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SHORT NOTE

SURFACE WATER CIRCULATION IN KRILL FISHING AREAS NEAR THE SOUTH SHETLAND ISLANDS

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Abstract

This paper describes tracks followed by six surface drifting buoys that were deployed in shelf and oceanic waters to the north of the South Shetland Islands. Each buoy was deployed with a drogue attached at a depth of 30 m to assess flow patterns at the depth range where krill tended to be most abundant. The buoys were tracked using the ARGOS satellite positioning system. Based on buoy tracks, the surface circulation to the north of the South Shetlands shelf was described as a slow sluggish southwest current with a series of small-scale circular and semi-circular flows in the shelf region, whereas the circulation in the oceanic region was described as the strong northeast current. Between these counter-flowing currents a shear current was found in the slope region. The direct current measurements demonstrated that the oceanographic regime in these waters is not well described by geostrophic calculations. The picture obtained of the surface circulation was considered in conjunction with the distribution of krill catches taken in the area by Japanese vessels during the period from 1981 to 1994. It is suggested that the sluggish and shear currents observed to the north of the islands may have properties which contribute to the formation of stable krill concentrations in the area. The observed long-distance movements of three buoys also suggested that oceanic currents may transport krill from the South Shetland Islands to the South Georgia and South Orkney Islands on a time scale of 110 to 120 and 85 days respectively.

Résumé

Cette communication décrit les trajets suivis par six bouées dérivantes, déployées dans les eaux du plateau et les eaux océaniques au nord des îles Shetland du Sud. Chaque bouée tirait une ancre de cape située à 30 m de profondeur, pour évaluer les mouvements du courant dans l'intervalle de profondeur où le krill est susceptible d'être le plus abondant. Les bouées étaient suivies au moyen du système ARGOS de positionnement par satellite. D'après le trajet des bouées, la circulation des eaux de surface au nord du plateau des îles Shetland du Sud est qualifiée de courant du sud-ouest particulièrement lent avec une série de flux circulaires et semi-circulaires à petite échelle dans la région du plateau, alors que dans la région océanique, la circulation est qualifiée de courant fort du nord-est. Entre ces courants contraires on a trouvé un courant de cisaillement dans la région de la pente. Les mesures directes du courant démontrent que le régime océanographique dans ces eaux n'est pas bien décrit par les calculs géostrophiques. Le schéma des flux de surface a été examiné parallèlement à la répartition des captures de krill effectuées dans ce secteur par les navires japonais de 1981 à 1994. L'auteur suggère que les courants particulièrement lents et de cisaillement observés au nord de ces îles ont des propriétés qui contribuent à la formation de concentrations stables de krill dans le secteur. Par ailleurs, le fait que trois des bouées se soient déplacées sur de longues distances laisse entendre que les courants océaniques peuvent transporter le krill des îles Shetland du Sud jusqu'en Géorgie du Sud et aux îles Orcades du Sud, à une échelle temporelle respective de 110 à 120 et de 85 jours.

Резюме

В данной работе описываются маршруты шести дрейфующих по поверхности воды буев, установленных в шельфовых и океанических водах к северу от Южных Шетландских островов. К каждому бую был прикреплен дрейф-якорь на глубине 30 м с целью оценки закономерностей течения на горизонтах, где криль наиболее многочисленен. Местонахождение буев определялось при помощи спутниковой системы АРГОС. На основе этих маршрутов циркуляция поверхностных вод к северу от Южных Шетландских островов была описана как медленное, слабое и плохо выраженное юго-западное течение с мелкомасштабными циркулярными и полуциркулярными потоками в районе шельфа, тогда как циркуляция в океаническом регионе была описана как сильное северо-восточное течение. Между этими течениями, идущими в противоположных направлениях, в районе склона было обнаружено срезывающее течение. Непосредственные измерения течения показали, что геострофические расчеты плохо описывают океанографический режим в этих водах. Данная картина поверхностной циркуляции была рассмотрена в связи с распределением уловов криля, полученных в данном районе японскими судами в период с 1981 по 1994 г. Предполагается, что слабое и срезывающее течения, наблюдавшиеся к северу от этих островов, возможно, характеризуются качествами, которые влияют на формирование устойчивых концентраций криля в данном районе. Наблюдавшееся перемещение трех буев на большие расстояния также указало на то, что океанические течения могут перемещать криль с Южных Шетландских островов до Южной Георгии и Южных Оркнейских островов за 110-120 и 85 суток соответственно.

Resumen

Este trabajo describe las trayectorias de seis boyas superficiales a la deriva que fueron lanzadas al norte de las islas Shetland del Sur en aguas oceánicas y de la plataforma. Cada boya fue lanzada con un ancla flotante fija a una profundidad de 30 m para evaluar la configuración del flujo en el estrato de profundidad donde la abundancia de kril fue mayor. Las boyas fueron rastreadas con el sistema de posicionamiento automático ARGOS. De los resultados de las trayectorias de las boyas, se describió a la corriente superficial al norte de la plataforma de las Shetland del Sur como lenta, en dirección suroeste y con varios flujos circulares y semicirculares a pequeña escala en la región de la plataforma, mientras que la corriente en la región océanica fue descrita como la corriente fuerte en dirección noreste. Entre estas contracorrientes se encontró una corriente transversal en la región de la pendiente. Las mediciones directas de las corrientes demostraron que los cálculos geostróficos no describen en forma adecuada el régimen oceanográfico de estas aguas. La descripción obtenida de la corriente superficial fue analizada conjuntamente con la distribución de las capturas de kril realizadas por barcos japoneses en el área durante el período de 1981 a 1994. Se ha planteado que la corriente lenta y la corriente transversal observadas al norte de las islas puede tener propiedades que contribuyen a la formación de concentraciones estables de kril en la zona. Los desplazamientos a grandes distancias observados para las tres boyas sugieren además que las corrientes oceánicas pueden transportar kril desde las islas Shetland del Sur a las islas Georgia del Sur y Orcadas del Sur en una escala temporal de 110 a 120 días y 85 días, respectivamente.

Keywords: CCAMLR, drifting buoys, fishing grounds, krill distribution, surface currents

INTRODUCTION

Water circulation is considered to be a main environmental factor affecting the overall distribution and movement of Antarctic krill, *Euphausia superba* (Miller and Hampton, 1989; Everson and Murphy, 1987; Huntley and Niiler, 1995). Everson and Murphy (1987) showed that in the Atlantic ocean sector of Antarctic waters patches of krill were carried along the main current in Bransfield Strait, suggesting strong current-related passive transport of krill. According to analyses of commercial catches, most krill concentrations in the Atlantic sector are found around main island groups (Everson and Goss, 1991; Ichii et al., 1996). How water circulation may influence the formation and occurrence of krill concentrations around these islands, however, remains unclear because the oceanographic regime in these areas is not well described by geostrophic calculations (SC-CAMLR, 1994a and 1994b). The CCAMLR Working Group on Krill (WG-Krill) recommended that direct current measurements in particular were needed in key areas, such as shelf and shelf-break regions. It was also emphasised that analyses of data to determine regions of rapid water transport with little eddy activity and areas of high eddy activity and drifter retention would be extremely useful (SC-CAMLR, 1994b).

MATERIALS AND METHODS

In order to obtain direct measurements of surface currents, four drifting buoys (model C-2243, TOYOCOM, Japan) were released in the area north of the South Shetlands during the 1990/91 austral summer and another two (model C-2340, TOYOCOM) during the 1994/95 austral summer. Each buoy was deployed with a drogue (curtain type - 4 m long x 1 m wide in 1990/91; cylindrical type - length 8.6 m, diameter 0.94 m in 1994/95) at a depth of 30 m to assess flow pattern at the depth range where krill tended to be most abundant (Anon., 1993). The buoys were tracked using the ARGOS satellite system. Typically, twelve locations per day were obtained for each buoy with location accuracy to within several hundred metres. Daily locations of each buoy were plotted to show the buoys' drifting tracks (Figures 1 and 2).

To obtain a picture of spatial and temporal distribution of krill concentrations in the South Shetlands, the Japanese krill catches from 1980/81 to 1993/94 were re-calculated for each 5′ latitude x 10′ longitude block (5 x 5 n miles) for each month of the fishing season (Figure 3). Large-scale krill distributions over the Scotia Sea were obtained from trawling positions of Japanese fishing vessels in the past 13 years, and also from krill abundance in KYMT net samples during the 1987/88 cruise of the RV *Kaiyo Maru* (Figure 4).

RESULTS

Waters north of the South Shetlands may be subdivided into the following three regions: oceanic (deeper than 3 000 m); continental slope (200 - 3 000 m); and shelf (shallower than 200 m). Tracks of the buoys exhibited different patterns for these three regions (Figure 1).

Buoys 1 and 5 deployed in the oceanic region moved north-east with a meandering current (Figures 1(a) and 1(c)) that travelled generally along the 3 000 m depth contour of the continental slope and a submarine ridge (the Shackleton Fracture Zone) respectively. These two buoys followed different routes across the Scotia Sea but both reached the South Georgia area 110 to 120 days after they had left the South Shetlands (Figures 2(a) and 2(b)). At South Georgia, Buoy 1 was trapped for 23 days in the shelf region and then moved north-east (Figure 2(a)).

Buoys 2, 3 and 6 released in the slope region initially showed circular and irregular movements. Buoys 2 and 3 subsequently became entrained in the shelf regions of Livingston/King George Islands and Elephant Island respectively (Figures 1(a) and 1(b)). These buoys further travelled anticlockwise around the islands, revealing a sluggish current with eddy activities on the northern side and a faster and steadier current on the southern side of the islands. The residence time of Buoy 2 was as long as 90 days on the northern side and as short as 15 days on the southern side. The deployment location of Buoy 6 corresponds to the centre of the intensively fished area on the northern slope of Livingston/King George Islands (Figures 1(c) and 3(b)). After entrainment there for 25 days (as indicated by semicircular movements), it moved northeast along the slope and reached the South Orkneys 85 days later (Figure 2(b)). The buoy was then trapped on the slope of the South Orkneys for 20 days before drifting to South Georgia.

Buoy 4, deployed in the shelf region, moved east then reversed its direction to west and became trapped in Barclay Bay on the northern side of Livingston Island (Figure 1(b)). This buoy also confirmed the occurrence of eddy activities along the northern shelf break.

Buoys 1, 5 and 6 which travelled across the Scotia Sea to South Georgia and the South Orkneys followed different tracks but each track was closely associated with the bottom topography (Figures 2(a) and 2(b)).

Tracks of all buoys were considered in relation to the distribution of krill catches (Figures 3 and 4). Fishing usually begins in January (Figure 3).

Catches of krill in January/February are located over the insular slope to the north of Livingston/King George Islands and northwest of Elephant Island (Figures 3(b) and 3(c)). When the krill spawning season is almost over (in March/April), fishing shifts onto the shelf of Livingston and Elephant Islands (Figures 3(d) and 3(e)). Fishermen indicate that numerous rocks off the northern coasts of King George Island, discourage intensive trawling in the shelf areas where krill may be abundant (Ichii et al., 1992). The areas of krill concentrations, i.e. the insular slope and shelf, were characterised by the currents which had properties of retention.

In addition to positions of catches for the past 13 years, tracks of Buoys 1, 5 and 6 which travelled across the Scotia Sea to South Georgia and the South Orkneys were considered in relation to information on krill abundance derived from net samples from the 1987/88 survey by RV *Kaiyo Maru* (Figures 4(a) and 4(b)). The areas of high krill abundance in the oceanic region between these island groups were found to be in association with the currents revealed by the buoys.

DISCUSSION

The analyses of buoy tracks obtained during this study confirmed the existing understanding of the overall circulation in the Atlantic sector of the Southern Ocean (e.g. Clowes, 1934; Gordon, 1967; Grelowski et al., 1986; Stein, 1988; Stein and Heywood, 1994).

Direct current measurements were used to describe the surface currents over the insular slope and shelf regions (Figure 1). In the waters north of the South Shetland Islands, the strong northeast current was observed in the oceanic region, whereas a sluggish southwest current with eddy activities was observed in the shelf region. Between these counter-flowing currents a shear current was found in the slope region. A general picture of the surface water circulation around the South Shetlands is shown in Figure 1(e). Mean current speeds are 14.6 cm/s for the strong eastward flow in the oceanic region, and 4.3 cm/s for the sluggish westward flow over the shelf. In comparison to direct measurements, geostrophic calculations for the same region and season (i.e. 1990/91 austral summer) describe a westward surface flow both in the oceanic and shelf regions with a speed of 10.9 cm/s and 0.8 cm/s respectively (Naganobu et al., 1993). This highlights once again the limitations of the geostrophic method for describing circulations over shelf regions. One of these limitations is that wind-induced surface currents are not taken into account in the geostrophic analyses (Stein, 1989; Stein and Heywood, 1994; SC-CAMLR, 1994b).

The surface water circulation for krill fishing areas depicted by buoys showed a sluggish current with eddy activities in the shelf region and a strong shear current on the slope. This implies that mechanical retention may contribute to the formation of krill concentrations. Considering that most buoys were eventually trapped in the shelf region, this retention may be stronger on the shelf than on the slope. The slope and shelf areas are also food-rich areas (Kopczynska, 1985; Ichii et al., 1991; Helbling et al., 1995), so that krill may be highly adapted to exploiting food resources by utilising flow patterns which cause retention in these areas.

Buoys 1, 5 and 6 revealed the existence of oceanic currents strongly associated with the Scotia Sea topography. High krill abundances in offshore waters appear to be associated with these currents. Sprong and Schalk (1992) reported that krill merged into large swarms at 58-59°S along 49°W, which happens to be on the route of the oceanic currents leading from the South Shetlands to South Georgia (Figures 2(a) and 2(b)). The occurrence of higher concentrations of krill larvae were also reported along this current (Hempel, 1983; Brinton and Townsend, 1984; Rakusa-Suszczewski, 1984). Furthermore it is suggested that South Georgia is an area where there is no successful krill spawning and that the stocks there rely on recruitment from the south (Everson, 1977). This study supports the notion of large-scale horizontal transport of krill by currents and suggests that the time scales for advection of krill from the South Shetlands to South Georgia and to the South Orkneys are 110 to 120 days and 85 days respectively.

There was discussion about the possible drift of krill from the Antarctic Peninsula to the South Orkneys and South Georgia and back to the Antarctic Peninsula (SC-CAMLR, 1991). With regard to this hypothesis, the present study shows no evidence for a loop drift, i.e. a drift which would lead to the Scotia Sea containing a single stock consisting of interlinked populations.

In general terms, the formation of krill concentrations is probably the result of several interacting factors, both environmental (e.g. water circulation) and behavioural (e.g. active maintenance by krill of its position in slow currents, active vertical migrations). However, it should be noted that a detailed consideration of krill accumulation mechanisms was not the specific objective of this study.

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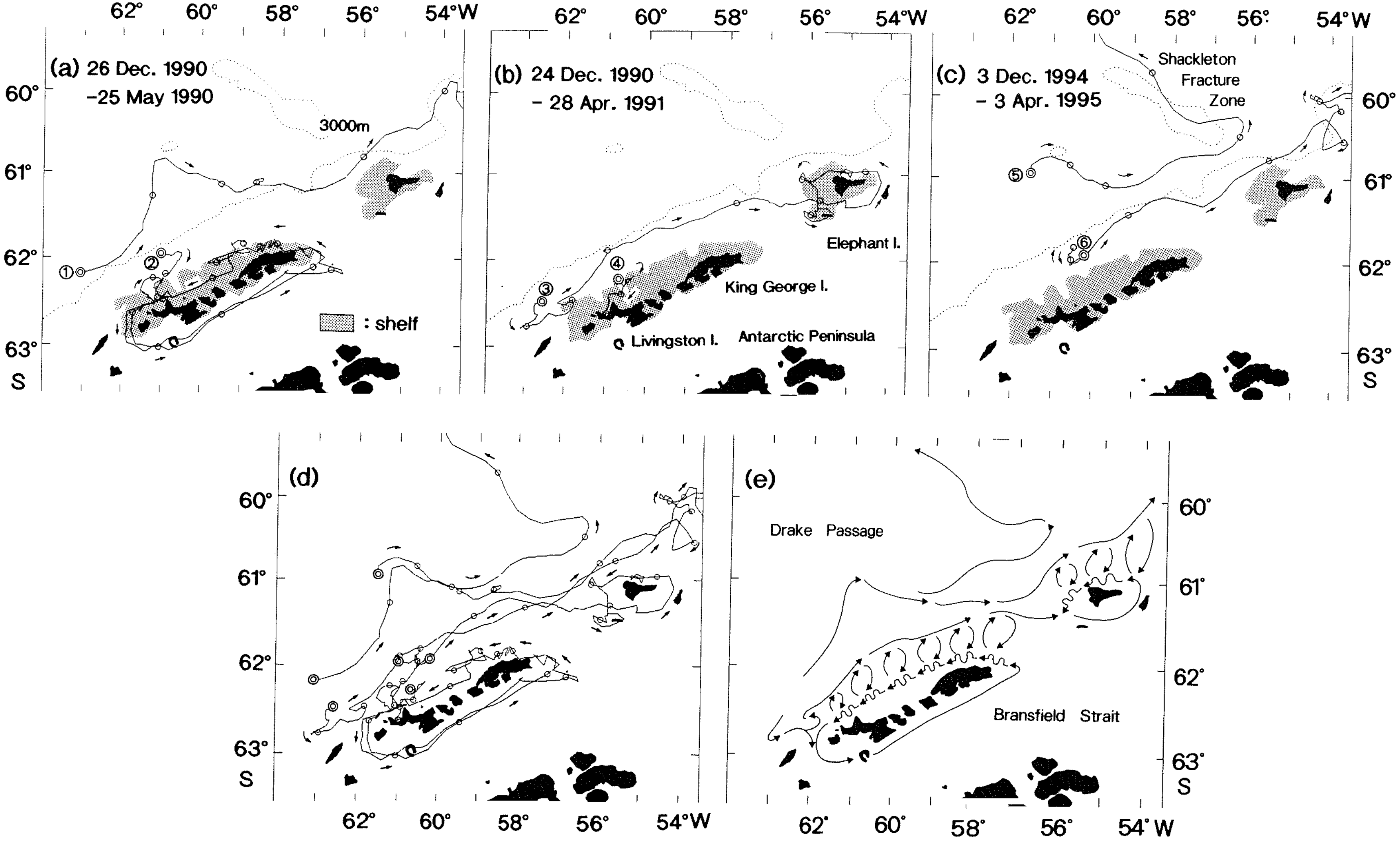

Figure 1: (a) to (c) - buoy tracks in the South Shetlands area. Buoy launch sites are indicated by double open circles with buoy identification numbers. Open circles indicate positions of buoys each 10 days. Dates show periods of tracking buoys. (d) - combined tracks of all buoys. (e) - schematic circulation patterns derived from buoy tracks. The length of arrows represents approximately the distance drifted by buoys each 10 days.

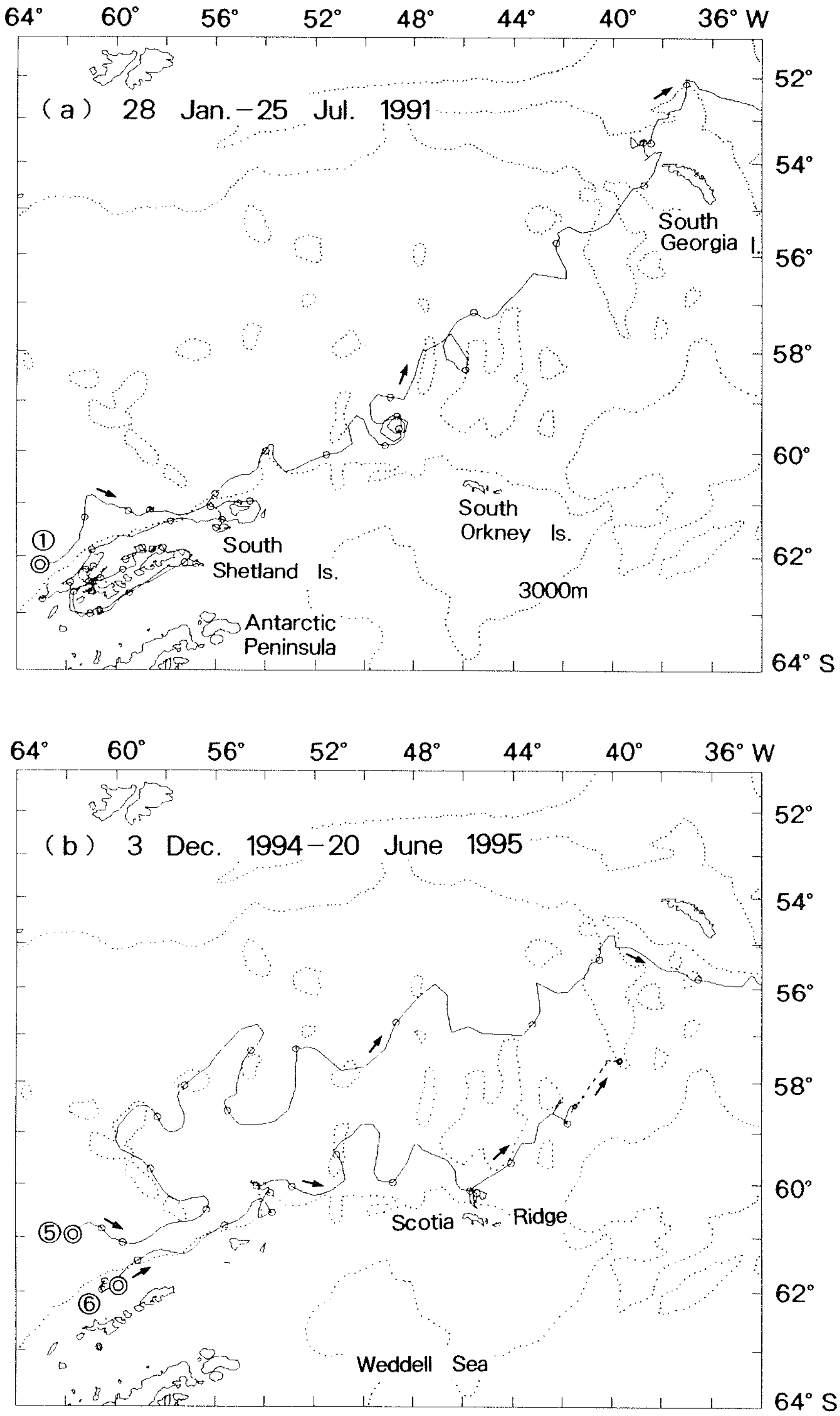

Figure 2: (a) and (b) - buoy tracks in the Scotia Sea. (See legend to Figure 1.) Dotted lines show 3 000 m depth contours.

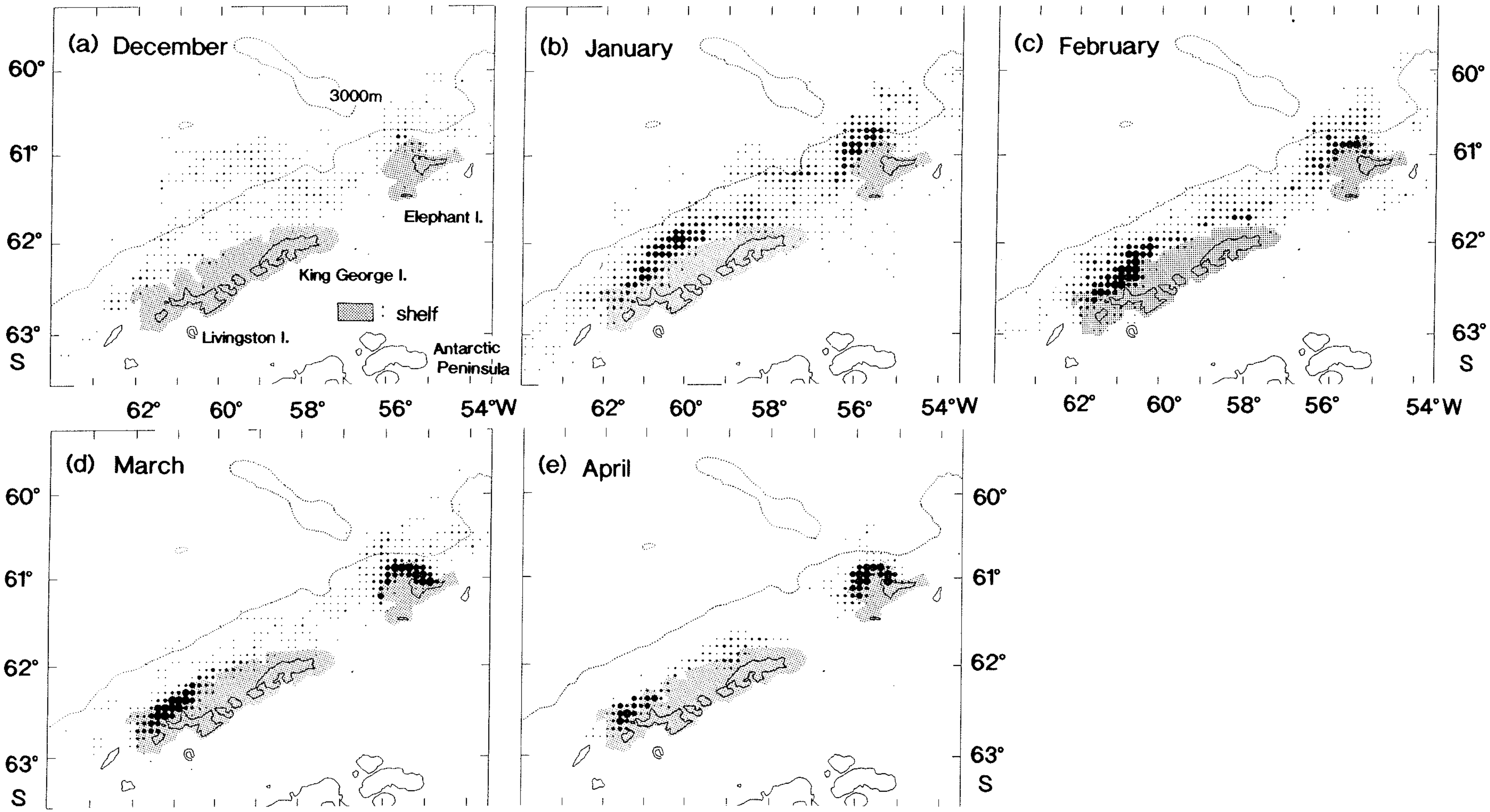

Figure 3: (a) to (e) - distribution of accumulated krill catches from 1980/81 to 1993/94 for each month in the South Shetlands area. The size of closed circles is proportional to the catch size, e.g. closed circles with maximum diameter (1.3 mm) correspond to catches of more than 3 000 tonnes. Shaded areas indicate the shelf (200 m depth or less). Dotted lines show 3 000 m depth contours.

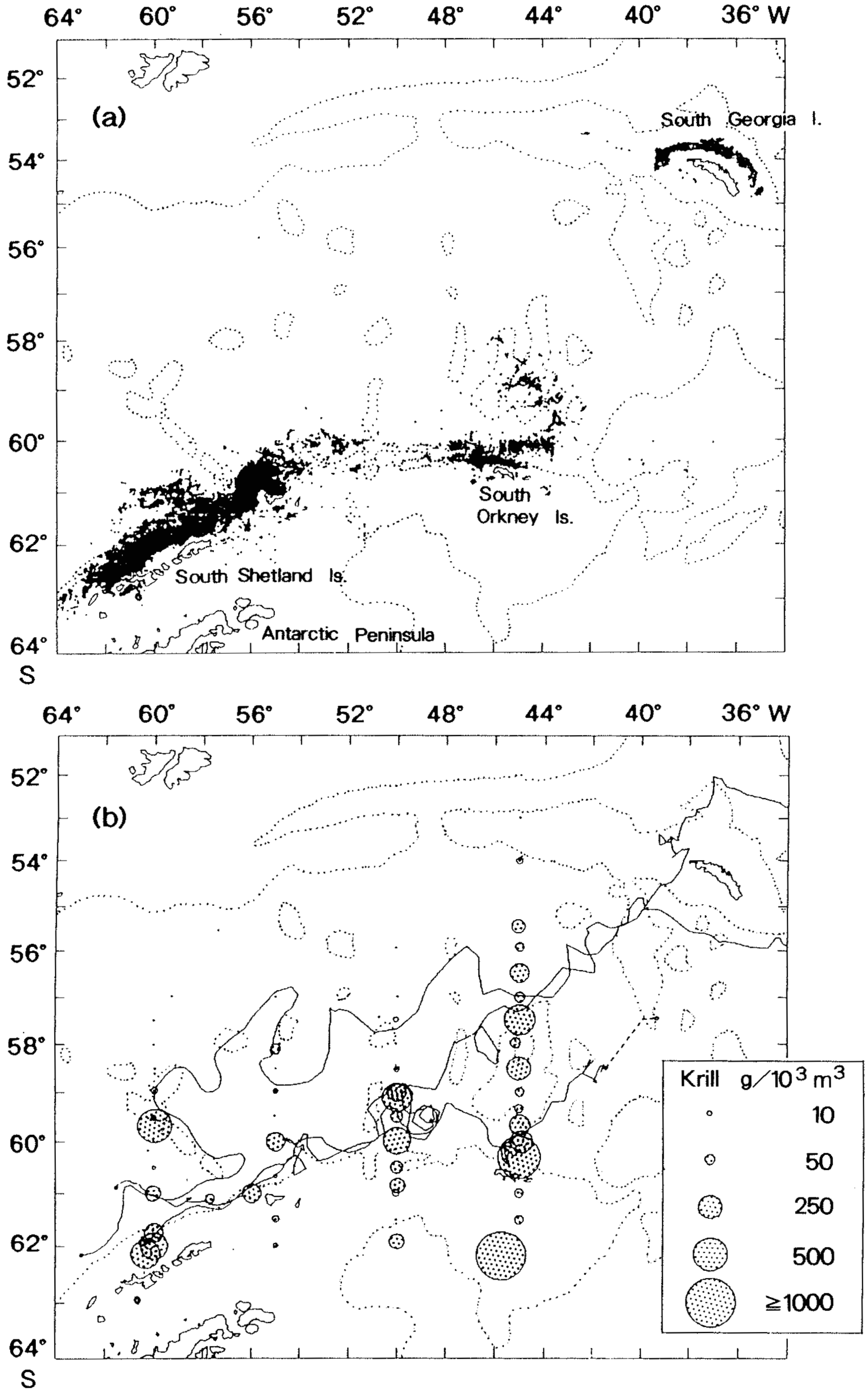

Figure 4: (a) - trawling positions of krill fishing vessels from 1980/81 to 1993/94 in the Scotia Sea. (b) - krill abundance in areas of buoy tracks. Krill abundance estimates are derived from net samples collected during the 1987/88 cruise of RV *Kaiyo Maru* (Anon., 1989).

Liste des figures

Список рисунков

Lista de las figuras

decir, los círculos con un diámetro máximo (1.3 mm) corresponden a las capturas de más de 3 000 toneladas. Las zonas sombreadas indican la región de la plataforma (200 metros o menos de profundidad). Las líneas entrecortadas muestran contornos de 3 000 metros de profundidad.

Figura 4: (a) - caladeros de la pesca de arrastre de los barcos de pesca de kril desde 1980/81 a 1993/94 en el mar de Escocia. (b) - abundancia de kril en las zonas de trayectoria de las boyas. Las estimaciones de abundancia de kril se deducen de las muestras recogidas con redes durante la campaña 1987/88 del BI *Kaiyo Maru* (Anon., 1989).