# A top

E. crystallorophias (primarily found on-shelf). In some locations, E. superba occurred at high densities underneath ice floes, where they foraged on the sea-ice microbial community. Two general fish communities, oceanic and shelf, were distinguished. Off-shelf fishes were members of the classic oceanic midwater fish fauna, whereas on-shelf fishes

Fig. 1. DMSP visible satellite image (28 December 1999) of the Ross Sea, showing the APIS cruise track (thick lines) and helicopter survey transects (thin lines), conducted between 28 December 1999 and 7 February 2000. The left (western) end point of the cruise line is at McMurdo Station.

the west, eastward to about 125°W, where the Amundsen Sea begins near the King Edward VII Peninsula of Marie Byrd Land (Spezie and Manzella 1999). In the study area in the eastern Ross Sea (east of 160°W), the continental shelf is relatively narrow, with depths of 500–700 m, and then drops off rapidly to depths exceeding 3000 m. Consequently, the distances between the ice-shelf front or fast-ice edge and deep water habitats are often around 30 km or less.

In early summer, just prior to the surveys, the residual pack-ice zone in the eastern Ross Sea was large and highly congested. It consisted mostly of annual ice formed locally, but there was also pack ice that had been advected westward from the Amundsen and Bellingshausen seas, and perhaps from over the continental shelf along the Ross Ice Shelf (http://polar.jpl.nasa.gov/). The seasonal enlargement of the persistent Ross Sea polynya, from a coastal winter location near Ross Island, typically envelops most of the western continental shelf and extends north to just west of 180°W longitude. That open-water pattern leaves three residual sea-ice fronts in summer: (1) the northern edge of the outer pack ice; (2) the western edge of the pack ice along the eastern side of the Ross Sea polynya; and (3) a shore lead near and parallel to the edge of the continent along the southern boundary of the pack ice (Fig. 1). The pack ice that persists through summer in the eastern Ross Sea continues eastward through the Amundsen and Bellingshausen seas.

## Sea ice

We divided the study area into five generalized zones, based on pre-cruise knowledge of several physical and biological criteria (Fig. 2). The western edge of the area was known as the Ross Polynya Ice Zone (RPIZ), and the northern edge the Northern Marginal Ice Zone (NMIZ). The southern area over the continental shelf, bounded by fast ice to the south, was divided into the Coastal Polynya Zone (CPZ) and the Ice Covered Shelf Zone (ICSZ). The region between those zones is the Interior Pack Ice Zone (IPIZ).

Sea-ice conditions and properties were documented using satellite imagery (for example, Figs 1, 2); airborne

Fig. 2. DMSP visible satellite image taken on 5 February 2000, reßecting sea-ice conditions at the end of the cruise period. Compared to Figure 1, the western and northern boundaries of the sea ice have both retreated. The sea ice is also dispersed, and younger ice has melted leaving mostly the large ßoes (ÔßoatingislandsÕ) of multi-year ice visible on the image, particularly in the southern areas of the pack ice. The generalized study zones are: RPIZ = Ross Polynya Ice Zone; NMIZ = Northern Marginal Ice Zone; IPIZ = Interior Pack Ice Zone; ICSZ = Ice Covered Shelf Zone; and CPZ = Coastal Polynya Zone.

digital video recorders on the survey helicopters; shipboard observations of ice thickness, concentration, oe size, and spatial percentage of ridging; and analyses of thickness and other ice properties by direct sampling of ice cores.

The sea ice in the Ross Sea is remarkably complex. Although annual ice dominated the ice habitat in late summer, large ice oes were also scattered about, evidently having broken away from the shore fast ice along the coast. On occasion, icebergs were embedded in those oes. Moreover, multi-year oes, up to several kilometres long, were scattered throughout the area. These oes seem to have originated in the Amundsen Sea, being consolidated into shore fast ice during subsequent winters.

The sea ice retreated in the western and northern parts of the study area throughout the summer (Fig. 2). The ice that was left in the south was dominated mostly by very large, multi-year oes (with at least two surface layers of annual snow), usually longer than 20 km, heavily ridged, and thicker than 3 m. These ‘ oating sea-ice islands’ are rarely found in other pack-ice habitats in the Southern Ocean. We think that these oes originate as shore-fast ice, because of their similarities in surface topography and thickness, and that they then become concentrated along the offshore fast ice front, perhaps remaining there for several years before they eventually break apart and drift north into pack-ice regions. Drifting westward in the interior pack ice, with the prevailing near-continent surface current, those large oes are protected from the physical action of waves and swell by the concentrated pack ice to the north, unlike in other areas where they are quickly eroded and broken (Wadhams and others 1987). Consequently, the large oes in the eastern Ross Sea remain large (that is, > 10 km diameter) for some time, and appear to be important platforms for some seals and penguins, until they eventually drift towards the northern reaches of the pack ice. The oes in the two southern zones (CPZ and ICSZ) were indistinguishable, based on thickness of ice and snow cover, and were dominated by thick and substantially ridged multi-year ice (Fig. 3). The sea ice in the NMIZ, IPIZ, and RPIZ was, however, mostly less than a year old, thinner, less ridged, and with less snow cover than the ice in the southern zones. Of those three areas, the ice in the RPIZ was thinnest, owing to its more recent origin in the Ross Sea polynya region in late winter 1999.

penguin predators capable of diving to and foraging in demersal habitats.

## The biological environment

### Seals

Prior to the APIS cruise, little was known about the distribution and abundance of seals in the interior pack ice of the eastern Ross Sea. Although there had been research cruises in the western Ross Sea, they had not been dedicated to studying seals. Most of those cruises occurred in areas along the shore-lead, the outer fringe of

breeding season was over (Stirling and Siniff 1979). This observation contrasts with the suggestion that leopard seals may breed as late as January (Siniff and Stone 1985), based on anatomical examinations of seals collected in the Antarctic Peninsula area. Overall, however, both the few observations of leopard seals and the absence of their underwater vocalizations suggest that they were not common in the study area.

### Weddell seals

Weddell seals in the eastern Ross Sea, as elsewhere, were common in the coastal fast ice. However, substantial numbers were also found well out into the pack ice (0.1–0.2 seals km$^{-2}$; and see Stewart and others 2003), even though their relative abundance declined with increasing distance from the coast. Most of those seen offshore were young and non-reproductive, and were seen mostly on large ice floes. Some of these large floes were located over deep water, suggesting the seals were feeding in the water column or possibly on the epontic (sub-ice) community. Since the data from trawls suggested that few fish were located in the first 500 m, it was probably necessary for

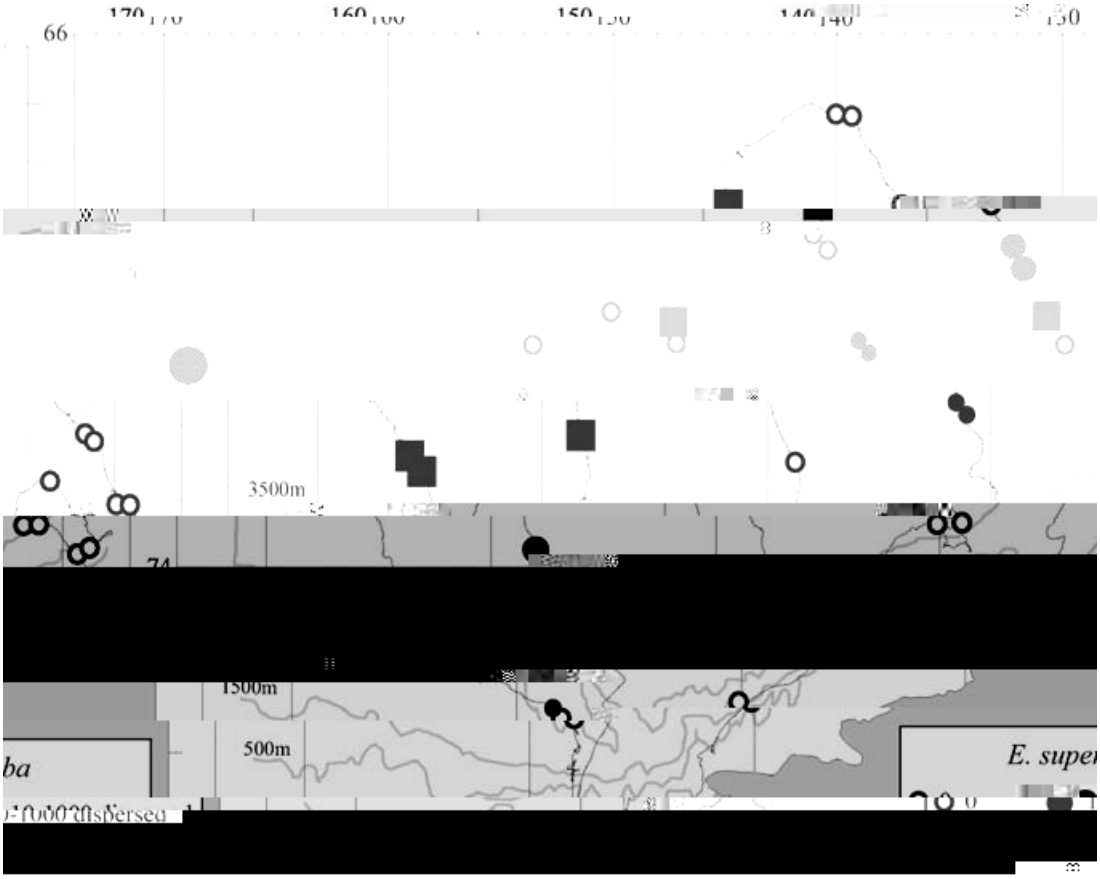


Fig. 6. *E. superba* densities from dive observations. Numbers are the number of individuals seen in a survey of a 350 $m^2$ area under the ice.

Ross Sea, but the distributions of the other two species were more limited and mutually exclusive, correlating with hydrography and bottom topography. *E. superba* was coupled to the under-surface of the sea ice (Fig. 6), and

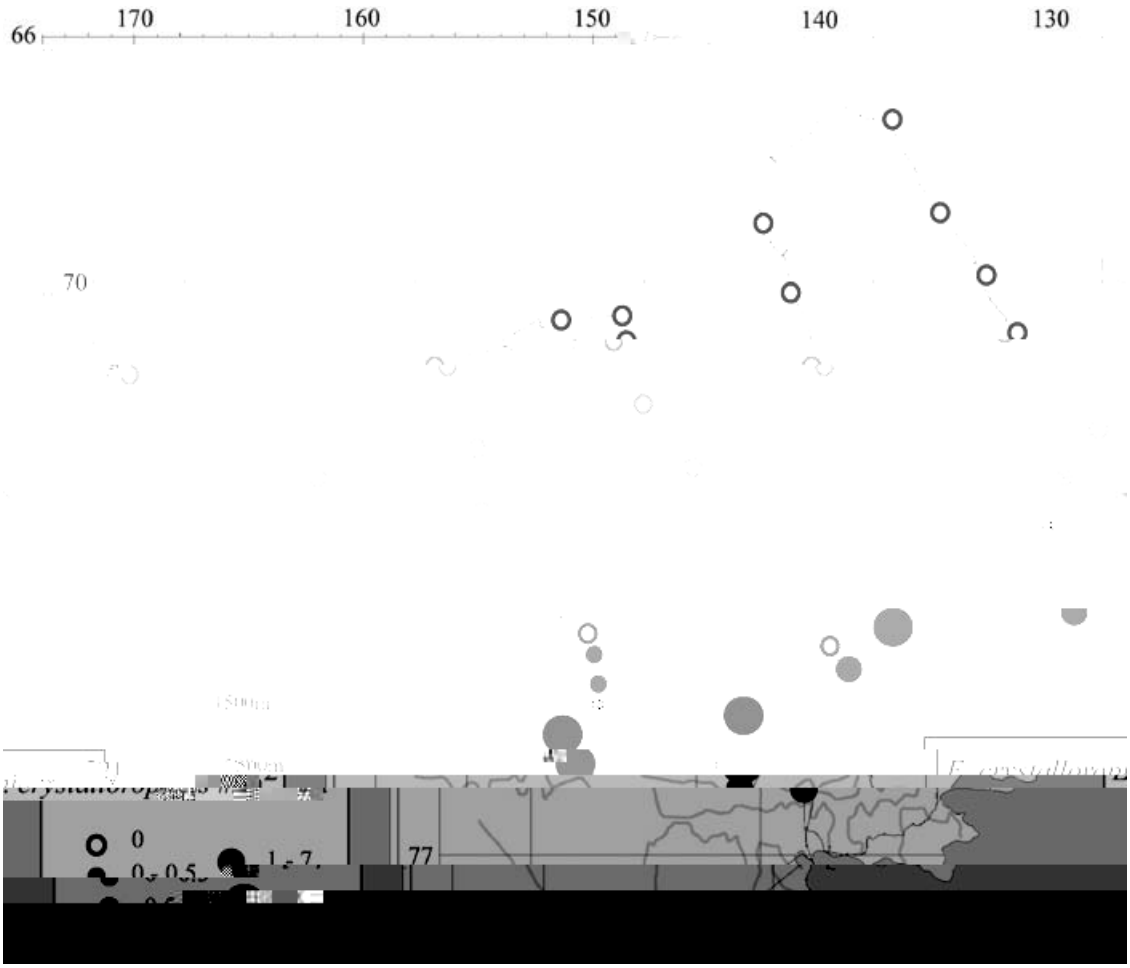


Fig. 7. *E. crystallorophias* densities (number of individuals per 1000 $m^3$) from net tows.

## Conclusions

The eastern Ross Sea appears to be a key habitat for apex seal and penguin predators, evidently owing to the

Laake), OPP-9816011 (Stewart), OPP-9816016 (Quetin and Ross), OPP-9816035 (Yochem and Stewart), OPP-9816086 (Jacobs), OPP-9815973 (Torres), OPP-9815176 (Castellini), OPP-0196490 (Daly), OPP-9815786 (Siniff and Stirling), and OPP-9908694 (Ackley).

## References

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