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AN ASSESSMENT OF THE IMPACT OF THE KRILL FISHERY ON PENGUINS IN THE SOUTH SHETLANDS

T. Ichii, M. Naganobu and T. Ogishima
National Research Institute of Far Seas Fisheries
5-7-1, Orido, Shimizu, 424 Japan

Abstract

An assessment of the competition between the Japanese krill (*Euphausia superba*) fishery and penguins during the penguins' breeding season (December to March) in the South Shetland Islands (Subarea 48.1) was made based on available information on the fishery, penguins and krill. The krill catch is very low in December while the catch rate for the following three months is roughly constant (3 000 to 10 000 tonnes/10-day period) due to an increase in fishing intensity in areas closer to the northern shelf of either Livingston or Elephant Island. In contrast, food consumption by penguins is estimated to be high to the north of King George, Nelson and Robert Islands (9 746 tonnes/10-day period), and around Low (6 102 tonnes/10-day period) and Clarence (5 663 tonnes/10-day period) Islands, but small to the north of Livingston (1 921 tonnes/10-day period) and Elephant (1 991 tonnes/10-day period) Islands. Thus, the overlap between the main fishing and foraging areas is insignificant and implies a low level of competition between the fishery and penguins. Krill biomass was estimated to be as large as 200 to 1 500 x 10^3 tonnes within the preferred fishing areas during the breeding season. Compared with the level of biomass (≥200 x 10^3 tonnes) and its variability (the order of 100 x 10^3 tonnes/10-20-day period), the present catch rate (≤10 x 10^3 tonnes/10-day period) is smaller by one or more orders of magnitude within the localised areas. Thus, the present fishery is very unlikely to have an adverse impact on the local krill biomass, and hence on penguins, when catch levels are also taken into account.

Résumé

La concurrence entre la pêcherie japonaise de krill (*Euphausia superba*) et les manchots pendant leur saison de reproduction (de décembre à mars) aux îles Shetland du Sud (sous-zone 48.1) a été évaluée à partir des informations disponibles sur la pêcherie, les manchots et le krill. La capture de krill, très faible en décembre, est suivie d'un taux de capture à peu près constant (de 3 000 à 10 000 tonnes/période de 10 jours) pendant les trois mois suivants, à la suite d'un accroissement de l'intensité de pêche dans des secteurs plus proches du plateau septentrional de l'île Livingston ou de l'île Eléphant. Par contre, la consommation de nourriture des manchots est estimée élevée au nord des îles du roi George, Nelson et Robert (9 746 tonnes/période de 10 jours) et autour des îles Low (6 102 tonnes/période de 10 jours) et Clarence (5 663 tonnes/période de 10 jours) mais faible au nord des îles Livingston (1921 tonnes/période de 10 jours) et Eléphant (1991 tonnes/période de 10 jours). Le chevauchement des principaux secteurs de pêche et d'approvisionnement est donc insignifiant et laisse entendre un faible taux de concurrence entre la pêcherie et les manchots. Pendant la saison de reproduction, la biomasse de krill présente dans les lieux de pêche les plus fréquentés a été estimée de l'ordre de 200 à 1 500 x 10^3 tonnes. Par comparaison au taux de biomasse (≥200 x 10^3 tonnes) et à sa variabilité (de l'ordre de 100 x 10^3 tonnes/période de 10-20 jours), le taux de capture actuel (≤10 x 10^3 tonnes/période de 10 jours) est inférieur à 10% de la biomasse à l'intérieur des secteurs localisés. La pêcherie actuelle est donc fort peu susceptible d'avoir un impact fâcheux sur la biomasse du krill local et de ce fait sur les manchots, si l'on prend également en considération les taux de capture.

Резюме

На основе имеющейся информации о промысле, пингвинах и криле была выполнена оценка конкуренции между японским промыслом криля (*Euphausia superba*) и пингвинами во время сезона размножения пингвинов. Декабрьский вылов криля очень низок, однако в течение следующих трех месяцев интенсивность лова более или менее стабильна (3 000 - 10 000 тонн/10-дневный период), что вызывано увеличением промысловой интенсивности в районах ближе к северному шельфу о-вов Ливингстон или Элефант. По сравнению с этим, по оценкам, уровень потребления пищи пингвинов высок около северной части о-вов Кинг-Джордж, Нельсон и Роберт (9 746 тонн/10-дневный период), Лоу (6 102 тонны/10-дневный период) и Кларенс (5 663 тонны/10-дневный период), но низок около северной части о-вов Ливингстон и Элефант (1991 тонна/10–дневный период). Поэтому совмещение основных промысловых участков и нагульных ареалов незначительно и указывает на низкий уровень конкуренции между промыслом и пингвинами. В пределах предпочитаемых промысловых участков во время сезона размножения биомасса криля оценивалась в 200 - 1 500 x 10^3 тонн. По сравнению с уровнем биомассы (≥200 x 10^3 тонн) и ее изменчивостью (порядка 100 x 10^3 тонн/10-20-дневный период), в пределах локализованных районов современная интенсивность лова (≤10 x 10^3 тонн/10–дневный период) меньше на один или более порядков. В связи с этим, если принять во внимание уровень вылова, то весьма маловероятно, что существующий промысел неблагоприятно скажется на локальной биомассе криля и, тем самым, на пингвинах.

Resumen

Se evaluó el grado de competitividad entre la pesquería japonesa de kril (*Euphausia superba*) y los pingüinos de las islas Shetland del Sur (Subárea 48.1) durante su época de reproducción (diciembre a marzo). Esta evaluación se hizo sobre la base de la información disponible de la pesquería, pingüinos y kril. El nivel de captura de kril en el mes de diciembre es muy bajo, mientras que el nivel de captura de los tres meses siguientes se mantiene relativamente constante (3 000 a 10 000 toneladas por período de 10 días). Esto es causado por un aumento en la intensidad de la pesca efectuada en las zonas más próximas a la plataforma septentrional de las islas Livingston y Elefante. En contraste, se estima que el kril consumido por pingüinos cerca del norte de las islas rey Jorge, Nelson y Robert (9 746 toneladas por período de 10 días), y cerca de Low (6 102 toneladas por período de 10 días) y Clarence (5 663 toneladas por período de 10 días) es alto. Por el contrario, hay un bajo consumo de kril al norte de las islas Livingston (1 921 toneladas por período de 10 días) y Elefante (1 991 toneladas por período de 10 días). Así, la superposición entre la pesca más importante y las zonas de alimentación es insignificante, suponiendo un bajo grado de competencia entre la pesquería y los pingüinos. La biomasa de kril se estimó de 200 a 1 500 x 10^3 toneladas dentro de la zona de pesca preferida durante la época de reproducción. Al contrastar este valor con el nivel de biomasa (≥200 x 10^3 toneladas) y su variabilidad (del orden de 100 x 10^3 toneladas por período de 10 a 20 días), el nivel actual de captura (≤10 x 10^3 toneladas por período de 10 días) resulta inferior en uno o más órdenes de magnitud dentro de las zonas localizadas. De esta manera, cuando se consideran los niveles de captura, resulta muy poco probable que la pesca actual perjudique a la biomasa de kril local, y por consiguiente, a los pingüinos.

Keywords: krill, fishery, penguins, competition, CCAMLR

INTRODUCTION

Although the current level of Antarctic krill (*Euphausia superba*) harvesting is very low in comparison to the total krill biomass, the fishery is concentrated in localised areas in the South Atlantic sector (Everson and Goss, 1991). Agnew (1992) has indicated that in the South Shetland Islands (Subarea 48.1) (Figure 1) a substantial fishery consistently operates within the foraging ranges of land-based krill predators during their critical breeding periods. This temporal and spatial overlap between fishing and foraging activities has raised serious concerns regarding the potential impact of localised krill catches on predators (SC-CAMLR, 1992).

However, the actual competition between predators and the fishery should be assessed not only in terms of overlap, but also in terms of the influence of fishing on the availability of krill to predators (Croxall, 1987; Croll, 1990). Unfortunately, estimates of krill availability are not yet to hand; only those of krill biomass in penguin foraging areas are obtainable. Since there may be some relationship between krill availability and biomass, information on biomass should be taken into consideration when assessing the level of competition. The objective of this study is to make a more realistic assessment of the potential competition in Subarea 48.1 by considering not only the overlap between the fishery and predators, but also local krill biomass.

In Subarea 48.1 the Japanese catch has amounted to as much as 80% of the total catch for the past ten years (CCAMLR, 1993), so only Japanese data were used here. As regards land-based predators, we considered only penguins, which are the major predators in terms of krill consumption in this subarea (Croll, 1990). Antarctic fur seals (*Arctocephalus gazella*) have not been included here because their estimated total consumption of food is only 1% of that of penguins (Croll, 1990).

SPATIAL AND TEMPORAL PATTERNS OF KRILL CATCHES

In order to clarify the distribution and timing of fishing effort, krill catches were calculated for each square of 10 minutes latitude by 20 minutes longitude (=10 x 10 n miles) per 10-day period during the penguin breeding season. The breeding season was assumed to be the four months from December to March (Agnew, 1992). The two most recent fishing seasons (i.e., the 1990/91 and 1991/92 seasons) and the 1988/89 season, when the largest catch was taken from Subarea 48.1, were chosen for the study of the pattern of fishing activities.

In the 1988/89 season the fishery began with a low catch in late December, followed by catches of 3 300 to 10 000 tonnes/10-day period for the following three months (Figure 2). Fishing was initially (in early and mid-January) concentrated over the slope to the west or northwest of Elephant Island. It then shifted to the north of Livingston Island in late January, when it was concentrated over the shelf and slope. Fishing activities in the area to the north of Livingston Island gradually moved closer to the coast until mid-March. The total catch from December to March amounted to 67 056 tonnes, which is the highest value recorded in the history of the Japanese krill fishery.

The 1990/91 fishing season began with very low catches in late December, followed by roughly constant catch levels (3 000 to 6 000 tonnes/10-day period) for the following three months (Figure 3). Fisheries activities tended to spread over the slope to the north of Livingston Island during early January to mid-February. In late February and early March fishing operations became concentrated over the Livingston Island shelf. The fishery then shifted to an area north of Elephant Island in mid-March, and was concentrated over the shelf until late March. The total catch from December to March was 41 492 tonnes.

In the 1991/92 season the fishery began with a low catch in December, followed by roughly constant catch levels of 4 300 to 5 800 tonnes/10-day period for the following three months (Figure 4). Initially (from early January to late February), fishing tended to spread over the shelf and slope of Livingston Island, except in mid-January when it was concentrated over the shelf of Livingston Island. From early March onward fishing operations were concentrated in the Livingston Island area and moved increasingly closer to the island itself. The total catch from December to March amounted to 46 648 tonnes.

When other fishing seasons are taken into account, the following observations may be made regarding catches in Subarea 48.1: in December catches are very low, whereas throughout the following three months they remain roughly constant, between 3 000 and 10 000 tonnes/10-day period; they are initially widely distributed over the shelf and slope and are later confined to particular areas on the shelf of either Livingston or Elephant Island.

SPATIAL PATTERN OF FOOD CONSUMPTION BY PENGUINS

Krill consumption by penguins was estimated for each 10 x 10 n mile square per 10-day period to allow a comparison with the pattern of krill catches. Due to the lack of data, no account is taken of temporal changes in foraging intensity for each square. The distribution of penguin foraging effort was evaluated, based on: (i) the location and size of breeding colonies; (ii) their foraging ranges; and (iii) estimated consumption of krill. Details on the size and location of colonies were available for chinstrap (*Pygoscelis antarctica*), Adélie (*P. adeliae*) and gentoo (*P. papua*) penguins from Woehler (1993). The above-mentioned species comprise 94, 4 and 2% respectively of the total penguin population in Subarea 48.1. Where an estimate of colony size was given in terms of a minimum-maximum range, we chose the maximum estimate. With regard to foraging ranges, predators were assumed to forage equally within radii of 60 km of their respective colonies for chinstraps, 80 km for Adélies and 20 km for gentoos (Everson, 1987; Trivelpiece *et al.*, 1987; Agnew, 1992). Consumption rates of krill were assumed to be 1 090 g/adult/day for chinstraps, 1 240 g/adult/day for Adélie and 1 130 g/adult/day for gentoos, which were presented by Agnew (1992) as values for the period of highest food demand.

Considerable differences were noted in the location of chinstraps, Adélies and gentoos (Figure 5). Large colonies (≥200 x 10^3 breeding adults) of chinstraps were located on the northern shores of King George, Nelson and Robert Islands. It should also be noted that Low, Clarence and Deception Islands supported large chinstrap populations, and the fishery has never occurred near there. In contrast, Adélie and gentoo colonies were all small (≤40 x 10^3 breeding adults) and were scattered on the southern sides of King George and/or Livingston Islands.

The consumption by penguins in a 10-day period was estimated to be 36 725 tonnes over the region shown in Figure 6. The overall distribution of food consumption by penguins reflects that of chinstraps, which are by far the dominant species in the region (Figure 6). High consumption was confined to the northern shelf and slope of King George, Nelson and Robert Islands (9 746 tonnes/10-day period) and around Low (6 102 tonnes/10-day period) and Clarence (5 663 tonnes/10-day period) Islands. Consumption was lower in the waters over the shelf and slope to the north of Livingston Island (1 921 tonnes/10-day period) and to the west and north of Elephant Island (1 991 tonnes/10-day period) where fishing is most active. Total consumption from December to March amounted to 440 700 tonnes throughout the region shown in Figure 6.

SPATIAL AND TEMPORAL PATTERNS FOR KRILL BIOMASS

Estimates of krill biomass are available for grid squares of 20 x 20 or 30 x 30 n miles from recent surveys (1989/90 and 1990/91). The krill biomass for each of these squares was divided equally so as to be given on the same grid (10 x 10 n miles) as for catch and consumption.

During the 1989/90 season, four successive sets of acoustic data were obtained in the vicinity of Elephant Island during January and February (AMLR, 1990; Hewitt and Demer, 1993). During the first survey (mid-January; Figure 7(1)), a major krill concentration (352 x 10^3 tonnes) was observed on the shelf and slope to the northwest of Elephant Island. During the second survey (late January; Figure 7(2)) the krill concentration increased over the northern (268 x 10^3 tonnes) and northeastern (610 x 10^3 tonnes) shelf and slope of the island. In the course of the third survey (mid-February; Figure 7(3)), krill biomass was observed to have increased further near the northeastern slope of Elephant Island (996 x 10^3 tonnes), while it had decreased to the northwest of the island. A considerable amount of krill (1 134 x 10^3 tonnes) was also observed in deeper water off the slope to the northeast of the island. During the fourth survey (late February; Figure 7(4)) krill concentrations generally combined and appeared to move westward, making krill biomass along the northern slope of the island as much as 1 495 x 10^3 tonnes. A high biomass of krill was also observed in deep water off the slope to the north (711 x 10^3 tonnes) and northeast (326 x 10^3 tonnes) of Elephant Island.

Thus, krill abundance varied both spatially and temporally with the overall biomass along the shelf and slope of Elephant Island increasing from 500 to 1 800 x 10^3 tonnes throughout the two-month observation period. It should be noted that large krill concentrations, having a biomass of 200-1 500 x 10^3 tonnes, occurred regularly within the traditional fishing grounds. During this season the principal fishing activities took place in the Elephant Island area from mid-February onward, and coincided with areas of highest krill concentration north of the island (Figure 7(5)). The distribution of food consumption by penguins is also shown for comparison with krill biomass and catches (Figure 7(6)).

In the 1990/91 season two successive sets of data were obtained around Elephant Island and the eastern end of King George Island in late January and early March (AMLR, 1991; Hewitt and Demer, 1993). During the first survey (late January; Figure 8 (1)), a high krill biomass was observed along the shelf and slope to the northwest (186 x 10^3 tonnes) and north (224 x 10^3 tonnes) of Elephant Island, and in deeper water northeast of the island (235 x 10^3 tonnes). Approximately 200 x 10^3 tonnes of krill in total were found around King George Island. During the second survey (early March; Figure 8(2)) the biomass along the shelf and slope north of Elephant Island intensified to 660 x 10^3 tonnes, but few krill were detected around King George Island.

Thus, the overall krill biomass along the shelf and slope of Elephant Island increased from 500 to 1 000 x 10^3 tonnes over a period of approximately one month. High krill concentrations with 220 to 660 x 10^3 tonnes of biomass occurred within the preferred localised fishing grounds. Intensive fishing took place in the area of the highest biomass from mid-March onward (Figure 8(3)).

An additional set of acoustic data, for the area north of the South Shetland Islands in late January, was also available for the 1990/91 season (Figure 9(1)) (Ichii *et al.*, 1991). Krill biomass was estimated to be 1 220 x 10^3 tonnes over the shelf and slope north of the South Shetland Islands and was very high from the north of Livingston Island to the northwestern end of King George Island (650 x 10^3 tonnes). During this period fishing activity was widespread over the shelf and slope north of Livingston Island (Figure 9(2)).

DISCUSSION

Agnew (1992) indicated that 90% of the catch in Subarea 48.1 is usually taken within 80 km of penguin colonies, suggesting that there is potential for competition between penguins and krill fishing. This study, by showing that the densest colonies of chinstraps are not close to the areas of highest fishing intensity, may help to quell concerns regarding this possible competition. In other words, there is little overlap between the major fishing and foraging areas. This implies that less potential exists for competition between the fishery and penguins than is implied by Agnew (1992).

The largest colonies of chinstraps are located in the areas where little or no fishing takes place. Croll *et al.* (1993) suggested that chinstraps do not require extremely dense aggregations of krill in order to capture sufficient krill to meet their energy needs. This implies that chinstraps are associated not only with krill abundance, but also with other factors such as ice conditions or space for nest sites. According to the sea-ice maps (Zwally *et al.*, 1983), Low Island is located within a coastal polynya (an area of open water in the midst of consolidated pack-ice) during the austral winter. Open waters were also observed near Clarence Island during spring while the sea was still ice-covered near Elephant Island (Anon., 1987). Volcanic activity at Deception Island keeps its surrounding waters ice-free (Anon., 1985). Since the breeding success of chinstraps is closely connected with the date of break-out of ice in spring (Croxall *et al.*, 1988), the earlier annual occurrence of open water may be closely linked to the formation of large colonies of chinstraps at Low, Clarence and Deception Islands, and probably at King George, Nelson and Robert Islands as well.

Foraging ranges used in this study are maximum ranges estimated from a knowledge of swimming speed, activity budgets and foraging trip duration (Everson, 1987; Trivelpiece *et al.*, 1987). During shipboard studies at Seal Island, near Elephant Island, empirical measurements were taken of the foraging ranges of chinstrap penguins. These show that chinstraps performed most of their foraging dives at a distance of about 3 to 25 km offshore, irrespective of annual conditions, i.e., even in a krill-poor year (AMLR, 1990, 1991; Bengtson *et al.*, 1993). If chinstraps do not require dense aggregations of krill, as is suggested in Croll *et al.* (1993), the more limited foraging range derived from the empirical measurements may indicate that the actual overlap between the major fishing and foraging areas is even less than that implied by this study.

Krill trawling locations are selected on the basis not only of the quantity of krill, but also its quality, such as greenness, size, proportion of gravid females and mixture of salps (Ichii, 1987). This may give the impression that fishing grounds do not necessarily correspond to areas of high krill density. This study, however, suggests that krill biomass in fishing areas is usually very high. For example, although the biomass varied substantially within the preferred favourite fishing areas near Elephant Island, as a result of immigration and emigration of krill into and out of the area (Amos *et al.*, 1990), a high krill biomass (200-1 500 x 10^3 tonnes) was regularly observed there (Figures 7 and 8). In comparison with the biomass of krill ($\geq$200 x 10^3 tonnes) and taking into account local variability (in the order of 100 x 10^3 tonnes) on a temporal scale of 10 to 20 days, the present catch rate ($\leq$10 x 10^3 tonnes/10-day period) is smaller by one or more orders of magnitude in the areas of intense fishing. Therefore, when catch sizes are also taken into account, the fishery is at present very unlikely to have an adverse impact on local krill biomass and hence on penguins (Agnew, 1992).

The fishery is not as active near King George, Nelson and Robert Islands, where the penguin colonies are congregated. Fishermen indicate that numerous rocks exist off the northern coasts of these islands, discouraging intensive trawling near the shelf where krill is abundant.

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REFERENCES

Agnew, D.J. 1992. Distribution of krill (*Euphausia superba* Dana) catches in the South Shetlands and South Orkneys. In: *Selected Scientific Papers, 1992 (SC-CAMLR-SSP/9).* CCAMLR, Hobart, Australia: 287-303.

AMLR. 1990. US AMLR 1989/90 Field Season Report: Objectives, Accomplishments, and Tentative Conclusions. Southwest Fisheries Science Center Administration Report LJ-90-11: 104 pp.

AMLR. 1991. J. Rosenberg and R. Hewitt (Eds.). US AMLR 1990/91 Field Season Report: Objectives, Accomplishments and Tentative Conclusions. Southwest Fisheries Science Center, Administration Report LJ-91-18: 97 pp.

Amos, A.F., J.L. Bengtson, O. Holm-Hansen, V.J. Loeb, M.C. Macaulay and J.H. Wormuth. 1990. Surface water masses, primary production, krill distribution and predator foraging in the vicinity of Elephant Island during the 1989/90 austral summer. Document *WG-CEMP-90/11.* CCAMLR, Hobart, Australia: 65 pp.

Anon. 1985. *Science in Antarctica: 9 Data Complication.* National Institute of Polar Research, Tokyo: 288 pp. (In Japanese.)

Anon. 1987. Report of the 1986-87 IWC/IDCR Southern Hemisphere Minke Whale Assessment Cruise, Area II. Document *SC/39/Mi14* submitted to 1990 Int. Whal. Comm: 46 pp.

Bengtson, J.L., D.A. Croll and M.E. Goebel. 1993. Diving behavior of chinstrap penguins at Seal Island. *Antarctic Science,* 5 (1): 9-15.

CCAMLR. 1993. *Statistical Bulletin,* Vol. 5 (1983-1992). CCAMLR, Hobart, Australia: 123 pp.

Croll, D.A. 1990. Estimation of the energy and prey requirements of predators breeding on the South Shetland Islands. Document *WG-CEMP-90/30 Rev. 1.* CCAMLR, Hobart, Australia: 24 pp.

Croll, D.A., R.P. Hewitt, D.A. Demer and J.K. Jansen. 1993. Penguin foraging behaviour in relation to the distribution of prey. Document *WG-Krill-93/47.* CCAMLR, Hobart, Australia: 18 pp.

Croxall, J.P. 1987. Conclusions. In: Croxall, J.P. (Ed.). *Seabirds: Feeding Ecology and Role in Marine Ecosystems.* Cambridge, Cambridge University Press: 369-381.

Croxall, J.P., T.S. McCann, P.A. Prince and P. Rothery. 1988. Reproductive performance of seabirds and seals at South Georgia and Signy Island, South Orkney Islands, 1976-87: implications for Southern Ocean monitoring studies. In: Sahrhage, D. (Ed.). *Antarctic Ocean and Resources Variability.* Springer-Verlag, Berlin Heidelberg: 261–285.

Everson, I. 1987. Prey monitoring surveys. A discussion of the characteristics necessary in prey surveys. In: *Selected Scientific Papers, 1987 (SC-CAMLR-SSP/4).* CCAMLR, Hobart, Australia: 377-391.

Everson, I. and C. Goss. 1991. Krill fishing activity in the southwest Atlantic. *Antarctic Science,* 3 (4): 351-358.

Hewitt, R.P. and D.A. Demer. 1993. Dispersion and abundance of Antarctic krill in the vicinity of Elephant Island in the 1992 austral summer. *Mar. Ecol. Prog. Ser.,* 99: 29-39.

Ichii, T., H. Ishii and M. Naganobu. 1991. Krill (*Euphausia superba*) distribution in relation to water movement and phytoplankton distribution off the northern South Shetland Islands. In: *Selected Scientific Papers, 1991 (SC-CAMLR-SSP/8).* CCAMLR, Hobart, Australia: 123-140.

Ichii, T. 1987. Observations of fishing operations on a krill trawler and distributional behaviour of krill off Wilkes Land during the 1985/86 season. In: *Selected Scientific Papers, 1987 (SC-CAMLR-SSP/4).* CCAMLR, Hobart, Australia: 335-368.

SC-CAMLR. 1992. *Report of the Eleventh Meeting of the Scientific Committee (SC-CAMLR-XI).* CCAMLR, Hobart, Australia: 487 pp.

Trivelpiece, W.Z., S.G. Trivelpiece and N.J. Volkman. 1987. Ecological segregation of Adélie, gentoo and chinstrap penguins at King George Island, Antarctica. *Ecology*, 68: 351-361.

Woehler, E.J. (Compiler) 1993. *The Distribution and Abundance of Antarctic and Sub-Antarctic Penguins.* Scientific Committee on Antarctic Research (SCAR), Cambridge: 76 pp.

Zwally, H.J., J.C. Comiso, C.L. Parkinson, W.J. Campbell, F.D. Carsey and P. Gloersen. 1983. *Antarctic Sea-ice, 1973-1976: Satellite Passive-microwave Observations.* Nat. Aeronaut. Space Administr. Sci. Technol. Branch, SP-459, Washington DC: 206 pp.

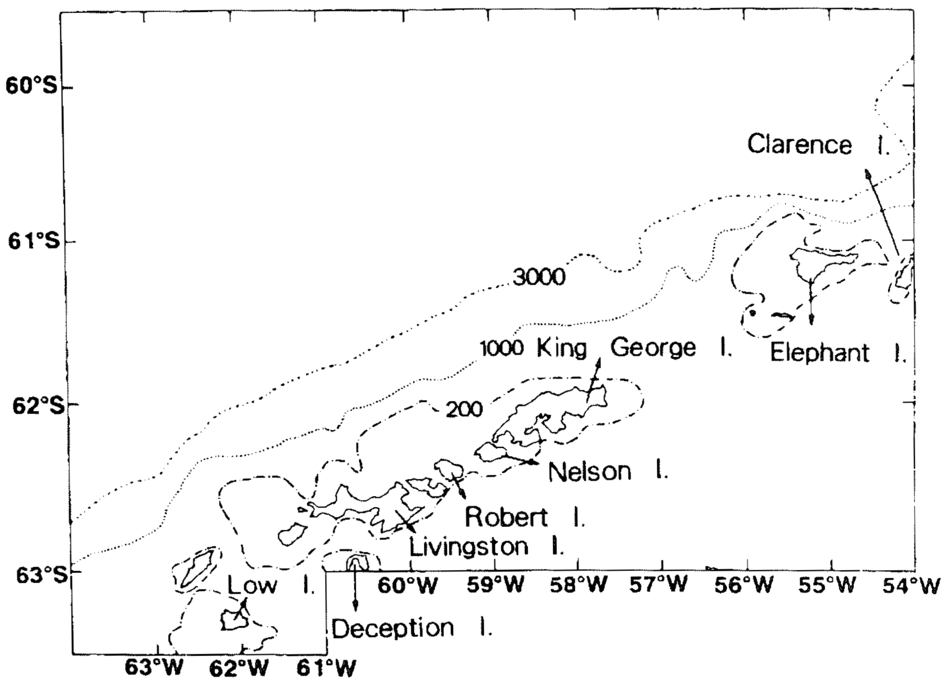


Figure 1: Map showing the study area in the South Shetland Islands. 200, 1 000 and 3 000 m depth contours are shown.

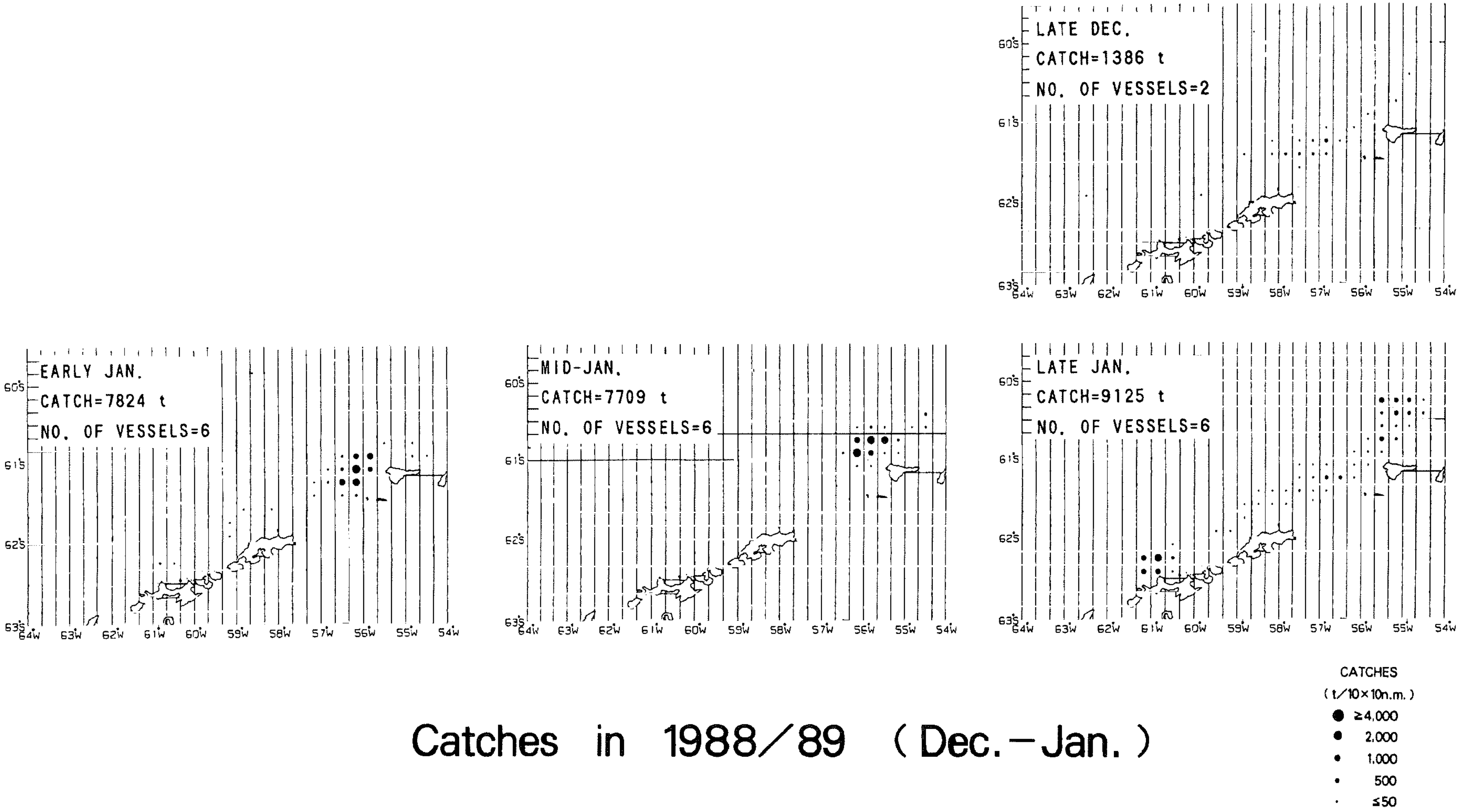


Figure 2a: Distribution of krill catches per 10-day period from December to January during the 1988/89 season.

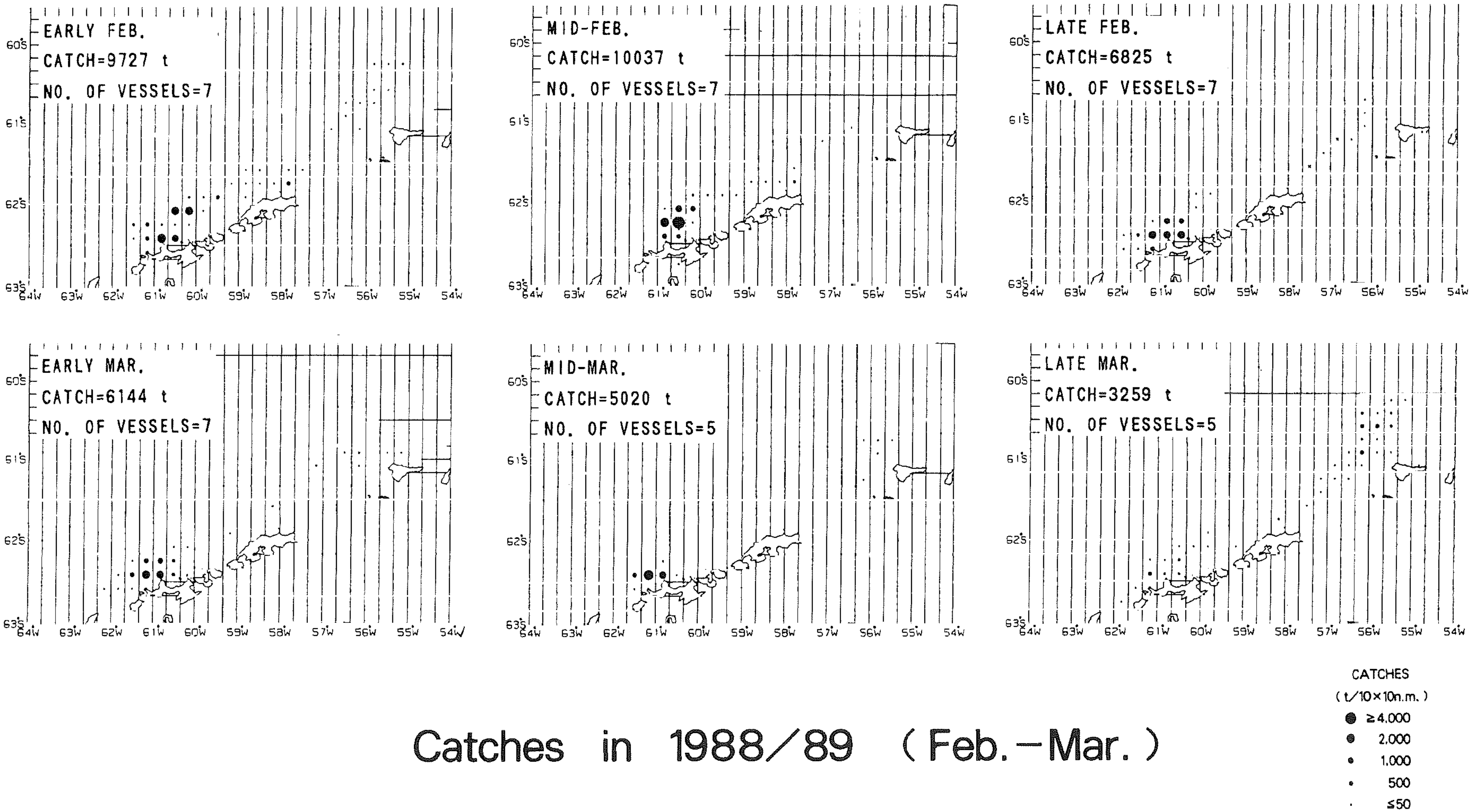


Figure 2b: Distribution of krill catches per 10-day period from February to March during the 1988/89 season.

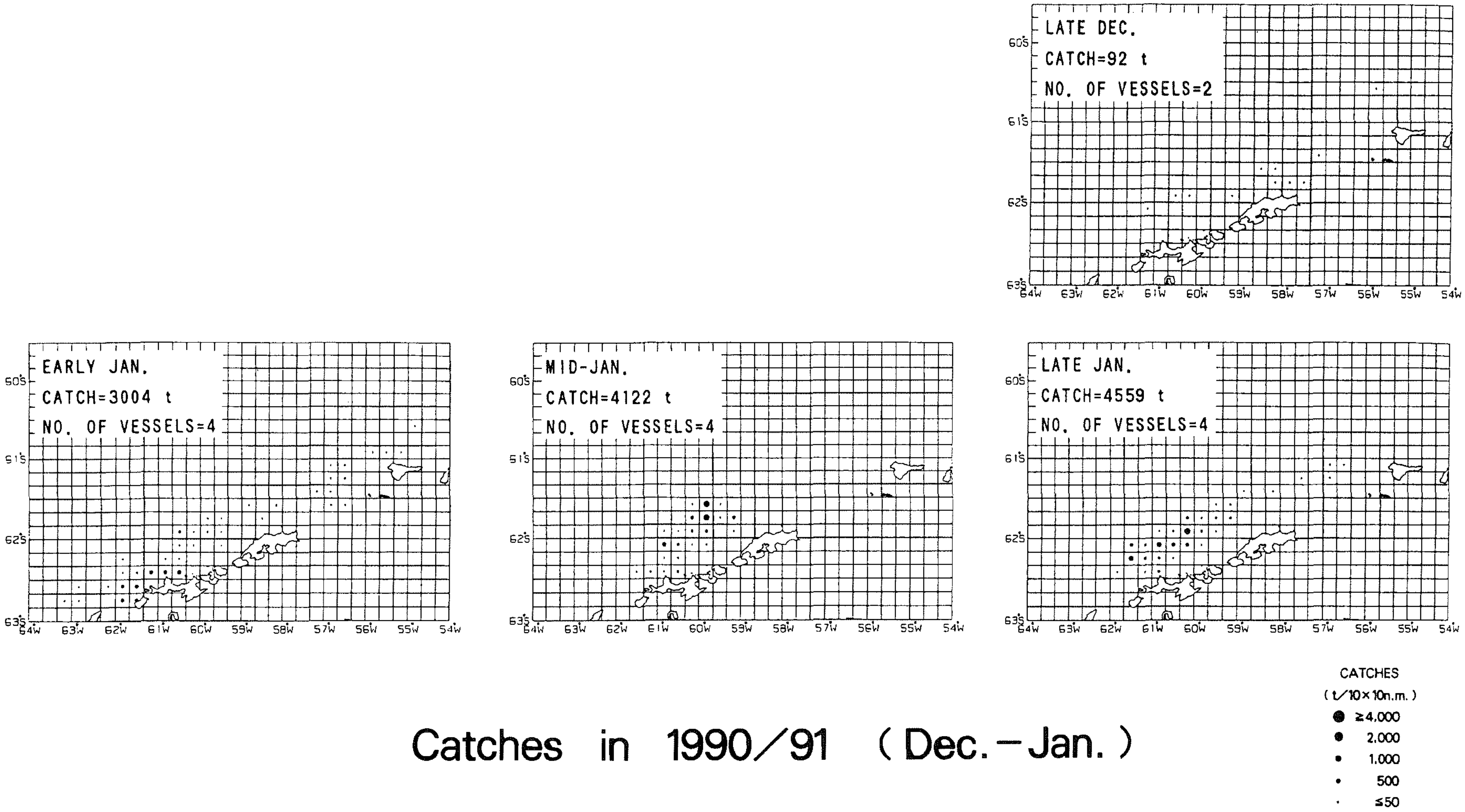


Figure 3a: Distribution of krill catches per 10-day period from December to January during the 1990/91 season.

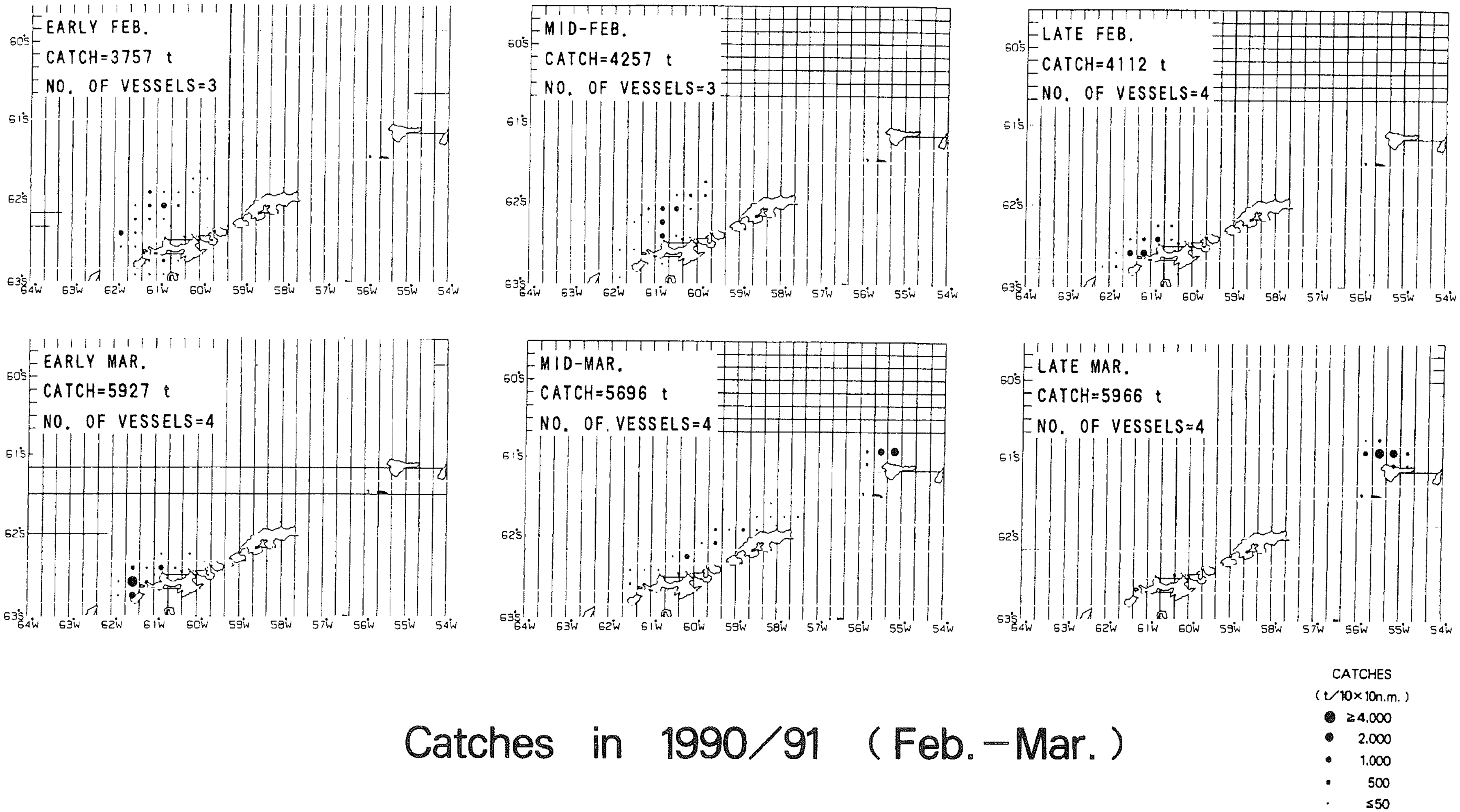
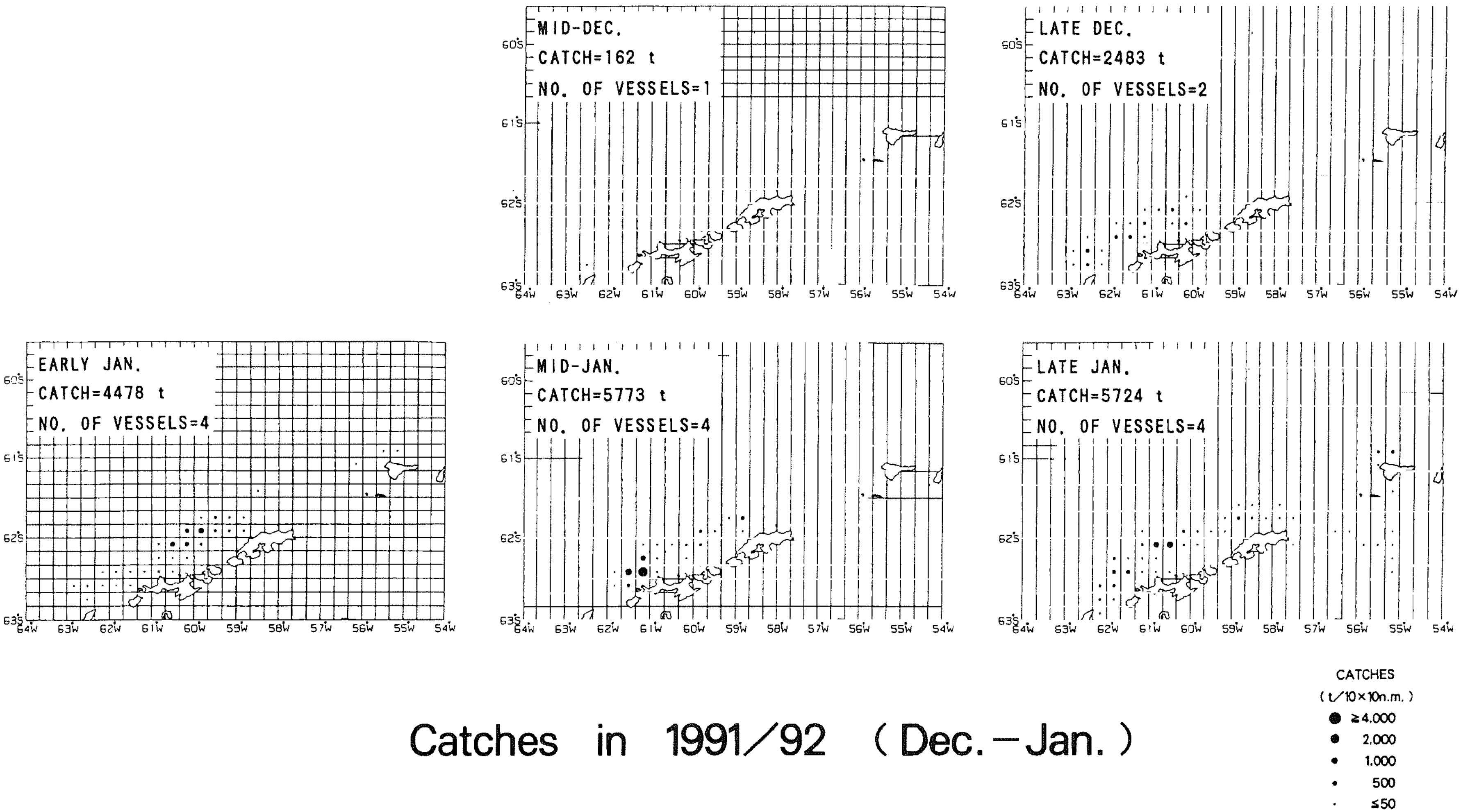


Figure 3b: Distribution of krill catches per 10-day period from February to March during the 1990/91 season.



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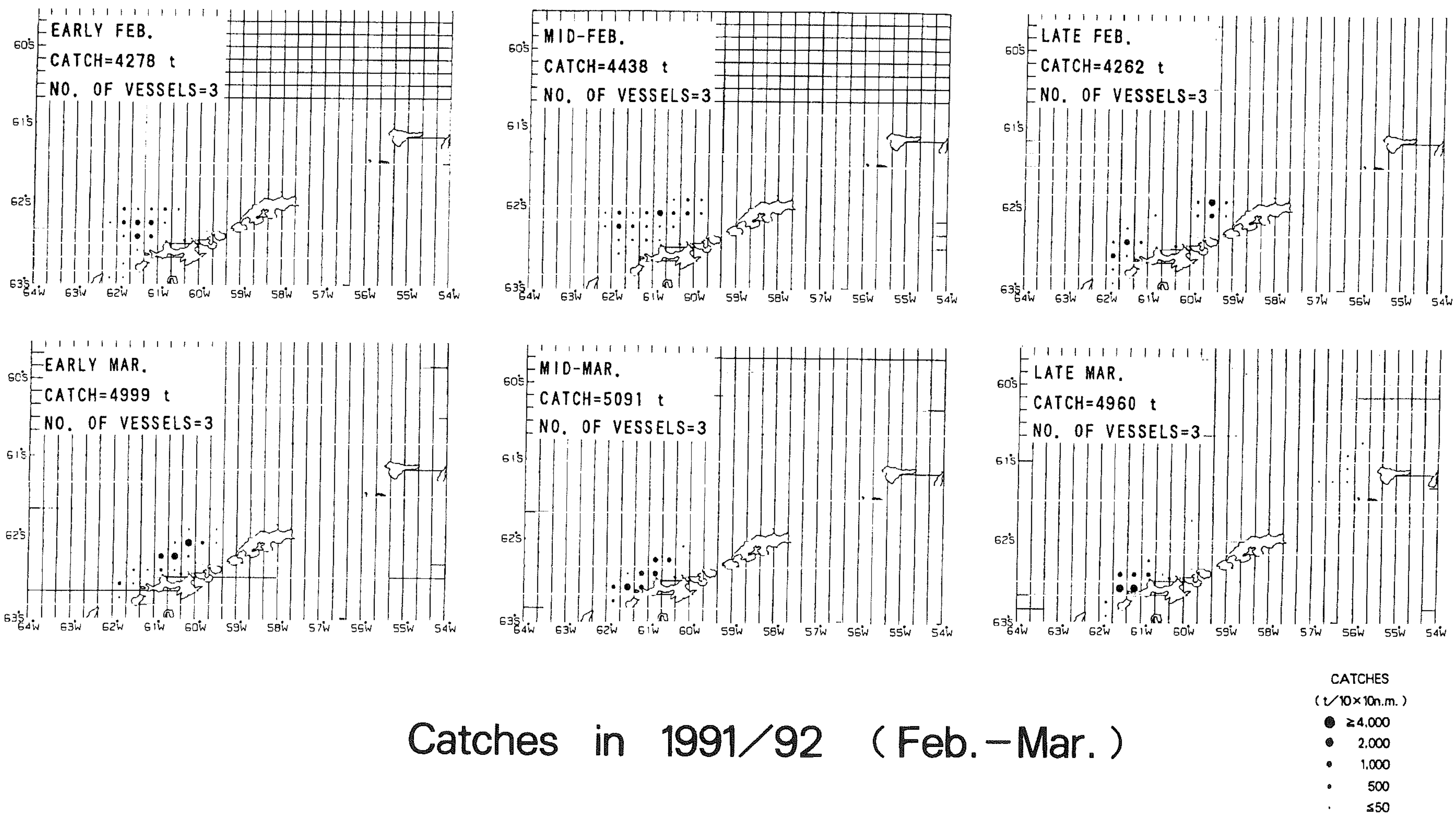

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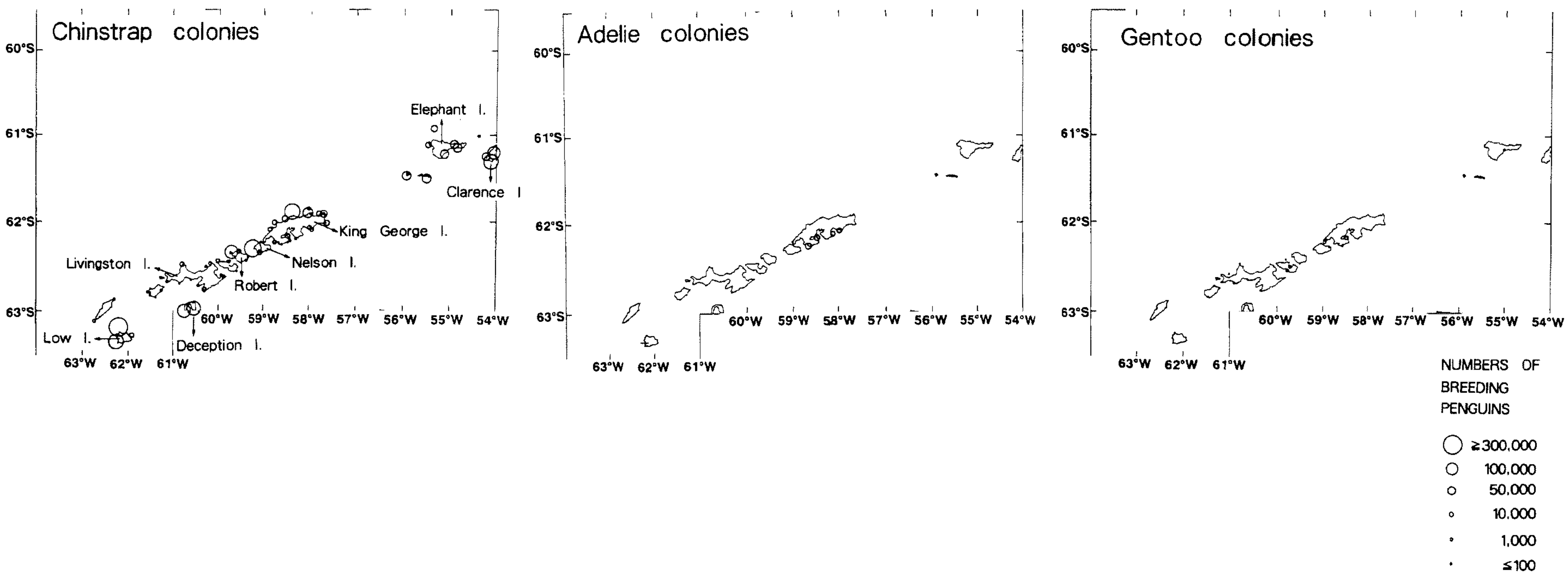

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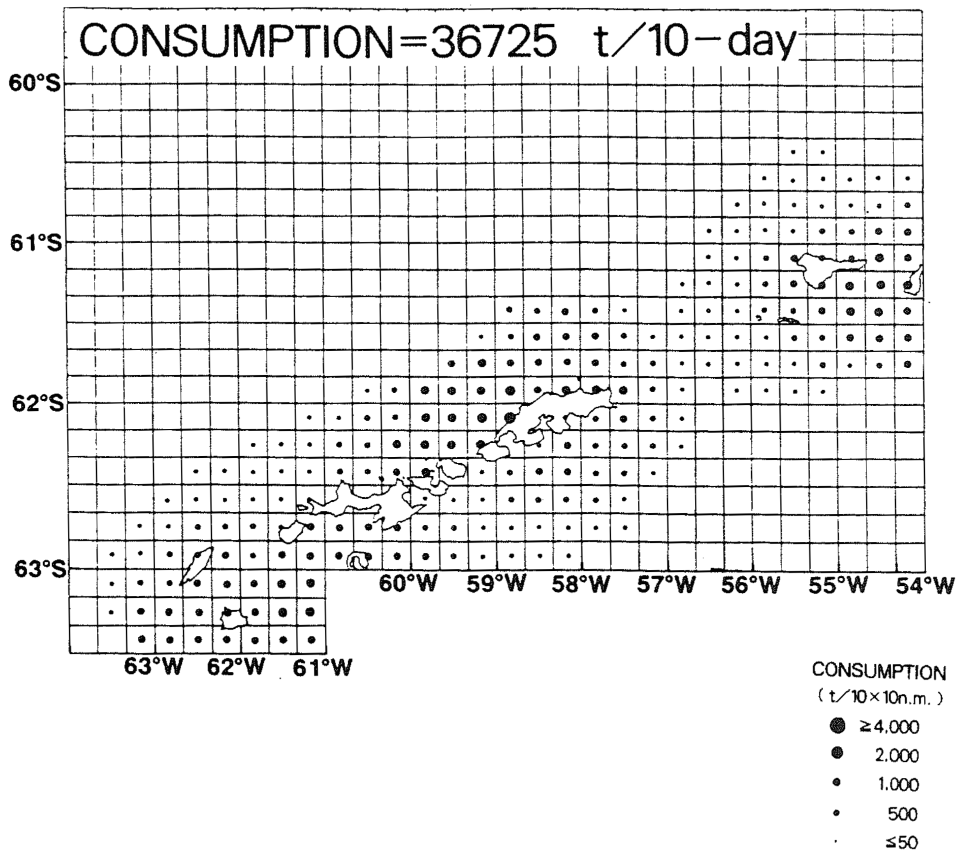

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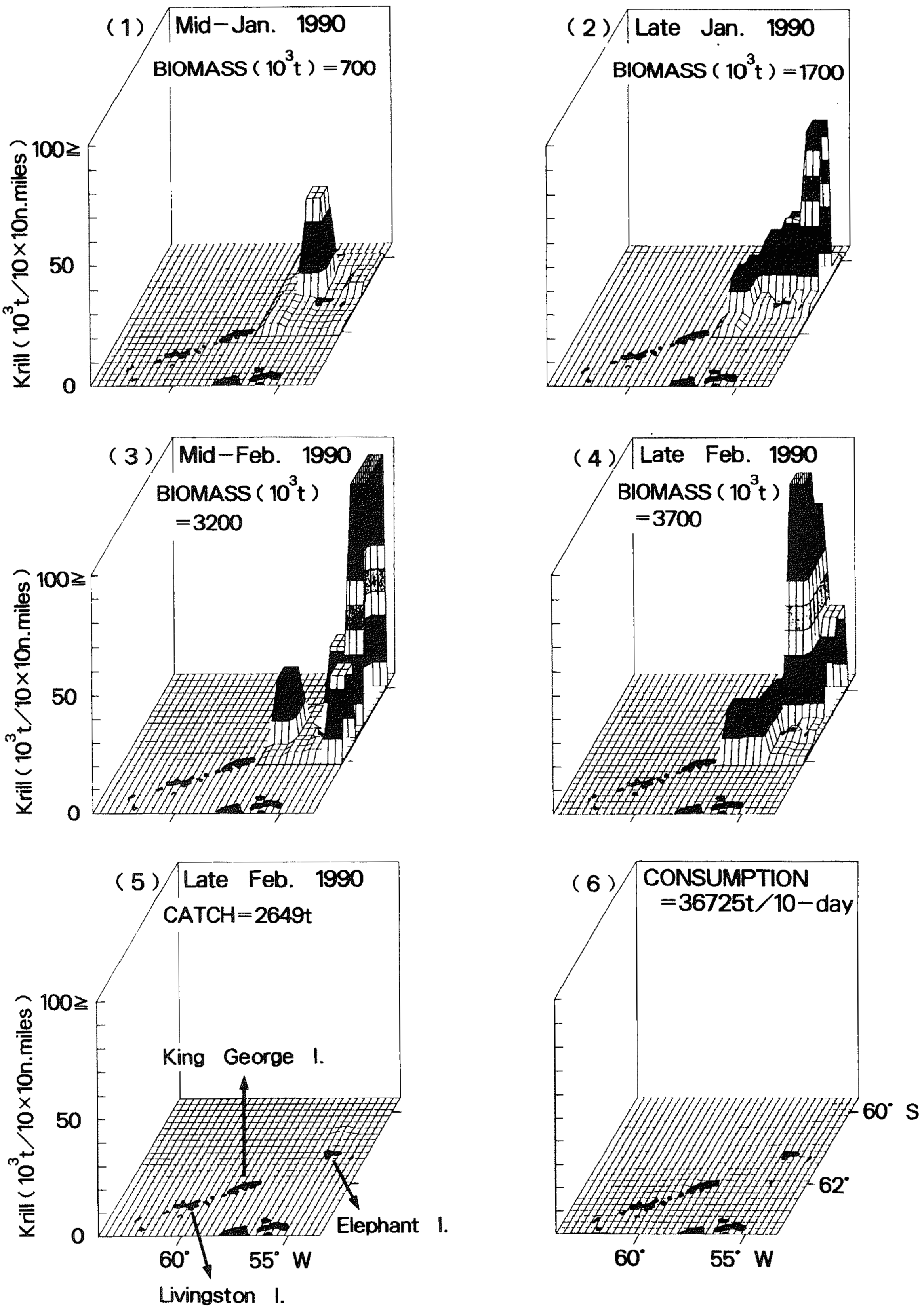

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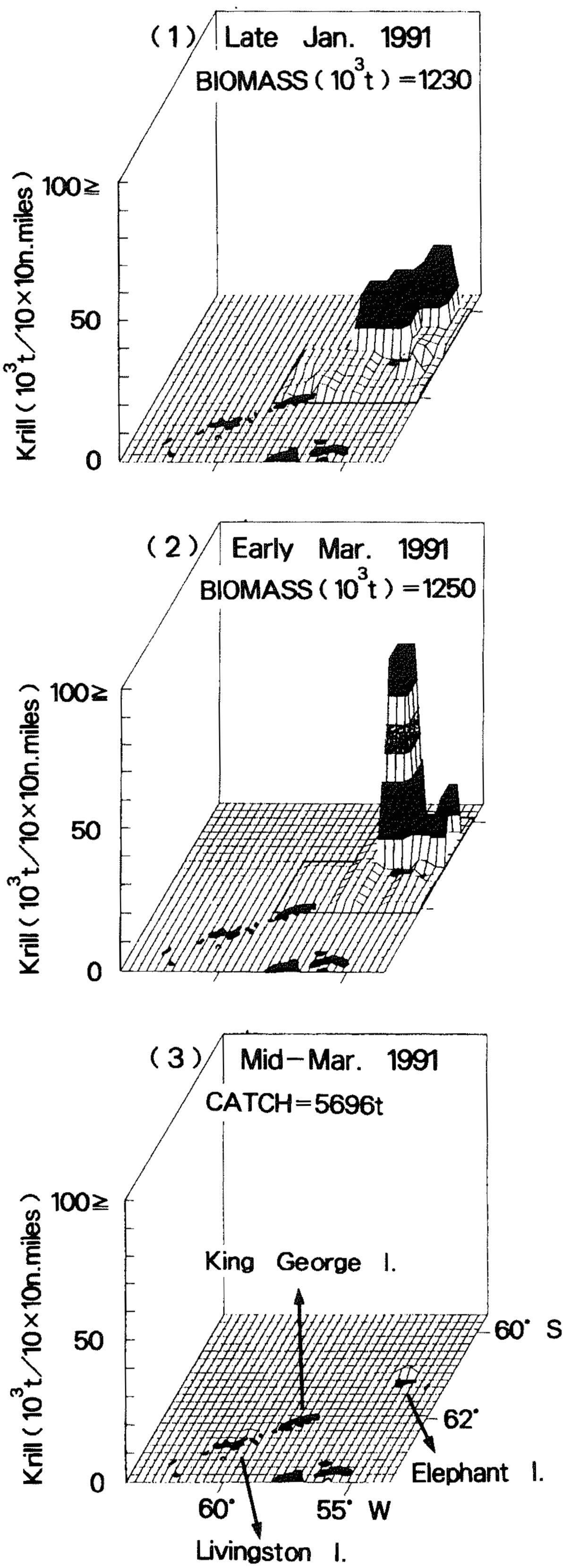

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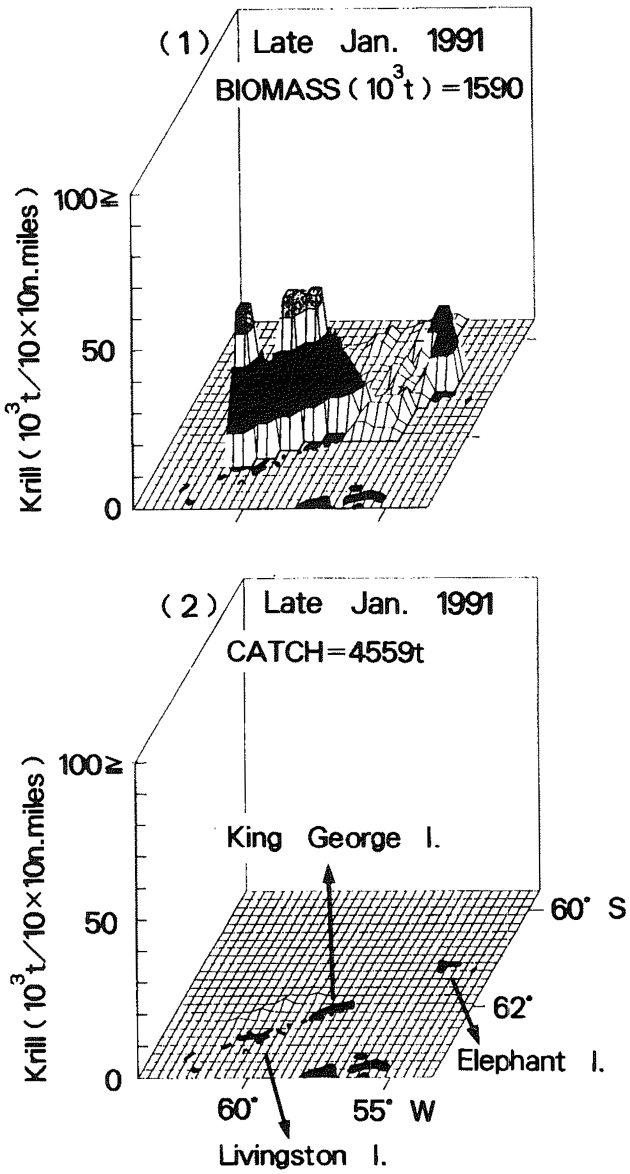

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