DIFFERENCES IN DISTRIBUTION AND POPULATION STRUCTURE OF KRILL (*EUPHAUSIA SUPERBA*) BETWEEN PENGUIN AND FUR SEAL FORAGING AREAS NEAR SEAL ISLAND

T. Ichii[1], H. Ishii[1], J.L. Bengtson[2], P. Boveng[2], J.K. Jansen[2] and M. Naganobu[1]

Abstract

Shipboard tracking studies of krill-eating predators (penguins and female fur seals) near Seal Island were conducted to identify and evaluate their foraging areas during early January 1990/91. Penguin foraging areas were found in inshore regions where krill frequently occurred but higher density areas of krill (≥250 g/m²) were rather limited. In contrast, fur seal foraging areas were found in offshore regions where krill occurred only occasionally but in large aggregations (surface length about 2 to 3 km) of higher densities (≥250 g/m²). In the inshore foraging areas krill undertake diurnal vertical migrations, tending to be at a deeper range from 50 to 100 m in the day while at a shallower range from 20 to 50 m at night. In the offshore foraging areas krill do not undertake any diurnal vertical migrations, staying close to the surface throughout the day. With regard to body size and maturity of krill in the inshore foraging areas, middle-sized krill (modal length 43 mm), which consisted mainly of non-gravid krill, were dominant with occasional occurrences of juveniles (modal length 21 mm). In contrast, in the offshore foraging areas large krill (modal length 47 mm) were dominant, the majority of which were gravid females. Thus, horizontal and vertical distributions and population structure of krill were totally different in the foraging areas of penguins and fur seals. The reasons why fur seals chose offshore foraging areas instead of inshore foraging areas are discussed.

Résumé

Afin d'identifier et d'évaluer les secteurs d'alimentation de certains prédateurs de krill (manchots et femelles d'otaries) à proximité de l''île Seal, des suivis ont été effectués à bord de navires début janvier 1991. Les secteurs d'alimentation des manchots ont été découverts dans les régions côtières souvent fréquentées par le krill mais rarement en densité élevée (≥250 g/m²). Par contre, les secteurs d'alimentation des otaries ont été découverts dans des secteurs du large où le krill n'est que rarement présent mais en concentrations étendues (d'environ 2 à 3 km de long) et de densités élevées (≥250 g/m²). Dans les secteurs d'alimentation côtiers, le krill effectue des migrations verticales nycthémérales, se concentrant plutôt à une profondeur de 50 à 100 m de jour alors qu'il fréquente une couche moins profonde, de 20 à 50 m de nuit. Au large, dans les secteurs d'alimentation, le krill ne migre pas dans la colonne d'eau pendant la journée: il reste jour et nuit proche de la surface. En ce qui concerne la taille du corps et la maturité du krill dans les secteurs d'alimentation côtiers, le krill de taille moyenne (d'une

[1] National Research Institute of Far Seas Fisheries, Orido 5-7-1, Shimizu, Shizuoka, 424 Japan
[2] National Marine Mammal Laboratory, National Marine Fisheries Service, 7600 Sand Point Way NE, Seattle, Wa. 98115, USA

longueur modale de 43 mm) consistant principalement en krill non gravide, dominait avec quelques cas de juvéniles (longueur modale, 21 mm). Par contre, dans les secteurs d'alimentation se trouvant au large, dominait le krill de grande taille (longueur modale, 47 mm) composé principalement de femelles gravides. Il en ressort que les distributions horizontales et verticales et la structure démographique du krill différaient entièrement dans les secteurs d'alimentation des manchots et des otaries. Les raisons pour lesquelles les otaries choisissent les secteurs d'alimentation éloignés de la côte, plutôt que côtiers, sont examinées.

Резюме

В начале января 1990/91 г.С борта судна велось слежение за хищниками, питающимися крилем (пингвинами и самками морского котика) около острова Сил с целью определения и оценки их нагульных ареалов. Нагульные ареалы пингвинов были обнаружены в прибрежных районах, где криль часто скапливается, но не образует плотных скоплений (≥250 г/м^2). По сравнению с этим, нагульные ареалы морских котиков наблюдались в открытом море, где криль встречалься лишь время от времени но в больших агрегациях (около 2-3 км длиной на поверхности) бòльших плотностей (≥250 г/м^2). В прибрежных нагульных ареалах криль предпринимает суточные вертикальные миграции - днем обычно находясь на глубине 50-100 м, а ночью ближе к поверхности в диапазоне 20-50 м. В нагульных ареалах в открытом море криль вообще не предпринимает суточных вертикальных миграций, придерживаясь днем близко к поверхности. Что касается длины тела и половозрелости криля в прибрежных нагульных ареалах, доминировал криль средних размеров (модальная длина - 43 мм), в основном неикряные особи - молодь встречалась только иногда (модальная длина - 21 мм). По сравнению с этим, в нагульных ареалах в открытом море доминировал криль больших размеров (модальная длина - 47 мм), в основном икряные самки. Итак, горизонтальное и вертикальное распределение и структура популяции криля в нагульных ареалах пингвинов и морских котиков полностью различны. Обсуждаются причины выбора морскими котиками нагульных ареалов в открытом море, а не в прибрежных водах.

Resumen

A principios de enero 1990/91 se llevaron a cabo estudios de seguimiento de especies krilófagas (pingüinos y hembras de lobo fino) en el mar a la altura de la la isla Foca, para determinar sus áreas de alimentación. Se encontraron zonas de alimentación de pingüinos cercanas a la costa en donde generalmente hay kril, aunque las áreas en las que el kril se encuentra en gran densidad (≥250 g/m^2) son muy limitadas. Por otra parte, las zonas de alimentación de lobos finos se encontraron en las zonas de alta mar en donde rara vez se encuentra kril pero cuando hay, se da en grandes concentraciones (extensión aproximada de 2 a 3 km) de gran densidad (≥250 g/m^2). En la zona de alimentación cerca de la costa se observaron migraciones diurnas del kril con una tendencia a permanecer a profundidades mayores (50 a 100 m) durante el día y en capas más superficiales (20 a 50 m) durante la noche. En alta mar no se da este fenómeno y el kril permanece cerca de la superficie durante todo el día. Con respecto a los estados de madurez y longitud del kril en las zonas de alimentación cercana a la costa, predominó el kril de tamaño medio (longitud modal de 43 mm) formado en su mayoría por kril sin ovas con alguno que otro juvenil (longitud modal de 21 mm). Por su parte, en las zonas de alimentación de alta mar hubo predominancia de kril de gran tamaño (longitud modal 47 mm), la mayoría del cual correspondía a hembras grávidas. Así se desprende que tanto las distribuciones horizontales como verticales y la estructura de la población del kril diferían totalmente en las zonas de alimentación de pingüinos y lobos finos. Se presentan las posibles razones de por qué los lobos finos eligen aquellas zonas de alimentación de alta mar en lugar de aquellas cercanas a la costa.

---

1. INTRODUCTION

The Seal Island area is one of the active sites in the Antarctic Peninsula Integrated Study Region of CEMP (CCAMLR Ecosystem Monitoring Program). In accordance with CEMP protocols, studies have been carried out since 1986/87 by NOAA (National Oceanic and Atmospheric Administration of the USA) to assess and monitor reproductive and foraging behaviour of krill predators breeding at the island. As part of CEMP-related activities, in the early summer of 1990/91, a predator tracking study was conducted on board the Japanese research vessel *Kaiyo Maru* in cooperation with NOAA (AMLR, 1991). The objectives of this study were:

(i) to locate foraging areas of predators (penguins and fur seals) and describe characteristics of prey (krill) distribution and environment in these areas; and

(ii) to monitor foraging behaviour of predators using time-depth recorders and evaluate how prey availability and environmental conditions may influence predators' foraging behaviour.

This paper presents preliminary results of those objectives described in subparagraph (i) above.

2. MATERIALS AND METHODS

2.1 Radio Tracking

Tracking studies were conducted aboard the *Kaiyo Maru* from 1 to 8 January 1991. Four Yagi directional antennae were mounted on the upper bridge of the *Kaiyo Maru* to assist in locating fur seals and penguins at sea. These antennae were connected to an automatic direction finding system which guided the ship while it followed the target individuals. The automatic direction finding system was operated around the clock during tracking. Information on instrumentation of predators will be described by NOAA in the near future. Tracking operations proceeded as follows: the ship waited off Seal Island (approximately 1 to 2 n miles) until a fur seal or penguin departed to sea on a feeding trip; at that time, the ship followed the individuals as long as possible or until the fur seal or penguin returned to shore at the end of its feeding trip. Location of the ship was monitored every 15 minutes by radar and a satellite navigation system.

Tracks to foraging areas were recorded for four chinstrap penguins (*Pygoscelis antarctica*) (six trips), one macaroni penguin (*Eudyptes chrysolophus*) and one female fur seal (*Arctocephalus gazella*). Most penguins were tracked for the majority of one entire feeding trip. The trip of the female fur seal was tracked only on its outbound leg to the apparent outer limit of her foraging range.

2.2 Hydroacoustic Survey

While the ship was tracking fur seals or penguins at sea, the presence and depth of krill in the water column were monitored using an echo sounder (Furuno Electric FQ-50) at a frequency of 200 kHz. Echoes were continuously integrated at intervals of 0.5 n mile for the depth range of 10 to 150 m or 10 m to the bottom if shallower. Detailed operating parameters of the acoustic system are described in Ichii *et al.* (1992).

2.3 Net Sampling

Prey (krill) samples in foraging areas were collected by towing an ORI-200 net (diameter 1.6 m and mesh size 2.0 mm). When a swarm was detected acoustically, the net was towed horizontally at a speed of about 3 knots at swarm depth. Oblique tows were conducted from about 100 m to the surface in cases when no swarms were detected.

A sample from each haul was preserved in a 10% buffered formalin-seawater solution for later examination in the laboratory ashore. 150 individuals of krill were randomly selected from each sample for measurement of body length and determination of maturity stage; all individuals were analysed for small catches of ≤150 krill. Body length was measured to the nearest millimetres from the tip of the rostrum to the end of the telson. All measurements were carried out by a single observer to avoid methodologically biased differences in length frequency data (Watkins *et al.*, 1985). Maturity stages were identified according to the classification of Makarov and Denys (1981).

2.4 Hydrographic Observation

The temperature profile of the water column in foraging areas was determined using expendable bathythermographs (XBTs). During the study period surface salinity was continuously measured with a thermo-salinograph (NEIL BROWN Inc., Smart CTD A) to identify the slope front. Subsurface current patterns (30 to 35 m depth) in the foraging areas were assessed by tracking drifting buoys which were deployed off northern Livingston Island (see Ichii *et al.*, 1992).

3. RESULTS

3.1 Foraging Areas

Foraging areas were located mainly to the north of Seal Island (Figure 1). Penguin foraging areas were located within inshore regions; maximum foraging range was 25 km from the island. By contrast, the fur seal went beyond the continental slope and foraged in offshore regions. The outer limit of her foraging range was, surprisingly, as far as 240 km from the island.

3.2 Hydrographic Features

The continental slope water front was identified by a relative sharp northward decrease in salinity (from 34.1 to 33.8‰) over the area from 1 000 m to 3 000 m deep (Figure 1).

Subsurface currents in inshore and offshore region were determined from the tracks of the two buoys (Figure 2). In the offshore region a complex eddying current was observed along the shelf break (approximately 200 to 500 m deep), encircling Elephant Island in a counterclockwise direction. The inshore region may be described as an area of hydrodynamic accumulation and retention, considering that the buoy deployed off northern Livingston Island (170 km southeast of Seal Island) became trapped in this region. In the offshore region, however, the buoy moved smoothly eastward along the depth contour of about 3 000 m. Finally, it reached as far as South Georgia and became entrained in its shelf break area.

Vertical profiles of temperature indicated that the inshore region had a low degree of stratification, with indications of vigorous vertical exchange processes. Conversely, in the offshore region warm surface water with a subsurface temperature minimum ("Winter Water") a strong thermocline forms in the subsurface (40 to 70 m).

3.3 Horizontal Distribution of Krill

In the inshore foraging areas krill frequently occurred in various forms of aggregations, but higher density areas of krill ($\geq$250 g/m^2) were quite limited. It seemed that penguins did not necessarily forage in the higher krill density areas. In contrast, in the offshore foraging areas krill occurred only occasionally, but tended to form extensive aggregations (approximately 2 to 3 km across) of high densities ($\geq$250 g/m^2) (Figure 3). The fur seal clearly fed on these aggregations.

3.4 Vertical Distribution of Krill

In the inshore foraging areas krill undertook diurnal vertical migrations, tending to be at a deeper depth range (50 to 100 m) in the daytime, while at a shallower layer (20 to 50 m) at night (Figure 4). In the offshore foraging areas, however, krill undertook no diurnal vertical migrations, staying close to the surface throughout the day, which is probably caused by the shallow thermocline in the region.

3.5 Size and Maturity of Krill

As shown by accumulated size composition data for each foraging area (Figure 5), middle-sized krill (modal length 43 mm) were dominant with occasional occurrences of small specimens (modal length 21 mm) in the inshore foraging areas, whereas large krill (modal length 47 mm) were dominant in the offshore foraging areas. As for maturity, the majority of female krill were still undergoing maturation (IIIBC) in the inshore foraging areas, whereas almost all females were gravid (IIID) in the offshore foraging areas. Juveniles (I) were restricted to the inshore foraging areas.

4. DISCUSSION

Contrary to what might be expected, feeding locations of the fur seal were well offshore during the study period (early January). Later in the season (mid-February) NOAA conducted another tracking study of fur seals on board the Chilean research vessel in order to compare fur seal foraging areas early and late in their reproductive season (AMLR, 1991). Foraging locations of fur seals in mid-February were quite different from those in early January; they were mostly within inshore regions in mid-February. Moreover, foraging trip duration was shorter in February (1 to 3 days) than in January (5 to 9 days) (AMLR, 1991). Since krill was less abundant than usual in January, NOAA suggested that this lower krill abundance during January may be responsible for the offshore feeding of fur seals at that time. Offshore feeding trips, however, may not be specifically linked with seasons of low krill abundance, but a rather usual event early in summer. The reason for such a conclusion is that tracking studies in 1988/89 and 1989/90 indicated that in January fur seals might utilise inshore as well as offshore areas (Bengtson and Eberhardt, unpublished data; AMLR, 1990).

The reasons why fur seals often choose offshore foraging areas over inshore ones, despite the former areas being far more remote from the island, are as follows.

In the case of fur seals, krill consumed during foraging trips is being digested and processed into milk, high energy concentrated food for pups. This enables fur seals to undertake long-distance foraging trips and to accumulate a large amount of food in the form of milk. In contrast, penguins are not capable of producing milk and can only accumulate krill in their stomachs. This means that for penguins, the amount of energy delivered to the chick per trip is limited, i.e., a stomach full of krill at most. Hence, long-distance feeding trips by penguins do not increase the amount of energy delivered per trip and may lead to chick starvation.

Secondly, the present study revealed that extensive and dense aggregations occasionally occurred in the offshore region. This may be a typical feature of early summer (Ichii, unpublished data), and toward the end of summer fewer and fewer krill may be distributed in the offshore region (Siegel, 1988). The occurrence of these exploitable aggregations is evidently another important reason why fur seals are attracted to offshore regions in early summer.

Finally, krill aggregations in the offshore region are favoured by predators because:

(i) krill are present in a shallower depth throughout the day and easily detected; only shallow diving is required to catch krill, even in the daytime; and

(ii) krill tend to be larger in size and gravid, i.e., of high nutritional value.

Expanding on (ii) above, in terms of energetic value gravid females have as much as 5.45 kJ/g wet weight as compared to 3.84 kJ/g wet weight for males (Clark, 1980). Costa (1991) suggests that due to the small size and low energy content of krill compared to fish, hunting krill is only viable for fur seals when only shallow diving is required. In fact, at South Georgia, fur seals made most dives at night when krill appeared near the surface (Croxall, 1985).

It may be suggested, therefore, that offshore foraging can be energetically advantageous for fur seals during early summer.

ACKNOWLEDGMENTS

We are grateful to Capain T. Morooka, the officers and crew of RV *Kaiyo Maru* for their kind assistance during the cruise. Our sincere thanks are to N. Obitus for valuable technical assistance with examining krill. H. Hatanaka (National Research Institute, Far Seas Fisheries) kindly reviewed this manuscript.

REFERENCES

AMLR (Antarctic Ecosystem Research Group Staff, Eds). 1990. AMLR 1989/90 Field Season Report: Objectives, Accomplishments and Tentative Conclusions. Southwest Fisheries Science Center Administration Report LJ-90-11. Document *WG-Krill-90/7*. CCAMLR, Hobart, Australia: 104 pp.

AMLR (ROSENBERG, J. and R. HEWITT, Eds). 1991. AMLR 1990/91 Field Season Report: Objectives, Accomplishments and Tentative Conclusions. Southwest Fisheries Science Center Administration Report LJ-91-18. Document *WG-CEMP-91/11*. CCAMLR, Hobart, Australia: 97 pp.

CLARKE, A. 1980. The biochemical composition of krill, *Euphausia superba* from South Georgia. *J. Exper. Mar. Biol. Ecol.*, 43: 221-236.

COSTA, D.P. 1991. Reproductive and foraging energetics of high latitude penguins, albatrosses and pinnipeds: implications for life history patterns. *Amer. Zool.*, 31: 111-130.

CROXALL, J.P., I. EVERSON, G.L. KOOYMAN, C. RICKETTS and R.W. DAVIS. 1985. Fur seal diving behaviour in relation to vertical distribution of krill. *J. Animal Ecol.*, 54: 1-8.

ICHII, T., H. ISHII and M. NAGANOBU. 1992. Abundance, size and maturity of krill (*Euphausia superba*) in the krill fishing ground of Subarea 48.1 during 1990/91 austral season. In: *Selected Scientific Papers, 1992 (SC-CAMLR-SSP/9)*. CCAMLR, Hobart, Australia. (See this volume).

MAKAROV, R.R. and C.J. DENYS. 1981. Stages of sexual maturity of *Euphausia superba* Dana. *BIOMASS Handbook*, 11: 1-13.

SIEGEL, V. 1988. A concept of seasonal variation of krill (*Euphausia superba*) distribution and abundance west of the Antarctic Peninsula. In: SAHRHAGE, D. (Ed.). *Antarctic Ocean and Resources Variability*. Springer-Verlag, Berlin Heidelberg: 219-230.

WATKINS, J.L., D.J. MORRIS and C. RICKETTS. 1985. Nocturnal change in the mean length of a euphausiid population: vertical migration, net avoidance, or experimental error? *Mar. Biol.*, 86: 123-127.

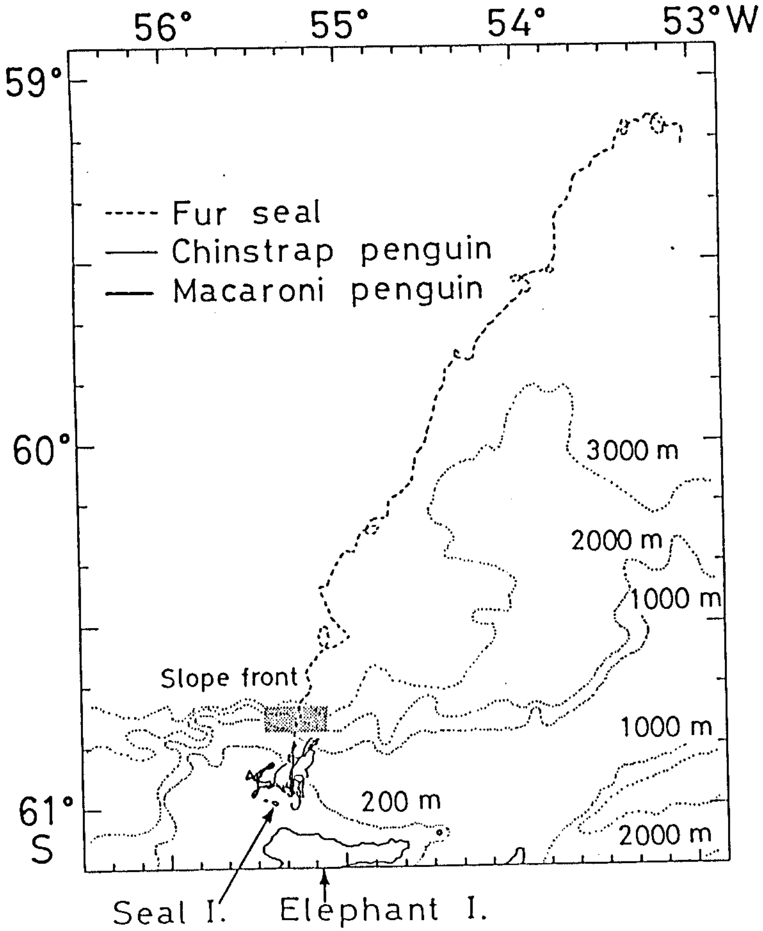

Figure 1: Fur seal and penguin foraging areas near Seal Island, 1 to 8 January 1991. Tracklines indicate the path of the ship during the tracking operations. Shaded area indicates slope front.

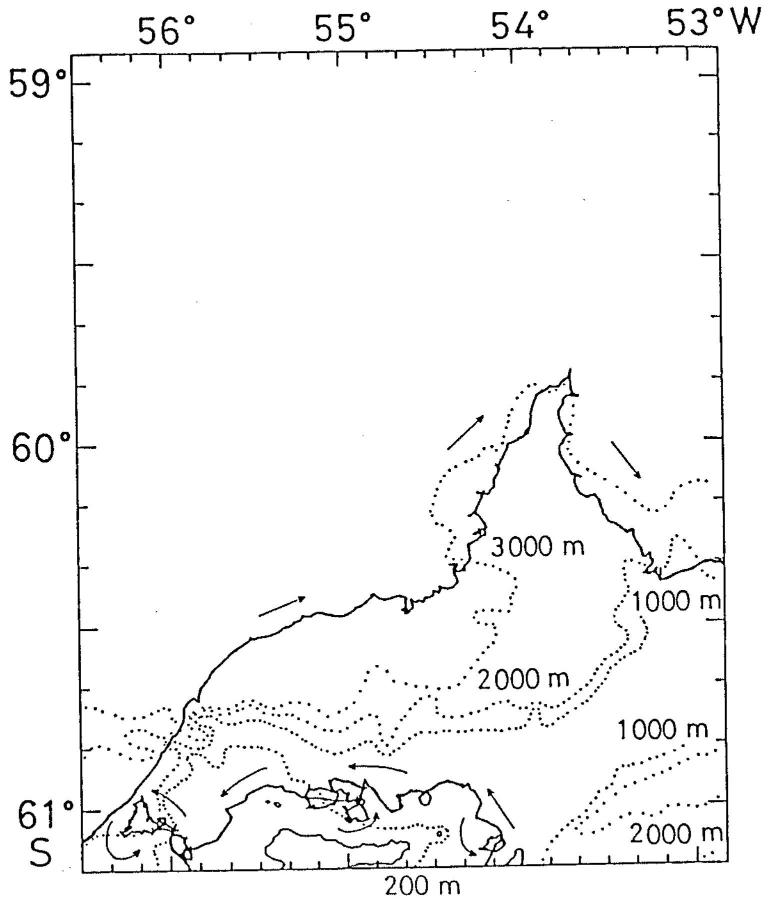

Figure 2: Subsurface (30 to 35 m depth) currents derived from the paths of two satellite-tracked buoys.

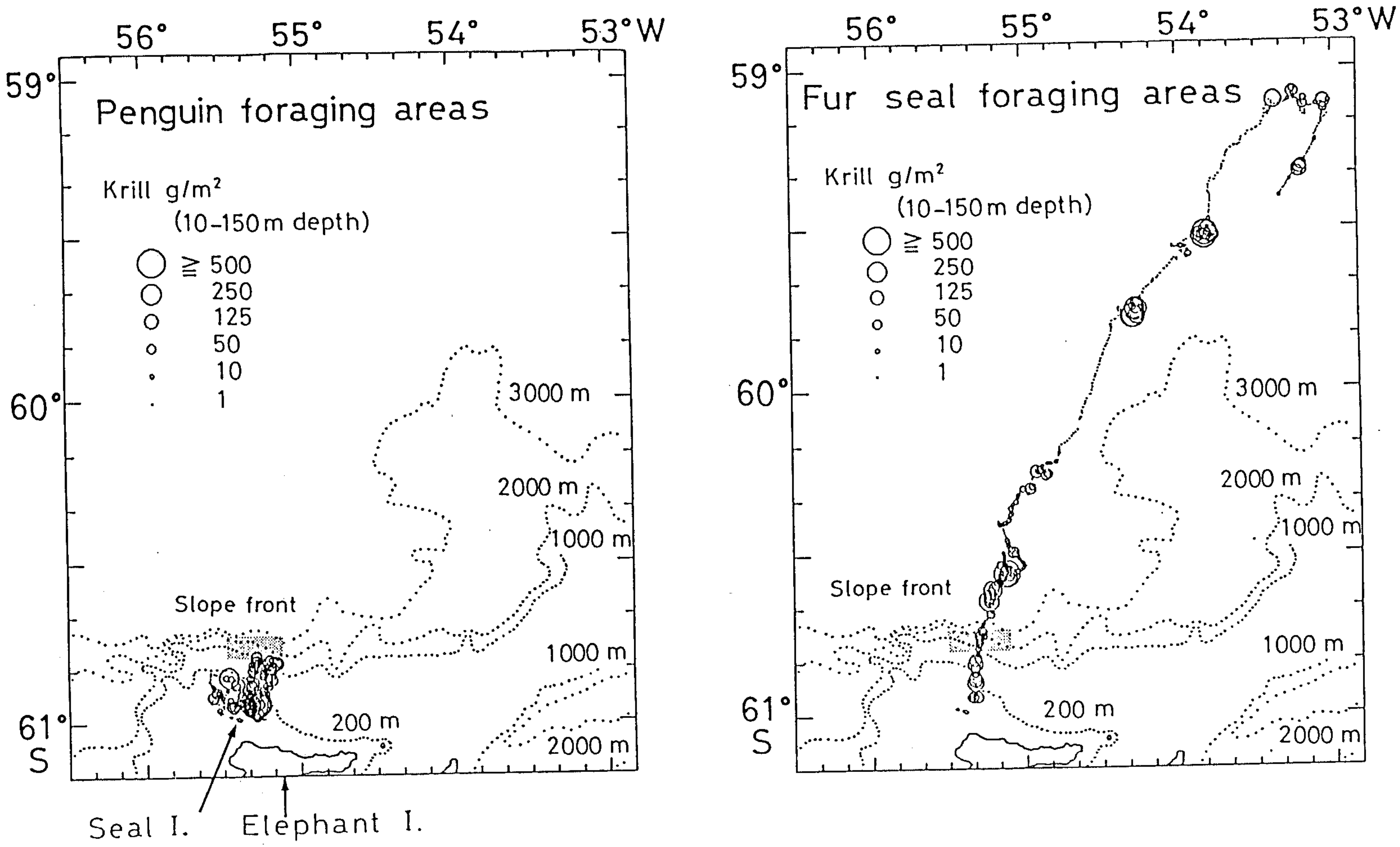

Figure 3: Horizontal distributions of krill detected during penguin (left) and fur seal (right) tracking. Shaded area indicates slope front.

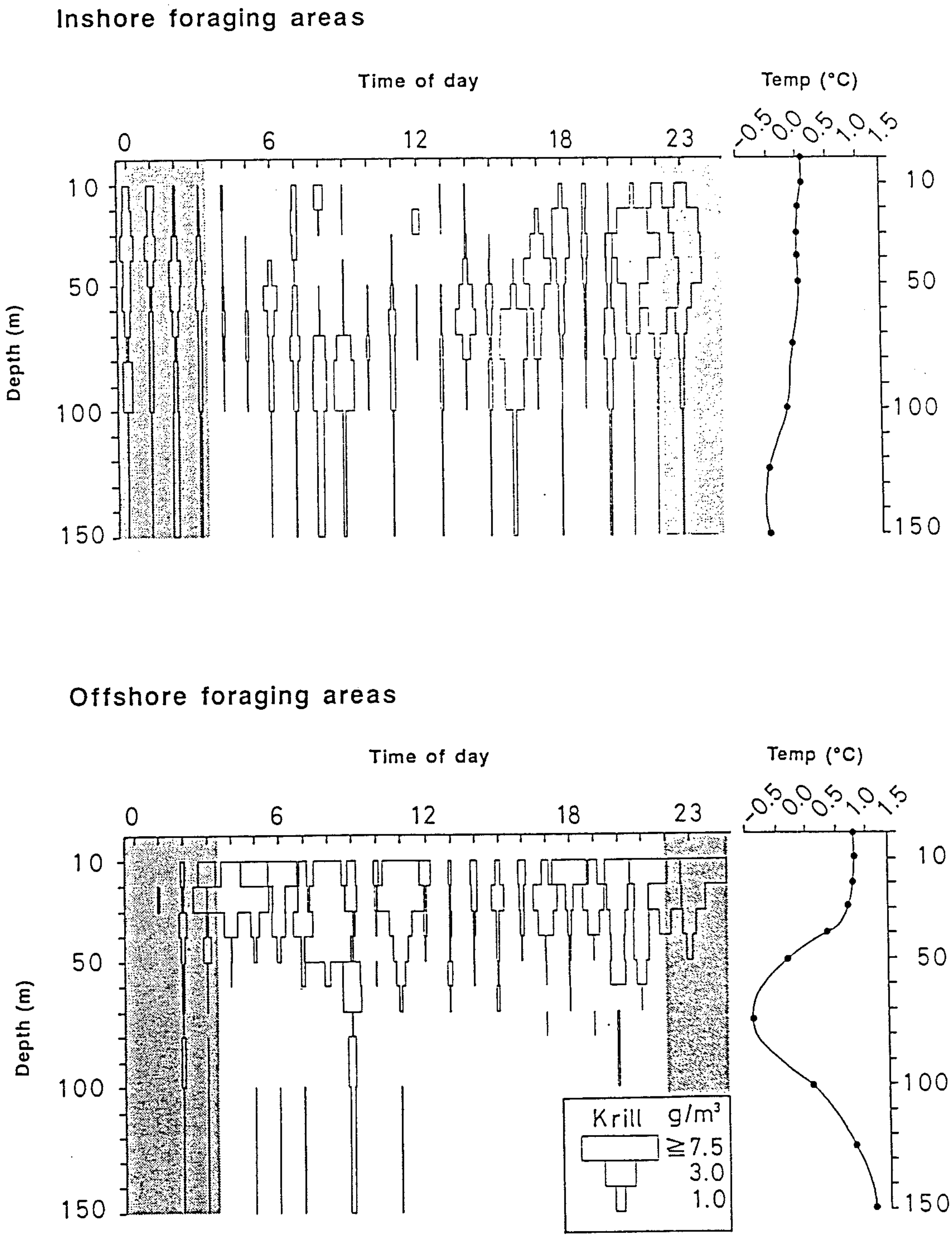

Figure 4: Diurnal vertical distributions of krill with vertical profiles of temperature in penguin (top) and fur seal (bottom) foraging areas. Shaded areas indicate night-time.

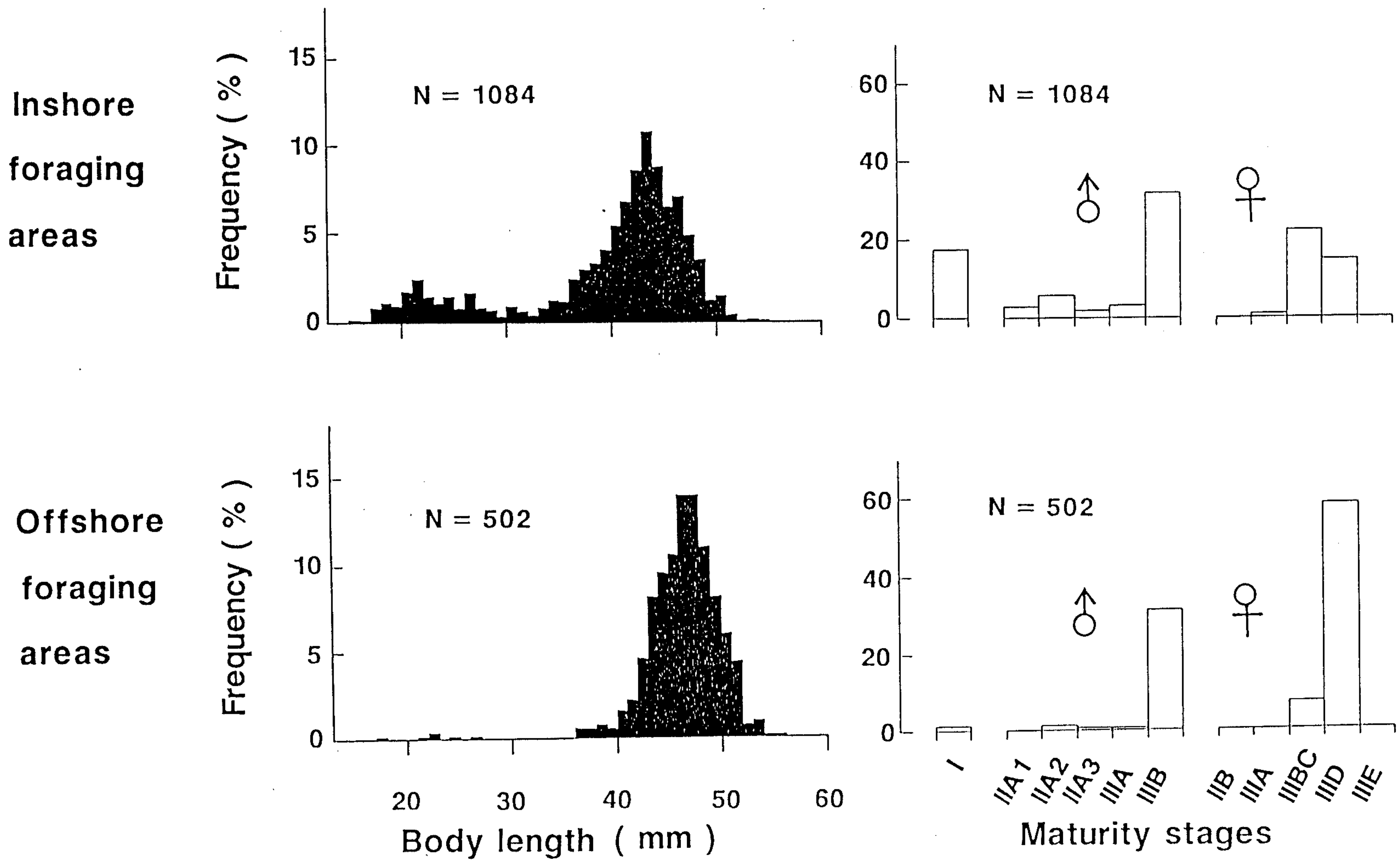

Figure 5: Body length and maturity stage compositions of krill in penguin (top) and fur seal (bottom) foraging areas.

Légende des figures

Figure 1: Secteurs d'alimentation des otaries et des manchots aux abords de l'île Seal du 1er au 8 janvier 1991. Les lignes indiquent le trajet du navire pendant les opérations de poursuite. La partie hachurée indique la zone du bord de la pente.

Figure 2: Courants sous la surface (à une profondeur de 30 à 35 m) dérivés des trajets de deux bouées suivies par satellite.

Figure 3: Distributions horizontales du krill détectées lors de la poursuite de manchots (à gauche) et d'otaries (à droite). La partie hachurée indique la zone du bord de la pente.

Figure 4: Distributions verticales diurnes du krill avec profils verticaux de température dans les secteurs d'alimentation du manchot (en haut) et de l'otarie (en bas). Les parties hachurées indiquent la nuit.

Figure 5: Composition en longueurs du corps et en stades de maturité du krill dans les secteurs d'alimentation du manchot (en haut) et de l'otarie (en bas).

Список рисунков

Рисунок 1: Нагульные ареалы морского котика и пингвинов около о-ва Сил, 1-8 января 1991 г. Линии указывают на маршрут судна в ходе работы по слежению. Затененная часть - фронтальный склон.

Рисунок 2: Подповерхностные течения (глубина 30 - 35 м), определенные по пути передвижения двух буев, за которыми велось слежение.

Рисунок 3: Горизонтальное распределение криля, обнаруженное в ходе слежения за пингвинами (левая сторона) и морским котиком (правая сторона). Затененная часть - фронтальный склон.

Рисунок 4: Суточное вертикальное распределение криля и вертикальный профиль температуры в нагульных ареалах пингвинов (верхняя часть) и морского котика (нижняя часть). Затененная часть обозначает ночное время суток.

Рисунок 5: Размерный состав и стадии половозрелости криля в нагульных ареалах пингвинов (верхняя часть) и морского котика (нижняя часть).

Lista de las figuras

Figura 1: Zonas de alimentación de lobos finos y pingüinos cerca de la isla Foca, 1° al 8 de enero de 1991. Las líneas indican el rumbo de la nave durante las actividades de rastreo. Las áreas sombreadas indican el frente de la pendiente.

Figura 2: Corrientes submarinas (profundidad de 30 a 35 m) obtenidas de las trayectorias de dos boyas rastreadas por satélite.

Figura 3: Distribución horizontal del kril detectada durante el rastreo de pingüinos (izquierda) y lobos finos (derecha). Las áreas sombreadas indican el frente de la pendiente.

Figura 4: Distribución vertical diurna del kril con perfiles verticales de temperatura en las zonas de alimentación de pingüinos (superior) y lobos finos (inferior). Las áreas sombreadas indican el frente de la pendiente.

Figura 5: Composiciones por talla y fase de madurez del kril en las zonas de alimentación de pingüinos (superior) y lobos finos (inferior).