THE COMMERCIAL HARVEST OF KRILL IN THE SOUTHWEST ATLANTIC BEFORE AND DURING THE CCAMLR-2000 SURVEY

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Abstract

A brief history of the commercial harvest and fishing patterns for krill (*Euphausia superba*) in the Atlantic Sector (Area 48) of the Southern Ocean is presented, with an emphasis on the commercial activities of the krill fishery at the time of the CCAMLR 2000 Synoptic Survey for krill in Area 48. During the time of the CCAMLR-2000 Survey, commercial krill fishing activities were centered in the South Shetland Islands in the southern Scotia Sea (Subarea 48.1). Fishing patterns, catches, catch rates, and biological information collected from the Japanese stern trawler *Chiyo maru No. 5*, which conducted krill fishing operations in CCAMLR Subarea 48.1 from January 31 to March 1, 2000 are also presented. Information on length and maturity composition is summarized based on 5 regions adjacent to the South Shetland Islands where the *Chiyo maru No. 5* fished. The biological information collected from the commercial fishery agrees well with the findings of the CCAMLR-2000 Survey, as well as a regional acoustic survey conducted by U.S. AMLR in Subarea 48.1 February 22 to March 7, 2000. We concluded that these surveys were conducted during a period of relatively high krill abundance in this region. The relationship between the commercial and survey information underscores the value of collecting fine-scale biological information from commercial krill fisheries in the Southern Ocean.

Introduction

Commercial fishing for Antarctic krill (*Euphausia superba*) in the Southern Ocean was established in the early 1970s following a decade of exploratory fishing. Catches of krill were reported between 1970 and 1973 (up to 7459 tonnes per year; Miller and Agnew, 2000), and comprehensive records of catch and effort have been held by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) since 1973 (eg CCAMLR Statistical Bulletin, 1990). Catches from krill fisheries are usually reported by split-year (1 July to 30 June of the following year; the year in which a split-year ends is used here as abbreviation).

Antarctic krill has been fished in the three major statistical areas of the CCAMLR Convention Area, and annual (ie split-year) catches have averaged 186239 tonnes (n: 28 years) in the South Atlantic (Area 48), 34400 tonnes (n: 22) in the southern Indian Ocean (Area 58) and 3040 tonnes (n: 14) in the Antarctic sector of the Pacific Ocean (Area 88). Eighty seven percent of reported catches of krill have been taken in Area 48.

CCAMLR is actively managing the krill fisheries in Area 48 and Area 58 (Divisions 58.4.2 and 58.4.1). These fisheries are considered to be in an early phase of development, and precautionary catch limits have been set based on the best available scientific information, including the results of the CCAMLR-2000 synoptic survey in Area 48, and principles encompassing CCAMLR's ecosystem approach to management. The current precautionary catch limits for krill are: 4.0 million tonnes in Area 48 (CCAMLR Conservation Measure 32/XIX); 440000 tonnes in Division 58.4.1 (106/XIX); and 450000 tonnes in Division 58.4.2 (45/XX). In addition, the precautionary catch limit in Area 48 has been sub-divided to 1.008 million tonnes in Subarea 48.1, 1.104 million tonnes in Subarea 48.2, 1.056 million tonnes in Subarea 48.3 and 0.832 million tonnes in Subarea 48.4; catch limits will be allocated to smaller management units when catches reach the trigger level of 620000 tonnes. The catch limit is also sub-divided in Division 58.4.1.

Catch and effort data on krill fisheries in the CCAMLR Convention Area are collected by Flag States. Biological data are collected by national scientific observers or observers deployed under CCAMLR's Scheme of International Scientific Observation (CCAMLR 2001). The information reported in this paper is based on data published in CCAMLR's Statistical Bulletin, and data collected by an international scientific observer deployed by the USA on board a Japanese-flagged trawler (Rain, 2000).

The Krill Fishery in Area 48

Two principal fleets have targeted krill in Area 48 (Figure 1): trawlers from the former Soviet Union from the 1970s to 1991; and Japanese-flagged trawlers from the 1980s to the present. Other countries have been involved with this krill fishery, notably Chile (1976, 1983-94), Republic of Korea (1987-92, 1998-present), Poland (1976-80, 1983, 1986-present), Russian Federation (1992-94) and Ukraine (1992-97, 1999-present).

The krill fishery in Area 48 has been characterized by annual catches exceeding 300000 tonnes in the 1980s and 1990s, with a peak of 425871 tonnes in the 1986 split-year (1 July 1985 to 30 June 1986), and two periods of sharp decline in catches. Relatively low catches in 1983 and 1984 were attributed to marketing and processing problems while the dramatic drop in annual catches after 1993 reflected the breakup of the Soviet Union in 1991 and the subsequent removal of fuel subsidies for Russian and Ukrainian-flagged trawlers (Miller and Agnew, 2000).

The krill fishery in Area 48 is also characterized by a seasonal pattern in fishing. Vessels target krill in the Southwest Atlantic, generally fishing in waters adjacent to South Georgia (Subarea 48.3) during the austral winter, and moving southward as the sea-ice retreats in spring to fish at the South Shetland Islands (Subarea 48.1) and South Orkney Islands (Subarea 48.2) during the summer (Figures 2 and 3). However, in recent years, the fishing period in Subarea 48.1 has become protracted, and vessels have remained in this subarea during the winter months (vessels have fished in June since 1996; July since 1997; August in 2000). As a result, recent activity in the 'winter' fishery in Subarea 48.3 has been low, and no catches of krill were reported over the 19-month period November 1998 to May 2000 (Figure 3).

January-March 2000

Between January and March 2000 (Quarter 3 reported in CCAMLR, 2001a), four commercial fleets targeted krill in the Southwest Atlantic (Japan: 4 vessels; Poland: 4 vessels; Republic of Korea: 1 vessel; Uruguay: 1 vessel). Fishing occurred in Subarea 48.1 and 48.2, and no fishing was reported from other subareas in Area 48 (Figure 4). A total of 26399 tonnes of krill was caught during these three months, of which 24957 tonnes (95%) were taken from 27 fine-scale (0.5^{o} latitude by 1.0^{o} longitude) rectangles adjacent to the South Shetlands Islands in Subarea 48.1. The remainder of this catch (1442 tonnes) was taken from 6 fine-scale rectangles in Subarea 48.2 (CCAMLR, 2001a).

Of the 27 fine-scale rectangles fished in Subarea 48.1 between January and March 2000, 23 rectangles were traversed during the CCAMLR-2000 survey (Watkins et al. *this volume*). We compared the catches reported in these 23 fine-scale rectangles with the densities of krill estimated from the CCAMLR-2000 survey. There was a significant correlation (r_s=0.366; n=23; P<0.10) between the ranked catches of krill reported in the 23 fine-scale rectangles and the corresponding ranked mean densities of krill estimated from the survey (Figure 5).

Mean catch rates (catch per unit effort) for fleets fishing for krill in Subarea 48.1 during January-March of each split-year reported, including the 2000 split-year, are plotted in Figure 6. Differences in catch rates between fleets may reflect difference in fishing strategies.

Two fleets (Japan and Poland) had fished in Subarea 48.1 in recent years, and their mean catch rates in January-March 2000 was higher than that reported in January-March 1999 (Figure 6). Further, the mean catch rate for Japanese-flagged trawlers over the period January-March 2000 (135 t/day) was the second highest value reported in the 19-year time series available for that fleet (range: 38-153 t/day). Similarly, the mean catch rate for Polish-flagged trawlers during January-March 2000 (33 t/day) was the third highest value reported in the 8-year time series for that fleet (range: 18-37 t/day).

Commercial Harvest of the Chiyo maru No. 5

Under the auspices of CCAMLR, a formal bilateral agreement between the governments of Japan and the United States was implemented prior to the CCAMLR-2000 Survey. This agreement enabled a U.S. scientist to conduct scientific observations aboard the Japanese-flagged trawler *Chiyo maru No. 5*. The *Chiyo maru No. 5* fished for krill in Subarea 48.1 from 31 January– 1 March 2000, overlapping with the CCAMLR-2000 Survey, and a regional acoustic krill survey conducted by the U.S. AMLR program in Subarea 48.1 from 22 February to 7 March, 2000 (Hewitt et al *this volume*). In this section, we summarize the findings of the scientific observations aboard the *Chiyo maru No. 5*, and compare the commercial catches in the context of the two acoustic surveys.

During its voyage, the *Chiyo maru No. 5* conducted a total of 253 commercial hauls targeting krill in waters to the north of Elephant Island and the western part of the South Shetland Islands (Figure 7). Detailed information on hauling operations was reported by Rain (2000). Fishing operations were conducted around the clock and the average tow duration was 39 minutes. The target depth of the hauls averaged 39 m (range 1-140 m), and there was a tendency to fish in shallower water between 1800-0600 h (local time), and deeper water between 0600-1800 h. The bottom depth is the region ranged from 100–4000 m.

We categorised haul locations into 5 regions, based on tow distance and fishing depth (Figure 7). Region 1 consisted of 7 hauls taken during the first fishing day, and was located north of Elephant Island in waters with a bottom depth of 3000 - 3500 m. Region 2 was located northwest of Elephant Island, and consisted of 33 tightly clustered hauls in water depths between 3500 and 4000 m; this was the deepest and most offshore of the five regions considered. Region 3 consisted of 73 hauls in an area located directly north of Livingston Island in a bottom depth of 100 - 250 m; this was the most shallow and inshore region. Region 4 included 54 hauls located northwest of Livingston Island taken in waters between 1000 and 1500 m. This region also included 7 hauls taken in bottom depths of 250 and 500 m. Finally, Region 5 consisted of 85 hauls taken in bottom depths between 1500 and 2500 m north of Smith Island. A single haul was made north of King George Island and this was excluded from further analysis.

The total catch of krill taken from all hauls was estimated at 2542 tonnes. Most of the catch was taken in Region 5 (Table 1, Figure 7), where the majority of the hauls occurred. However, the highest nominal catch rate (t/h) was in Region 3 (Table 1, Figure 7). We found significant differences in catch rates between regions. Regions 3-5 demonstrated significantly higher variability and mean catch rates than Region 2 (F test series, ANOVA $P<0.0001$). In addition, Region 3 demonstrated significantly higher catch rates than Region 5 (although not Region 4). This may have been the result of a number of factors, although the complexities of krill demographics do not easily lend themselves to draw any conclusions about fishing success as a function of geographic location at any one point in time.

The U.S. AMLR acoustic survey covered all regions of the South Shetland Islands fished by the *Chiyo maru No. 5*. The timing of the U.S. AMLR survey and the trawler's fishing operations overlapped by 9 days, at which time the scientific observer on board the trawler visually sited the U.S. AMLR survey vessel off the lower South Shetland Islands. This opportunity allowed for a semi real-time comparison of the findings of the U.S. AMLR scientific survey with those of the directed trawl fishery. When the densities estimated from the scientific survey (Hewitt et al. *this volume*) are overlaid with the commercial haul locations, the regions with the highest catches and catch rates of krill from the commercial trawler correspond to areas where the survey detected high densities of krill (Table 1; Figure 7), with the exception of Region 1 which had the lowest catch and catch rate of any region.

This number of sets, spatial distribution, and catch rates of hauls in Region 1 differed substantially to the fishing pattern observed in other regions, and the poor fishing success in Region 1 may have been a result of the initial "shake down" period on the first day of the commercial fishing expedition). Figure 7 also demonstrates that the commercial fishing operations did not necessarily target the highest densities of krill. The greatest concentrations appeared just to the northeast of Elephant Island, as well as to the north of King George Islands. Thus, the concentrations detected by the commercial hauls targeting krill represented only a small fraction of the true spatial distribution of concentrations that can were detected by the surveys. This finding underscores the importance scientific survey designs play in characterizing distribution and biomass of krill.

Length measurements were taken from a total of 12,984 krill across all regions. Measurements of body length (AT) of krill were taken from the front of the eye to the tip of the telson, and to the nearest millimetre below. Measured lengths by sex from the *Chiyo maru No.5* and net sampling from the U.S. AMLR acoustic krill survey are presented in Figure 8. The average length from all krill measured was 49.1 mm, with a modal length of 50 mm. Lengths ranged from 18 to 62 mm. There was no difference in variability of lengths between sexes, and mean lengths of females were significantly higher than males (*t*-test, $P<.0001$) for combined samples.

The overall length-frequency distribution of krill caught during the fishing operations of the *Chiyo maru No. 5* agreed with the distributions of krill collected in net samples from the U.S. AMLR survey (Figure 8), as well as krill collected in the South Shetland Islands during the CCAMLR-2000 Survey (Anonymous, 2000). The majority of the krill captured during fishing operations were adults, likely centered on an age 4 or 4+ year class. Length-frequency distributions by region demonstrated some distinct differences sizes. (Figure 9A-9E). The krill in Region 3, the most inshore and shallow region, had significantly smaller ($P<0.0001$) mean, median and modal length than krill caught in the other regions examined (Table 2; Figure 9C).

We also compared the length-frequency distribution of krill measured on board the *Chiyo maru No. 5* to the distributions of the CCAMLR2000 Survey (Anonymous, 2000). Three size clusters were identified in Area 48 based on an analysis of measured krill from the survey (Siegel et al., *this volume*). Regions 2, 4, and 5 which were fished by the *Chiyo maru No. 5* corresponded with the geographic extent of size cluster 3 from the CCAMLR-2000 Survey while Regions 1 and 3 were located in cluster 2 (Figure 6). Although the survey transects in this subarea were conducted primarily in January 2000, the length frequency of krill in regions I and 3 agreed well with that of size cluster 2 from the synoptic survey (Siegel et al., *this volume*), indicating that krill in these regions were mainly 4-year old animals. The size compositions of krill from other regions also largely agreed with the findings of the survey, although modal lengths were slightly less than those observed during the survey (50 mm mean aboard *Chiyo maru No. 5*, 52 mm mean observed from the CCAMLR 2000 survey). The *Chiyo maru No. 5* did not fish in regions where Siegel et al. (*this volume*) positioned boundaries for krill of size cluster 1.

The maturity stage of 4,841 krill was evaluated using the 6-point scale described in the *CCAMLR Scientific Observer's Manual* (2001b). Rain (2000) summarized the overall findings. Krill sampled had a strong bimodal maturity-frequency distribution with peaks at stage II (subadults) and stage V (spawning); all groups were represented, though there were very few juveniles (N = 8). There were significant regional differences in maturity stages (Figure 10A-D). Region 1 was excluded from this comparison because maturity stages were not sampled in this area. Region 3 was comprised mostly of subadult krill (stage II Figure 10B), while krill in regions 2, 4 and 5 were mostly fully gravid or in spawning condition (Figure 10A,C,D). This is not unexpected, since Region 3 was the most inshore region and catches had a higher proportion of small krill (Figure 9C). The maturity distribution of krill in region 2 (Figure 10A) consisted of less mature krill compared to regions 4 and 5, and did not contain krill that had transitioned to the resting stage (VI+). This was likely due to the time of sampling within region 2, which was well before the trawler had moved to fish in regions 4 and 5. The maturity distribution of krill in regions 4 and 5 was in agreement with the length-frequency distribution in these regions (Figures 10C and 9D).

Discussion and Conclusions

The krill fishery in the Southwest Atlantic is characterized by a seasonal pattern in fishing, with vessels targeting krill in waters adjacent to South Georgia (Subarea 48.3) during the austral winter, and moving southward to fish at the South Shetland Islands (Subarea 48.1) and South Orkney Islands (Subarea 48.2) during the summer. At the time of the CCAMLR-2000 Survey (January-February 2000), vessels were fishing for krill in Subareas 48.1 and 48.2; no fishing was reported from other subareas in Area 48. Data on krill fishing were available from quarterly and monthly summaries published in the CCAMLR Statistical Bulletin, and from scientific observations made by a U.S. scientist on board the Japanese-flagged *Chiyo maru No. 5*.

Overall, we found a good correlation between the spatial distributions in the abundance, size and maturity of krill caught in the commercial fishery in Subarea 48.1 at the time of the CCAMLR-2000 Survey and the US AMLR survey, and the corresponding distributions observed during these two surveys.

The size and maturity patterns of krill sampled from the commercial catches of the *Chiyo maru No. 5* showed distinctive differences between regions fished. While true that drawing inferences from any directed fishery can be misleading due to the non-randomness of the fishing operation, our findings clearly indicate that the collection of biological data from fishing trips can be beneficial to the understanding of the population. It is important to underscore how well the krill sampled during the fishing operation of the *Chiyo maru No. 5* agreed with the patterns of size and maturity described from both the CCAMLR-2000 Survey and the U.S. AMLR krill survey.

The distribution of krill catches taken in the fishery in Subarea 48.1 between January and March 2000 was also significantly correlated ($P<0.10$) to the density of krill observed in the CCAMLR-2000 Survey.

Our findings also indicated that the abundance of krill in Subarea 48.1, as estimated from catch rates in the fishery, was high during the period of the CCAMLR-2000 survey. The Japanese fleet reported the second highest mean catch rate in the 19-year time series of data, and the Polish fleet reported the third highest mean catch rate in 8 years of fishing. We concluded that the CCAMLR-2000 Survey in Subarea 48.1 was conducted during a period of relatively high krill abundance.

Although not available for use in this study, CCAMLR does hold more detailed catch and effort data for the krill fishery, with data reported by 10 x 10 nautical miles rectangles and by 10-day period, or on a haul-by-haul basis. Had haul-by-haul data been available for all vessels engaged in the fishery at the time of the surveys, then it may have been possible to examine the relationship between the fishery and the surveys in greater detail.

Countries that are involved in the krill fisheries in the Southern Ocean should be strongly encouraged to use scientific observers so that information such as that collected aboard the *Chiyo maru No. 5* can be gathered on a regular and consistent basis, leading to a better understanding of long-term changes and population dynamics of krill in the Southern Ocean.

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Table 1. Catch information by region for krill captured during fishing operations of the *Chiyo Maru No. 5*. Mean catch rates are on a haul-by-haul basis, and have been adjusted to tonnes per hour trawled.

	Region					
	1	2	3	4	5	All Sets
Total Catch (t)	43	358	755	547	826.5	2541.5
Mean Catch Rate (t/h)	7.455	13.599	19.527	18.130	16.833	17.211
Range Catch Rate	9.733	24.400	52.909	79.200	46.000	82.909
Minimum Catch Rate	3.600	3.600	1.091	4.800	4.000	1.091
Maximum Catch Rate	13.333	28.000	54.000	84.000	50.000	84.000
Number of Sets	7	33	73	54	85	253
Bottom Depth (m)	3000-3500	3500-4000	100-250	1000-1500*	1500-2500	

* in addition, 7 hauls were made in 250-500 m.

Table 2. Size composition of krill sampled in each region fished by the *Chiyo maru No.5* from 31 January to 1 March 2000.

	Region					
	1	2	3	4	5	Combined
Mean (mm)	47.3	51.0	45.5	50.7	48.9	48.6
Standard Error	0.228	0.087	0.048	0.089	0.046	0.037
Median	48	50	46	50	50	48
Mode	50	50	46	50	50	50
Standard Deviation	4.1	3.1	3.6	3.2	3.1	4.2
Sample Variance	16.8	9.7	12.7	10.5	9.7	17.9
Minimum	32	40	18	18	36	18
Maximum	56	60	58	58	60	62
Sample size	323	1277	5570	1315	4645	12984

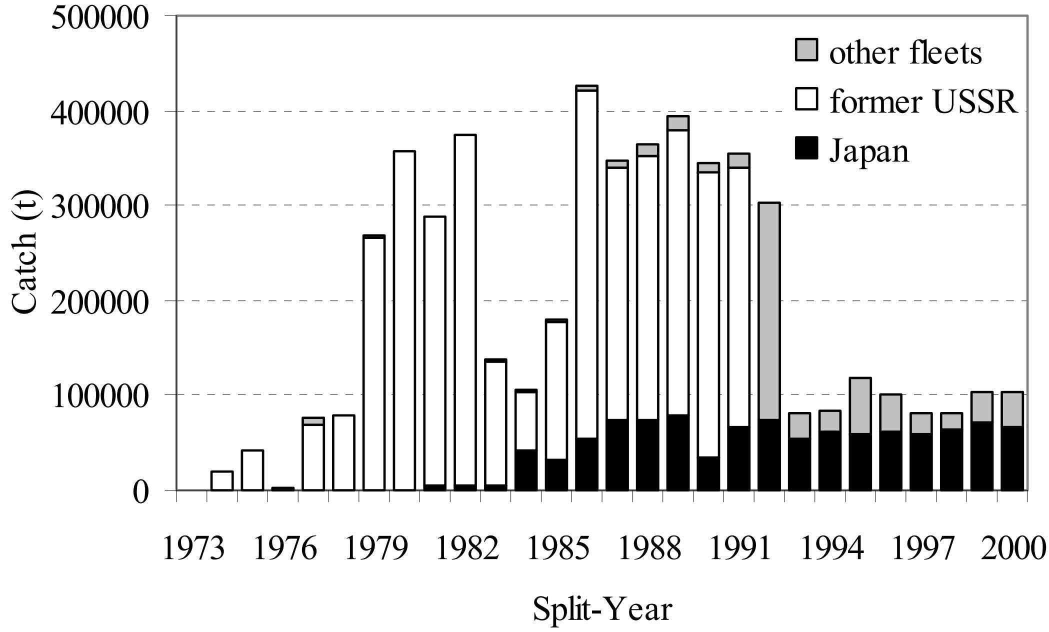


Figure 1: Catches of krill from Area 48 by split-year (July-June). Source: STATLANT data, CCAMLR.

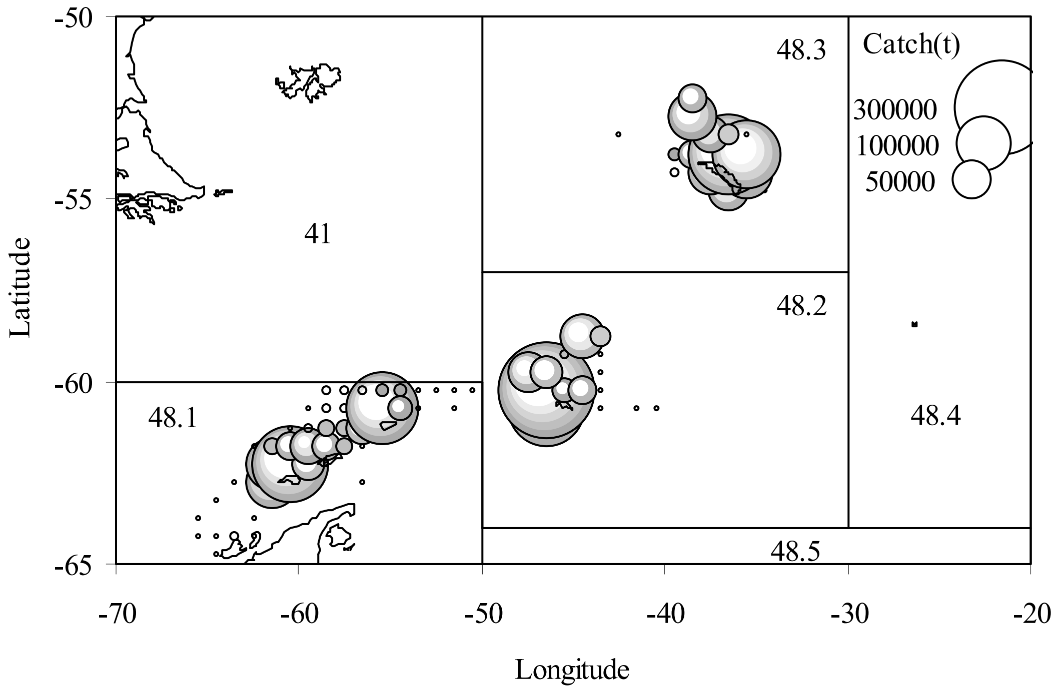


Figure 2: Catch (t) of krill reported from the Southwest Atlantic (Subareas 48.1, 48.2, 48.3, 48.4, 48.5) between the split-years 1974 and 2000. Catches are aggregated by fine-scale (0.5° latitude by 1.0° longitude) rectangles. Source: CCAMLR Statistical Bulletin (1990a, 1990b, 1991 and 2001a).

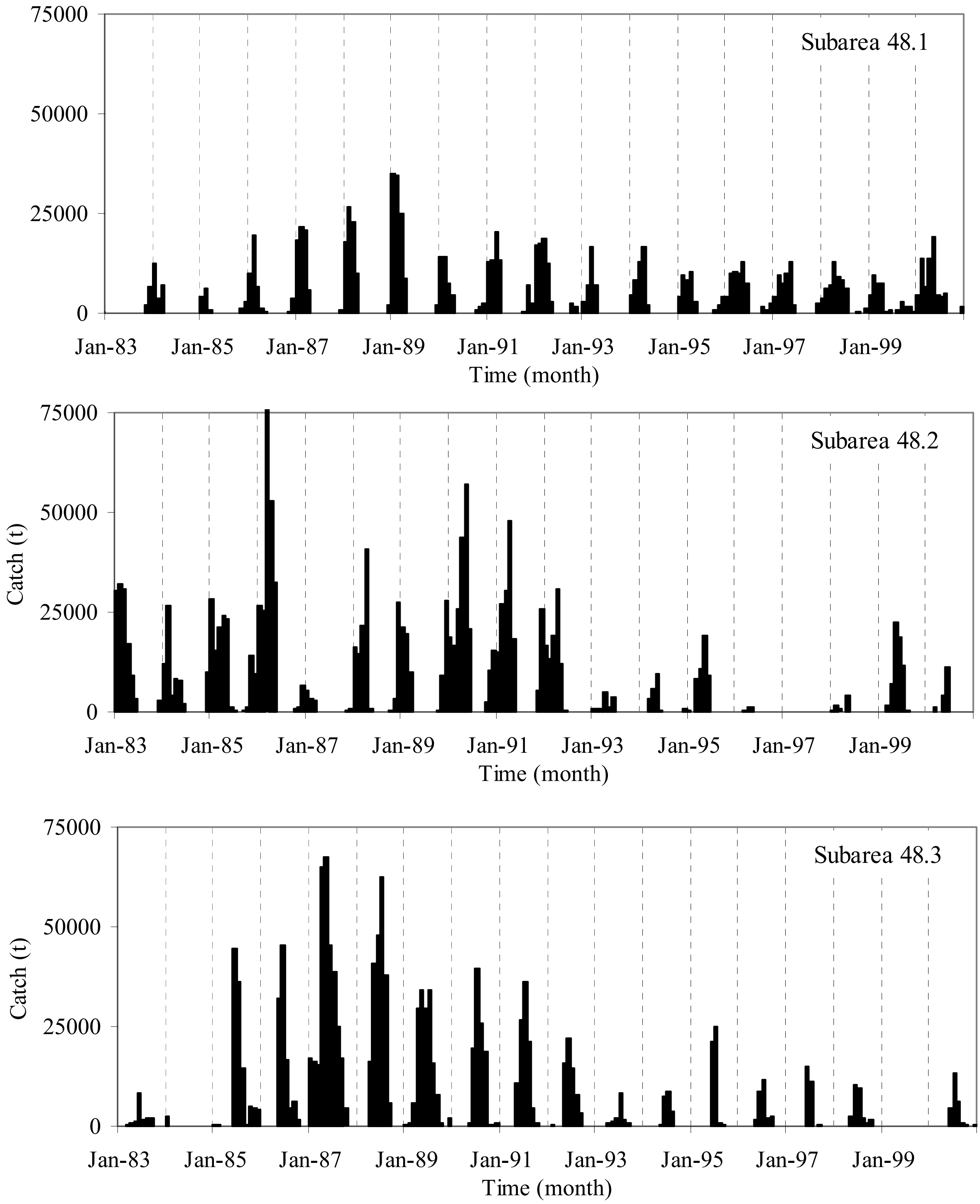


Figure 3: Monthly catch (t) of krill reported from the Southwest Atlantic (Subareas 48.1, 48.2, 48.3) between January 1983 and December 2000. Source: STATLANT data, CCAMLR.

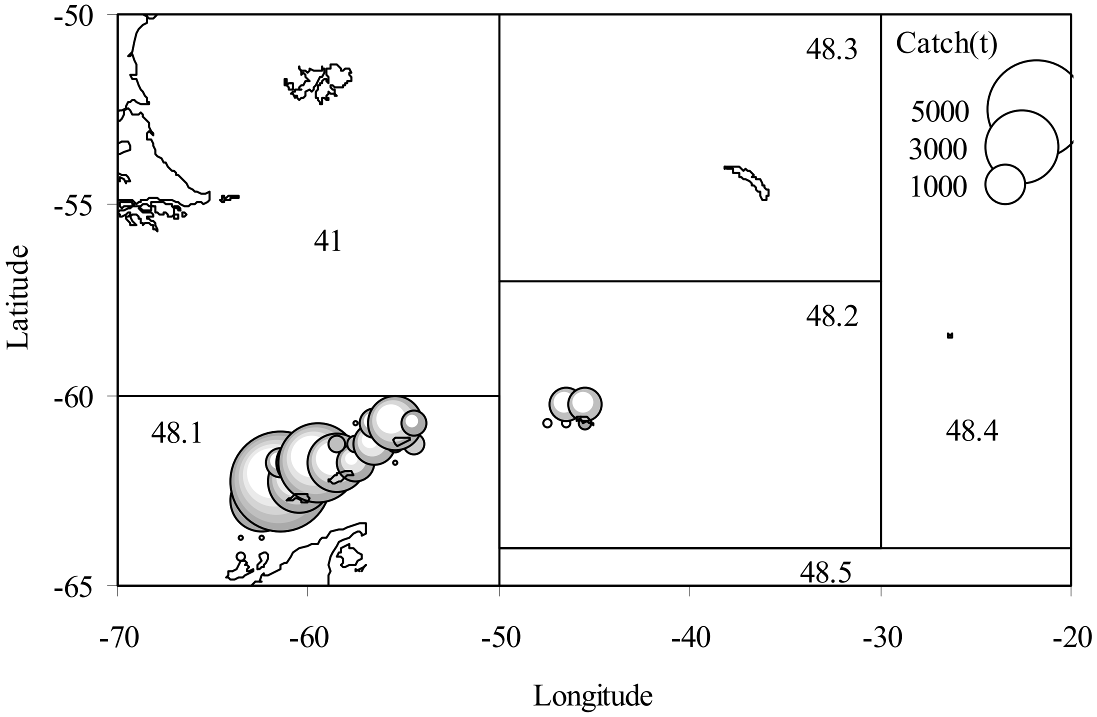


Figure 4: Catch (t) of krill reported in Area 48 between January and March 2000. Catches are aggregated by fine-scale (0.5° latitude by 1.0° longitude) rectangles. Source: CCAMLR Statistical Bulletin (2001a).

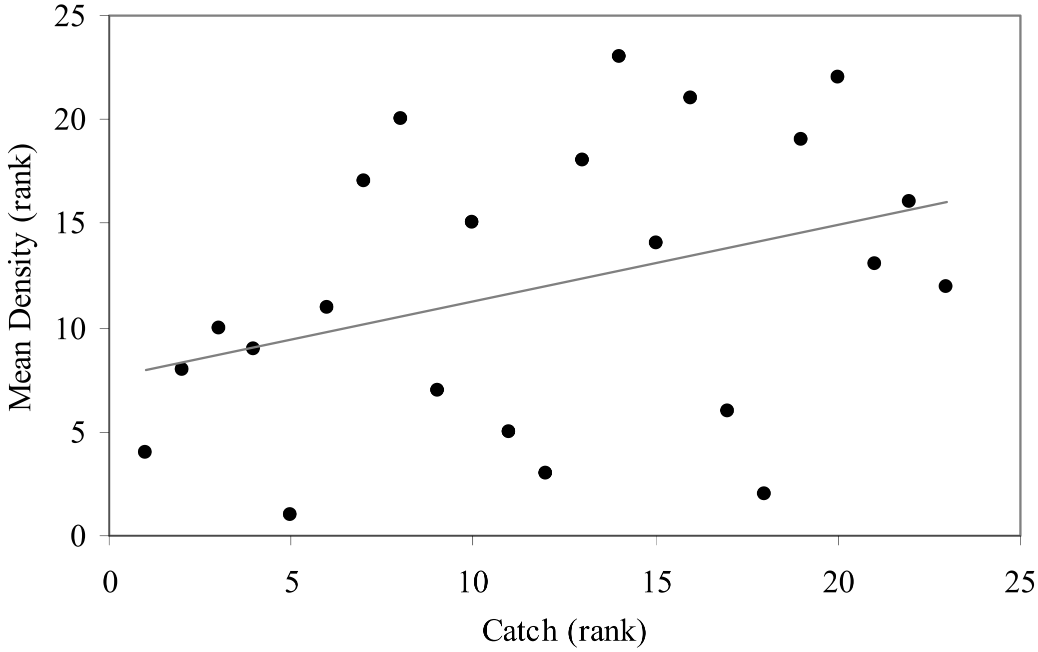


Figure 5: Spearman rank correlation between catches of krill reported in 23 fine-scale rectangles traversed during the CCAMLR-2000 Survey and the corresponding mean densities of krill estimated from the survey (rank 1: highest value; rank 23: lowest value).

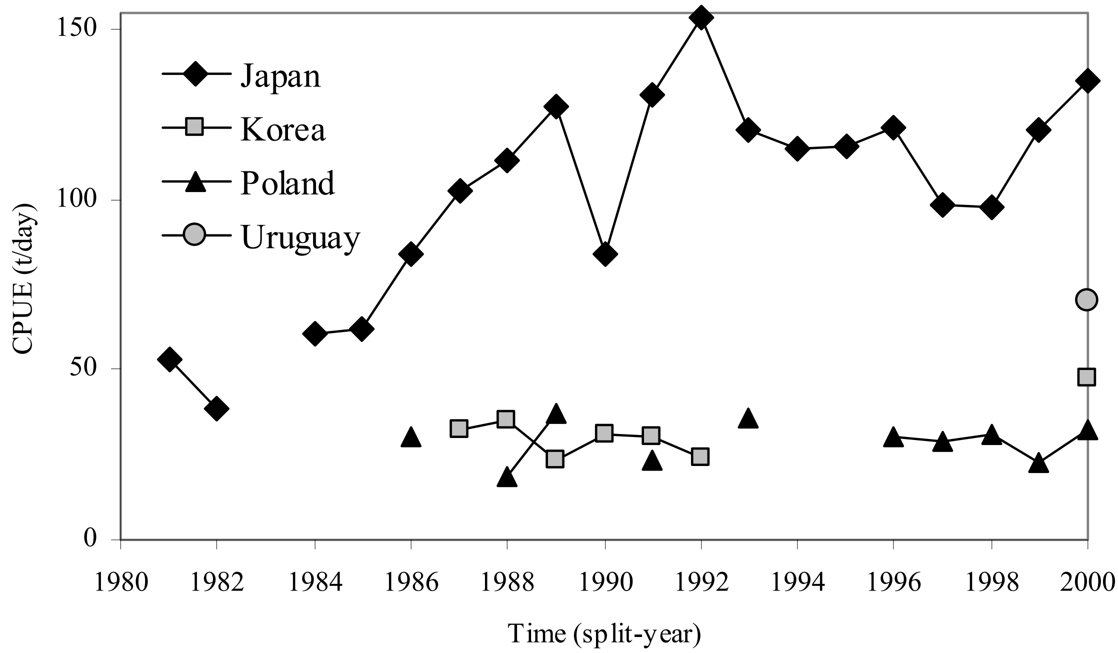


Figure 6: Mean catch rates for krill (t/day) in Subarea 48.1 during January-March of each split-year. Source: STATLANT data, CCAMLR.

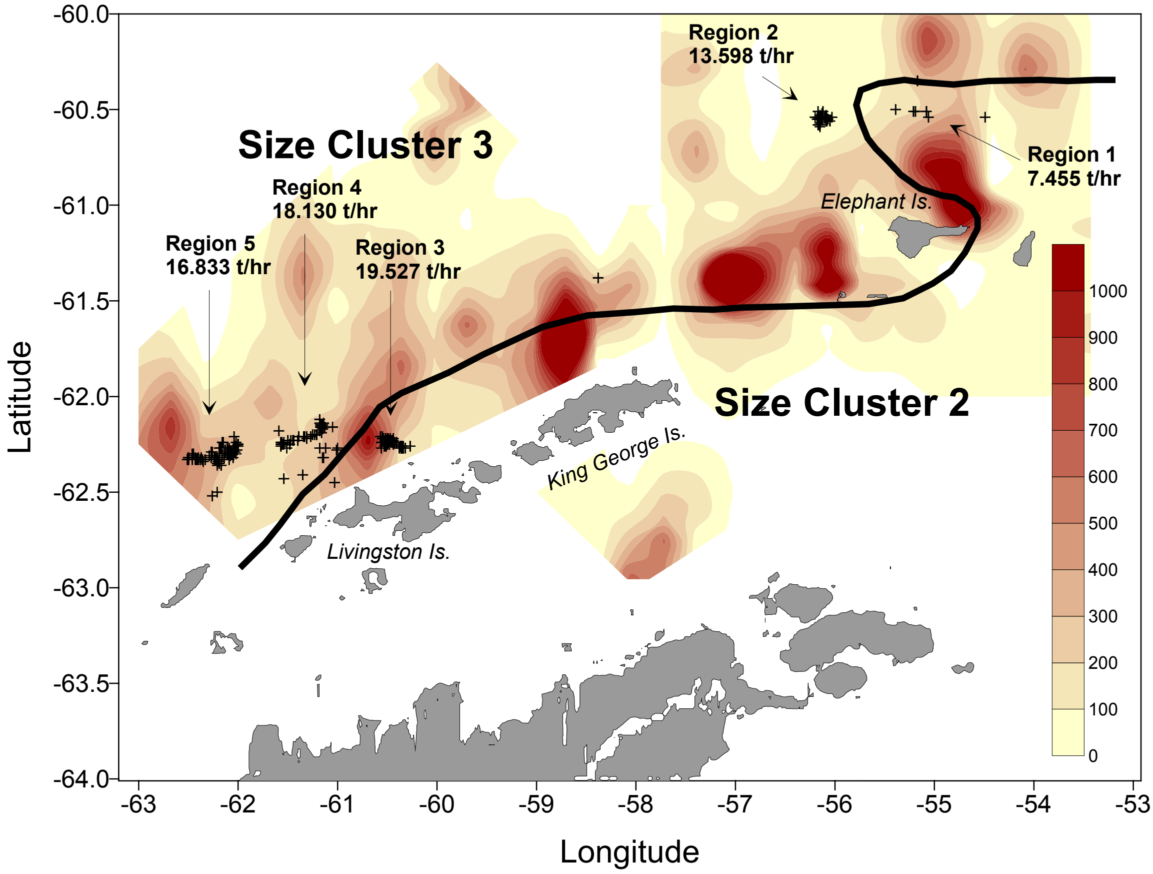


Figure 7: Location of hauls made by the trawler *Chiyo Maru No. 5* between 31 January to 1 March 2000. The shaded regions are krill densities estimated from the U.S. AMLR acoustic krill survey conducted 22 February to 7 March 2000 (Hewitt et al., *this volume*). The units are integrated nautical area scattering coefficient (m^2/n. $mile^2$) at a frequency of 120 KHz (proportional to krill abundance). The solid line represents the boundary between krill size clusters observed during the CCAMLR-2000 Survey (Siegel et al., *this volume*).

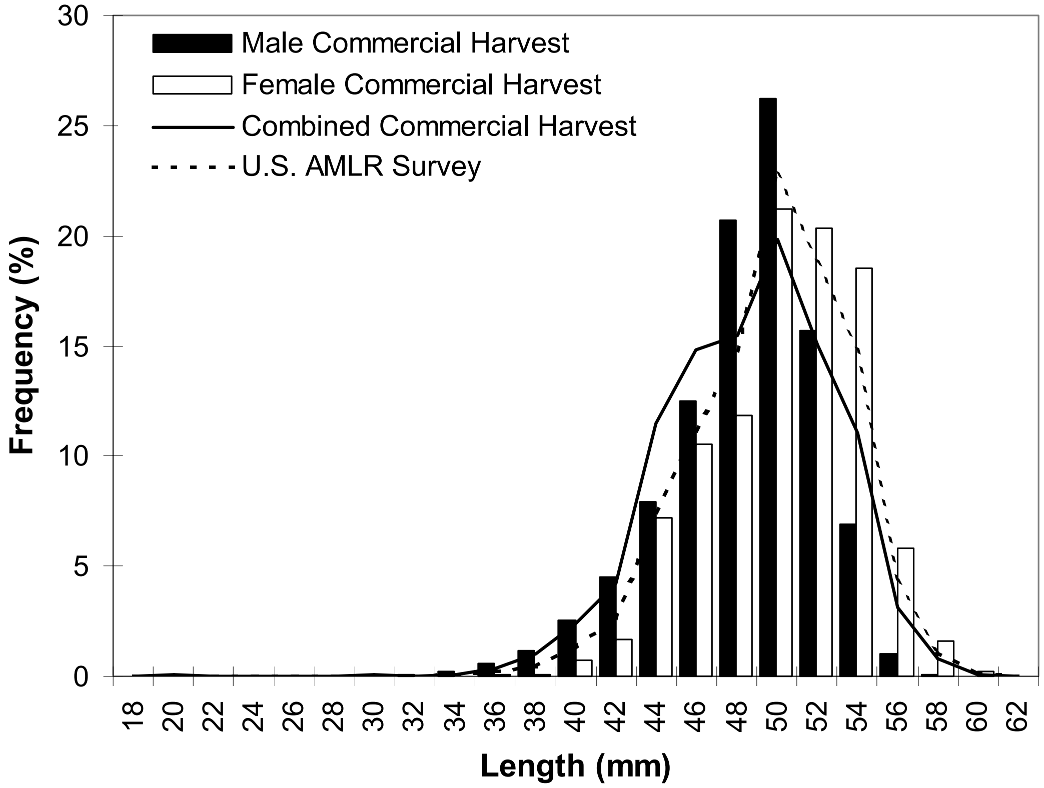
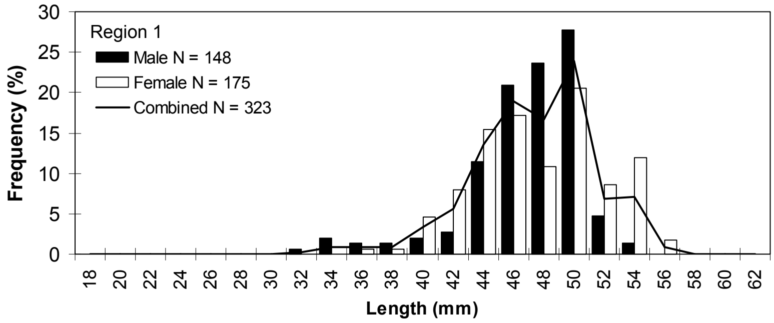


Figure 8: Body length (mm) of krill by sex sampled aboard the *Chiyo maru No.5* from 31 January to 1 March 2000 and during the U.S. AMLR acoustic krill survey conducted during 22 February to 7 March 2000 (Hewitt et al., *this volume*).

A)



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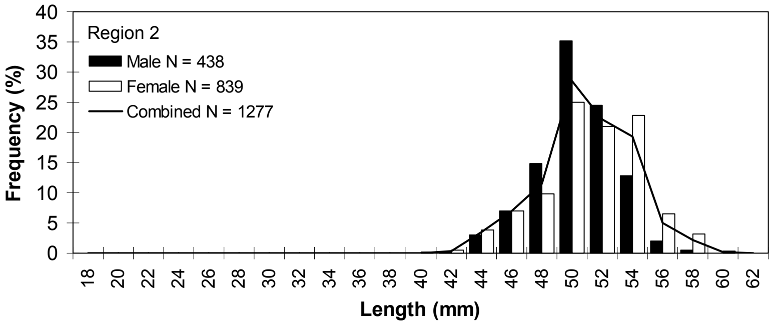

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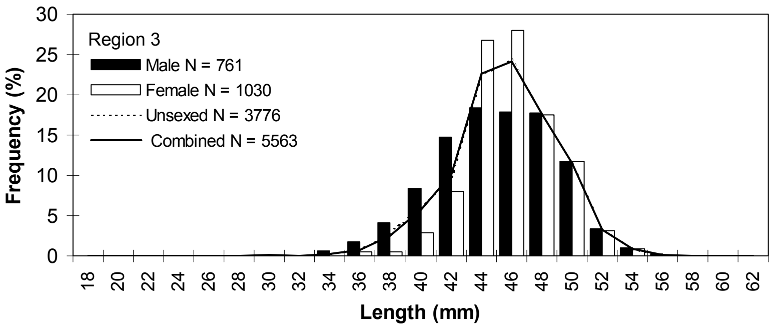

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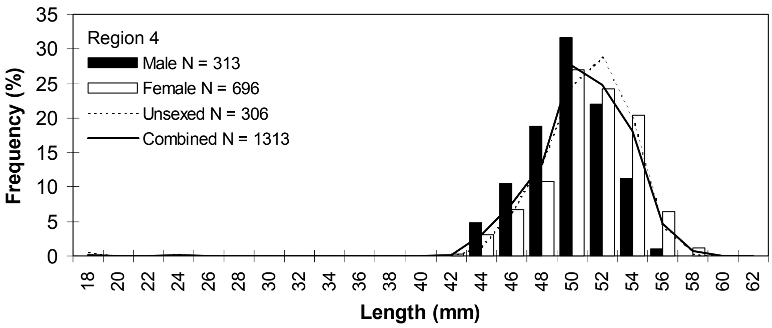

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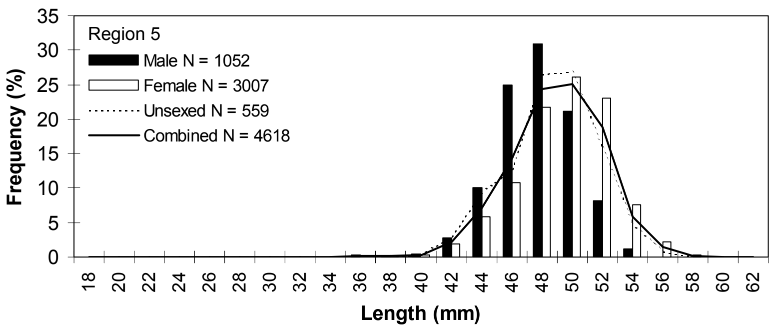

Figure 9: Length-frequency distribution of krill by region fished by the *Chiyo maru No.5* from 31 January to 1 March 2000.

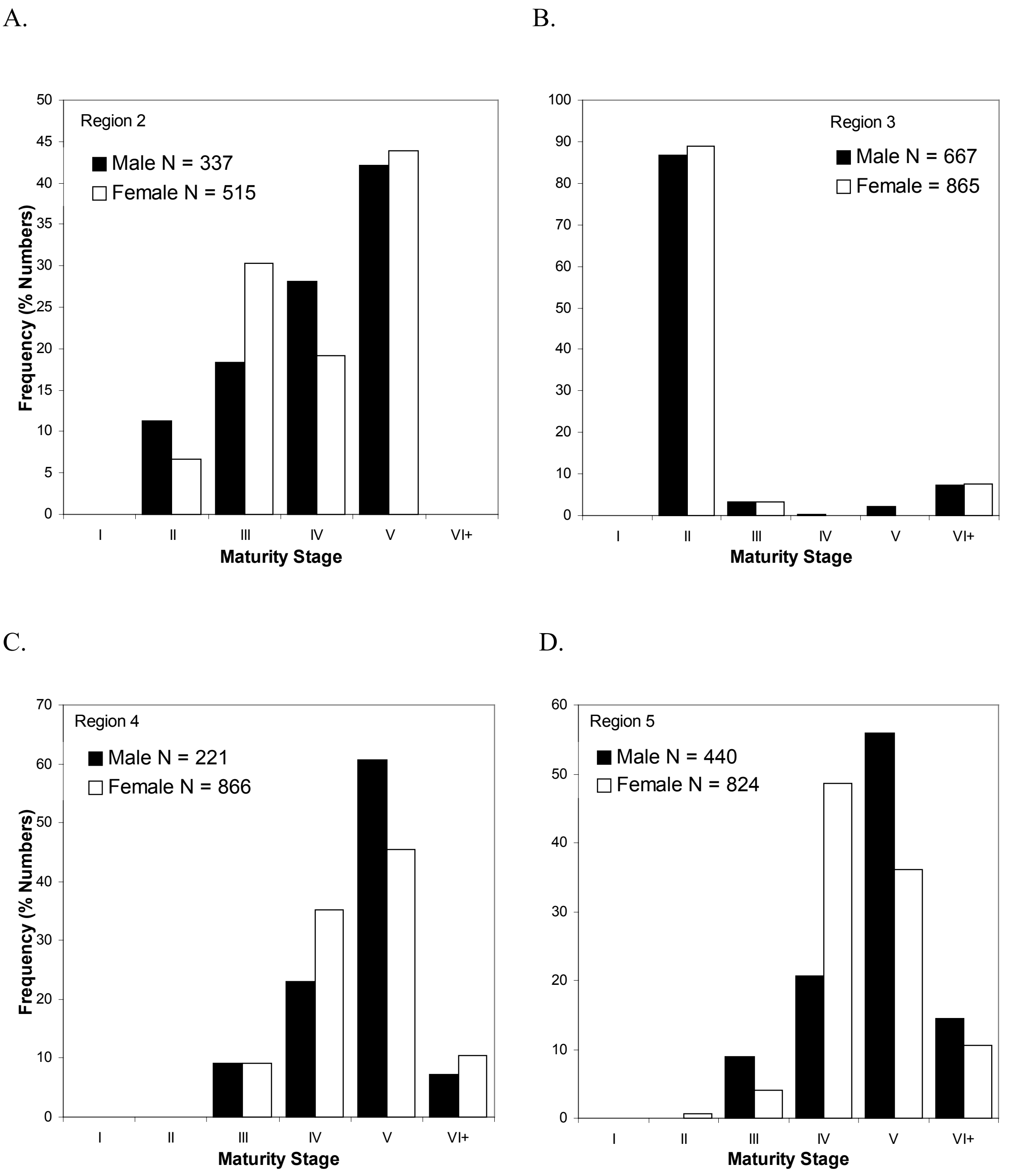

Figure 10. Maturity stages of krill by region fished by the *Chiyo maru No.5* from 31 January to 1 March 2000.