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:

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

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:

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

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.

Juvenile and Adult Krill

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 m³), 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 m³), 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.

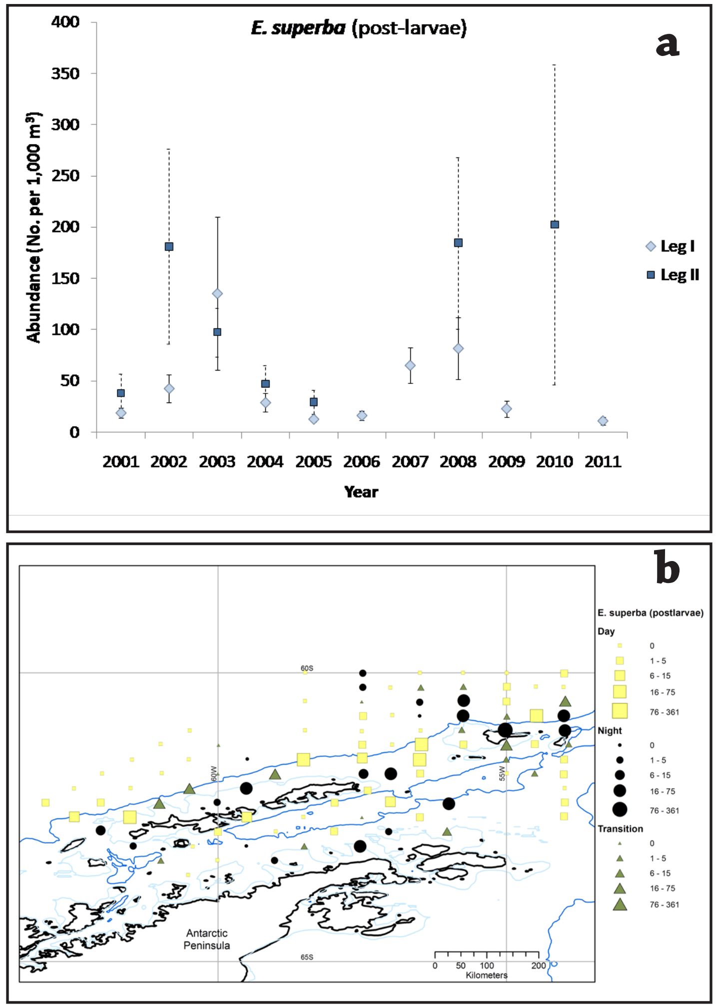

Figure 4.1. Historical catch rate (a) and 2011 Leg I distribution by time of day (b) of postlarval *E. superba*. Error bars are standard errors. The 200 m isobath is shown in light blue and 1000 m isobath in dark blue.

<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-

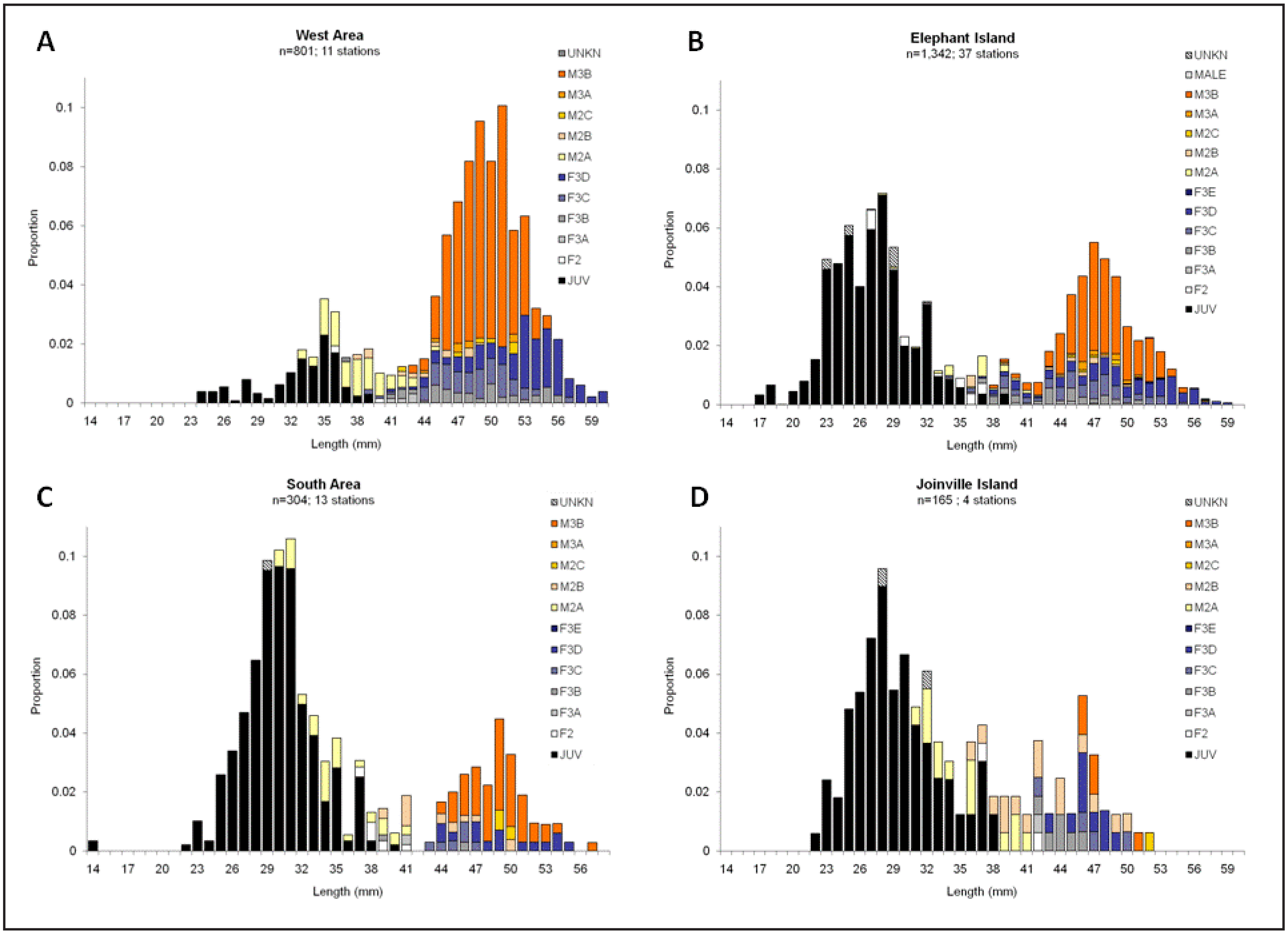

Figure 4.2. Length-frequency distribution of krill by gender, maturity stage and area. A) West Area; B) Elephant Island Area; C) South Area; and D) Joinville Island Area. M and F are Male and Female, respectively. Maturity stages according to Makarov and Denys (1981).

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

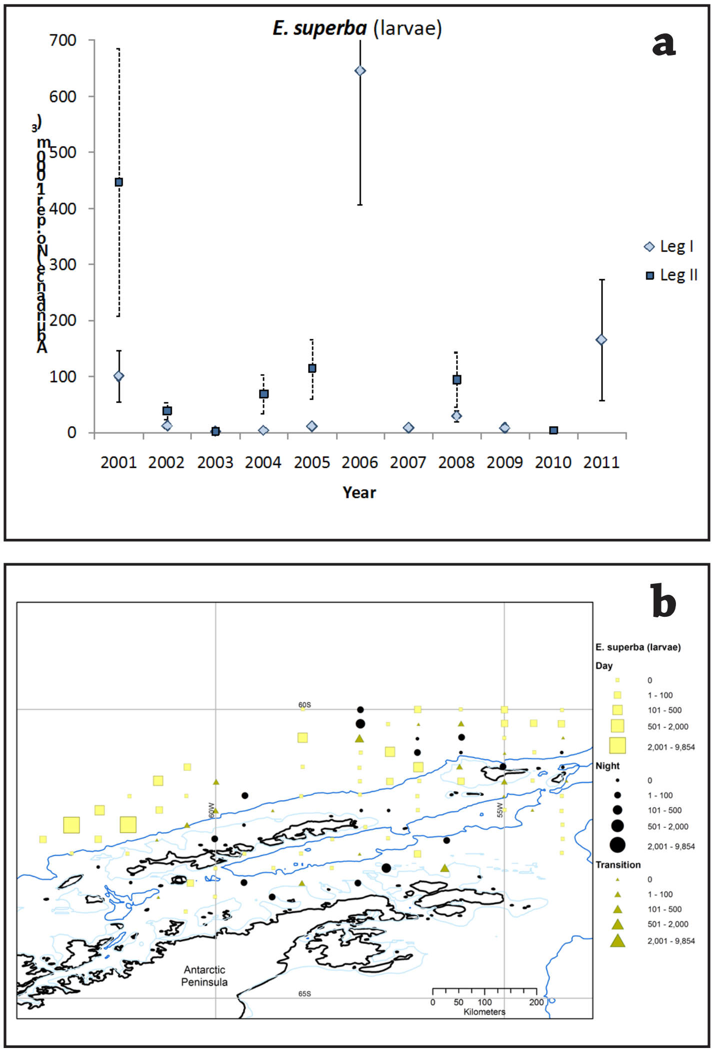

Figure 4.3. Historical catch rate (a) and 2011 Leg I distribution by time of day (b) of larval *E. superba*. Error bars are standard errors. Y-axis in (a) was limited to 700 in order to maintain resolution in other years; however, the full lower extent is shown.

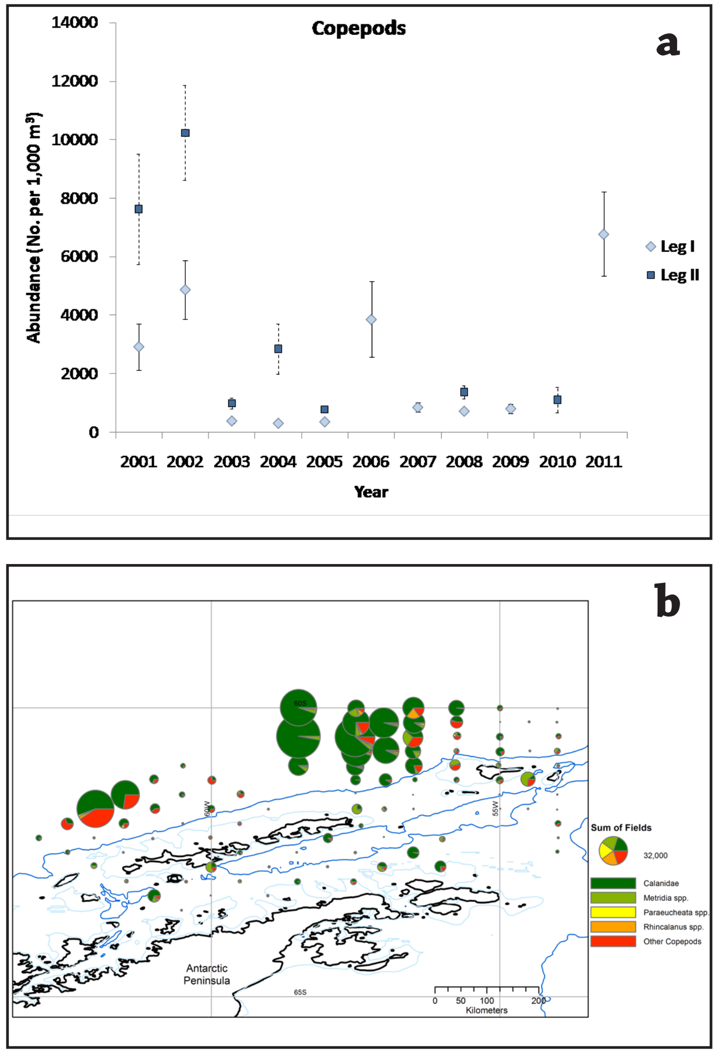

Figure 4.4. Historical catch rate (a) and 2011 Leg I distribution (b) of copepods. Error bars are standard errors. The size of the pie at each station is scaled to the sum of all five copepod categories; the symbol size in the legend represents 32,000 per 1000 m^3.

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

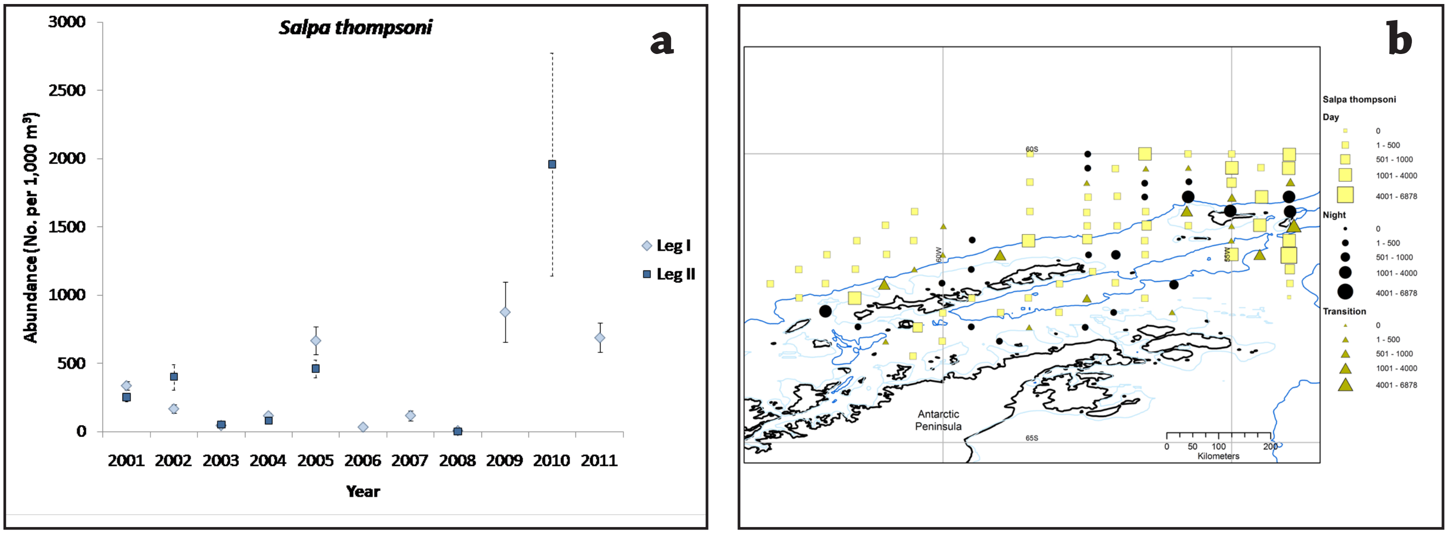

Figure 4.5. Historical catch rate (a) and 2011 Leg I distribution by time of day (b) of *Salpa thompsoni*. Error bars are standard errors.

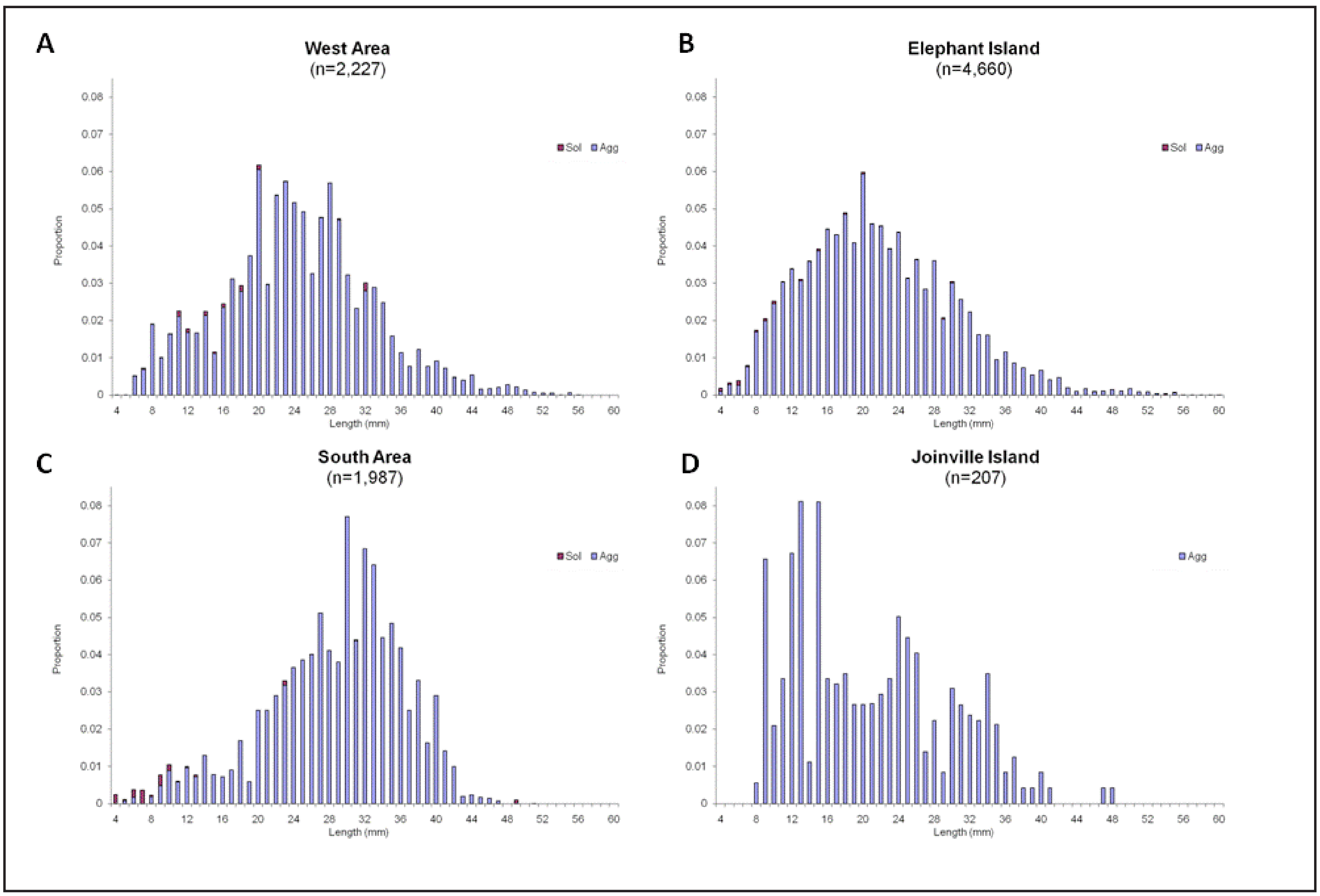

Figure 4.6. Salp length-frequency distribution by area: A) West Area; B) Elephant Island Area; C) South Area; and D) Joinville Island Area. Distribution was cropped at 60 mm as very few salps > 60 mm were encountered. Maximum length was 123 mm.

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

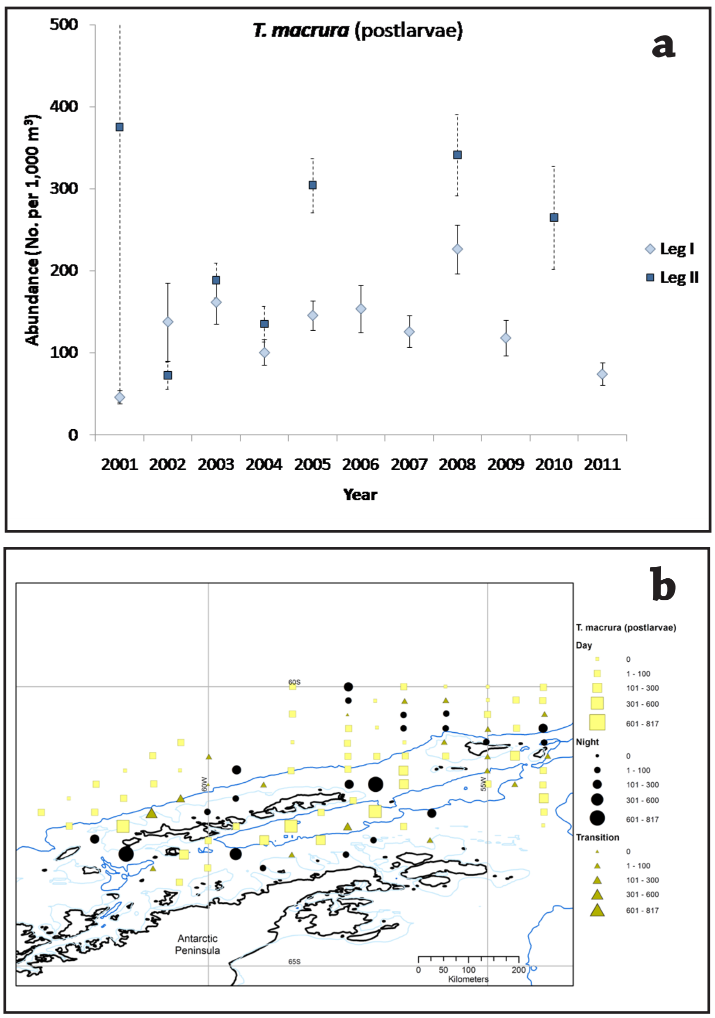

Figure 4.7. Historical catch rate (a) and 2011 Leg I distribution by time of day (b) of post-larval *T. macrura*. Error bars are standard errors. Y-axis in (a) was limited to 500 in order to maintain resolution in other years; however, the full lower extent is shown.

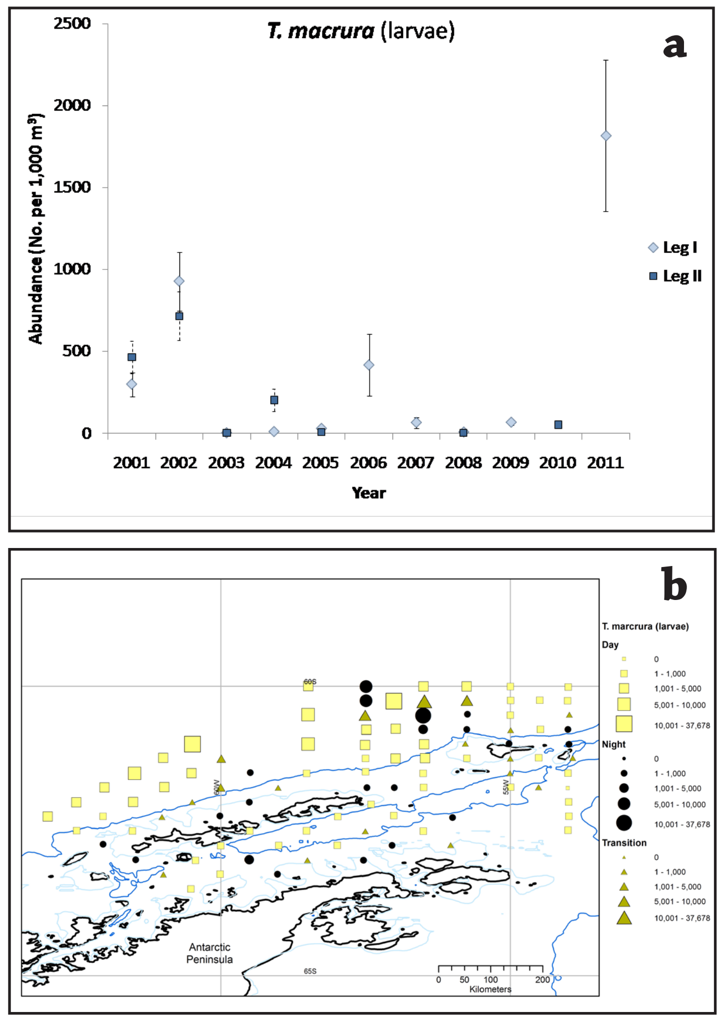

Figure 4.8. Historical catch rate (a) and Leg I distribution by time of day (a) of larval *T. macrura*. Error bars are standard errors. Y-axis in (a) was limited to 500 in order to maintain resolution in other years; however, the full lower extent is shown.

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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NOAA Technical Memorandum NMFS
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FEBRUARY 2014

AMLR 2010-2011 FIELD SEASON REPORT

Editor, Jennifer G. Walsh,

National Marine Fisheries Service
Southwest Fisheries Science Center
8901 La Jolla Shores Dr.
La Jolla, CA 92037

NOAA-TM-NMFS-SWFSC-524

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