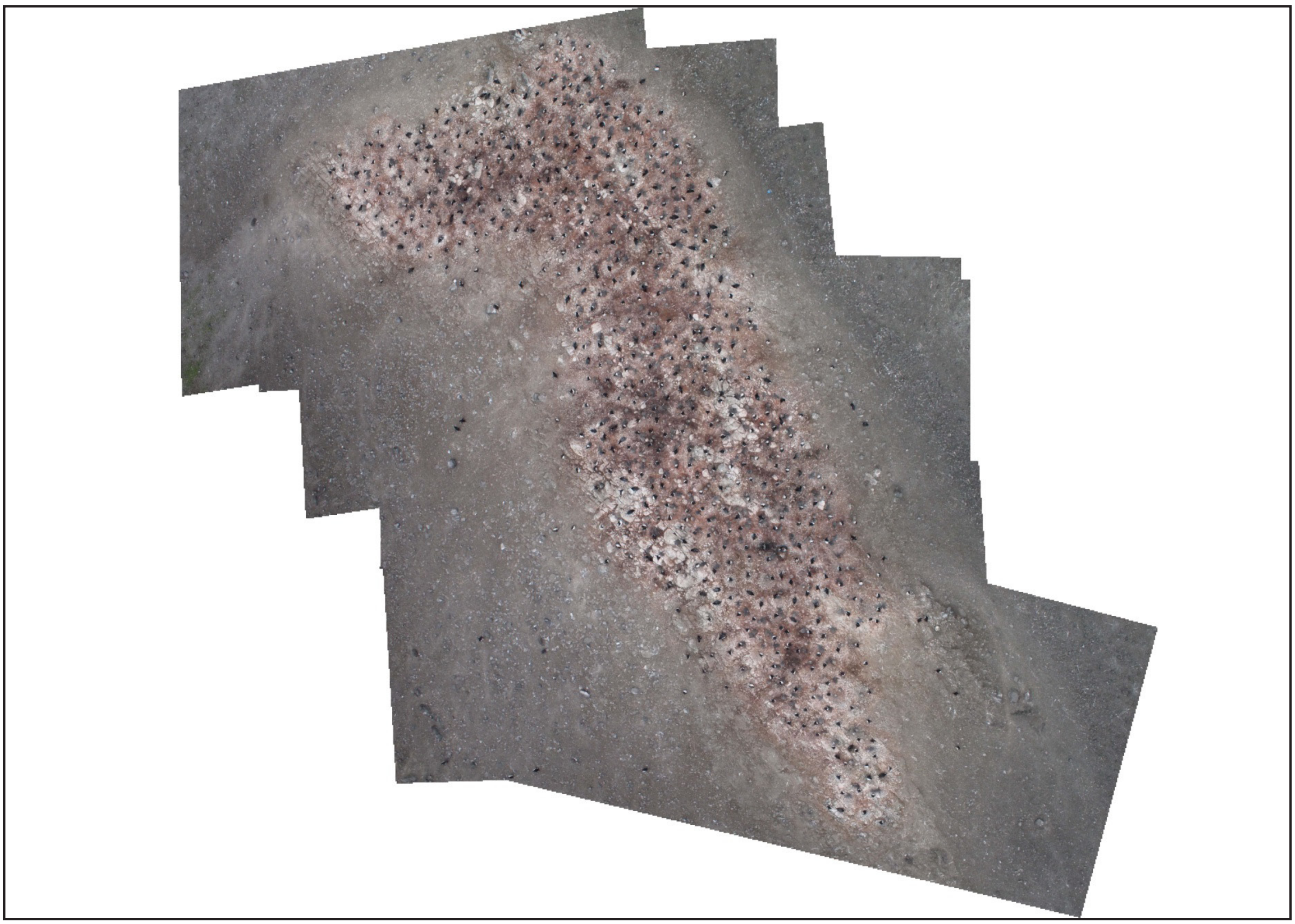


Figure 10.2. Mosaic of aerial photos of a large chinstrap penguin colony.

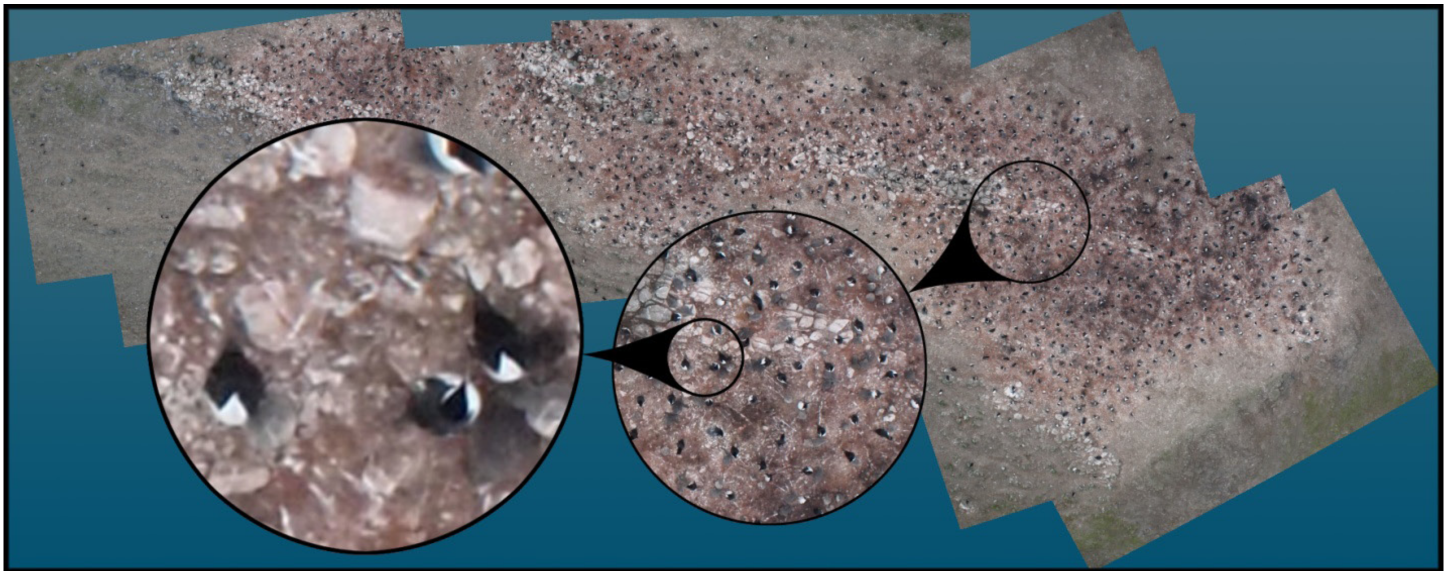


Figure 3. A chinstrap penguin colony showing visibility of both chicks and adults.

Table 10.3. Counts of penguin chinstrap and Gentoo penguin chicks made from composite aerial photographs and from the ground. Gentoo chick counts summed across common colonies due to movements of these chicks between count dates. All photographs taken from APH-22 aircraft.

Colony Number	Photo Counts	Ground Counts
3	745	848
5	102	97
8	103	106
9	27	23
10	616	618
11	617	604
12	67	32
29	970	1014
Gentoo (several)	433	429
Total counts (all)	3680	3771

Table 10.4. Calculated areas and chick densities for specific colonies based on counts and measurements from vertical aerial photographs taken from APH-22 aircraft. Some counts differ from those presented above because only well-defined nesting areas were used in area calculations.

Colony (species)	Chick Count (photo)	Colony Area (m^2)	Chick Density
3 (chinstrap)	745	886.7	0.84
5 (chinstrap)	102	49.4	2.065
5 (gentoo)	181	75.1	2.41
8 (chinstrap)	67	37.9	1.77
8 (gentoo)	138	156.9	0.88
10 (chinstrap)	580	227	2.555
11 (chinstrap)	617	512.3	1.204
29 (chinstrap)	970	933.1	1.04

restarting, the aircraft behaved normally. We tried that when we encountered the problem in the field and the second flight was worse than the first. The aircraft was almost out of control and made a hard landing, damaging the skids and breaking or cracking some carbon fiber components.

Rather than focusing on repairing the damaged aircraft, we decided to shift our field operations to the APH-22 (Figures 10.1a-c). We made 28 flights with the APH-22 aircraft, 18 for testing purposes and 10 for sampling, for a total of about 75 minutes of flight time (29 minutes for tests and 46 minutes for sampling).

Penguin Sampling

All of our penguin sampling flights were conducted on 21 Jan. We conducted three photographic sampling flights at the penguin blind (Figure 10.1b), each about 6 minutes in duration, at altitudes ranging between 50 and 140' (Figure 10.1c). Flight control was in direct or manual mode and passes over the colonies were made with the assistance of controllers on the ground who communicated via VHF radio to the spotter working with the aircraft pilot. We conducted the final flight of the day over the largest penguin colony on the island from the top of a 38 m hill. There were no signs of disturbance to the penguins caused by the aircraft during any of the survey flights.

We constructed a mosaic of each colony in Photoshop CS5 (Figure 10.2) from a subset of the images collected during the flights. Image resolution was consistently excellent and penguins were easily identified to species and chicks easily counted

(Figure 10.3). After our counts were completed, an independent team of seabird researchers completed ground counts of penguin chicks for the same colonies (Table 10.3). Counts from images and from the ground were not shared between teams until the counts had been completed. Although there were some small gaps in image coverage at a couple of colonies, there was no significant difference between the two data sets (paired t-test, $p < 0.05$). We also used Photoshop tools to calculate the areas of distinct colonies, converted those measurements to true areas on the ground and then calculated chick densities for each (Table 10.4). Mean density of chicks per colonies (both species) was 1.60 ± 0.07 chicks/m^2. Differences in densities probably reflect variability in survival rates of chicks to date of sampling.

Pinniped Sampling

Figure 10.4. An aggregation of Antarctic fur seals with tagged and instrumented individuals visible.

After several days of inclement weather, we conducted two test flights to evaluate the way-point flight control and "come home" systems, and then four sampling flights over groups of leopard seals (one flight) and Antarctic fur seals (three flights). Fur seal pups were easily detected in images taken from altitudes up to 50 m, and small tags on fur seals were also visible in images (Figure 10.4). At altitudes over 23 m we saw no sign that any pinnipeds (fur seals, Weddell seals, or leopard seals) were responding to the aircraft.

Leopard Seal Photogrammetry

There were four leopard seals hauled out on the U.S. AMLR fur seal study site during our flight over this area on 1 February 2011 (Figure 10.5). We measured standard length and width at the axilla for each seal on every image in which the animal was clearly visible. The level of precision in measurements taken from multiple images was very high (Table 10.2). Average length measurements from photographs of two seals for which we had capture data were 3 and 8% higher than those recorded by scientists on the ground (Table 10.5). This difference is likely the result of bias in scale calculations from pressure altimetry data.

Discussion

Although we experienced control and other issues with the md4-1000 both during test flights and in the Antarctic, we feel that we can work through these issues and this will be an excellent platform for longer-range missions. This aircraft also needs some engineering upgrades to make it more durable in the field. The landing gear is inadequate for hard landings in irregular terrain and the locking mechanism for the lid is flimsy, making it easy to pop off in flight. Because the lid is made of carbon fiber, which is opaque to GPS signals, the GPS antenna is mounted at the top of the lid, and each time the lid is removed (to replace batteries, for instance) the fitting for the GPS must be disconnected. For field use it would be better to replace the lid with something transparent to GPS signals that would have a positive connection to the main body of the aircraft.

Because the APH-22 was still being assembled when we arrived at Cape Shirreff, we had to

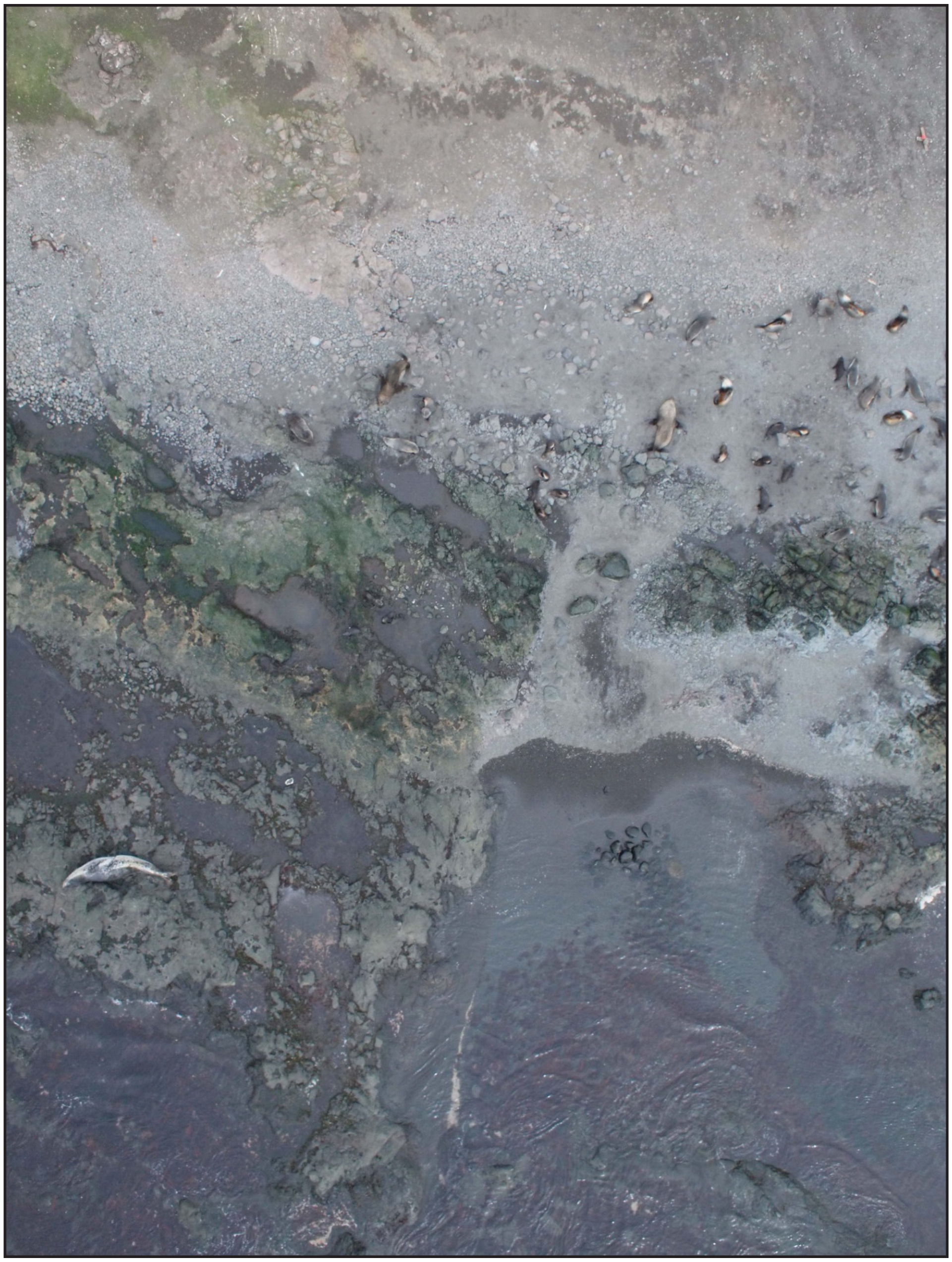


Figure 10.5. An aerial photo of a leopard seal (lower left) and fur seals (upper right).

blend a slow and methodical testing regime with the necessity of taking advantage of good weather conditions as they occurred. Almost all of our flying was done in the manual control mode, although we performed some waypoint and "come home" tests in the autonomous control option. Our sampling flights were all approximately six minutes, and we carefully inspected the aircraft after each flight. Batteries were changed after two flights and batteries were not allowed to go below a 50% charge level. For this small aircraft, we found that the pilot, with the aid of a spotter, could comfortably maintain visual contact with the aircraft out to about 150 meters.

Although we had to move rapidly through testing to sampling applications, this aircraft performed flawlessly. Images collected from this platform met all of our requirements, allowing us to accurately count penguin chicks, identify penguin adults and chicks to species, easily detect Antarctic fur seal pups, and remotely detect tagged fur seals. Originally, we had planned to use the images to count penguin nests, but by the time we arrived on the Island the crèche was well under way. Crèche refers to the transition from the period when an adult remains with the chicks to protect them from predators to the stage in which both adults must go to sea to feed to meet the demands of the rapidly growing chicks. Once both of the

Table 10.5. Length and width measurements for four leopard seals hauled out during test surveys of pinniped haul outs. N is the number of photos. Standard length measurements made during captures are in parentheses after mean length derived through photogrammetry.

	Length (cm)				Width (cm)				Width/Length			
Seal ID	**N**	**mean**	**stdev**	**cv**	**N**	**mean**	**stdev**	**cv**	**N**	**mean**	**stdev**	**cv**
White 8	1	302.4	na	na	1	86.3	na	na	1	0.285	na	na
Orange 36	8	324.4 (300)	5.54	0.017	8	74.6	1.44	0.019	8	0.23	0	0.019
Red/white 005	10	306.8 (297)	6.36	0.021	10	68.9	2.86	0.04	10	0.214	0.006	0.027
No Tag	13	285.9	5.96	0.021	9	68.9	2.86	0.042	9	0.241	0.006	0.024

adults begin making foraging trips, the chicks clump together for protection from predators (primarily skuas) and the nesting colonies begin to break down. Some of the differences in chick counts between photographs and the ground teams likely resulted from movements of groups of chicks between geographically defined colony sites.

These images also appear to provide a disturbance-free alternative for measuring size and shape of leopard seals. This will take some significant calibration efforts before the remote technique could be considered as a primary field-sampling tool. If photogrammetric sampling became a sampling focus in areas of very irregular terrain like we experienced in the Antarctic, a radar or laser altimetry system would be a valuable addition.

One of our requirements from the beginning was for a system that could be easily carried into remote locations by one or two people. The APH-22 is ideal for field applications that require a small team to carry all the sampling equipment and plenty of spare batteries into the field for a full day of work. This system is still being fine-tuned, but it is essentially ready to go into the field.

Our final objective was to conduct a mission from our support ship, the R/V Moana Wave, but at the end of the clearance process it was decided that a separate risk assessment was necessary before at-sea launch and recovery could be conducted. The md4-1000 has had some problems, but this is still an excellent long-range platform and the primary platform for sampling from ships. With some continued development and structural engineering support, this aircraft or one with similar endurance characteristics has great potential for sampling in the Antarctic.

Platform assessments

The APQ-16 was first designed as a primary sampling platform, but proved so effective as a trainer that this became its primary role. As we shifted to a heavier camera, this small quadrocopter became our third option for field operations.

The md4-1000 brings long endurance and greater lift capabilities that make it still the type of system that is well suited for ship to shore missions. We have had both reliability and structural issues with this system that need to be resolved before we decide how to move forward with this mission.

The APH-22 is an excellent shore-based sampling platform. It was reliable, rugged and has the lift to carry the larger cameras we selected for this project. It is a field ready system that meets all the required specifications for future work at Cape Shirreff and the South Shetlands.

These small UAS platforms are relatively easy to fly because computer chips integrate information from the pilot with data from onboard accelerometers, compasses, an altimeter, and a GPS unit. Changes in direction, speed, and altitude are made by simply changing the speed of the electrical motors attached to the propellers. To be successful in the field, the operator of one of these platforms must be able to fly the aircraft and thoroughly understand and test the components that interact to make flight relatively easy. In the case of the md4-1000, we had one of the first of this model to be built, the manual had not yet been completed, thorough test procedures and techniques were not provided, and we did not have the necessary information to truly understand how this system worked. When everything goes well, the aircraft is exceptionally stable in flight and flies well. If we had a better understanding of how the components of this aircraft interacted we would have been better equipped to troubleshoot problems.

With the APQ-16 and the APH-22, one person can hold the aircraft and test the responses to controls and stabilization systems with the motors running. The md4-1000 is too large and too powerful to do this safely by hand. A flexible test bed to hold the aircraft in place while systems are checked is required.

Wildlife Applications

The UAS systems we tested are exceptionally suitable for wildlife photogrammetry because of their portability, exceedingly quiet operation, stability in flight, hover ability and their ability to fly without disturbance to the animals. They are simple enough to fly that personnel with a modest amount of training can safely fly and operate the systems. Video capability provides an added element of flexibility and will no doubt be useful for longer missions from ship to shore. Programmability for pre-programmed flight operations to known locations provides additional benefits. With additional study these platforms will be useful to estimate size and mass of leopard seals without capture. With time and further development they should become a standard tool in monitoring wildlife populations.

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