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Large and Meso-Scale Distribution of the Ommastrephid Squid *Martialia hyadesi* in the Southern Ocean: A Synthesis of Information Relevant to Fishery Forecasting and Management

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ABSTRACT. The seven star flying squid, *Martialia hyadesi,* is a Southern Ocean ommastrephid with an oceanic distribution that extends to the edge of the shelves and slopes of continents and islands. Its range is circumpolar and it is generally associated with the Antarctic Polar Frontal Zone. It has been caught in commercial quantities in the Atlantic sector but is only recorded in smaller numbers from the Indian Ocean and Pacific sectors in scientific samples, the gut contents of predators and in mass strandings on island shores. It has only occasionally been found in commercial catches outside the Atlantic sector. In the northern part of its range in the South Atlantic, commercial catches are highly variable and apparently linked to large-scale oceanographic variability. *Martialia hyadesi* appears to concentrate in frontal areas where characteristics of the bathymetry generate meso-scale oceanographic features. Such concentrations have been observed at shelf breaks and in the deep ocean near a submarine ridge. Predator data confirm the circumpolar distribution of the species and its relationship with the APFZ. Grey-headed albatrosses appear to forage for *M. hyadesi* in the region of meso-scale oceanographic features associated with the bathymetry of submarine ridges and the shelves of oceanic islands. In the medium future, improved understanding of oceanographic variability of the Southern Ocean may provide the basis for long term forcecasting in a fishery for the species. In the nearer future, improved knowledge of the behaviour of the species in relation to meso-scale oceanography may provide the basis for short-term forecasting of the location of shoals based on remotely sensed images of surface oceanography. The life cycle of *M. hyadesi* is poorly understood and, in view of increased commercial interest in the species in recent years, and its conservation value in the CCAMLR area, there is a need for more information on the location of spawning and feeding grounds and seasonal migrations.

Key Words: distribution, fishery forecasting, Southern Ocean, squid

Introduction

The seven star flying squid, *Martialia hyadesi* Rochebrune and Mabille, 1889, is a large ommastrephid from the Southern Ocean. It was a little known species until about a decade ago when it appeared in the new squid fishery in the Southwest Atlantic. It was then identified in the gut contents and regurgitations of predators at South Georgia and was subsequently redescribed on the basis of new material (Rodhouse and Yeatman 1990). An analysis of the Antarctic cephalopod fauna suggested that the species was the one most likely to be exploited commercially in the Antarctic in the medium term (Rodhouse 1990). Subsequently there have been exploratory fishing ventures that have confirmed the presence of commercial concentrations in the South Georgia area (Rodhouse 1991; González and Rodhouse 1998).

This short review considers the pattern of distribution throughout the Southern Ocean as determined

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by direct sampling and from samples of the diet of predators, mostly those breeding on oceanic islands. It examines the limited data available on distribution in relation to the meso-scale oceanography in the sub-Antarctic range of the species and considers the possible use of this knowledge for fishery forecasting.

Large-Scale Distribution

Data on large-scale, global, distribution patterns in *Martialia hyadesi* come from commercial and exploratory fisheries and from scientific sources (Table 1). Most information is from the South Atlantic where the international fleet targeting *Illex argentinus* and *Loligo gahi* either sometimes redirect fishing effort to *M. hyadesi*, or take the species as an occasional by-catch.

Position data from the sources in Table 1 have been loaded onto Arc/Info version 7.0.2 (ESRI), a geographic information system (GIS) used at the British Antarctic Survey for analysis of Southern Ocean fisheries (Trathan *et al.* 1993). Individual locations of all samples from the literature cited in Table 1 are shown plotted with bathymetry, major frontal systems and the maximum/minimum extent of sea ice in Figs 1-3. *Martialia hyadesi* is a circumpolar, oceanic species with a range that extends to the slopes of continents and islands (Fig. 1). The species is rarely found over shelves but it may concentrate near the shelf slope. Occasional strandings on island shores where the slope lies close to the land (O'Sullivan *et al.* 1983; Nolan *et al.*, in press; C. Buxton, pers. comm.) probably result from exceptional weather/oceanographic conditions. The species is closely associated with, but not confined to, the Antarctic Polar Frontal Zone (APFZ) that lies between the Antarctic Polar Front (APF) and the sub-Antarctic Front (SAF) (Fig. 2). The APFZ extends furthest north, and is broadest, in the south west Atlantic in the region of the Falkland Current where the SAF lies parallel to the edge of the Patagonian Shelf (Peterson and Whitworth 1989). *Martialia hyadesi* has never been recorded south of the maximum extent of sea ice cover (Fig. 3). In the region of the APFZ it dominates a cephalopod community that replaces epipelagic fish (Rodhouse and White 1995).

Table 1. Sources of position data for the large-scale GIS plots of *Martialia hyadesi* distribution in the Southern Ocean based on material from scientific nets, commercial trawls, commercial jigs and mass strandings

Sector	References
Atlantic Ocean	Rochebrune and Mabille (1889)
	Castellanos (1967)
	Nesis and Nigmatullin (1972)
	Brunetti *et al.* (1990)
	Rodhouse (1991)
	Rodhouse *et al.* (1992; 1996)
	Coggan *et al.* (1996)
	González and Rodhouse (1996)
	Arkhipkin and Silvanovich (1997)
	González *et al.* (in press)
	Rodhouse P.G. (unpubl. data)
Indian Ocean	Piatkowski *et al.* (1991)
Pacific Ocean	O'Sullivan *et al.* (1983)
	Uozumi *et al.* (1991)
	Alexeyev (1994)

The large-scale distribution of the cool water *Martialia hyadesi* is probably influenced by large scale oceanographic variability, especially at the edge of its range. Catches of *M. hyadesi* in the fishery at the edge of the Patagonian Shelf have been highly variable over the decade up to 1995 and there have only been three or four years when substantial numbers have been caught. The years of large catches have coincided with the onset of negative SST anomalies in the area (González *et al.* 1997). However, it is not obvious how these oceanographic events influence *M. hyadesi*. There are two alternative, but not mutually exclusive, hypotheses for a mechanism: either a warm event favours the reproductive success of a generation giving rise to a strong recruitment in the next generation as the ensuing cold event develops at the edge of the geographical range, or the species is able to extend its range to the Patagonian Shelf edge early in the

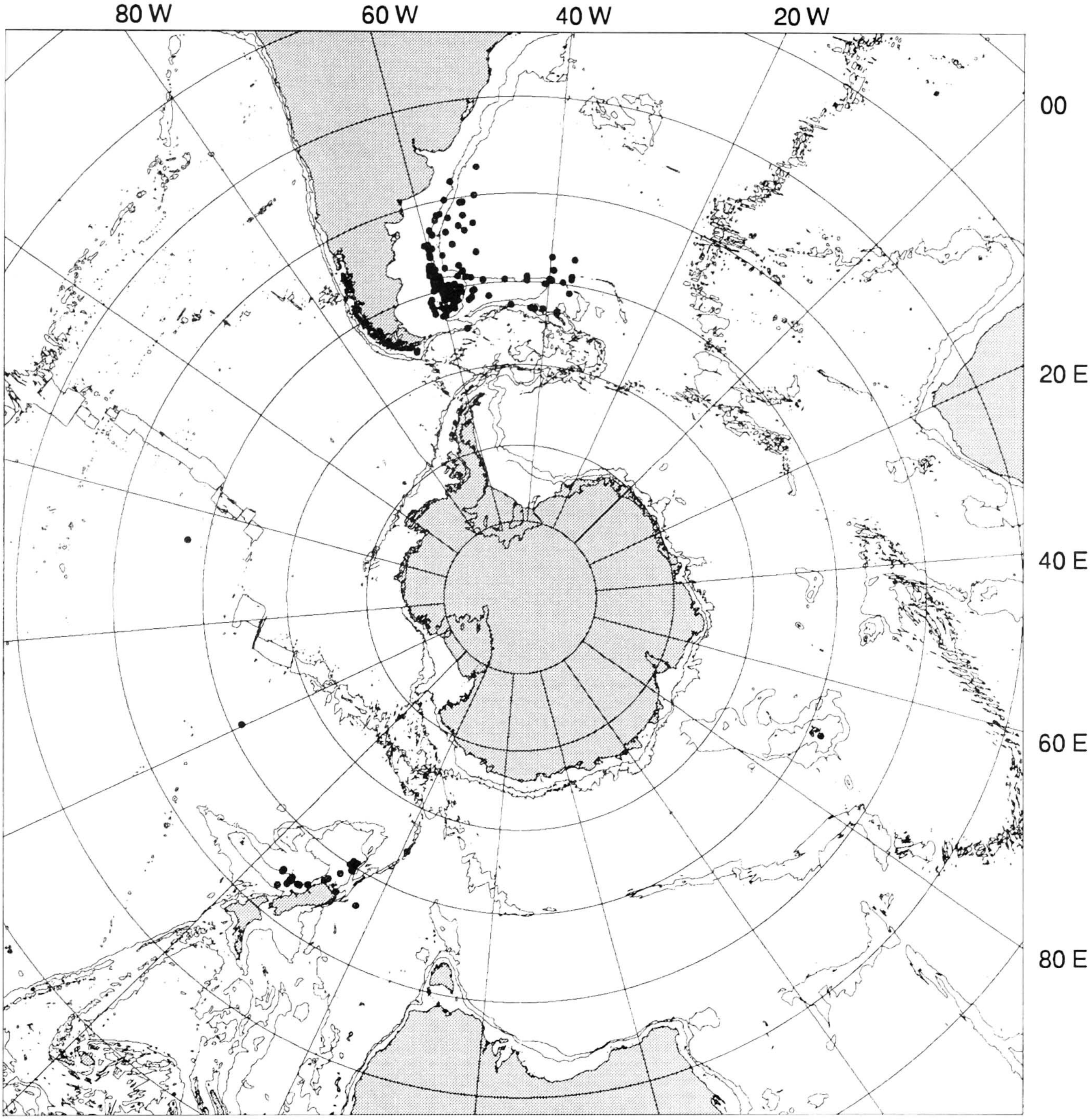

Fig. 1. Map of the Southern Ocean showing the locations of *Martialia hyadesi* samples caught by nets and jigs in relation to bathymetry.

sequence of a cold event. In either case the oceanographic effects probably influence *M. hyadesi* via its prey. There seem to be teleconnections between the oceanographic anomalies in the south Atlantic, which effect *M. hyadesi*, and ENSO events in the Pacific. The south Atlantic anomalies may also be associated with the sub-decadal Antarctic circumpolar wave (ACW) described by White & Peterson (1996) and the circumpolar precession of anomalous sea ice extent in the Antarctic (Murphy *et al.* 1995).

Meso-Scale Distribution

Information on meso-scale distribution of *Martialia hyadesi* comes from studies in the south west

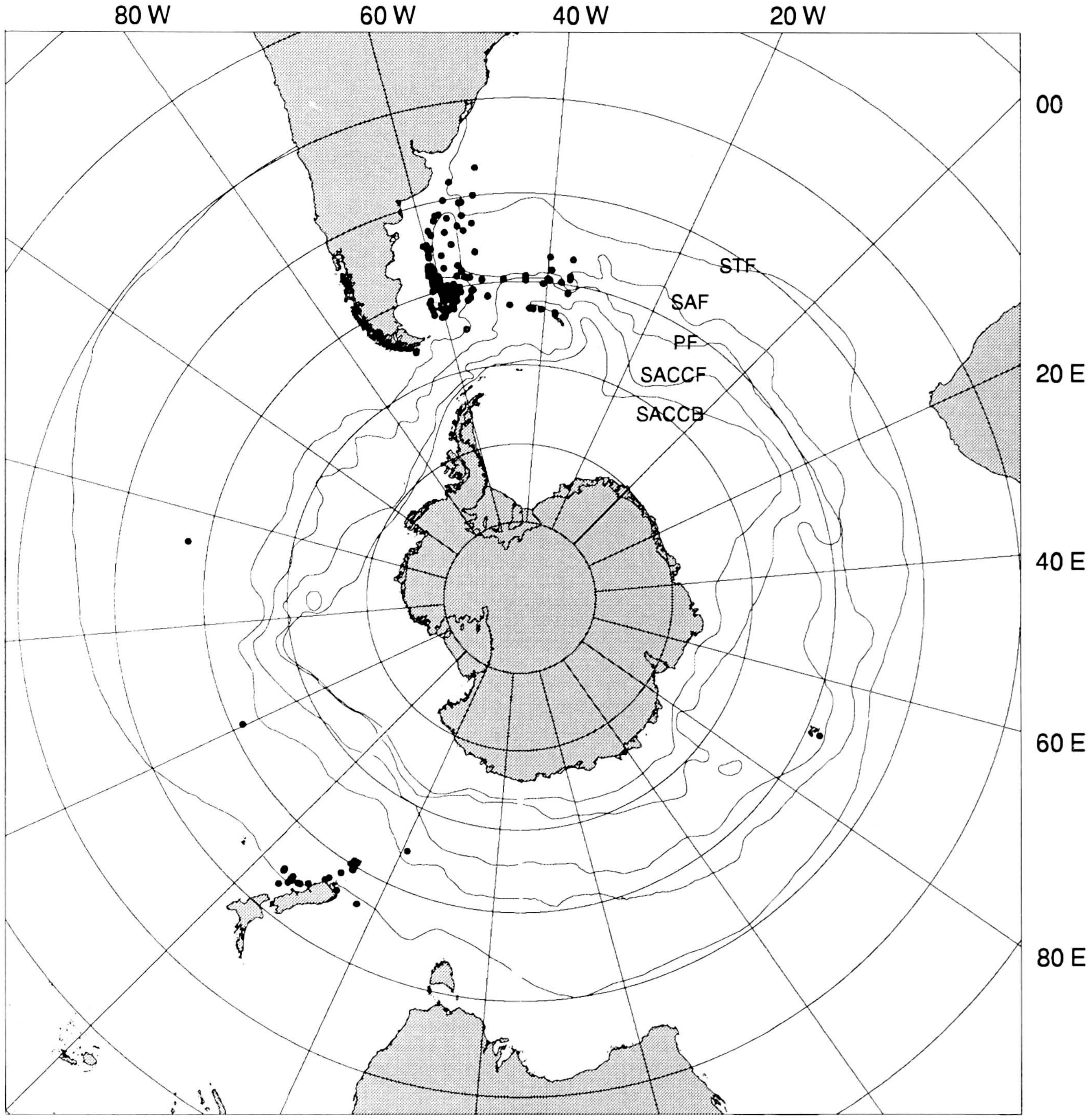

Fig. 2. Map of the Southern Ocean showing the locations of *Martialia hyadesi* samples caught by nets and jigs in relation to major frontal systems (STF: Subtropical Front; SAF: sub-Antarctic Front; PF: Polar Front; SACCF: Southern Antarctic Circumpolar Current Front; SACCB: Southern Antarctic Circumpolar Current Boundary).

Atlantic. This is an area with a high incidence of meso-scale eddies, with dimensions measured in tens of kilometers (Peterson and Whitworth 1989), which are generally known to be features where oceanic production processes are stimulated (Mann and Lazier 1991) and which are implicated in the generation of phytoplankton blooms (Whitehouse *et al.* 1996) and zooplankton concentrations (Atkinson *et al.* 1990) to the south of the APF in the south west Atlantic. Figure 4 shows a series of such eddies to the west of South Georgia. Recent research has demonstrated concentrations of *M. hyadesi* feeding on mesopelagic fishes and epipelagic crustaceans associated with an eddy structure in the APFZ

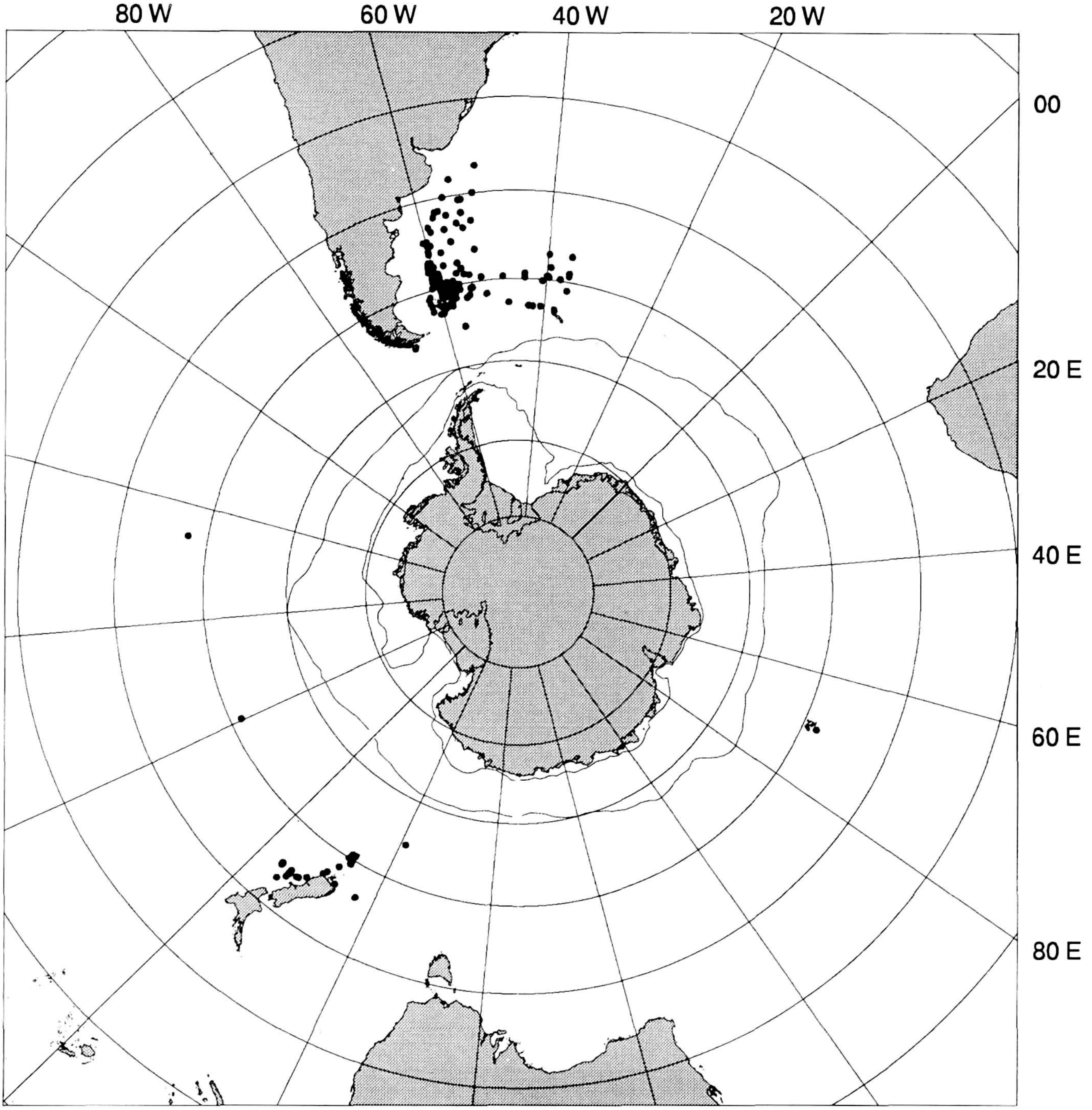

Fig. 3. Map of the Southern Ocean showing the locations of *Martialia hyadesi* samples caught by nets and jigs in relation to the maximum and minimum extent of sea ice.

which was sampled using research and commercial nets (Rodhouse *et al.* 1996).

Martialia hyadesi concentrations also appear to be associated with meso-scale oceanographic features at the interface of the open ocean and the slope. The unusually high catches taken on the edge of the Patagonian Shelf in 1995 were associated with meso-scale features where the SAF runs parallel to the north/south orientated continental slope (González *et al.* 1997). Similarly, in the austral winter of 1996 *M. hyadesi* was found in high densities close to the South Georgia shelf edge near the 1000 m bathymetric contour (González and Rodhouse, submitted), an area where the long-line fishery for the Patagonian toothfish, *Dissostichus eleginoides* is also concentrated (Croxall and Prince 1996).

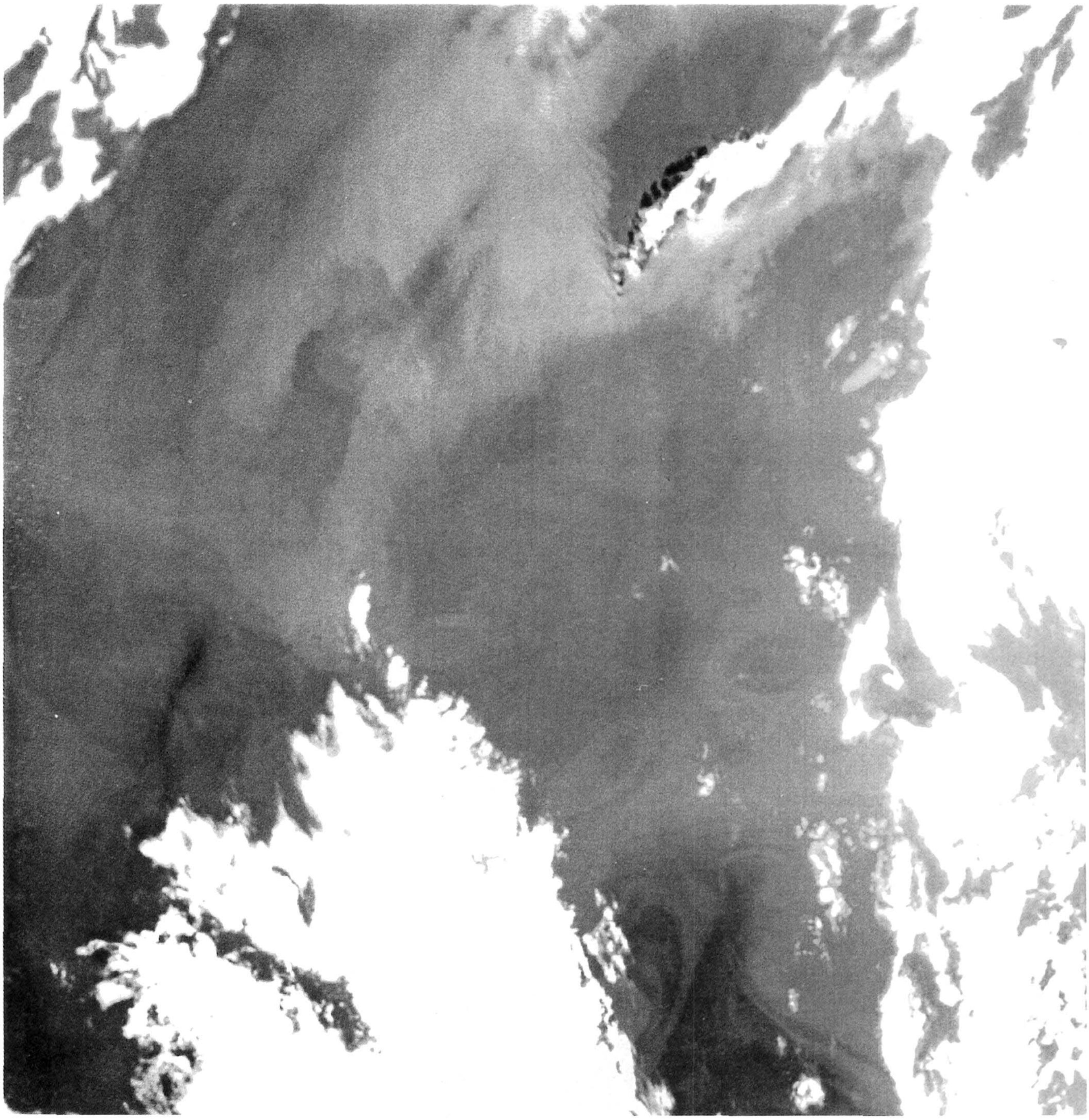

Fig. 4. Satellite sea surface temperature image (AVHRR) of the south west Atlantic showing meso-scale eddies to the west of South Georgia (20:30 GMT, 3 February 1994).

A common feature of these observations has been that the meso-scale features with which *Martialia hyadesi* concentrations have been associated are found in the vicinity of bathymetric features. In the case of the open ocean at the APFZ north of South Georgia these were deep features on the North Scotia Arc, elsewhere at they were associated with the rise of the slope. Records of *M. hyadesi* close to the sub-Antarctic Kerguelen Islands and Macquarie Island (Cherel and Weimerskirch 1995; O'Sullivan *et al.* 1983) suggest that concentrations may be present in association with bathymetric features in the Indian Ocean and Pacific sectors too. The implication of this apparent connection between bathymetry, meso-scale oceanography and *M. hyadesi* is that the squid may concentrate in more or less predictable areas.

Table 2. Predators of *Martialia hyadesi* recorded from the Atlantic, Indian Ocean and Pacific sectors of the Southern Ocean

	Atlantic Ocean sector	Indian Ocean sector	Pacific Ocean sector
Seabirds	*Diomedea chrysostoma*[a]	*Diomedea chrysostoma*[t]	*Aptenodytes patagonicus*[s]
	Diomedea melanophrys[b]	*Diomedea melanophrys*[l,t]	*Eudyptes schlegeli*[u]
	Diomedea exulans[c]	*Diomedea exulans*[t]	*Eudyptes chrysocome*[v]
	Phoebetria palpebrata[d]	*Diomedea chlororhynchos*[t]	
	Procellaria aequinoctialis[e]	*Phoebetria fusca*[w]	
	Macronectes halli[f]	*Phoebetria palpebrata*[w]	
	Macronectes giganteus[f]	*Aptenodytes patagonicus*[m,q,r]	
	Aptenodytes patagonica[g]		
	Eudyptes chrysolophus[h]		
Seals	*Mirounga leonina*[i]		*Mirounga leonina*[o]
	Arctocephalus gazella[j]		
Whales		*Hyperoodon planifrons*[n]	
Fish	*Dissostichus eleginoides*[k]		*Allothunus fallai*[p]

Sources: [a]Rodhouse *et al.* (1990); [b]Rodhouse and Prince (1993); [c]Rodhouse *et al.* (1987); [d]Thomas (1982); [e]Croxall *et al.* (1995); [f]Hunter (1983); [g]Rodhouse (unpubl. data); [h]Reid (unpubl. data); [i]Rodhouse *et al.* (1992); [j]North (1996); [k]González and Rodhouse (submitted); [l]Cherel and Weimerskirch (1995); [m]Cherel *et al.* (1996); [n]Slip *et al.* (1995); [o]Green and Burton (1993); [p]Yatsu (1995); [q]Adams and Klages (1987); [r]Brown *et al.* (1990); [s]Hindell (1988a); [t]Ridoux (1994); [u]Hindell (1988b); [v]Cooper *et al.* (1990); [w]Cooper and Klages (1995)

Predator Data

Martialia hyadesi has been recorded in the gut contents of predators (seabirds, seals, whales and fish) from locations throughout the Southern Ocean (Table 2). Seabirds and seals have been sampled ashore while breeding and moulting. Data from fish have been gathered from commercial or research fishery samples while the whale data are scant and come from strandings.

The most detailed information about predation on *Martialia hyadesi* is available from South Georgia (Atlantic sector). Here, reliable census data for predator population sizes are also available (e.g. Croxall *et al.* 1990; Prince *et al.* 1994; Boyd *et al.* 1996) enabling estimates of total predator consumption of *M. hyadesi* in the Scotia Sea area to be made (Rodhouse *et al.* 1993; Rodhouse 1997). Estimates range from a conservative 245,000 tonnes per year to an upper estimate of 550,000 tonnes if less reliable data are included in the calculation (Rodhouse 1997).

In the Indian Ocean sector predators from the Kerguelen Islands, Marion Island, the Crozet archipelago and Heard Island have been found to include *Martialia hyadesi* in their diet and in the Pacific sector predators from Macquarie have similarly been shown to take *M. hyadesi.* These locations are all close to the APFZ, confirming the general conclusion, based on data from other sources, that the species is associated with this large-scale oceanographic feature.

Satellite-tracked squid predators from South Georgia including grey-headed and black-browed albatrosses (*Diomedea chrysostoma* and *D. melanophrys*) apparently forage for *Martialia hyadesi* at the APFZ (Prince *et al.*, in press) where they are located in meso-scale eddies (Rodhouse *et al.* 1996). At the Kerguelen Islands black-browed albatrosses preying on *M. hyadesi* forage near the shelf break and over a submarine bank beyond the slope (Cherel and Weimerskirch 1995), suggesting that they exploit similar meso-scale distribution patterns as the predators from South Georgia.

Discussion

Although far from adequate for a detailed account of the distribution of *Martialia hyadesi*, the data currently available allow some broad conclusions to be drawn. The species is found throughout the Southern Ocean associated with the APFZ. Most records come from the Southwest Atlantic where the APFZ is widest and where fisheries for other squid mean that it is caught by commercial vessels from time to time. At the meso-scale, distribution is associated with eddies that are probably generated by the bathymetry of submarine ridges and island slopes and in this context one of the most important areas for the species identified so far is the Scotia Sea, especially in the vicinity of South Georgia. Data from predators breeding at South Georgia highlight this conclusion.

The life cycle and migrations of *Martialia hyadesi* are poorly known. Although most commercial catches have been taken near the edge of the Patagonian Shelf these are intermittent and apparently associated with large-scale oceanographic anomalies in the northern part of the species range. Commercial-scale catches near the APF in summer (Rodhouse 1991; Rodhouse *et al.* 1996) and near the South Georgia slope in winter (González and Rodhouse, in press) support the simple hypothesis that there is a southwards migration during the austral winter to feeding grounds where they appear to be preyed on by toothfish. There are few data on larval and juvenile distribution patterns or the distribution of ripe, spawning or spent adults that would indicate the location of spawning grounds.

At large spatial and temporal scales, variability in the distribution of the *Martialia hyadesi* stock in the South Atlantic seems to be related to large scale oceanographic variability. In the longer term, as our understanding of the physical processes develop, we may be able to predict fisheries on these scales. In the shorter term, as our knowledge of the relationships between meso-scale processes and the behaviour of *M. hyadesi* improves short term prediction of meso-scale distribution may become possible, based on the use of remote sensing imagery of surface oceanography.

Given the difficulty of scientific sampling for this highly active, aggregated species which inhabits one of the remotest parts of the world's oceans, there are only limited opportunities for increasing our knowledge. However, if a commercial fishery were to commence in the Scotia Sea, as seems likely in the medium term, then every effort should be made to capitalise on the opportunity of developing close collaboration between science and industry arising from the mutual interest of the international scientific and fishing communities in effectively managing this resource in the CCAMLR area.

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