Relationship between the distribution of euphausiids and baleen whales in the Antarctic examined using JARPA data.

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ABSTRACT

Whale sighting and hydroacoustic surveys part of the Japanese Whale Research Program under a Special Permit in the Antarctic (JARPA) were conducted from the same research vessel platform in 1998/1999 and in 1999/2000. High densities of minke whales and large aggregations of euphausiids were observed along the ice edge above the continental slope in south-east stratum of Area IV and south-west stratum of Area V. The importance of the continental slope zone is recognized as a minke whale feeding area. These two strata are considered as the core feeding area of minke whales in Areas IV and V which determine their movement in the Antarctic. Minke whales were rarely sighted in the offshore region even if euphausiids were abundant. Distributions of humpback whales were correlated with high euphausiids density zones regardless of the bottom topographic features. Humpback whales were sighted in both the offshore and the continental slope zone where euphausiids were abundant. Several schools of blue whales were sighted in the small area along the ice edge where euphausiids were abundant although more observation is needed to confirm the distribution pattern of blue whales in the feeding area. Both baleen whales and euphausiids were scarce in the area east of 170°W where sea ice covered the continental shelf and slope zone.

INTRODUCTION

Euphausiids are the key species in the Antarctic marine ecosystem because baleen whales as well as other animals, such as seals, birds, fishes and squids rely on euphausiids as the major component of their diet (Laws, 1985). Even a relatively simple model showed that population dynamics of euphausiids apparently affect the abundance of whales (Murphy, 1995). Though euphausiids have been known as the major food source of baleen whales other than Bryde's whales (*Balaenoptera edeni*) in the Southern Ocean, that knowledge came mainly from examination of dead animals and we have little in-situ knowledge of interspecific and intraspecifc competitions among them for food (Kawamura, 1994). Although theories of ecosystem alternation caused by whaling operations have been suggested for a long time (Mackintosh and Wheeler, 1929; Laws, 1977) few evidence such as the decline of mean age at sexual maturity of minke whales (Kato, 1987) has been reported.

In addition to the ecosystem alternation being driven by the biotic factors, recent studies have suggested that abiotic factors, such as retreat of sea-ice extent due to global warming and an increase in radiation of ultraviolet light due to the ozone hole may substantially affect the Antarctic marine ecosystem (Tynan and DeMaster, 1997) but the effects of abiotic factors on cetaceans is have not been studied. For example fluctuation of krill abundance due to the changes in sea ice extent during winter was reported (Loeb *et al.*, 1997) but the effect of the fluctuation on cetacean abundance was not measured. Because spatiotemporal variations in euphausiids distribution and abundance could affect the behavior of whale stocks in the Southern Ocean, knowledge of dynamics of euphausiids could be helpful to confirm stock identity (Pastene and Goto, 1999).

For those reasons understanding the relationship between the distribution and abundance of euphausiids and baleen whales may provide useful information for developing management strategies for the sustainable use of baleen whale resources. To understand the relationship between the distribution of minke whales and euphausiids in the same given spatial and temporal environment, both acoustic surveys of euphausiids and sighting surveys of whales must be conducted simultaneously. This paper is a the preliminary report of the results of sighting surveys of baleen whales and hydroacoustic surveys of euphausiids that were conducted in 1998/1999 and in 1999/2000 as part of the Japanese Whale Research Program Under Special Permit in the Antarctic (JARPA). Underlying hypotheses are (1) whether the distribution of baleen whales is related to the distribution of euphausiids given same temporal and spatial environment, (2) whether the abundance of baleen whales is related to the abundance of euphausiids, and (3) whether there is any evidence that shows interspecific competition among baleen whales.

JARPA has been conducted during the austral summer every year since the 1987/1988 season. The primary objectives of the JARPA are (1) elucidation of the stock structure of the Southern Hemisphere minke whales (*B. acutorostrata*) to improve the stock management, (2) estimation of biological parameters of the Southern Hemisphere minke whales to improve the stock management, (3) elucidation of the role of whales in the Antarctic marine ecosystem through the study of whale feeding ecology and (4) elucidation of the effect of environmental changes on cetaceans. Among these four objectives this study related mainly to objective (3).

MATERIAL AND METHODS

Research area

The 1998/1999 JARPA was conducted in the Antarctic Area V and the western part of Area VI (VI-W) from 13 January to 31 March 1999. Area V was divided into three strata; north-west (V-NW), south-west (V-SW), and south-east (V-SE). The 1999/2000 JARPA was conducted in the Antarctic Area IV and eastern part of Area III (III-E) from 5 December 1999 to 9 March 2000. Area IV was divided into five strata; north-west (IV-NW), south-west (IV-SW), north-east (IV-NE), south-east (IV-SE) and Prydz Bay (IV-PB). III-E was divided into two strata; south (III-E-S) and north (III-E-N). The details of the 1998/1999 and 1999/2000 JARPA area stratification were described by Nishiwaki *et al.* (1999) and Ishikawa *et al.* (2000), respectively. Fig. 1 is a schematic map of research area.

Sighting survey of cetaceans

Details of cruise track design and sighting survey methods in the 1998/1999 and the 1999/2000 JARPA are described by Nishiwaki *et al.* (1999) and Ishikawa *et al.* (2000), respectively. The sighting vessel (SV), *Kyoshinmaru No.2* (368 GT) was engaged in the sighting of the minke whales as well as other large baleen whales over the entire area. Principally the SV conducted the survey 8 hours per day by passing mode and 4 hours per day by limited closing mode. The sighting survey was conduced during diurnal hours. The nominal steaming speed of SV on the track line was 10.5 knots. Density index (DI, number of whales seen per 100 n. miles) of minke, blue, fin and humpback whales in each stratum were calculated to see density differences among strata.

Acoustic survey

A Simrad EK500 scientific echo sounder (Norway) with software version 5.30 operating frequency at 38, 120 and 200 kHz on board the SV was used to collect data for the acoustic survey. Data collected at 120 kHz were used for further data analysis. The transducers were hull-mounted at the depth of 4.3 m from the surface. Each transducer was covered with a 40 mm polycarbonate acoustic window to minimize the damage on the transducer surface from contacting sea ice. The hydraulic oil filled the space between the transducer surfaces and the acoustic windows. Calibrations were carried out before the survey in temperate waters off the coast of Matsuyama, Japan (29 October 1998 and October 28 1999) and at the middle of the survey (2 February 1999 and February 2000) in the Antarctic. The copper sphere technique that described in EK 500 operation manual (Simrad, 1997) was applied for the calibrations. Data were stored and interpreted with the aid of Simrad BI 500 post processing system.

We adapted the acoustic data analysis described by Hewitt and Demer (1993) and Demer and Hewitt (1995). The following procedures came from those papers. Mean backscattering area per square n. mile of survey transect (s_A) attributed to krill for every 1 n. mile of survey transect over 10 to 250 m depth was calculated by following formula;

$$s_A = 4\pi r_0^2 1852^2 \int_{r_1=10}^{r_2=250} s_V dr \left(\frac{m^2}{nmi^2}\right)$$

where r is depth from the surface, $r_0 = 1$m representing the reference range for backscattering strength and $s_V = 0$ if $10 \log (s_V) \leqq -81$dB, because threshold backscattering was set at –81 dB. Because direct sampling method to identify species was not available, the potential euphausiids swarms detected on the echogram were attributed to euphausiids for this preliminary analysis.

Krill backscattering cross section area (ó) was calculated with the following formula based on krill target strength described by Greene et al. (1991):

$$\sigma = 4\pi r_o^2 10^{-12.745} l^{3.485}$$

where l was standard length of krill. Krill wet weight (w) was calculated with the following formula based on Siegel (1986):

$$w = 0.00193 l^{3.325}$$

Average area krill biomass density ($\bar{\rho}$) was calculated as follows;

$$\bar{\rho} = S_A \frac{w}{\sigma} = 0.249 l^{-0.16} S_A$$

Then frequency distribution of euphausiids standard length (f_i) was applied to the following formula;

$$\bar{\rho} = 0.249 \sum_{i=1}^{n} f_i (l_i)^{-0.16} S_A$$

Because minor variation in the frequency distribution of krill length did not affect the krill biomass estimate, a combined distribution data based on Loeb and Siegel (1992) was used (Demer and Hewitt, 1995) as follows;

$$\sum_{i=1}^{n} f_i (l_i)^{-0.16} \cong 0.562$$

With this formula mean krill biomass of each transect in each stratum was calculated.

Mean krill biomass density ($\bar{\rho}$) of each stratum was;

$$\bar{\rho} = \frac{\sum_{i=1}^{N} \bar{\rho}(n_i)}{\sum_{i=1}^{N} n_i}$$

where N = number of transects, $\bar{\rho}_i$ = mean density on the ith transect and n_i = number of 1 n. mile averaging intervals on the ith transect. In this formula, each transect was regarded as a single biomass density sample (Hampton, 1987; Jolly and Hampton, 1990). Then variance of ρ was calculated with the formula (Jolly and Hampton, 1990; Simmonds *et. al.*, 1991);

$$\bar{\rho} = \frac{N}{N-1} \frac{\sum_{i=1}^{N} (\bar{\rho}_i - \bar{\rho})^2 n_i^2}{\left(\sum_{i=1}^{N} n_i\right)^2}$$

95% confidence interval of ñ was computed with the following formula adopted at the POST-FIBEX Acoustic Workshop (1986);

$$95\%CI(\rho) = \pm t(N-1)\sqrt{Var(\rho)}\,.$$

Comparison of distribution and abundance of baleen whales and euphausiids

For visual spatial analysis, we drew thematic maps that included sighting, echo sounder, ice edge line and topography data with the aid of the Marine Explorer geographic information system (GIS) (Environmental Simulation Laboratory Inc., Japan). The ice edge line was constructed based on observations of the research vessel and Ice Analysis (National Ice Center, U.S.). Because the position of the ice edge was significantly changed as the season progressed, the ice edge line that was observed during the southern stratum research periods was drawn on the figure. The 500m interval isobaths between 500 m and 3,000 m were drawn because the steep continental slope exists within this depth range around the Antarctic continent. Qualitative analysis was made using these maps.

RESULT

Baleen whale sightings

Cetacean searching distances were 3,181.4 n. miles in the 1998/1999 season and 4,963.2 n. miles in the 1999/2000 season (Table 1). Cruise tracks is shown in Fig. 2. A summary of primary sightings and DI for minke, blue (*B. musculus*), fin (*B. physalus*) and humpback (*Megaptera novaeangliae*) whales in each stratum is shown in Table 2. Geographical distributions of baleen whales in the 1998/1999 JARPA are shown in Figs 4–6 and in the 1999/2000 JARPA are shown in Figs 8-10.

1998/1999 season

The highest minke and humpback whale DIs were recorded in V-SW while the lowest DIs were recorded in VI-W. Though minke whale DI in V-NW was relatively high, most sightings were concentrated in the southern part of the stratum (Fig. 4). High fin whale DI was recorded in V-SE. Only 15 individuals (6 schools, including secondary sightings) of blue whales were sighted throughout all surveyed strata. Of these, 13 individuals of 5 schools were recorded in the small marginal ice edge zone above the continental slope on January 21, 1999 (Fig. 12). Other baleen whales, minke, fin and humpback whales were also detected in this small area. Few baleen whales were sighted in the offshore region between 130°E and 165°E and in the area east of 170°W.

1999/2000 season

DIs of minke and humpback whale were exceptionally high in IV-SE. Minke whale DIs were higher in the southern stratum (including Prydz Bay) than in the northern stratum in both Area III east and Area IV. Humpback whale DIs did not show a distinctive north-south difference. Relatively high humpback DI was recorded in IV-NE. High DIs of fin whale were observed in III-E and IV-NE. Blue whales were sighted in III-E-N, III-E-S and IV-NE.

Euphausiids distribution and density

A total of 3,688 n. miles and 6,538 n. miles of data were analyzed for 1998/1999 and 1999/2000 seasons, respectively (Table 3). Table 3 also shows the densities of euphausiids in each stratum. Acoustic transects are shown in Fig. 3. Geographical distributions of euphausiids in the 1998/1999 and in the 1999/2000 JARPA are shown in Fig. 7 and Fig. 11, respectively.

1998/1999 season

Euphausiids densities were higher in V-SW and V-SE than the others though the variances were high because the difference between the highest and the lowest densities were large in both strata. Western half of V-SW (transect 10-17) showed higher densities than eastern part of the stratum (transect 1-9). This west-east trend was also found in V-NW to some extent. Significantly low density was recorded in VI-W.

1999/2000 season

Euphausiids densities were high in IV-NW and IV-NE but these were due to the contributions of the first transects in each stratum (Table 3(c)). High concentrations of euphausiids on these transects (IV-NW=56.3g/m^2; IV-NE=43.9g/m^2) could be associated with their close location to the ice edge line when the survey was conducted. Euphausiids densities in IV-NW and IV-NE were 8.8g/m^2 (variance = 0.9, CL = ±2.3) and 13.0g/m^2 (variance = 2.2, CL = ±3.5) respectively, without the first transects for each stratum. Because the accuracy was increased after excluding the first transect in each stratum, first transect excluding densities were seemingly applicable to these stratum. These values were used for comparison among strata. Euphausiids density was the highest in III-E-S. IV-SE and IV-PB showed relatively high densities. Density was the lowest in IV-NW.

Relationship between distribution of baleen whales and euphausiids

High concentrations of minke whales were correlated with large aggregations of euphausiids along the ice edge above the continental slope in both research seasons. These situations were apparent between 153°E and 160°E (V-SW) and between 104°E and 117°E (IV-SE) (Figs 4, 7, 8, and 11). Few minke whales were sighted in offshore regions even if euphausiids were concentrated.

Distribution of humpback whales was associated with large aggregations of euphausiids independent from topographic future. These situations were found in III-E (35°E to 70°E) and in the eastern part of Area IV (100°E to 130°E) (Figs 5, 7, 9, and 11).

It is difficult to see the relationship between distribution of fin and blue whales and distribution of euphausiids because of small number of sightings. Fin whale distribution was generally high where euphausiids were dense but some sightings were made where euphausiids were scarce. Blue whales also tended to aggregate in the high euphausiids density area. Blue whale schools sighted on January 21, 1999 were associated with high density of euphausiids (Figs 12 and 13).

Relatively few baleen whale sightings were made in the area east of 170°W where euphausiids were scarce.

DISCUSSION

Hydroacoustic surveys revealed that high density of euphausiids were formed in the areas where the ice edge was located just above the continental slope in V-SW and IV-SE in the 1998/1999 and in the 1999/2000 JARPA surveys, respectively. High densities of minke whale coincided with high densities of euphausiids in these areas. Areas along the ice edge above the continental slope in IV-SE and V-SW were identified as the potential core feeding areas of minke whales from January to February. Most of the cruise tracks in those areas during the surveys covered the area where the ice edge and continental slope zone were coincident. Considerably large number of minke whales compared with previous surveys was sighted in V-SW during the 1998/1999 JARPA (Nishiwaki *et al.*, 1999) and in IV-SE during the 1999/2000 JARPA (Ishikawa *et al.*, 2000). These sightings could be associated with the presence of large aggregation of euphausiids in those areas.

At least three factors could have contributed to the formation of the core feeding area. Firstly, the Antarctic slope front is characterized by a noticeable gradient of water temperature and chemistry hence enhancing the biological productivity (Jacobs, 1991). Secondly, the ice edge region is expected to have a high phytoplankton density because of the stabilized water column (Smith and Nelson, 1986) thus it could serve as feeding ground for euphausiids. Finally, the Antarctic slope zone is considered as favorable euphausiids spawning ground (Ichii *et al.*, 1998(b)). These multiple factors likely interact with each other to provide suitable habitat for euphausiids. As a result, a high euphausiids density area could be formed. Minke whales then aggregate in such areas for feeding.

The encounter rate of minke whales during IDCR cruises (1976-1988) was relatively high in the above mentioned area (Kasamatsu *et al.*, 1996). It should be noted that the continental slope region in V-SW was covered by sea ice during the austral summer months in the 1994/1995 JARPA which resulted in poor body fat condition of minke whales due to food shortage in that year (Ichii *et al.*, 1998(a)). This result strongly supports the idea that the continental slope zone in V-SW is an important minke whale feeding ground. Though yearly environmental change exists, IV-SE and V-SW are seemingly consistent feeding areas which may influence the movement of minke whales in the Ataractic. Minke whale distribution was concentrated in the area where the ice edge and the continental slope were coincident and rarely seen in offshore regions even if euphausiids were abundant. The reason for this phenomenon is open to question.

In contrast to minke whale, humpback whale distributions were associated with the high euphausiids concentration areas formed in the continental slope and in the offshore zones. The euphausiids high density area in the offshore zone is associated with the ice edge retreating (Ichii, 1990). In the waters around 60°S, 100°E, many humpback whales were sighted and high euphausiids density was observed These waters were covered with sea ice one week before the survey took place. Thus high density of euphausiids in these waters could be related to the rapid retreating of sea ice. High density of euphausiids related to the retreating ice edge was also observed in III-E. In addition to the effect of ice retreating, northward water flow has been detected in the waters around 60°S, 100°E (Ichii, 1990) which may be related to the distribution of euphausiids in the offshore zone. Krill transport by means of large scale flow is suggested in the Scotia Sea (Hofmann *et al.*, 1999). An XCTD oceanographic study in 1997/98 indicated that distribution of humpback whales between 80°E and 120°E could be related to presence of the southern boundary of the Antarctic Circumpolar Current (SB-ACC) (Matsuoka *et al.*, 2000 (a)). Oceanographic features must be considered in future research. It is uncertain why humpback whales utilize both offshore and continental slope zones at this time but this characteristic could be an advantageous feeding strategy over other baleen whales in the Antarctic.

Several schools of blue whales tended to aggregate in the area where euphausiids were dense though sightings were too few to draw conclusions. Blue whale calls were recorded by the retrievable sonobuoy system in the area where blue whales aggregated on January 21, 1999 (Matsuoka et al., 2000 (b)). Blue whale vocalization may be related to aggregation in the feeding area but this required further study.

Few baleen whale sightings were made in the area east of 170°W where euphausiids were also scarce. Euphausiids are rarely found in the Pacific sector (80°W to 180W°) because sea ice totally covers the continental shelf (Ichii, 1990). Only immature minke whales were observed around there during the 1998/1999 JARPA. The result was different from the 1996/1997 JARPA when the proportion of pregnant females in the stratum was high (Nishiwaki *et al.*, 1999). The reason for the different distribution pattern of minke whales is uncertain but euphausiids abundance in the area may affect the distribution pattern of minke whales.

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Table1. Research periods and searching distance of sighting surveys in 1998/1999 season (a) and 1999/2000 season (b).

(a)

Area	Stratum	Research Period		Searching
		Start	End	Distance
V	NW	1/14/99	2/2/99	961.8
	SW	2/3/99	2/21/99	647.5
	SE	2/22/99	3/13/99	377.3
VIW		3/14/99	3/28/99	542.0

(b)

Area	Stratum	Research Period		Searching
		Start	End	Distance
IIIE	North	12/5/99 12/21/99	12/13/99 12/26/99	715.9
	South	12/14/99	12/21/99	322.4
IV	NW	12/27/99	1/11/00	999.1
	NE	1/11/00	1/26/00	1043.7
	SE	1/28/00	2/18/00	819.5
	SW	2/18/00 3/6/00	2/29/00 3/9/00	670.8
	Prydz Bay	3/1/00	3/6/00	391.8

Table 2. Summary of baleen whale primary sightings and density index (DI, number of whales seen per 100 n. miles) in 1998/1999 season (a) in Area III east in 1999/2000 season (b) and in Area IV in 1999/2000 season (c).

(a)

Species	V									VI-W		
	NW			SW			SE					
	sch.	ind.	DI	sch.	ind.	DI	sch.	ind.	DI	sch.	ind.	DI
Minke whale	53	301	31.30	114	476	73.51	36	105	27.83	61	68	12.55
Blue whale	2	4	0.42	-	-	-	1	2	0.53	-	-	-
Fin whale	4	17	1.77	-	-	-	11	96	25.44	4	13	2.40
Humpback whale	8	21	2.18	15	31	4.79	4	11	2.92	3	4	0.74

(b)

Species	III E					
	North			South		
	sch.	ind.	DI	sch.	ind.	DI
Minke whale	10	12	1.68	60	126	39.08
Blue whale	5	9	1.26	1	4	1.24
Fin whale	7	36	5.03	7	22	6.82
Humpback whale	15	28	3.91	13	32	9.93

(c)

Species	IV														
	NW			NE			SE			SW			Prydz Bay		
	sch.	ind.	DI	sch.	ind.	DI	sch.	ind.	DI	sch.	ind.	DI	sch.	ind.	DI
Minke whale	6	7	0.70	58	78	7.47	178	973	118.73	122	391	58.29	57	184	46.96
Blue whale	-	-	-	4	6	0.57	-	-	-	-	-	-	-	-	-
Fin whale	1	1	0.10	3	91	8.72	-	-	-	2	4	0.60	-	-	-
Humpback whale	14	28	2.80	72	131	12.55	89	169	20.62	32	68	10.14	3	6	1.53

Table 3. Euphausiids density in each stratum in 1998/1999 season (a), in eastern part of Area III in 1999/2000 season (b) and in Area IV in 1999/2000 season (c). n_i = number of 1 n. mile averaging intervals on *i*th transect; SA = mean backscattering area per square n. mile of sea surface; ñ = weight density of euphausiids per square mater (g/m^2).

(a)

Area	V									VI		
Stratum	NW			SW			SE			Western part		
Transect	ni	SA	ρ	ni	SA	ρ	ni	SA	ρ	ni	SA	ρ
1	85	14.5	2.0	79	40.8	5.7	111	107.3	15.0	12	0.665	0.093
2	313	108.9	15.2	45	328.5	46.0	39	708.4	99.2	53	6.377	0.893
3	329	251.3	35.2	38	63.3	8.9	0	0.0	0.0	61	8.537	1.195
4	405	127.6	17.9	45	5.9	0.8	22	217.0	30.4	39	0.000	0.000
5	273	176.8	24.7	108	6.8	1.0	12	44.6	6.2	134	0.045	0.006
6				38	0.0	0.0	55	15.9	2.2	18	0.000	0.000
7				119	62.5	8.7	58	20.6	2.9	35	0.181	0.025
8				54	1.0	0.1	34	125.0	17.5	37	0.216	0.030
9				40	4.4	0.6	76	426.0	59.6	76	0.000	0.000
10				49	349.3	48.9	41	182.1	25.5	45	0.000	0.000
11				77	124.6	17.4	19	129.0	18.1	55	0.000	0.000
12				93	149.8	21.0	34	18.5	2.6	25	0.000	0.000
13				125	640.4	89.7	40	32.0	4.5			
14				48	429.2	60.1						
15				96	242.8	34.0						
16				28	216.6	30.3						
17				70	123.4	17.3						
Σ ni	1405			1152			541			590		
Weighted mean ρ			21.7			25.3			24.7			0.210
Weighted variance ρ			18.8			71.9			78.7			0.020
CL ρ			12.0			18.0			19.5			0.310

(b)

Area	III East					
Stratum	North			South		
Transect	ni	SA	ρ	ni	SA	ρ
1	383	54.4	7.6	48	9.5	1.3
2	350	167.3	23.4	106	89.7	12.6
3	100	92.3	12.9	43	61.2	8.6
4	88	125.0	17.5	51	176.1	24.6
5	391	15.6	2.2	39	362.6	50.8
6				39	488.4	68.4
7				66	14.1	2.0
8				45	87.2	12.2
Σ n_i	1312			437		
Weighted mean ρ			11.3			19.1
Weighted variance ρ			24.0			48.4
CL ρ			13.6			16.5

(c)

Area	IV														
Stratum	NW			NE			SE			SW			Prydz Bay		
Transect	ni	SA	ρ	ni	SA	ρ	ni	SA	ρ	ni	SA	ρ	ni	SA	ρ
1	240	402.0	56.3	282.0	313.9	43.9	93	12.7	1.8	0	0.0	0.0	147	144.0	20.2
2	244	78.1	10.9	311.0	88.6	12.4	40	7.4	1.0	44	232.4	32.5	100	33.3	4.7
3	299	52.3	7.3	309.0	121.0	16.9	112	91.3	12.8	101	65.5	9.2	156	137.1	19.2
4	311	66.0	9.2	332.0	86.4	12.1	46	37.6	5.3	0	0.0	0.0	25	211.3	29.6
5	23	0.0	0.0	23.0	0.0	0.0	96	5.9	0.8	44	214.5	30.0			
6							45	31.0	4.3	42	52.8	7.4			
7							119	133.4	18.7	123	64.1	9.0			
8							47	69.3	9.7	45	30.6	4.3			
9							86	266.5	37.3	75	77.9	10.9			
10							39	117.3	16.4	33	0.0	0.0			
11							91	398.8	55.8	108	34.8	4.9			
12							41	23.7	3.3	0	0.0	0.0			
13							93	194.8	27.3	78	194.0	27.2			
14							51	53.3	7.5	45	30.3	4.2			
15							62	53.8	7.5	108	203.7	28.5			
16										46	52.7	7.4			
17										34	70.9	9.9			
Σ n_i	1117			1257.0			1061			926			428		
Weighted mean ρ			19.0			20.3			16.3			13.7			16.7
Weighted variance ρ			105.8			46.8			22.2			8.9			14.3
CL ρ			28.5			19.0			10.1			6.3			12.0

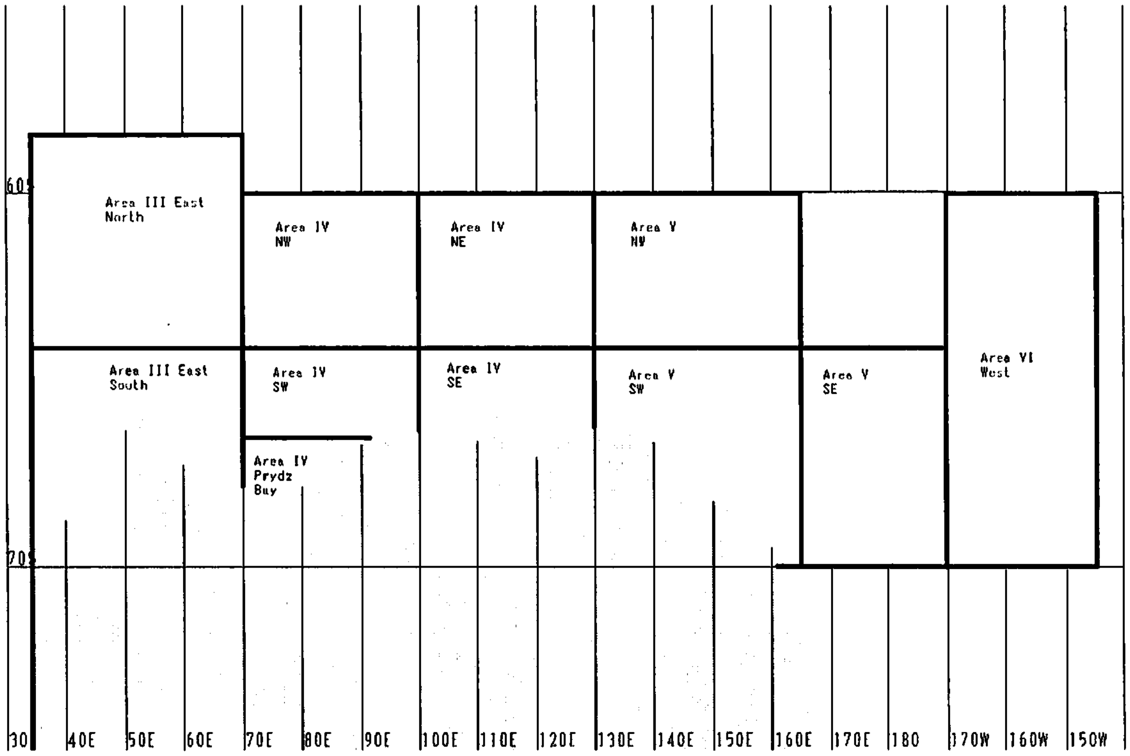


Figure 1. Schematic map of research area in 1998/1999 and 1999/2000 in JARPA surveys.

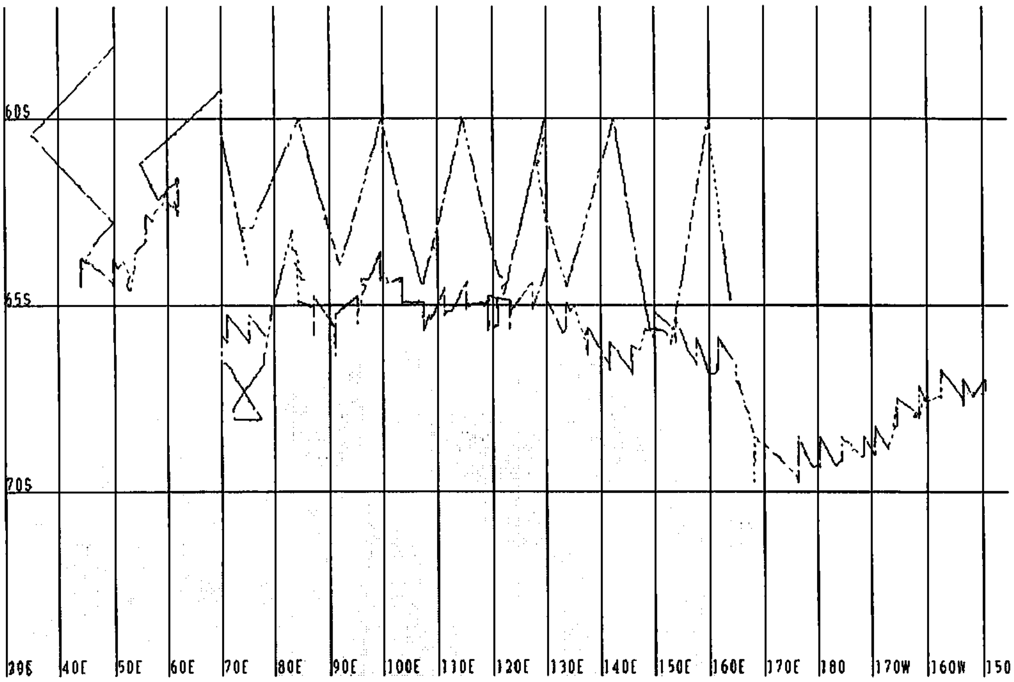


Figure 2. Sighting survey tracklines in the 1998/1999 and 1999/2000 JARPA surveys. Solid line = on effort; dashed line = off effort.

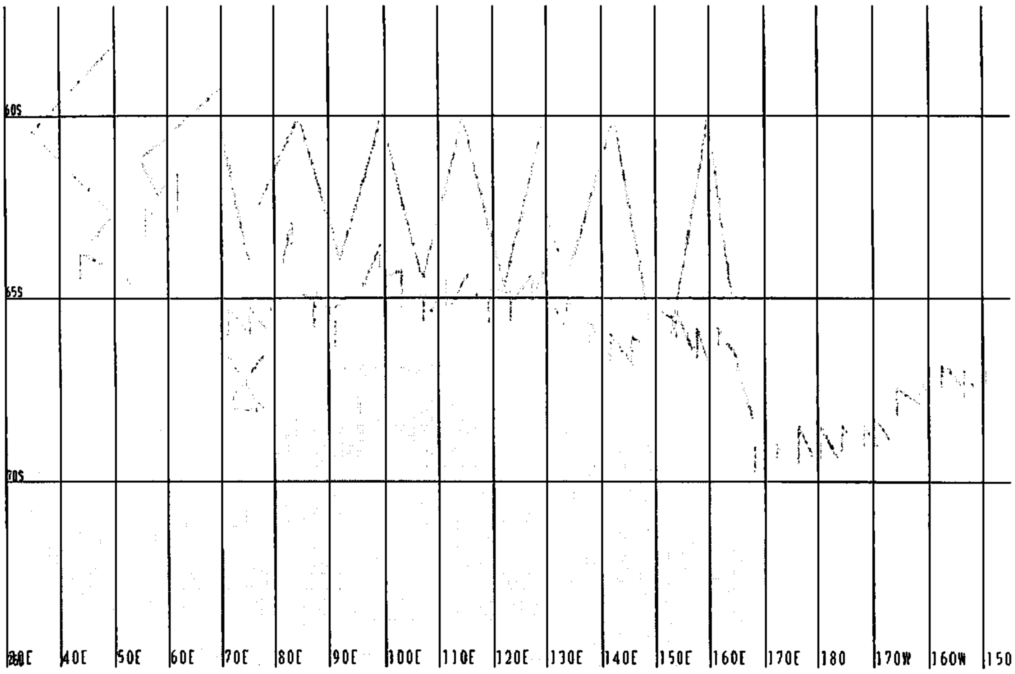
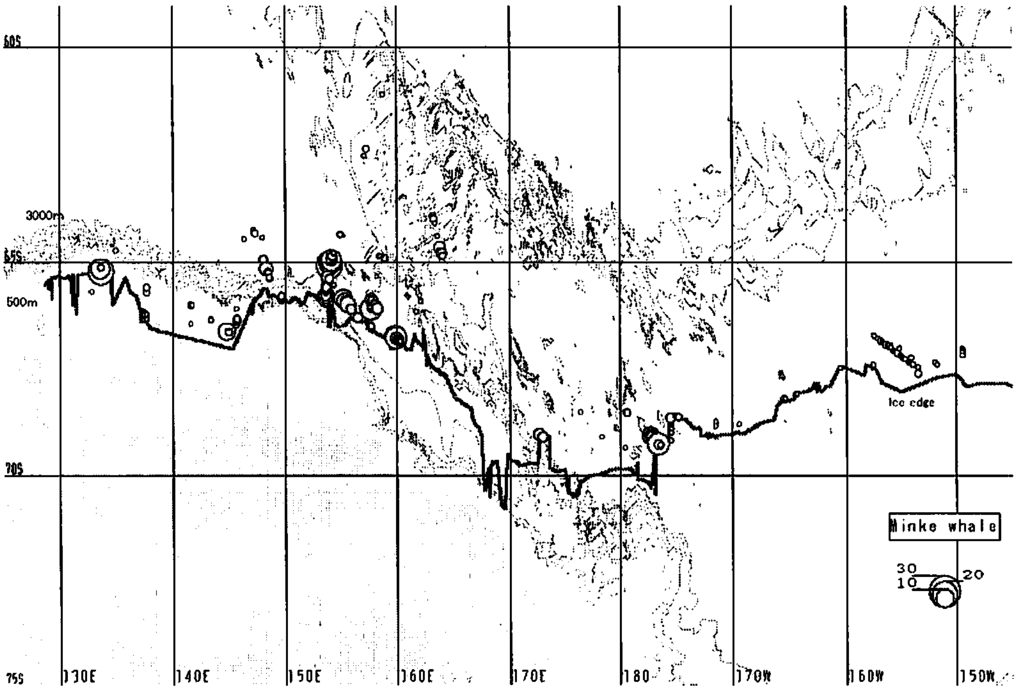


Figure 3. Acoustic transects in the 1998/1999 and 1999/2000 JARPA surveys.



Fiugre 4. Primary sighting positions and school sizes of minke whales in the 1998/1999 JARPA. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

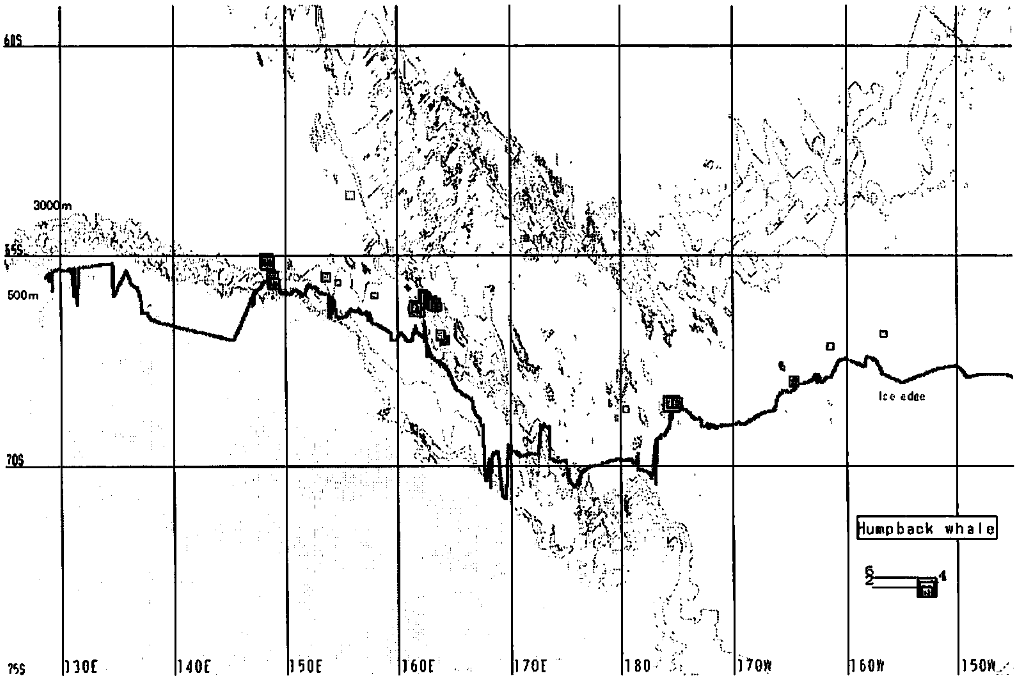


Figure 5. Primary sighting positions and school sizes of humpback whales in the 1998/1999 JARPA. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

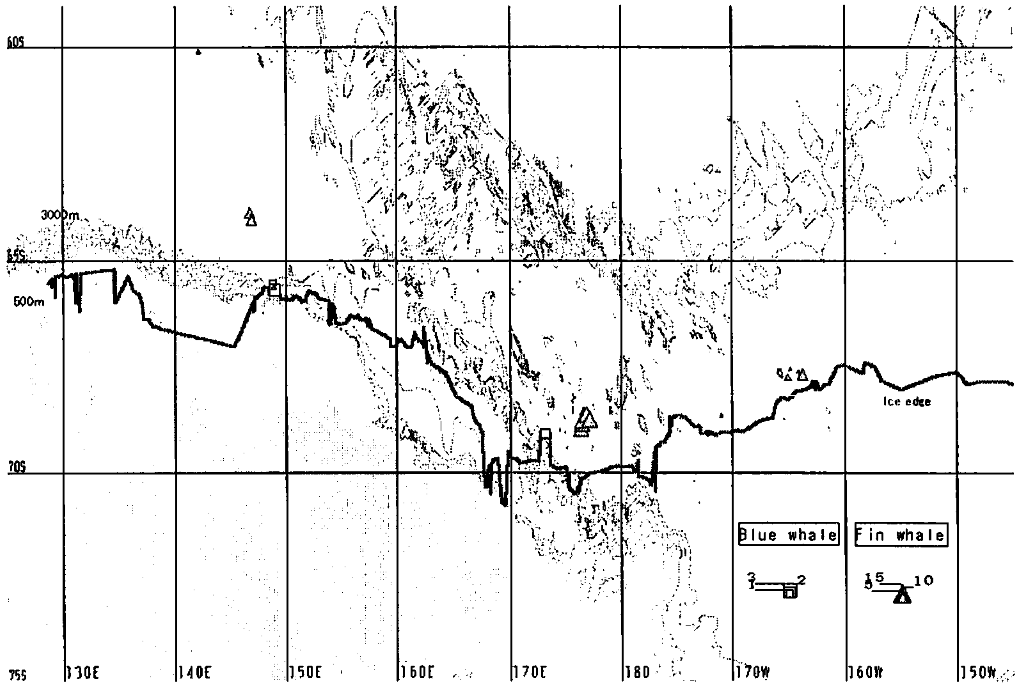


Figure 6. Primary sighting positions and school sizes of blue and fin whales in the 1998/1999 JARPA. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

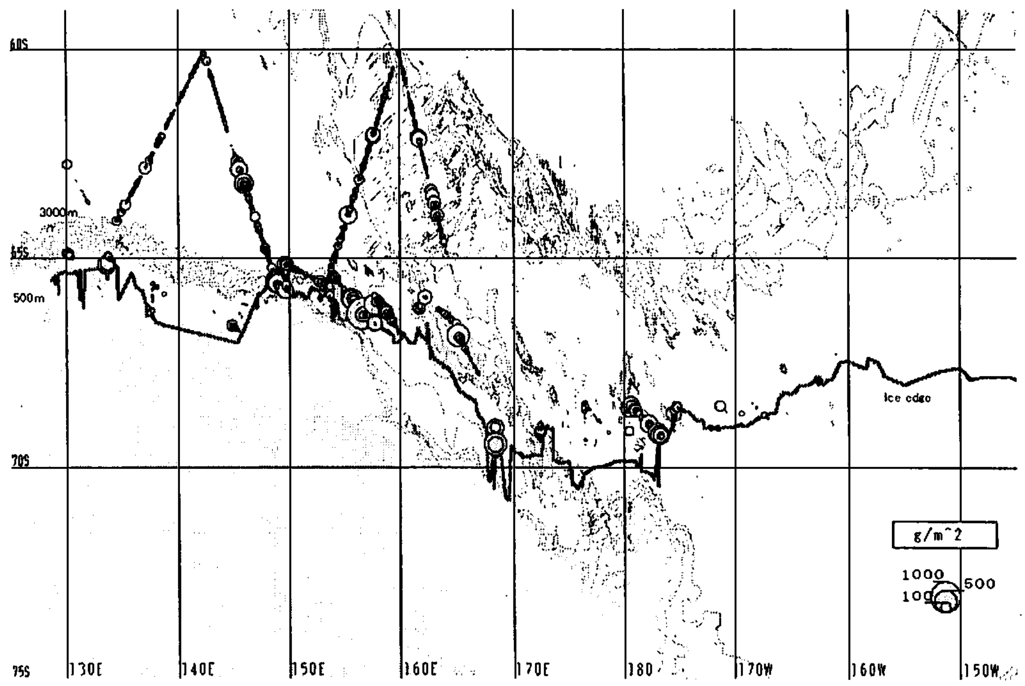


Figure 7. Weight densities (g/m^2) per 1 n. mile integrated interval of euphausiids in the 1998/1999 JARPA. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

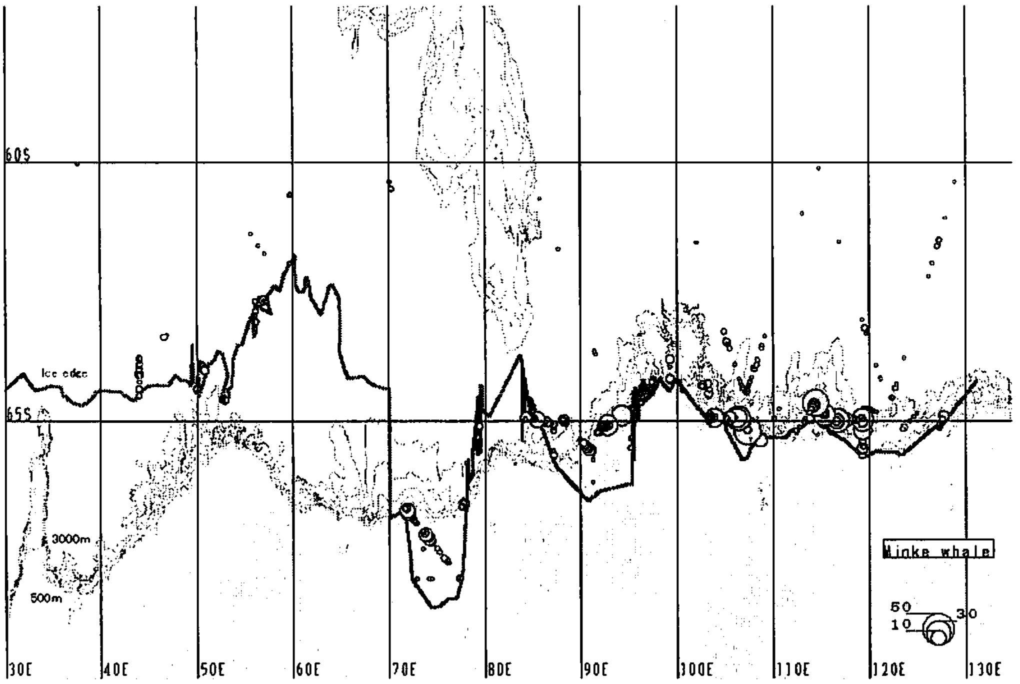


Figure 8. Primary sighting positions and school sizes of minke whales in the 1999/2000 JARPA. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

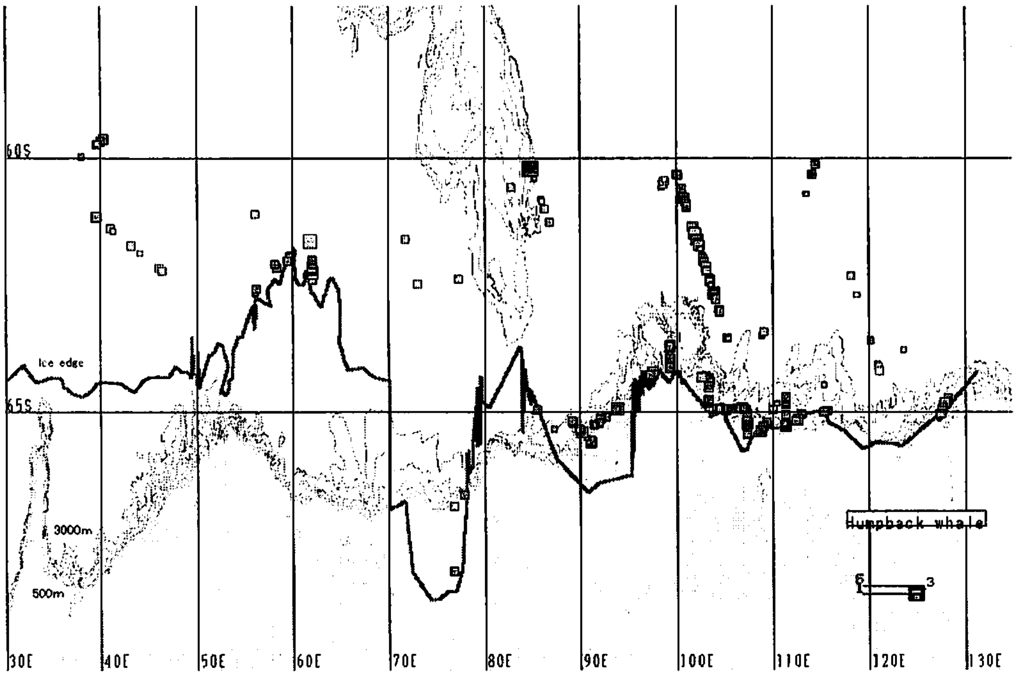


Figure 9. Primary sighting positions and school sizes of humpback whales in the 1999/200 JARPA. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

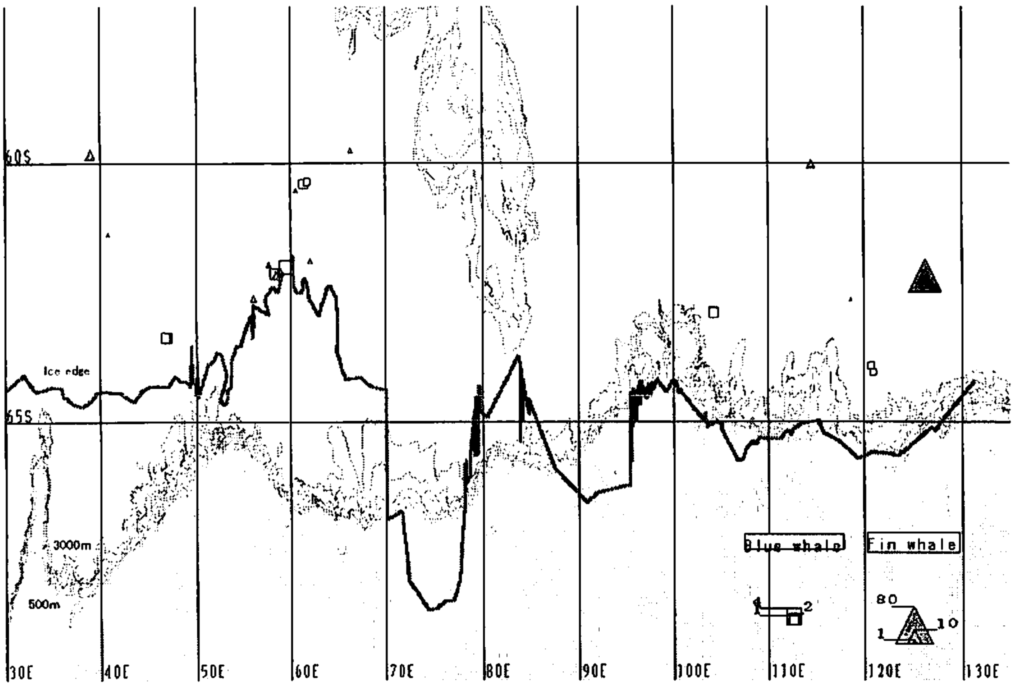


Figure 10. Primary sighting positions and school sizes of blue and fin whales in the 1999/2000 JARPA. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

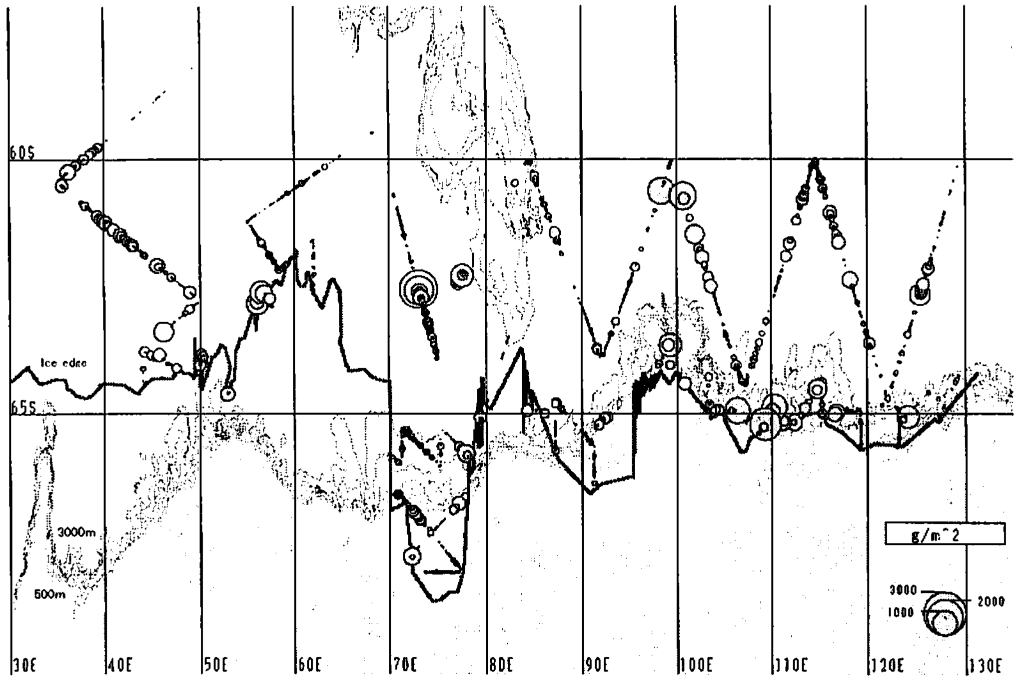


Figure 11. Weight densities (g/m^2) per 1 n. mile integrated interval of euphausiids in the 1999/2000 JARPA. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

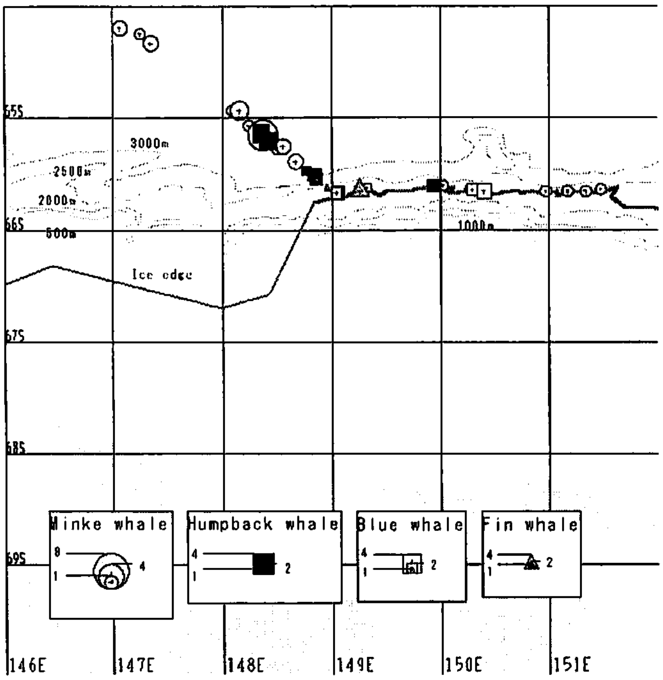


Figure 12. Sighting positions and school sizes of baleen whales in the area where 13 individuals of blue whales were sighted on January 21 1999. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.

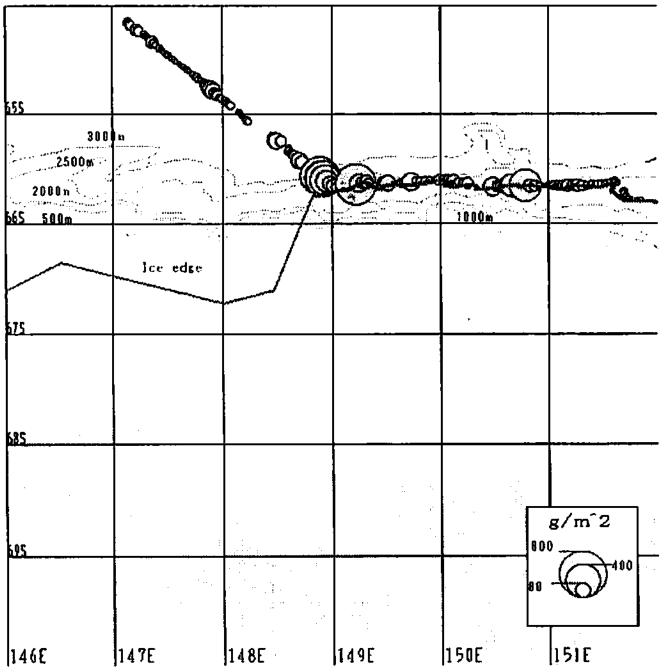


Figure 13. Weight densities (g/m^2) per 1 n. mile integrated interval of euphausiids in the same area in Fig. 12. Bold line = ice edge line; thin lines = 500 m interval isobath from 500 m to 3000 m depth.