Southern elephant seal (Mirounga leonina) populations appear remarkably unaffected by interactions with humans. They are very tolerant of close human presence whilst they are ashore for pupping, mating and moulting. Their behaviour in close proximity to helicopter operations suggests disturbance of moulting male M. leonina is minimal. There is no evidence that M. leonina have been affected by persistent organic pollutants; and few M. leonina have been reported as having been injured or killed by interactions with fishery gear. The number of prey species common to their diet and commercial fisheries in the Southern Ocean are few; but one commercial squid species, Martialis hyadesi, accounted for as much as 94% of the biomass consumed by M. leonina. Two harvested commercial squid species (Mar. hyadesi and Todarodes filippovae) were found in the stomachs of M. leonina; and some other squid species (Allureuthis antarcticus, Brachiotethis spp., Gonatus antarcticus, Histoteuthis spp., Kondokovia longimana, Moroteuthis ingens, Mor. knipovitchi, Pholidoteuthis boschmanni and Psychroteuthis glacialis) have potential as commercial catch too. There is cause for concern if a future directed fishery for any of these species escalates or the by-catch of Mar. hyadesi and T. filippovae in the Illex and Nototodarus fisheries increase. There is also concern if fish-fish fisheries expand and take more of those species already taken by both M. leonina and fisheries. These species are benthic (Notothenia squamifrons), benthopelagic (Dissostichus eleginoides and Champsocephalus gunnari) and, perhaps most importantly, the pelagic myctophid species (e.g., Electrona carlsbergi).

Key words: southern elephant seal, Mirounga leonina, anthropogenic effects, persistent organic pollutants (POPs), human disturbance, climate change, sea-ice position, fisheries, fisheries interactions, diet, Myctophidae, cephalopods.

H. Burton and J. van den Hoff, Australian Antarctic Division, Channal Highway, Kingston, 7050. Tasmania. Australia. E-mail: harry_bur@antdiv.gov.au, john_van@antdiv.gov.au. Manuscript received 13 August 2001; accepted 15 January 2002.
change) is based on literature from the whole ocean environment.

METHODS

Diet

Data were collected for *M. leonina* hauled out at Macquarie Island, Heard Island and the Windmill Islands (Fig. 1). Seals were captured and the administration of an intravenous injection of ketamine (2.0 - 3.0 mg/kg) and diazepam (0.05 - 0.2 mg/kg, Virbac, Australia, McMahon et al. 2000a) anaesthetised the seals while the stomach contents were lavaged. For a detailed account of this procedure see Slip (1995). The stomach was collected in a 0.5 mm sieve and stored in 75% ethanol until sorting. Prey remains from the sorted samples were identified to species wherever possible with reference to identification guides and to voucher and reference collections. The results were expressed as frequency of occurrence (FOO) which is the proportion of samples, of the total number of samples, in which each prey species occurred (Rodhouse et al. 1992). Importance by mass (IBM) is the proportion that each prey species (whose mass has been estimated by using beak to mass relationships) contributed to the total mass (Rodhouse et al., 1992). Already published diet data (Clarke and McLeod 1982; Rodhouse et al. 1992; Green and Burton 1993; Slip 1995; Daneri et al. 2000) were incorporated in Tables 1 and 2 with our recent unpublished observations of seals. These were aged from one to five years both at Macquarie Island and the Windmill Islands (males = 23). The Macquarie Island samples were collected throughout the year between 1993 and 2000) were incorporated in Tables 1 and 2 with our recent unpublished observations of seals. These were aged from one to five years both at Macquarie Island and the Windmill Islands (males = 23). The Macquarie Island samples were collected throughout the year between 1993 and 1998; and the Windmill Island samples were collected between January and March, 2001.

Disturbance

The behavioural response of 14 male *M. leonina*, aged five to eight years, to helicopter cargo lifting operations on the isthmus at Macquarie Island was assessed both from video footage taken opportunistically by one of us and from direct observations (two hours) made during late March 2001. We observed the video later and determined if the seals were moving away from the area or showed reactions (e.g., head lifting, Engelhard et al. 2001b) that might be related to the external disturbance.

RESULTS AND DISCUSSION

General background and history

Humans have had effects on *M. leonina* populations over several thousand years. There is evidence that humans have hunted individuals from *M. leonina* colonies where the colonies and humans co-existed (Bryden et al. 1999). Colonies of *M. leonina* existed on the north-west coast of Tasmania; and, on the basis of excavations from the dated layers of nearby aboriginal middens, there was regular hunting of the seals, including pups (26%) and many breeding females, during their periods ashore. The final disappearance of *M. leonina* remains from the stratigraphic sequence of the middens at ~1000 yrs BP was interpreted as the extinction of the seals from this area by the hunter/gatherer population. A similar situation of exploitation of *M. leonina* colonies, but by Maori hunters on the New Zealand mainland, has also been reported (Smith 1989). Smith concluded that whilst *M. leonina* numbers had been higher in prehistoric times, there was no conclusive evidence that they existed as colonies on the main islands prior to the Maori arrival. European sealers began collecting blubber-oil on King Island in Bass Strait where *M. leonina* existed without an aboriginal presence (Mangin 1868). The sealers made short work of eliminating the *M. leonina* colony of ~10,000 - 17,000 seals within ~20 years from 1802 (Ling 1999). *M. leonina* never re-established at any of these areas above but they have recovered in numbers at some more remote subantarctic islands from the sealing pressures of the 19th century (Laws 1994). At Macquarie Island, numbers of *M. leonina* were reduced quickly (numbers were approximately halved in the first 20 years) after the population was discovered in 1810 (Hindell and Burton 1988); however the numbers had recovered by ~1913.

More recently *M. leonina* have been recorded visiting the south-eastern rim of Australia as determined from shore-sightings of marked and unmarked animals (Pemberton and Skira 1989; van den Hoff 2001a). However they are rarely seen at sea because they are deep divers and need only 2 – 4 min at the surface to allow them to dive for 40 min to depths of 200 - 800 m (Slip et al. 1994). Thus, it is not surprising that there is only one reference to *M. leonina* feeding at sea (Reid and Nevitt 1997). This was a large male observed eating, at the sea surface near South Georgia, what was surmised to be a Patagonian toothfish (*Dissostichus eleginoides*).

Sightings of *M. leonina* on shorelines of Tasmania and New Zealand have been regular (Pemberton and Skira 1989; van den Hoff 2001a). There have been about three *M. leonina* seen a year in Tasmania in recent years (Department of Primary Industries Water and Energy, Tasmania Records). At least five births of *M. leonina* have occurred in Tasmania since 1958, the most recent was a female pup born near Dover (southern Tasmania) in October 2000. She weaned on 17th Nov. 2000. These shore records support seal tracking data (Australian Antarctic Division (AAD), unpubl. data) which
Fig. 1. Map showing the main breeding and haul-out sites (bold text) for the southern elephant seal (*Mirounga leonina*).

suggest that some *M. leonina* are regularly utilising Tasmanian and New Zealand waters where active human fisheries are also operating.

**Trawl, gill-netting and long-line fishing gear**

A long-line hook was found in (and removed from) the nose of a *M. leonina* at Macquarie Island (McMahon et al. 2000b). The hook was thought most likely to come from the relatively close Campbell Plateau long-line fisheries or from the exploratory *Dissostichus* spp. fisheries in the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) area 88.1 to the south of New Zealand. There has also been a report of a *M. leonina* drowned in a trawl net in 1997 close to Macquarie Island and another of a *M. leonina* caught in a trawl net on the Kerguelen Shelf in 1995 (CCAMLR records). There are no records of seals taken as by-catch or through direct interactions between *M. leonina* and fisheries in New Zealand waters (I.S. Wilkinson, pers. comm.). An unknown percentage of the *M. leonina* population at Peninsula Valdés (Argentina) are entangled with line and sometimes line with lures of the same type as those used in the squid *Illex argentina* fishery (C. Campagna, pers. comm.). Thus deaths of *M. leonina* directly attributable to fishery operations have occurred; but very few have been reported.

It may be noted that mortalities of northern elephant seals (*M. angustirostris*) are also rarely recorded as a consequence of trawling and long-lining activities. However, 78 individuals of this species were estimated to have been killed in the Californian gill-net fishery during 1999 (Cameron and Forney 2000). Thus if gill-net fisheries were to expand in the Southern Hemisphere to areas used by
M. leonina for foraging, then some mortalities of M. leonina would be expected.

Aquaculture, fishing gear discards & firearms
Unlike many otariids, M. leonina are rarely seen entangled in netting, line or bait-box strapping that is either discarded or lost from the fishing vessels; but one juvenile (1 - 2 years of age) seal was observed dead in 1998 after entanglement in an aquaculture perimeter net near Dover in Tasmania (AAD, unpubl. data).

Mortalities of M. leonina from human activity can also arise through animals being deliberately killed (usually by being shot). Two M. leonina were shot on a beach at Maatsuyker Island (Tasmania) in the 1990’s and one adult female was shot (euthanased) on Ocean Beach near Strahan in 1998 (van den Hoff, pers. obs.). No other mortalities have been reported in Australia as a result of human causes (see Mawson and Coughran 1999). There appears to be only limited awareness by fishermen, wildlife workers and the public about M. leonina in the marine ecosystem, their onshore behaviour and interaction with commercial fisheries. The regular occurrences of the seasonal haul-out of M. leonina have been misinterpreted as stranding events; and one seal has been euthanised (above) through a lack of awareness of what is normal behaviour in this species.

Overlap in the diet of M. leonina and commercially fished species
Interactions between fisheries and M. leonina can take the form of overlap between the prey of the seals and species targeted by the fishery (Tables 1, 2, Fig. 2). Competition for prey between seals and a fishery is dynamic and seals can select prey only from what is actually there in their ocean environment at the moment of foraging. A fishery, by merely selecting some prey items rather than others, can modify greatly the prey choice available to seals. Seals have been shown to take particular ratios of prey species that are quite different when a fishery is, or is not, operating (Trites et al. 1997, 1999). Trites et al. also show, that when Stellar sea-lions (Eumetopias jubatus) are foraging in competition with fisheries, the prey they do consume are much less sustaining overall for the seals than when fisheries are not operating. This is also supported by captive feeding trials where E. jubatus lost mass when fed to satiation on pollock alone (Rosen and Trites 2000). Thus the decrease in the E. jubatus population seems related to the fact that the more energy rich prey, which the sea-lions once fed on, are now far less available as they are the target species of a large fishery (Trites et al. 1999).

From stomach lavage studies, M. leonina diet appears to be dominated by cephalopods, but fish make some uncertain contribution. However diet investigations are few and some studies describe only the cephalopod component in their diet (e.g., Rodhouse et al. 1992; Daneri et al. 2000). It appears that the fish component of M. leonina diet is difficult to assess. No studies have been published that describe the diet of M. leonina from New Zealand’s subantarctic islands nor at the fourth largest colony of M. leonina at Peninsula Valdés, Argentina.

Our sampling of the diet of M. leonina at Macquarie Island, Heard Island and at the Windmill Islands on the coast of Antarctica has provided spatial information about prey species that dominate the diets. Reconstructed prey biomass from species found in the stomachs of M. leonina was dominated by the subantarctic cephalopods (Moroteuthis ingens, Mor. knipovitchi, Martialia hyadesi, Todarodes filippovae, and Histeoteuthis spp. (Table 1). Frequency of occurrence (FOO) indexes for fish were dominated by species from the family Myctophidae (e.g., Electrona spp. and Gymnosceliidae spp.) (Table 2). Regular sampling of M. leonina at Macquarie Island has also shown that there are prey remains of squid species believed to be restricted to coastal Antarctica (e.g., Kondakovia longimana, Psychroteuthis glacialis and Alluroteuthis antarcticus). Two of these species (P. glacialis, A. antarcticus) were also the only squid species found in the stomachs of M. leonina sampled at the Windmill Islands on the Antarctic coast. They were also seen in the diet of M. leonina at King George Island (Daneri et al. 2001) and South Shetland Islands (Clarke and McLeod 1992). Thus the percent contribution of ‘Antarctic’ squid species to the diet of M. leonina is likely to be underestimated from studies conducted at only their breeding locations. The presence of the remains (beaks) of Antarctic squid species, in the stomachs of M. leonina sampled at subantarctic locations, is possibly due to them being caught or lodged in the seal’s stomach folds for an extended period. Alternatively, the geographical range of the squid species themselves is more extensive than currently understood.

There are differences in species composition, FOO and importance by mass (IBM) between the diets of M. leonina at different sites in the Southern Ocean (Table 1); and none of the squid species found in M. leonina stomachs are part of a current large southern fishery operation. But Mar. hyadesi and T. filippovae have been caught commercially or as by-catch (Roper et al. 1984; Rodhouse 1993) and may continue to be fished. Of the remaining cephalopod species, nine (45%) have been identified as suitable
### Table 1. Cephalopod taxa identified from beaks recovered from the stomachs of southern elephant seals (*Mirounga leonina*). Frequency of Occurrence (FOO) and Importance by Mass (IBM), are given as the range of percentages from the published and unpublished data. 1, Clarke and McLeod 1982; 2, Daneri et al. 2000; 3. Fischer and Hureau 1985; 4, Green and Burton 1993; 5, Rodhouse 1990; 6, Rodhouse and unpublished data. 7, Slip 1995; 8, van den Hoff 2001b; 9, Wadley 1990; 10, Wadley and Dunning 1998; 11, Wadley and Dunning 1998; 12, Roper et al. 1984.

<table>
<thead>
<tr>
<th>Taxa</th>
<th>FOO (%)</th>
<th>IBM (%)</th>
<th>Commercial quantities captured</th>
<th>Suitable as a commercial species</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CEPHALOPODA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alluroteuthis antarcticus</td>
<td>11 - 78</td>
<td>0.3 - 35.0</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Brachioteuthis sp.</td>
<td>3 - 67</td>
<td>0.1 - 0.5</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>C. affinis</td>
<td>8 - 33</td>
<td>0.02 - 0.6</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Galiteuthis glacialis</td>
<td>0.5 - 38</td>
<td>0.1 - 2.7</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Gonatus antarcticus</td>
<td>9.4 - 71</td>
<td>0.9 - 3.9</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Histeoteuthis eltanina</td>
<td>5 - 71</td>
<td>2.6 - 71.8</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Kondakio longimana</td>
<td>3 - 67</td>
<td>0.7 - 50.4</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Liochactia sp.</td>
<td>5 - 25</td>
<td>0.2 - 94.4</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Martialis hysides</td>
<td>4 - 22</td>
<td>0.1 - 56.6</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Masetoteuthis sp.</td>
<td>3</td>
<td>0.01</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Chiroteuthis sp.</td>
<td>9 - 67</td>
<td>0.2 - 2.9</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Moroteuthis regis</td>
<td>3 - 67</td>
<td>0.7 - 50.4</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Moroteuthis knipovitchi</td>
<td>5 - 71</td>
<td>3.9 - 43.7</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Pholidoteuthis boschmanni</td>
<td>5</td>
<td>0.3</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Psychroteuthis glacialis</td>
<td>6 - 100</td>
<td>0.2 - 81.4</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Taonius pavon</td>
<td>6 - 17</td>
<td>0.01 - 0.6</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Pareledone polyomorpha</td>
<td>1.6</td>
<td>12.5</td>
<td>4.2</td>
<td>N</td>
</tr>
<tr>
<td>P. charcoti</td>
<td>37.5</td>
<td>13.2</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>P. turritella</td>
<td>12.5</td>
<td>4.2</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td><strong>FISH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bathylagidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bathylagus sp.</td>
<td></td>
<td></td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Myctophidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrona antarctica</td>
<td>3</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>E. subaspera</td>
<td></td>
<td></td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>E. carlsbergi</td>
<td>12</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Electrona sp.</td>
<td></td>
<td></td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Gymnosomus braueri</td>
<td></td>
<td></td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>G. nicholson</td>
<td>4</td>
<td>N</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Gymnosomus sp.</td>
<td></td>
<td></td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>Nototheneidae</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notothene squamifrons</td>
<td></td>
<td></td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>N. acuta</td>
<td></td>
<td></td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Nototheneiops mizops</td>
<td></td>
<td></td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Dissostichus eleginoides</td>
<td>4</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Channichthyida</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Channichthys rhinoceratus</td>
<td></td>
<td></td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Channichthys gunnari</td>
<td>&lt;5</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td><strong>CRUSTACEA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euphausia crassilata</td>
<td>7</td>
<td>N</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>E. superba / valentini</td>
<td>12</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Parapathes rathbuniae</td>
<td></td>
<td></td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Paraphysichthys gaudichaudii</td>
<td>21</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

Table 2. Fish and crustacean taxa identified from remains recovered from the stomachs of southern elephant seals (*Mirounga leonina*). 1, Fischer and Hureau 1985; 2, Green and Burton 1993; 3, Slip 1995; 4, R. Williams pers. comm.; 5, this study.
for commercial fishing (Table 1) and there are fisheries for members of the same families elsewhere in the world (Rodhouse 1990). The squid species seem to be associated with pelagic fish of the Myctophidae family which exist in large numbers within the upper mixed layer (~200 m) of the sea at numerous mid-ocean locations (Fischer and Hureau 1985). Although the reporting of fish remains is less than that for cephalopods, the fish species that overlap reported M. leonina diet and commercial fishing are also few (28%) and limited (Table 2, Fig. 2).

After six years of collections at Macquarie Island, toothfish otoliths (D. eleginoides) have been recovered from only one (in 1999) out of ~400 M. leonina stomach contents samples (I. Field, pers. comm.). Otoliths of D. eleginoides have also been found in three of 79 M. leonina sampled from Heard Island (Slip 1995). Thus D. eleginoides does not appear to be a major part of the diet there either. The rarity of this finding suggests that toothfish are either not important in the diet or the remains have been well-digested prior to our sampling. The commercial toothfish fishery in waters surrounding Macquarie Island has a complex trophic relationship with the marine predators that forage within the economic zone but the overlap seems small (Goldsworthy et al. 2001).

There are four species of fish recorded as eaten by M. leonina and also subject to commercial use (Table 2). Their commercial value at present appears to be as fish-meal for the feeding of livestock. These species are likely to be more exploited in the future, as the world demand for food from the oceans continues to rise; and they may be joined by others, e.g., Channichthys rhinoceratus (Table 2) which have been assessed as having some commercial value. However pelagic fisheries in the Southern Ocean are still only barely established. There was a brief fishery for Electrona carlsbergi by the USSR in 1989-1992; but this was not economically viable. The major species taken by both M. leonina and fisheries are benthic (Notothenia squamifrons) or benthopelagic (D. eleginoides and Champsocephalus gunnari) (Table 2). These species occur over continental and island shelves, slopes and plateaus near subantarctic islands (Fischer and Hureau 1985) near where M. leonina have been sampled by stomach lavaging. Therefore it would be expected, that, if these fish species were eaten to a considerable extent by M. leonina, then their otoliths would be found more commonly than they have been (FOO < 5%). Alternatively, the seals may be feeding on these species during the outward part of the foraging migration directly after a lengthy fasting period, but not on the return leg when they have fattened; and thus the digestion of their prey remains is complete. It is also possible that myctophid fish are seen in M. leonina diet, to some extent, as a result of secondary ingestion by squid. Myctophid fishes are an important component in the diet of Mor. ingens around Macquarie and Heard Island (Phillips et al. 2001) and New Zealand (Jackson et al. 1998). Mor. ingens is itself important as prey for M. leonina.

There is little diet data for M. leonina when at their major foraging grounds in the pelagic zone and

---

Fig. 2. Proportion composition (%) of taxa (identified in M. leonina diet) caught by Southern Ocean fisheries. (Source: FAO Vol 86/1 1998).
over the Antarctic Continental Shelf (McConnell et al. 1992; Slip et al. 1994; Jonker and Bester 1998; Campagna et al. 1999; van den Hoff, unpubl. data). If these diet collections were substantial, comparisons of the diet distant and local to the breeding islands could be made and the relative degree of dependence that elephant seals have upon any region or prey species, particularly those of commercial interest, could be determined. For example, studying the diet of *M. leonina* from Macquarie Island foraging near to Campbell Island and Antipodes Island may reveal the importance of commercially fished species such as orange roughy (*Hoplostethus atlanticus*) and arrow squid (*Nototodarus sloani*) to the diet. *M. leonina* breeding on Marion Island, Peninsula Valdés, and Falkland Islands also have yet to be sampled to assess the importance of commercial species such as toothfish (*D. eugeniae*) and the squid *Illex argentinus* in their diets.

It is disturbing that in 1998 the world harvest of *I. argentinus* was approximately 650,000 tonnes from the Patagonian Shelf in the south west Atlantic sector of the Southern Ocean and that no diet studies of *M. leonina* had been carried out there. The population of *M. leonina* at Peninsula Valdés is increasing (Lewis et al. 1998) so the very active *Illex* fishery appears to have little effect on the seal population to date. Male *M. leonina* from Peninsula Valdés dive to the sea bottom over the Patagonian shelf and to mid-water depths (Campagna et al. 1999) whilst depth distribution of *I. argentinus* is from the surface to 800 m (Roper et al. 1984). Spatial overlap seems highly probable. Trites et al. (1997) suggested the specialised feeding habits of some Pacific Ocean marine mammals upon deep-water squid and fish species has resulted in minimal overlap there. Elephant seals have deep diving capabilities up to 1,500 m; but the mean dive depths are usually less than 500 m (Slip et al. 1994). This implies that many of the prey species are at these depths and overlap of *M. leonina* with commercial surface squid jiggling and shallow water trawl fisheries should be minimal while use of the current fishing gear is continued. The situation is likely to be different for each population sector as fish species and their proportions are different and the various *M. leonina* age classes feed in different areas (Bornemann et al. 2000). In that paper, foraging locations of weaned pups from King George Island are different to those of adult females.

Trites et al. (1997) reported a 35% diet overlap between the marine mammals in the Pacific Ocean and the fisheries there. This was “far less than expected considering the frequent complaints about marine mammals by some fishers”. At present there is commercial interest in 18% of the prey species in the diet of *M. leonina* (Tables 1 and 2) and this might not appear to be severe; but they are the species that contribute a large proportion of the biomass consumed by *M. leonina*. One squid species, *Mar. hyadesi*, can account for as much as 94% of the biomass consumed (Table 1). Clearly there is cause for some concern here if a directed fishery escalates or the by-catch of *M. hyadesi* and *T. filippovae* in the *Illex* and *Nototodarus* fisheries increases.

Crustacean species in common with *M. leonina* diet and fisheries are shown in Table 2 and Fig. 2. One of the three Euphausiidae, *Euphausia superba*, is of commercial value and is currently harvested. The FOO of euphausiids in *M. leonina* diet is low. At Heard Island it was 12% and the biomass consumed appears insignificant (Slip 1995). But the fact that most diet studies have been carried out at the breeding sites of *M. leonina* probably leads to an underestimation of the importance of rapidly digestible species such as krill. The relatively undigested remains of *E. crystallorophias* found in *M. leonina* at the Windmill Islands suggest direct ingestion rather than secondary ingestion. Krill fishing in Antarctic waters is regulated by the CCAMLR. *E. superba* is the commercial krill species and has been harvested from seas surrounding the Antarctic continent; but the areas of concentrated fishing are now the South Atlantic, along the Antarctic Peninsula and South Georgia (Nicol and Endo 1997). Regardless of whether krill are directly ingested or not, they are a pivotal component to the Antarctic ecosystem (Nicol and Endo 1997) and the prey of *M. leonina* are themselves largely reliant upon krill. Again the relative importance of krill to *M. leonina*, directly or indirectly, is poorly understood and thus the expansion of a krill fishery has uncertain consequences.

**Human disturbance**

A long term and intensive research effort investigating the relationships between ecological and population parameters of *M. leonina* at Macquarie Island during the pupping period was carried out over a seven year period beginning in 1993. The study area where human interactions between *M. leonina* females and their pups are concentrated is the isthmus. During each pupping period between 1993 and 2000, harems on the isthmus were searched each day of the breeding season for new-born pups. Each year, approximately 1,000 pups were weighed and provided with flipper tags within 24 hours of birth by a team of 4 - 5 persons. This handling procedure required a brief (1 - 3 min) separation of the pup from the mother. Tagged pups were re-weighed at weaning.

Engelhart et al. (2001a) took advantage of this regular weighing and marking effort of *M. leonina* at
Macquarie Island to compare the effects of disturbance on *M. leonina* at regularly researched beaches with those at little used beaches. The parameters examined were weaning mass and serum levels of cortisol (a hormonal measure of the stress response; Engelhard *et al.* in press) in relation to a number of behavioural measures (Engelhard *et al.* 2001b). Weaning mass was selected as it represents a quantitative summary of all maternal investments during gestation and lactation. If weaning mass was reduced at beaches with daily research work undertaken then there would be evidence that the lactation period had been shortened, perhaps by disturbed suckling or earlier cow departures. The pups from those beaches would then likely have fewer resources (stored as fat) to use while they were learning to forage successfully. The results of Engelhard *et al.* showed that with the size of cow allowed for (mother size is the major determinant of pup size, Arnbom *et al.* 1993), there was no difference in weaning mass between the beaches with high and low levels of human activity. Cortisol responses were also similar for mother-pup pairs in these two areas (Engelhard *et al.* in press). Moreover, no behavioural differences were observed; in particular, there was no difference in the time spent suckling, an aspect of the behaviour which is associated with pup weaning mass (Engelhard *et al.* 2001b). Alertness of females (as recorded by the frequency of head lift behaviour) was raised threefold in the presence of people near harems; but quickly returned to pre-disturbance levels once the people departed.

Few other behavioural studies with reference to human disturbance have been carried out at *M. leonina* breeding sites. One study carried out about a decade ago at the Antarctic Peninsula or Peninsula Valdés was inconclusive (C. Campagna, pers. comm.). The influence of humans on the behaviour of *M. leonina* while hauled out during the breeding season and rest periods appears minimal (Wilkinson and Bester 1988). The authors rejected onshore human disturbance as a significant factor in the decline of *M. leonina* at Marion Island and other *M. leonina* populations in decline. With the increased pressures from the booming tourism industry in the subantarctic and the Antarctic there is no reason to suspect that the seals will be affected detrimentally.

Helicopter operations appear to be noisy and obtrusive disturbances for humans. Therefore the reactions of *M. leonina* to heavy-lift helicopter operations, on the isthmus at Macquarie Island, were observed during March 2001. A group of 14 male *M. leonina* was hauled out directly between the resupply ship and the helicopter drop-zone 20 m from the seals. The Sikorsky S-76 helicopters were observed while sling loading cargo over two days and thus the engine noise was periodically noisy then quiet as the helicopters arrived and departed during daylight hours. The only discernible difference in behavioural responses of the *M. leonina* between the presence and absence of the helicopters was increased head-lifting. This response was also observed with harem females by Engelhard *et al.* (2001b) when they were assessed while researchers were working at the harems. No comment can be made regarding whether some other animals may have joined the group had there been no noise.

**Ocean environment change**

The Southern environment has generally lower concentrations of industrial and agricultural pollutants than elsewhere due to its greater distance from the major sources (Iwata *et al.* 1993). Thus it might be expected that animals living only in southern waters would have concentrations of pollutants in their fat in the lowest range of global values. This is often the case. However, most of the global transport of organochlorines is made aerially (Riseborough *et al.* 1976); and the more volatile components are carried further into polar regions and kept there (Calamari *et al.* 1991; Simonitch and Hites 1995). They accumulate because the very low temperatures can cause their deposition (through condensation) onto substrates such as soils, water and ice (Wania and Mackay 1993). Their degradation rates there may be reduced due to the very low temperatures and less photolysis during the low light winters (Wania and Mackay 1993). Thus concentrations of volatile persistent organic pollutants (POPs) may even be higher in some animals in Antarctica, such as birds (van den Brink 1997), than in the same species in warmer environments, for example Europe, which are closer to the main areas of actual use of the chemicals. Trends in the concentrations of POPs in animals in the Arctic, where monitoring studies have been more common than in the Antarctic, are generally downwards (Gabrielsen and Henrichsen 2001). It is likely that similar trends exist in Antarctic waters.

A thorough review of environmental contaminants and marine mammals (O’Shea 1999) concluded that “no marine mammal deaths in the wild have conclusively been shown to be a direct result of organochlorine or toxic element exposure”. However the breeding success of grey seals (*Halichoerus grypus*) and ringed seals (*Phoca hispida botnica*) of the Baltic Sea declined sharply in the 1960s and 1970s (Bergman 1999a), resulting in a serious decline in numbers and even the possibility of local extinction. It is thought that POPs were contributing to the problem although hunting was also very important in initially lowering seal numbers.
As top predators, seals can accumulate pollutants already concentrated by the food webs from their environment. High concentrations of chlorinated hydrocarbons and heavy metals have been found in seals from the Baltic Sea (O’Shea 1999). Aberrations were found in cultured blood-cell chromosomes such as chromatid breaks, gaps, and fragmentations (Hongel 1996). More complicated rearrangements were rare. Hongel (1996) concluded that chromosome aberrations in cultured blood cells were probably caused by the chemical pollutants in the media. Thus perinatal exposure to coplanar (dioxin-like) PCBs and organochlorine pesticides could be associated with subtle alterations in immune and endocrine function. Even the blood samples taken from captive harbour seals fed large doses of organochlorine compounds (from contaminated fish) had low concentrations of retinol (a precursor of vitamin A) and thyroid hormones (Brouwer et al. 1989). Their normal reproduction also suffered (Brouwer et al. 1989).

Increases in the concentrations of “greenhouse gases” from human activities (Ledley et al. 1999) are believed to be a factor in global warming which itself is associated with changes in sea-ice positions, fluxes and glacier melt rates (Morison et al. 2000; Vincent et al. 2001). These changes will eventually translate into changing flows of ocean currents (Hansen et al. 2001). Already Hansen et al. have shown that the flow of cold bottom water (created by sea-ice formation) from the Arctic past the Faroe Islands has decreased by ~20% in the last fifty years; and there is the likelihood of reduced return flows in the warmer Gulf Stream as a result. The implications for M. leonina from changing flows in Southern Ocean currents resulting from the retreat of the sea-ice edge in the middle 1960s (de la Mare 1997) would be that the positions, types and quantities of their diet items would change too. Possibly this has already happened and is associated with the concurrent decrease in M. leonina. Significant changes in body condition, which are related to sea-ice conditions, have been shown to occur with P. hispida in the Arctic (Harwood et al. 2000). The variable sea-ice extent, recorded for over 240 years since 400 BP, has been related to the success of fisheries off Iceland (Ogilvie and Jonsdottir 2000). One linking mechanism they suggested was enhanced or reduced nutrient concentrations dependant on proximity to the sea-ice edge. Thus there is agreement that polar climates and oceans are changing; but it seems too early, in the data gathering effort for climate modelling, for current models to lead to agreement about the extent of the change brought about by human contributions to greenhouse gases. However the consensus is that the contribution is real (Ledley et al. 1999).

**CONCLUSIONS**

Past interactions of humans and M. leonina have been decidedly negative for the seals; but the current situation is not so bleak. Humans do not now seem to be affecting M. leonina in any significant way. From studies so far there is only very limited evidence of disturbance on shore (see papers by Engelhard et al.); and there appears to be only a small similar effect on M. leonina by close helicopter operations. With helicopters, there was only the observation of increased head lifting responses when the helicopters arrived; but unmonitored metabolic and hormonal changes related to stress were possible. Further study would be needed here for quantitative understanding of these relationships; but the issue of negative effects by humans on M. leonina at their moultng and breeding sites does not seem established as an important one. There are no negative interactions (for the seals at least!) reported between numerous tourists and M. leonina; and by analogy with similar experiences (Allen 1999) of M. angustirostris, few would be expected.

Pollutant concentrations are not as high (Ellis 1999) in M. leonina tissues as in seals from places, eg the Baltic Sea, where some damage to seals has been reported from such pollutants (O’Shea 1999). However more analyses of POPs in M. leonina are required to be certain on this point as the ranges of POP concentrations are large and many samples are needed to establish the limits of those ranges (O’Shea 1999). Just as importantly, the variance between samples needs to be apportioned according to sex, age, nutritional status, reproductive status and location so that comparisons of pollutant concentrations can be made usefully between seals of the same kind (O’Shea 1999). There is no current evidence to show that the concentrations of anthropogenic substances in M. leonina are at levels
that could cause mortalities in sufficient numbers to reduce M. leonina population numbers.

Studies of the diet of M. leonina have been scant at some populations. However, the diets of M. leonina at Heard and Macquarie Islands have been studied; and lists of prey species are known (Tables 1 and 2). The cephalopod portion of the diet at South Georgia and South Shetland Islands has been published but there are no diet records from other important breeding sites in the Southern Hemisphere. Therefore, the contribution of commercial species to the diet of M. leonina may be more important than currently indicated; and certainly will be more so as the demand for marine resources from the, as yet relatively unexploited, stocks of squid and fish in the Southern Ocean increases in the future. For example, while the dissolution of the USSR and the establishment of 200 nautical mile economic limits caused a decrease in Soviet activities, efforts by other fishing fleets have increased and taken their place (FAO data in Trites et al. 1997).

Although there are only two species of squid in the diet of M. leonina (Table 1) which have been commercially harvested, or caught as by-catch, they are important prey of M. leonina and common to populations that are geographically separated. These squid species might be of future economic interest. Elsewhere in the world members of these families are caught directly or as by-catch with species of commercial value (Rodhouse, 1990). Cephalopod species that are palatable (non-ammoniacal), big enough and neither gelatinous nor strap-like in texture (Table 1) have commercial potential. There is enough and neither gelatinous nor strap-like in

We judge that if any human activity is to reduce M. leonina numbers in the future then it will most likely be by increased fisheries catches in the Southern Ocean; but at the moment the catches by seals and the catches by commercial fisheries do not overlap to any appreciable extent.

ACKNOWLEDGMENTS

We thank Claudio Campagna and Ian Wilkinson who searched filing cabinets and other dusty places for records of interactions from South America and New Zealand respectively. We thank Georg Engelhard, Cecilia Eriksson, Mark Hindell, Clive McMahon and Dick Williams for their most useful corrections and comments on the paper.

REFERENCES


WADLEY V, 1990. Squid from the west and north-west slope deepwater trawl fisheries. Illustrated booklet for scientific observers and skippers of commercial vessels. CSIRO Division of Fisheries: North Beach, WA.


