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THE FORAGING RANGE OF ADÉLIE PENGUINS - IMPLICATIONS FOR CEMP AND INTERACTIONS WITH THE KRILL FISHERY

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Abstract

This paper presents a summary of the foraging locations of Adélie penguins, determined by satellite tracking, at seven widely-spaced breeding colonies along the coast of eastern Antarctica between 55°E (Enderby Land) and 175°E (Ross Sea). Adélie penguins feeding chicks regularly travelled up to 120 km offshore to the continental shelf and returned with krill, *Euphausia superba*. Locations of penguins on foraging trips were compared with historical records of fine-scale krill catch data for the regions of interest. The potential for overlap with krill fishing occurs particularly where ice conditions permit the fishing fleet to approach the edge of the continental shelf or where penguins forage downstream from the fishery. It is suggested that the potential for overlap between foraging areas of Adélie penguins and fishable concentrations of krill be investigated before a decision is made to establish a new CEMP site.

Résumé

L'auteur présente une récapitulation des secteurs d'approvisionnement déterminés par des suivis par satellite de manchots Adélie de sept colonies de reproduction largement espacées le long de la côte est de l'Antarctique, entre 55°E (terre Enderby) et 175°E (mer de Ross). Les manchots Adélie nourrissant leurs jeunes parcourent régulièrement jusqu'à 120 km au large, jusqu'au plateau continental et reviennent avec du krill, *Euphausia superba*. La position des manchots lors des sorties alimentaires est comparée aux anciennes données à échelle précise de captures de krill des régions en question. Il est possible que la pêcherie de krill entre en compétition avec les manchots, notamment lorsque les conditions glaciaires permettent à la flottille de pêche de s'approcher de la bordure du plateau continental ou lorsque les manchots s'approvisionnent en aval de la pêcherie. Il est suggéré d'étudier le chevauchement potentiel des secteurs d'alimentation des manchots Adélie et des concentrations exploitables de krill avant que ne soit prise la décision de mettre en place de nouveaux sites du CEMP.

Резюме

В настоящей работе представлена сводка данных по нагульным ареалам пингвинов Адели, определенным с помощью спутникового слежения, из семи далеко расположенных друг от друга гнездовых колоний вдоль восточного побережья Антарктиды между 55°в.д. (Земля Эндерби) и 175°в.д. (море Росса). Пингвины Адели, кормившие своих птенцов, регулярно добывали криля (*Euphausia superba*) на континентальном шельфе, т.е. в 120 км от побережья. Данные по местоположению пингвинов, совершивших походы за пищей, были сравнены с ретроспективными мелкомасштабными данными по уловам криля, полученным в изучаемых районах. Наилучшие условия для конкуренции между пингвинами и промыслом криля создаются тогда, когда ледовая обстановка

позволяет судам работать близко к границе шельфа или нагульный ареал пингвинов находится вниз промыслового участка по течению. Делается предложение о том, чтобы до принятия решения об учреждении нового участка CEMP был подвергнут изучению вопрос возможного совмещения нагульных ареалов пингвинов Адели и промысловых концентраций криля.

Resumen

Este trabajo presenta un resumen de los lugares de alimentación de los pingüinos adelia, determinados mediante el rastreo por satélite de siete colonias de reproducción situadas a gran distancia entre sí, a lo largo de la costa este de la Antártida entre los 55°E (Territorio de Enderby) y 175°E (Mar de Ross). Los pingüinos adelia que alimentaban a sus polluelos hicieron viajes regulares hasta la plataforma continental (aprox. 120 km de la costa), y retornaron con kril, *Euphausia superba*. Se hizo una comparación entre las zonas de alimentación de los pingüinos y los registros históricos de las capturas de kril a escala fina en las regiones de interés. La posibilidad de que ocurra una superposición con la pesquería de kril aumenta cuando las condiciones del hielo son tales que permiten un acercamiento de la flota pesquera al borde de la plataforma continental, o cuando los pingüinos se alimentan corriente abajo del lugar donde está operando la pesquería. Se propone investigar primero la posible superposición entre las zonas de alimentación de los pingüinos adelia y las concentraciones explotables de kril, antes de decidir el establecimiento de nuevas localidades del CEMP.

Keywords: Adélie, Casey, CEMP, Dumont d'Urville, foraging, krill, Mawson, monitoring, penguin, satellite tracking, Terra Nova Bay, CCAMLR

INTRODUCTION

The CCAMLR Ecosystem Monitoring Program (CEMP) seeks to determine whether the harvest of krill is likely to have an impact on krill predators. Although Adélie penguins are being monitored at a number of sites around Antarctica, a spatial overlap between the foraging areas of these birds and the areas where krill fishing has taken place in the previous seasons was demonstrated only in the case of Béchervaise Island (67°31'S, 62°49'E) near Mawson Station (Kerry et al., 1992, 1995a). The possibility of an overlap between the krill fishery and the foraging areas of penguins at locations in the Antarctic Peninsula region (Subarea 48.1) was investigated by Agnew (1992) based on the time penguins are away from their colonies and their average swimming speed as reported by, for example, Lishman (1985) and Trivelpiece et al. (1987). Since then, however, significant competition between the overall penguin population and this krill fishery has been considered unlikely because the preferred fishing areas are not adjacent to the largest penguin colonies (Ichii et al., 1994; Agnew and Phegan, 1995).

We have been tracking Adélie penguins on foraging trips by satellite for up to five breeding seasons at seven sites along the coast of eastern Antarctica. Four of the sites are in CCAMLR Statistical Division 58.4.2, two in Division 58.4.1 and one in Subarea 88.1 (Figure 1). This work was undertaken to determine the foraging range of breeding Adélie penguins and to examine the temporal and spatial constraints facing them when it comes to obtaining food for their offspring. The following presents a synthesis of all tracking data obtained from the above sites between the 1992/93 and 1995/96 breeding seasons, and compares these foraging locations with fine-scale catch data on Antarctic krill, *Euphausia superba*, for each of the subareas.

METHODS

Locations of the Adélie penguin colonies from which tracking was undertaken are shown in Figure 1. The numbers of penguins tracked, the numbers of trips and the years over which tracking took place are provided in Table 1.

The ARGOS satellite Global Positioning System (GPS) was used to track penguins. The method for tracking birds by ARGOS satellite telemetry is given in Kerry et al. (1995a). The locations of all satellite fixes of ARGOS quality 1 or better (i.e. the geolocation should be within 1 km of the true position; ARGOS, 1996) are plotted in Figure 2 for the Mawson and Davis regions, and in Figure 3a–c for Casey, Dumont d'Urville and Edmonson Point. Foraging locations of birds rearing chicks were determined at each site during every season in which tracking was carried out. In addition, penguins foraging

Table 1: Number of Adélie penguins tracked for each location.

Colony	Location of Colony	Years	Birds	Trips
Béchervaise Island (Mawson)	67°31'S 62°49'E	1992–1996	46	112
Scullin Monolith	67°48'S 66°42'E	1996	5	10
Ufs Island	67°28'S 61°08'E	1996	6	9
Magnetic Island (Davis)	68°33'S 77°54'E	1994	3	5
Shirley Island (Casey)	66°17'S 110°29'E	1996	13	27
Petrel Island (Dumont d'Urville)	66°40'S 140°01'E	1996	15	30
Edmonson Point	74°21'S 165°10'E	1995, 1996	25	54

during incubation were tracked at Béchervaise Island, Magnetic Island and Edmonson Point. No distinction is made between male and female foraging patterns, although differences have been demonstrated (Clarke et al., 1995). The position data are presented as a cloud of points since the purpose of this paper is to show where the birds concentrate to forage rather than to present individual foraging trips.

The data on krill catches presented in Figures 2b and 3a-c were derived from the records submitted by Japan and held in the CCAMLR Data Centre. These data are shown as the sum of all past harvests of krill taken within a grid of 0.5° latitude by 1° longitude (approximately 30 km by 30 km) between 1972 and 1994. They are taken as indicating the consistent presence of harvestable amounts of krill. Details of a hydroacoustic survey which covers areas close to Casey and Dumont d'Urville in March 1996 are presented separately in Nicol et al. (1996) and Pauly et al. (1996).

RESULTS

Mawson and Davis Regions (Figure 2)

The four sites from which birds were tracked in this region lie within Division 58.4.2 (Figure 1). Adélie penguins from all these sites foraged out to the edge of the continental shelf break at some stage during the breeding season. This is a direct-line distance of 100 to 120 km, except from Davis where the distance is approximately 200 km.

During the incubation period penguins from Béchervaise Island remained within the pack-ice zone and travelled progressively westward at approximately the position of the continental shelf break. Individual tracks of penguins from this colony are reported in Kerry et al. (1995a). At Davis, birds foraging during the incubation period headed northwards and some reached the continental slope.

Penguins foraging for their chicks at the Béchervaise Island CEMP site travelled up to 120 km north to northwest from the colony in a V-shaped area with an angle of approximately 30°. Whilst fast-ice was still present they walked to the closest edge of a polynya which forms each year in this region (Kerry et al., 1995a). The location of this polynya may often be identified from the colony by the presence of 'water sky'[1]. Birds from Ufs Island tracked during the early creche period also showed a similar V-shaped foraging area. At Scullin Monolith, to the east of Mawson, birds tended to move in a northeasterly direction, but once out near the shelf break moved to the west before returning to the colony. Penguins foraging for their chicks at Davis remained within Prydz Bay, normally feeding within a 100-km radius and rarely reaching the shelf break.

Penguins which foraged above the continental slope generally returned with *E. superba* (unpublished data). Analyses of stomach contents during chick rearing showed *E. superba* to be the major dietary component in most seasons at Mawson (Table 2). In two seasons, however, fish (mainly *Pleuragramma antarcticum*) predominated. *Euphausia crystallorophias* was more important in the diet of penguins feeding chicks at Davis (Table 2), especially in the early stages when birds foraged in shallower waters over the continental shelf.

[1] The under-surface of clouds above open water within the pack-ice zone often appears dark. This is called 'water sky'. Its appearance contrasts with a light under-surface caused by the reflection of light from sea-ice. The presence of 'water sky' is obvious at a distance and is used for vessel navigation in ice. It is possible that the same phenomenon is used by penguins to locate open water among the sea-ice.

Table 2: Diet composition (% mass) of Adélie penguins at five locations.

Colony	*E. superba* (%)	*E. crystallorophias* (%)	Krill Mush (%)	Fish (%)	No. of Seasons
Mawson *	11 – 84	1 – 9	5 – 21	8 – 59	7
Davis **	25 – 77	13 – 42		5 – 32	3
Casey *	4	57	8	31	1
Dumont d'Urville *	33	30	6	31	1
Edmonson Point *	0 – 2	4 – 9	7 – 39	47 – 76	2

* Unpublished data ** From Whitehead (1991)

Casey (Figure 3a)

The region offshore from Casey is dominated by the relatively shallow Petersen Bank which is generally less than 500 m in depth. At the western and northern edges of the bank the continental shelf slopes steeply down to a depth of 1 000 m or more. Sea-ice remains over the bank for most of the summer, and shipping must skirt to the west of it before approaching Casey. This would also apply to fishing vessels.

Penguins from Shirley Island (about 1 km offshore from Casey) were tracked during the chick-rearing period until the end of January. They foraged along the western margin of the Petersen Bank and at its northern edge to a maximum distance of 135 km. Stomach analyses showed that the penguins were feeding predominantly on *E. crystallorophias* (Table 2), although some *E. superba* (less than 20% of the total) occurred in the diet of birds during the chick guard phase.

Dumont d'Urville (Figure 3b)

Adélie penguins were tracked from Petrel Island during the guard and early creche phases of chick rearing. These birds foraged only to about 50 km from the colony and thus much closer inshore than at other locations. The bottom depth is between 200 and 500 m very close inshore. The penguins ingested 33% *E. superba* and 30% *E. crystallorophias* overall. Net hauls carried out in the foraging region of these penguins several weeks later were dominated by the nearshore euphausid, *E. crystallorophias*. The bottom topography to the northwest of Dumont d'Urville is poorly mapped and it is possible that a deep-water channel exists which brings upwelling water close to the colony itself. This in turn may bring *E. superba* closer to shore than at other locations and explain the differences between bird stomach contents and net haul samples.

Edmonson Point (Figure 3c)

The coast to either side of Edmonson Point extends north–south and the Adélie penguins there must forage to the east of the colony. This contrasts with all other sites where the coast runs east–west. The continental shelf, however, is a similar distance offshore at approximately 80 to 100 km. During the incubation period penguins foraged east and southeast of the colony over the continental slope. Those which travelled southeast appeared to be feeding within a large polynya associated with the Drygalski Ice Tongue. This recurrent feature has been previously described in relation to a nearby Emperor penguin colony (Kooyman and Mullins, 1990).

Penguins rearing chicks often foraged out to the edge of the continental shelf east of the colony and returned with *E. superba* in their stomachs. Many birds also foraged closer inshore where they consumed a higher proportion of fish (Table 2). Although *E. superba* appears to be an important part of the diet of these Adélie penguins, there are no recorded major concentrations of *E. superba* in the region.

Foraging Range in Relation to the Krill Fishery

The locations of penguins on foraging trips are shown in Figures 2 and 3 and are related to or superimposed on a background of historic krill catch data. Bathymetric data are also presented. The edge of the continental slope is approximated by the 1 000-m isobath.

Although there is currently very little krill fishing in eastern Antarctica, a spatial overlap does occur between the foraging range of Adélie penguins and the locations where krill fishing has

taken place. The potential for overlap for birds from Béchervaise Island near Mawson (Figure 2) was described earlier by Kerry et al. (1992, 1995a). At Scullin Monolith and Ufs Island in the Prydz Bay region the known foraging range of 100 to 120 km would imply overlap also.

The northern extremity of the foraging range of penguins at Casey coincided with the area in which krill had been harvested previously, indicating that an overlap between penguin foraging areas and the krill fishery is possible. However, the existence of the Petersen Bank and the associated persistence of sea-ice into late summer could serve to keep the fishery to the north of the foraging range of the penguins in many seasons. Although penguins at Dumont d'Urville appeared to find sufficient food within 50 km of the coast in the season of our study, the edge of the continental shelf, where krill has previously been harvested, may lie within their foraging range in other years.

DISCUSSION

These data suggest that Adélie penguins in eastern Antarctica regularly forage within a range of up to 120 km from their colonies during chick rearing. At all locations covered by this report (except Dumont d'Urville) it appears that the maximum foraging distance of penguins feeding chicks was related to the location of the edge of the continental shelf where concentrations of *E. superba* tend to occur (Hosie and Cochran, 1994). The birds are capable of foraging further afield but this may be at the expense of successfully rearing their offspring. At Mawson in the 1994/95 breeding season when birds attempted to forage up to 170 km from the colony, no chicks were fledged and there appeared to be an absence of krill within the normal foraging range and beyond (Kerry et al., 1995b).

The foraging range of breeding penguins is constrained by the need to feed chicks at frequent intervals, especially when they are small. Any direct overlap or downstream impact of a krill fishery that prevents effective foraging within these time constraints may reduce the productivity of a colony. The presence of sea-ice may also limit foraging ranges during early chick rearing since birds can only walk over ice at about 2.4 km/hr; they swim at approximately twice this speed (Kerry et al., 1995a).

When chicks have grown sufficiently to be left alone, each parent has double the time to forage and bring back larger meals. For all sites except Davis this meant that the birds were able to reach the edge of the continental shelf easily once chicks had creched. It is noteworthy that at all sites the end of the guard phase tended to coincide with the period of minimum sea-ice coverage.

The results of this study show that for all sites examined between 50°E and 160°E there is the possibility of an overlap of penguin foraging areas with any krill fishery that extends to the edge of the continental slope if the fishery is closer than 100 km, in a direct line, from the penguin colony. Such an overlap has been demonstrated for penguins breeding along the Mawson Coast. Studies at Davis suggest an overlap could occur during the incubation period but is unlikely when the birds have chicks. At Casey penguins have the potential to overlap a fishery throughout chick rearing, but at Dumont d'Urville the situation is less certain as the penguins foraged much closer to the coast in the season of our study.

Although a spatial overlap can be inferred from the data, the timing of the fishing (usually January to March) and the extent of the sea-ice cover through each season suggest that for eastern Antarctic waters a temporal overlap between foraging birds and fishing is most likely while the penguins are feeding chicks. It is also important to note that, although direct spatial overlap may occur at a particular time, competition for krill cannot be assumed.

CCAMLR has developed the concept of the 'critical period-distance' (CPD) as an indicator of the potential overlap between predator foraging and the krill fishery (Agnew, 1992). The CPD refers to the proportion of the total catch of krill in a subarea which is within 100 km of penguin colonies between December and March when the foraging range of breeding birds is limited. This concept was refined by Agnew and Phegan (1995) into a new index, the 'foraging-fishery overlap' (FFO). This index is the total number of penguins presumed to be foraging in fine-scale squares multiplied by the catch in those squares and the consumption over December to March. These indices are useful for describing the distribution of a krill fishery with respect to its predators but again cannot be used to indicate competition.

CONCLUSIONS

The data described above provide some insight into the foraging behaviour of Adélie penguins along a very large part of the Antarctic coastline. At Mawson it is clear that there is potential for overlap with the fishery. At Davis

this is so during part of the breeding cycle only, while at Casey and Dumont d'Urville the situation is equivocal. It is suggested, therefore, that if the establishment of a new CEMP site is to be contemplated, then consideration should be given to demonstrating that the penguins forage on concentrations of *E. superba* which could be conceivably the target of commercial exploitation. CEMP sites which conform to this criterion but where there is no current fishing may be used to provide baseline data should harvesting occur at a later date. Satellite tracking or employing devices with accurate geolocation on penguins are useful for demonstrating congruence between foraging zones of the birds and locations of the fishery.

Additional information will be required on krill flux through the foraging zone of a particular penguin colony if there is potential for a fishery to occur upstream from the colony. Equally, a CEMP site upstream from the fishery may provide a useful control against which the impact of a fishery on an overlapping penguin foraging zone might be measured. It is suggested that new CEMP sites in eastern Antarctica would be best established where concentrations of *E. superba* occur closer than 100 km from the proposed colony to be monitored and where open water in January to March extends close inshore.

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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.

Agnew, D.J. and G. Phegan. 1995. A fine-scale model of the overlap between penguin foraging demands and the krill fishery in the South Shetland Islands and the Antarctic Peninsula. *CCAMLR Science*, 2: 99–110.

ARGOS. 1996. *User Manual.* CLS ARGOS Toulouse, France: 176 pp.

Clarke, J.R., K. Kerry and E. Franchi. 1995. Differences in the foraging strategies of male and female Adélie penguins. Document *WG-EMM-95/45.* CCAMLR, Hobart, Australia.

Hosie, G.W. and T.G. Cochran. 1994. Mesoscale distribution patterns of macrozooplankton communities in Prydz Bay, Antarctica – January to February 1991. *Mar. Ecol. Prog. Ser.*, 106: 21–39.

Ichii, T., M. Naganobu and T. Ogishimi. 1994. An assessment of the impact of the krill fishery on penguins in the South Shetland Islands. *CCAMLR Science*, 1: 107–128.

Kerry, K.R., J.R. Clarke and G.D. Else. 1992. The foraging range of Adélie penguins at Béchervaise Island, Mac.Robertson Land, Antarctica, and its overlap with the krill fishery. In: *Selected Scientific Papers, 1992 (SC-CCAMLR-SSP/9).* CCAMLR, Hobart, Australia: 337–344.

Kerry, K.R., J.R. Clarke and G.D. Else. 1995a. The foraging range of Adélie penguins at Béchervaise Island, Mac.Robertson Land, Antarctica as determined by satellite telemetry. In: Dann, P., I. Norman and P. Reilly (Eds). *The Penguins.* Surrey Beatty and Sons, Sydney: 216–243.

Kerry, K.R., J.R. Clarke, H. Gardner, R. Murphy, F. Hume and P. Hodum. 1995b. Adélie penguin chick deaths investigated. *ANARE News*, 75: 18–20.

Kooyman, G.L. and J.L. Mullins. 1990. Ross Sea Emperor penguin breeding populations estimated by aerial photopgraphy. In: Kerry, K.R. and G. Hempel (Eds). *Antarctic Ecosystems: Ecological Change and Conservation.* Springer-Verlag, Berlin Heidelberg: 169–176.

Lishman, G.S. 1985. The food and feeding ecology of Adélie and chinstrap penguins at Signy Island, South Orkney Islands. *J. Zool. Lond.*, 205: 245–263.

Nicol S., N. Bindoff, W. de la Mare, D. Gillespie, T. Pauly, D. Thiele, E. Woehler and S. Wright. 1996. An overview and some preliminary results of a biological/oceanographic survey off

the coast of east Antarctica (80–150°E) carried out in January to March 1996. Document *WG-EMM-96/29*. CCAMLR, Hobart, Australia.

Pauly, T., I. Higginbottom, S. Nicol, and W. de la Mare. 1996. Results of a hydroacoustic survey of Antarctic krill populations in CCAMLR Division 58.4.1 carried out in January to April 1996. Document *WG-EMM-96/28*. CCAMLR, Hobart, Australia.

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 (2): 351–361.

Whitehead, M.D. 1991. Food resource utilization by seabirds breeding in Prydz Bay, Antarctica. *ACTA XX Congressus Internationalis Ornithologici*: 1385–1392.

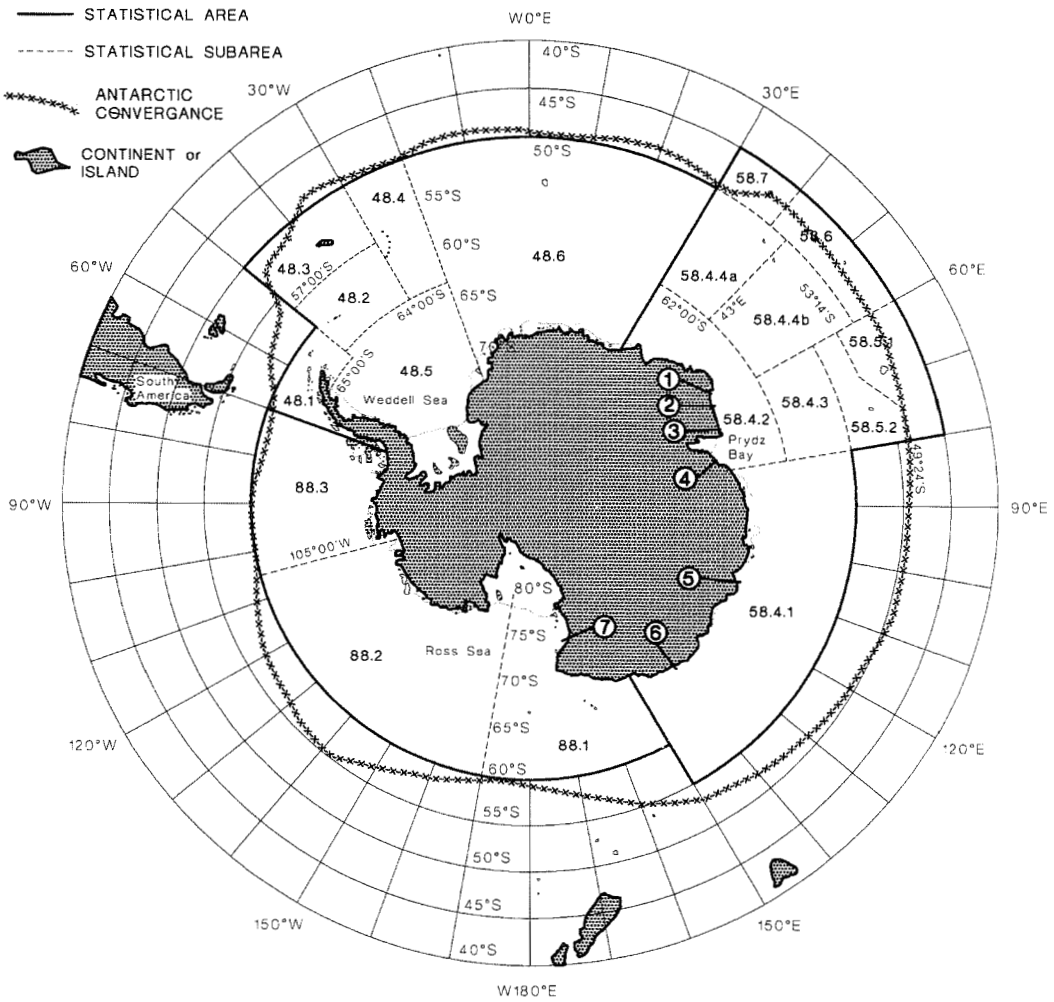


Figure 1: Map of Antarctica and the Southern Ocean showing the boundaries of the CCAMLR statistical divisions and the locations of Adélie penguin colonies from which satellite tracking of penguins was carried out.

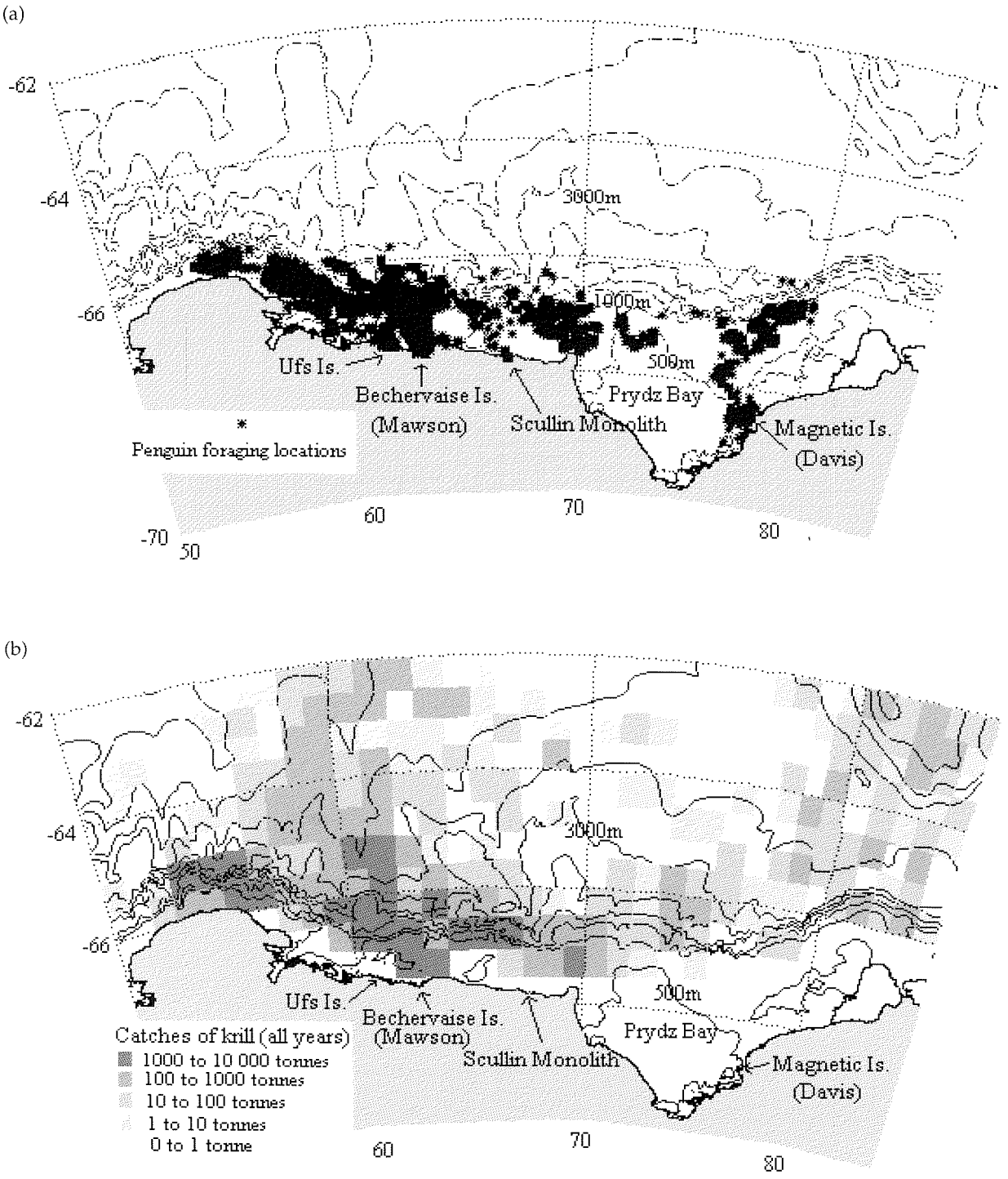
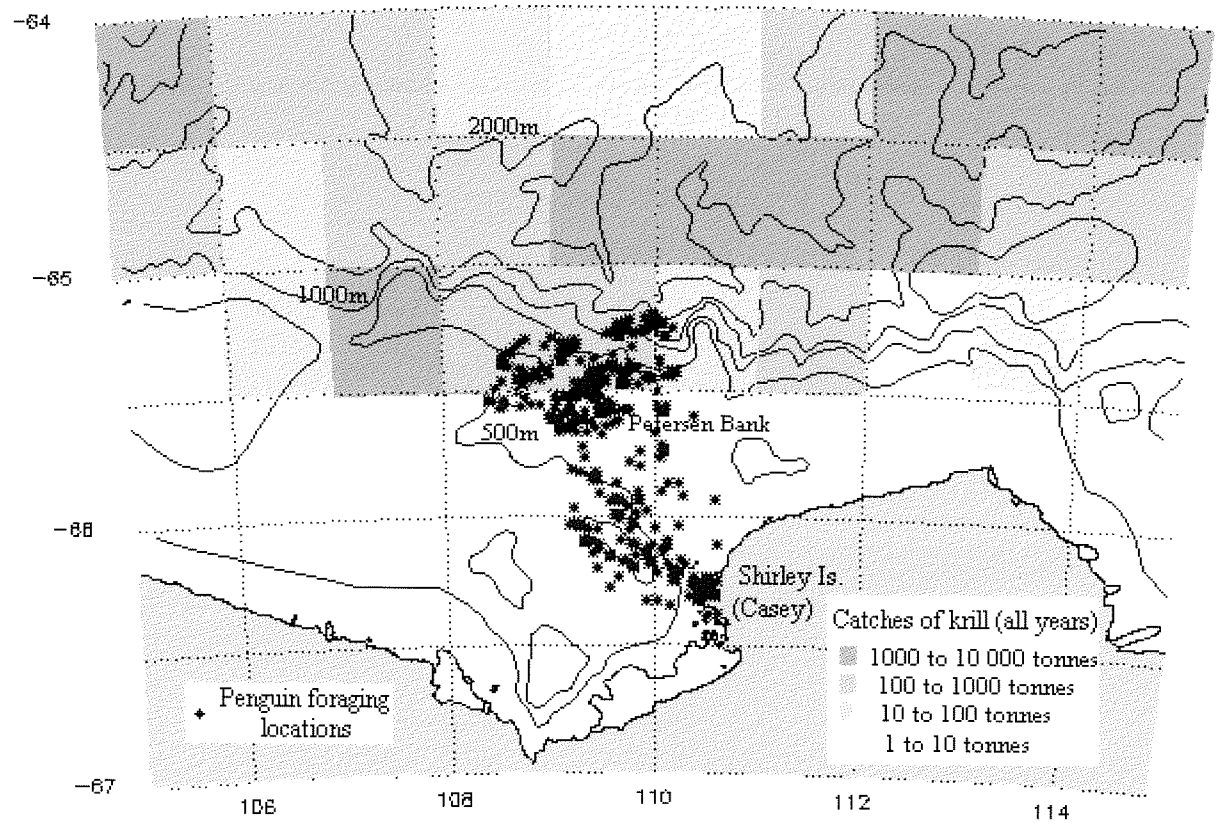


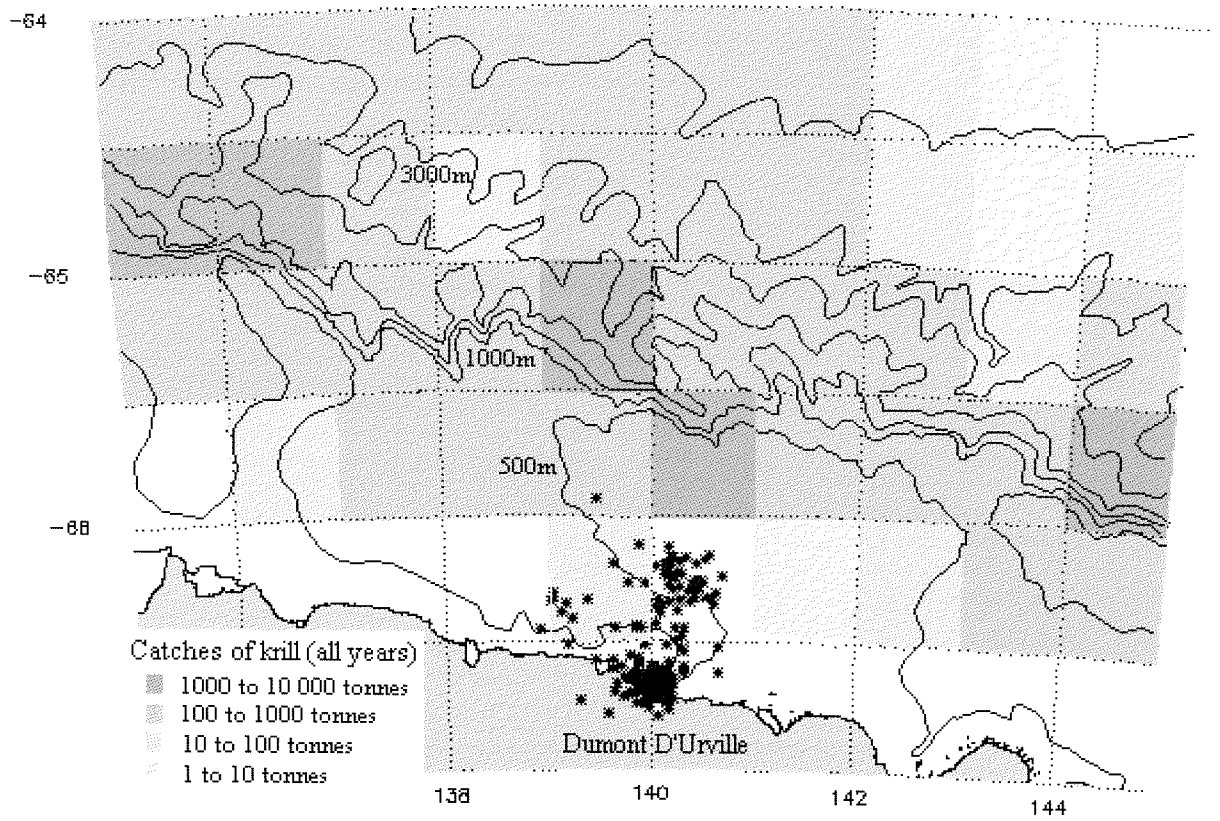
Figure 2: (a) The location of each position fix obtained from penguins carrying platform transmitter terminals (PTTs). The PTTs were placed on birds at the colonies shown on the map. Isobaths are given for 500-metre intervals.

(b) The krill catch for each 0.5° latitude and 1° longitude provided as a total for the years 1972–1994. These data are presented on a map at the same scale as Figure 2a.

(a)


-64
-65
-66
-67
106
108
110
112
114
2000m
1000m
500m
Petersen Bank
Shirley Is.
(Casey)
Penguin foraging
locations
Catches of krill (all years)
1000 to 10 000 tonnes
100 to 1000 tonnes
10 to 100 tonnes
1 to 10 tonnes

(b)


-64
-65
-66
136
140
142
144
3000m
1000m
500m
Catches of krill (all years)
1000 to 10 000 tonnes
100 to 1000 tonnes
10 to 100 tonnes
1 to 10 tonnes
Dumont D'Urville

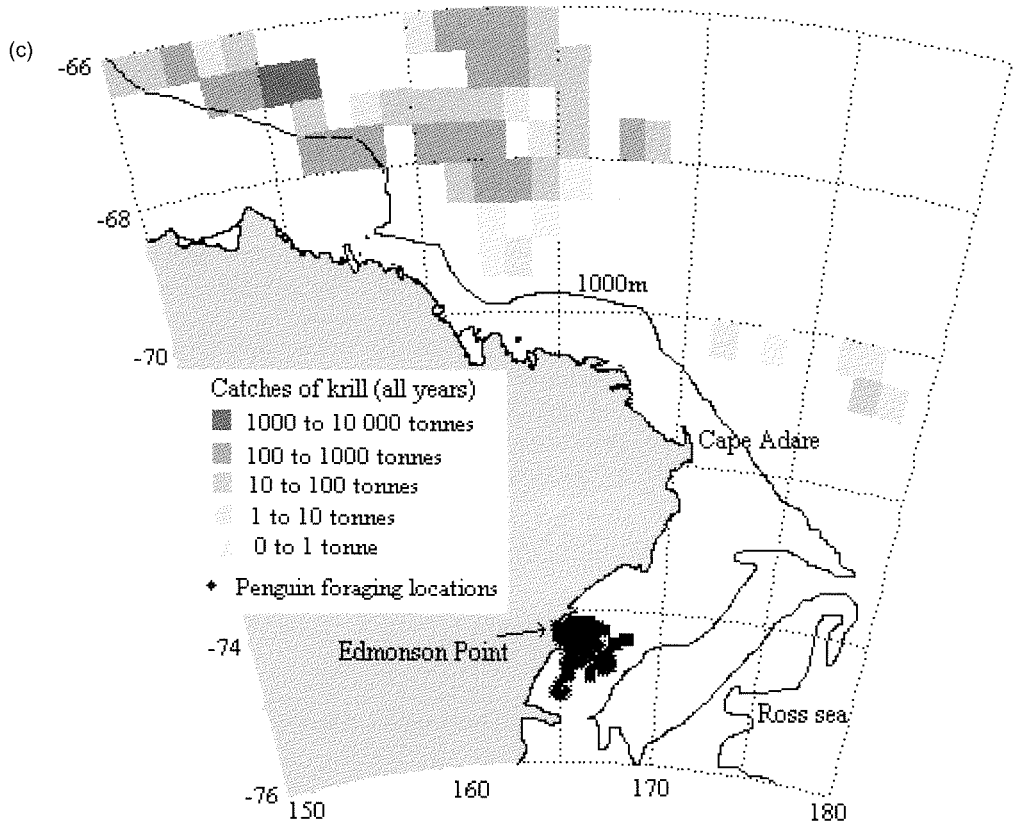


Figure 3: The positions of satellite fixes obtained from foraging Adélie penguins together with krill catch data from (a) Shirley Island (Casey, (b) Petrel Island (Dumont d'Urville) and (c) Edmonson Point. The krill catch for each 0.5° latitude and 1° longitude is provided as a total for the years 1972–1994.

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