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SQUID ECOLOGY PILOT STUDY

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MARINE SCIENCE LABORATORIES

SQUID ECOLOGY PILOT STUDY

THE DISTRIBUTION AND ABUNDANCE OF ARROW SQUID *NOTOTODARUS GOULDI* (McCOY, 1888) AND MAJOR PREDATORS IN RELATION TO WATER CIRCULATION AND NUTRIENT ENRICHMENT IN VICTORIAN COASTAL WATERS.

REPORT TO THE FISHING INDUSTRY RESEARCH COMMITTEE
DEPARTMENT OF PRIMARY INDUSTRY, CANBERRA, A.C.T.

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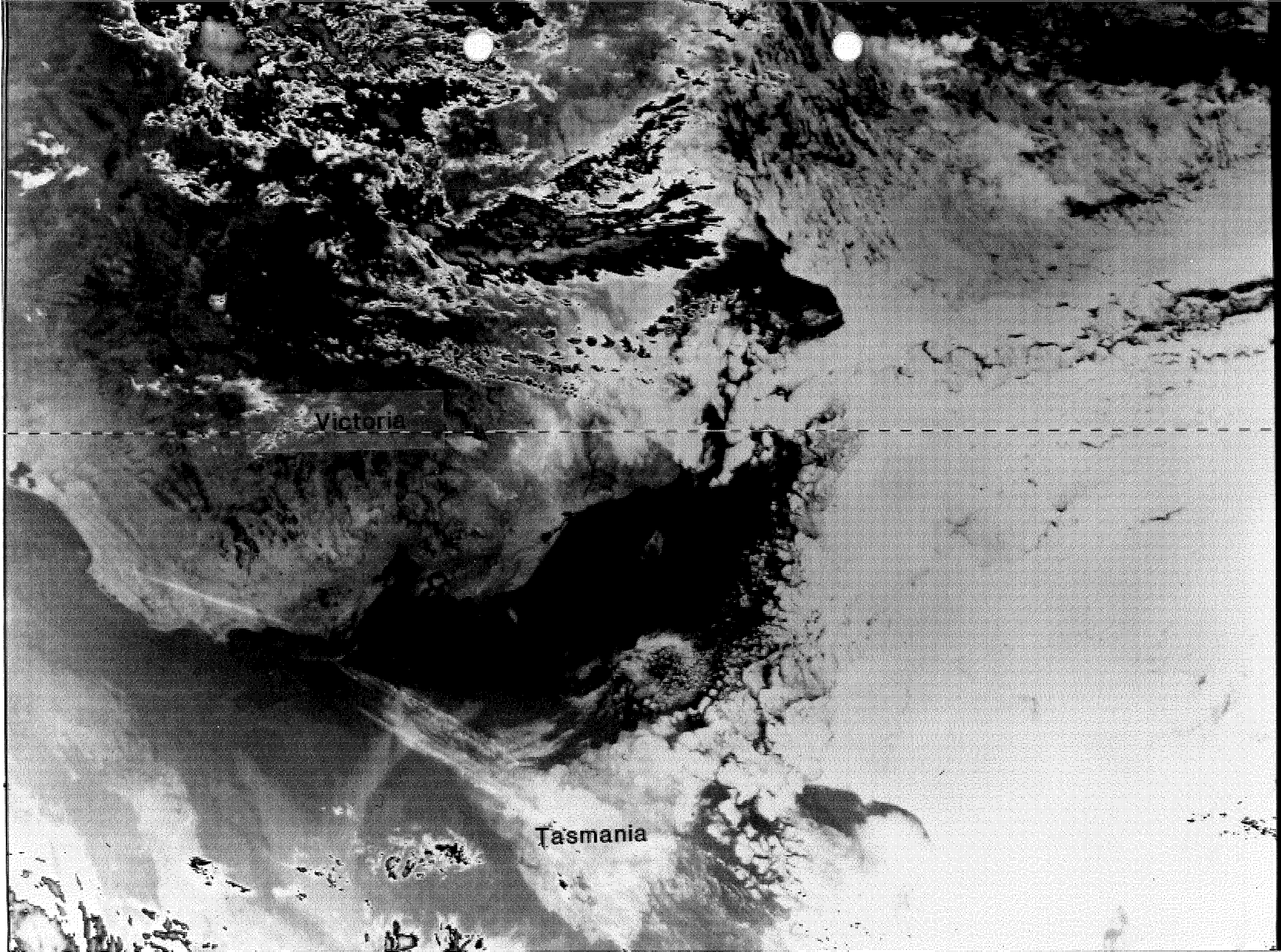
Frontispiece Infra-red satellite image of Bass Strait and western approaches to Bass Strait, 13/3/82. Cold water is indicated by light, and warm water by dark shading. The northward tongue of cold Subantarctic Surface Water splitting into northerly- and easterly- directions is apparent off north-western Tasmania.


Victoria
Tasmania

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INTRODUCTION

The high level of interest during the summers of 1978-79 and 1979-80 in exploitation of arrow squid *Nototodarus gouldi* (McCoy, 1888) by foreign jigging vessels was a cause of some concern to the Victorian fishing industry. The squid-jigging fleet was fishing mainly in south-east Australian waters, and the highly mobile and very brightly-lighted, night-fishing vessels were always a visible threat to those concerned for the resource. The main fears expressed were that removal of large quantities of squid would be to the detriment of commercial fishes which were thought to depend largely on squid as a food source. There was also concern on behalf of other marine animals such as mammals, penguins, albatrosses, petrels and other sea birds, which could also depend on arrow squid as a major food source.

This study was undertaken as a first step towards an understanding the importance of arrow squid in the offshore food web. The aim was to assess the possible effects of an increase in the commercial exploitation of squid upon populations of marine animals in Victorian coastal waters. The three objectives of this report are to:

- review existing information on the hydrology and circulation of Victorian coastal waters, and on the distribution and abundance of squid and their potential predators including fish, seals and sea-birds.
- assess the importance of squid in the diets of major predators.
- make recommendations on future research.

HYDROLOGY AND CIRCULATION

Victorian coastal waters are predominantly included within Bass Strait, a relatively broad area of shallow continental shelf between Victoria and Tasmania (Fig. 1).

Sea-surface temperatures increase eastwards and northwards across Bass Strait throughout the year (Rochford, 1975). Typical winter temperatures are 12-14°C in the west, and 14-15°C in the east. During summer, temperatures increase to 18-19°C in the west and 20-21°C in the east. During very calm periods, summer surface temperature may be 1-2°C higher (M. Marsden, *pers. comm.*) There is usually a sharp rise in temperature at the eastern approaches to Bass Strait.

Sea-surface salanities show a more complex pattern than temperatures, with highest values in north west Bass Strait, lower salinities in central and southern areas and sometimes higher salinities again at the eastern approaches to the Strait. There is sometimes a marked salinity gradient along the eastern margin of Bass Strait. Typical sea-surface salinity values are 35.20 - 35.65% (C. Gibbs unpublished data).

In some summers (e.g. 1979-80) there is little or no thermal or saline stratification in Bass Strait, probably because the relatively shallow depths (75m) and unsettled weather result in continuous mixing through the water column. However, in very calm periods, such as January 1982, XBT traces indicate that multiple thermal layering in the upper 50m can occur (M. Marsden *pers. comm.*) at the western approaches to the Strait.

The three major water masses which have some influence on the hydrology and circulation are cool, low salinity subantarctic water from the south; warm, high salinity subtropical water of the East Australian Current eddies; and high salinity water, referred to a "North Bass Strait Water", which possibly is derived from the Gulfs of South Australia or may be an extension of the Leenwin Current. There may be some influence in summer from subsurface water of the Central Tasman Sea, and throughout the year from intermittent upwelling of Subantarctic Water (Rochford, 1975, M. Marsden *pers. comm.*)

Evidence from drift bottles (Newell 1961) and historical surface temperature and salinity data (Edwards 1979, Godfrey *et al* 1980) indicate that surface circulation shows seasonal differences. The general pattern in winter (Fig. 1) is of high salinity "North Bass Strait Water" in the west entraining cool, low salinity subantarctic water along its southern front and being carried eastwards through Bass Strait under the influence of westerly gales. At the eastern margins some of this water mixes at the surface with warmer (but lower salinity) subtropical water of the East Australian Current eddies, while at depth some cascades down the continental slope (Godfrey, *et al.* 1980) below the less dense East Australian Water Mass sinking to as deep as 400m before leveling out. Recently analysed T/S/D curves suggest that the high salinity "Northern Bass Strait Water" can be carried northward along the east Australian coast over several hundred nautical miles before mixing with the East Australian current (Tomczak, 1981).

The general pattern reverses in summer with a change in prevailing winds to the south and east, resulting in a flow of mixed subtropical, Central Tasman Sea, and upwelled subantarctic water westward through Bass Strait (Fig. 2).

These seasonal patterns can be further complicated by variations in baroclinic and wind pressures. For example, current meters placed eastward of King Island in summer and autumn indicate that the subsurface and near-bottom currents sometimes flow south-eastwards and sometimes north-eastwards, opposite to the general current direction (M. Marsden, *pers. comm.*). There is also some evidence for reversed current direction of surface water in Banks Strait (N.E. Tasmania) in early summer.

NUTRIENTS, CHLOROPHYLL a AND ENRICHMENT

Australian marine waters are in general regarded as among the nutrient poor marine regions of the world (Rochford, 1980), because of limited run-off from the land, isolation from nutrient-rich subantartic waters in the south and limited upwelling. However, in the area of South-East Australia the Tasmanian shelf cuts across the subantarctic water mass and some enhanced nutrient values are possible.

Surface phosphate values are generally low in subtropical waters (<0.2 μg at. ℓ^{-1}). Higher values are found in Bass Strait (0.1 - 0.3 μg at. ℓ^{-1}) and in subantarctic water (>0.3 μg at. ℓ^{-1}) (Rochford 1980; C. Gibbs unpublished data). At depths below the euphotic zone (i.e. deeper than 100m) distribution of phosphate indicated potential enrichment if upwelling were to occur, with values of >0.5 μg at. ℓ^{-1} in the eastern approaches to Bass Strait and 0.5 - 0.7 μg at. ℓ^{-1} in subantarctic water (Rochford 1980). There is also some southwards transport of nutrient rich subsurface subtropical water into Bass Strait via the East Australian Current eddy system, which provides a "nutrient reserve for coastal upwelling and mixing of eastern Australia." (Rochford 1980, p.14).

Recent samples collected as part of a joint V.I.M.S. and Marine Science Laboratories program (C. Gibbs unpublished data) show high phosphate values off north-eastern Tasmania indicative of nutrient enrichment from subsurface waters (surface values are higher than surface subantarctic water values, indicating upwelling). High winter values (~0.3 μg at. ℓ^{-1}) between Tasmania and King Island possibly indicate the presence of a tongue of subantarctic surface water.

Surface nitrate values are generally $\leqslant 0.5$ μg at. ℓ^{-1} in Bass Strait and nearby oceanic waters (Rochford 1977, 1980). However, surface nitrate values, like those of phosphate values, are also higher at the shelf edge in both east and west approaches to Bass Strait. Samples collected by Marine Science Laboratories (C. Gibbs, unpublished data) show three areas of nutrient enrichment that could affect the productivity of Bass Strait. Off north-east Tasmania nitrate values are consistently high in all seasons (e.g. Figs 3 & 4), with winter peaks (Fig. 3) of over 7 μg at. ℓ^{-1}. A second area, south of Lakes Entrance had high winter values (over 6 μg at. ℓ^{-1}), and a third area off the north-west coast of Tasmania also had winter values of over 2 μg at. ℓ^{-1} (Fig. 3).

Surface silicate values are usually $\leqslant 1$ μg at. ℓ^{-1}) in Bass Strait and nearby oceanic and coastal waters (Rochford 1977). Unpublished Marine Science Laboratories data show higher values in winter and spring than summer and autumn. Highest values of 2 μg at. ℓ^{-1} occur off north-east Tasmania, indicative of subsurface upwelling. The east Victorian summer upwelling showed surface values of >3.5 μg at. ℓ^{-1} (Rochford 1977).

Chlorophyll values are generally low (<0.5 μg ℓ^{-1}) throughout Bass Strait (C. Gibbs unpublished data) with higher values in spring (Fig. 5) during the peak of primary productivity (expected during late winter and spring for temperate waters). Highest values occurred off north-west and north-east Tasmania with the station between King Island and Tasmania showing relatively higher values in all seasons (Figs. 5 & 6).

Upwelling has been shown to occur off the east Victorian coast in late summer (Rochford 1977), but only within near-shore (<8 Km) coastal waters of limited (15-30 Km) extent along the shore. The area of upwelling was small compared to major upwelling regions of the world. There is also suspected enrichment at the surface from upward convection of nutrients within a cyclonic gyre off the east coast of Tasmania during winter and spring (Rochford 1975).

The nutrient data (phosphate, nitrate, silicate, etc.) collected by Marine Science Laboratories (unpublished) confirm Rochford's observations that nutrient enrichment is occurring at the eastern approaches to Bass Strait, and suggest that a similar process is occurring off the north-west coast of Tasmania near King Island. A full report on those data is being prepared by C. Gibbs, Marine Science Laboratories, Queenscliff.

DISTRIBUTION AND ABUNDANCE OF ARROW SQUID AND MAJOR PREDATORS

Arrow Squid

Arrow squid *Nototodarus gouldi* (McCoy, 1888) are distributed from the Great Australian Bight to Southern Queensland (Wormuth, 1976). They are found in dense shoals in Bass Strait, South Australian waters and around Tasmania (see Slack, 1973; and papers in "The Biology and Resource Potential of Squids" Melbourne, March 1981). No estimate of real abundance (e.g. of potential yield) has been made.

Current knowledge of the distribution and abundance of arrow squid in Bass Strait is based on observations made from data provided by the Japanese jigging fleet during the 1979-80 season, when approximately 6500 tonnes of squid were landed by 62 vessels fishing between November 1979 and May 1980. Catch and effort data supplied by the Department of Primary Industry were analysed (see Mobley & Hyduke *in press* - appendix 1) for catch per unit effort (C.P.U.E.) estimates (tonnes per vessel-day). These monthly estimates of relative abundance mainly reflected the fleet distribution, rather than actual squid distribution, but did indicate consistently higher catch rates in western Bass Strait when compared with eastern Bass Strait. This is clearly indicated in the summary plot of C.P.U.E. for the whole season (Fig. 7). The area of highest catch rates appears as a tongue-like feature extending eastwards between King Island and North-west Tasmania, reminiscent of the chlorophyll *a* distribution, for that area, shown on Figs 5 and 6.

Commercial Fishes

The most important commercial marine fishes landed in Victorian ports are school shark *Galeorhinus australis* (Macleay), gummy shark *Mustellus antarcticus* (Gunther), snapper *Chrysophrys auratus* (Bloch & Sneider) tiger flathead *Neoplaytcephalus richardsoni* (Castelnau), gemfish *Rexea solandri* (Cuvier & Valenciennes), trevally *Usacaranx georgianus*, jackass morwong *Nemadactylus macropterus* (Bloch & Sneider), school whiting *Sillago bassensis* (Cuvier & Valenciennes), redfish *Centroberys affinis* (Gunther), and blue grenadier *Macruronus novaezelandiae* (Hector). Their general distributions in Victorian waters are given in Winstanley (1981) and are summarised for the shark fishery, trawl fishery and danish-seine fishery in the accompanying Figure 8 (T.I. Walker, *pers. comm.*).

The main edible sharks occur on the continental shelf and upper continental slope. Gummy shark is more abundant in coastal waters, especially eastern Bass Strait. School sharks have a similar distribution but dominate the catch from deeper waters (Fig. 8). Snapper are mainly caught by line and seine close to reefs and in coastal embayments. Tiger flathead, jackass morwong, and trevally are abundant in the outer shelf or continental slope, while gemfish and blue grenadier are caught by trawling mainly in deeper areas (200-600m) on the continental slope (Winstanley, 1981). Main and minor trawl grounds are shown in Fig. 8.

School whiting are caught by Danish-seining mainly in depths of 18-55m near Lakes Entrance (Fig. 8).

Also of note is the lightly exploited purse-seine fishery for anchovies *Engraulis australia antipodum* Gunther, and pilchards *Sardinops neopilchardus* (Steindachner). This is located off Lakes Entrance where fishing takes place between March and October during periods of calm seas. Although not a predator on arrow squid, anchovies usually occur in abundance in areas of nutrient enrichment, and their presence off Eastern Victoria indicates that the upwelling observed by Rochford (1977) and Gibbs (*pers. comm.*) may be a regular summer and/or winter feature in the region.

The distribution of the major trawl fisheries along the western boundary and to a larger extent, the eastern boundaries of Bass Strait may also be a reflection of enhanced biological productivity in these areas compared with shallower parts of Bass Strait.

Marine Mammals

Thirty-eight species of marine mammals have been recorded from south-eastern Australian waters (R. Warneke unpublished data, Tables 1 and 2). This list includes 25 species of whales, five species of dolphins, and eight species of seals. Three species of seals are resident in this region. The most abundant is the Australian fur seal *Arctocephalus pusillus* which has a population size of about 30,000. Most of the breeding colonies of Australian fur seals are in Victorian coastal waters and Bass Strait (Fig. 9). The most recent censuses indicate a total of 18000 to 21000 at breeding colonies. The total population would be greater than the sum of these counts, because a proportion is always at sea. For instance, at Seal Rocks (Victoria) shore counts are 5000-6000, but the pup count (c. 2000) multiplied by four (the estimate used for fur seals) gives a total population for Seal Rocks of c. 8000 (R. Warneke, *pers. comm.*).

TABLE 1. Cetaceans recorded in south-eastern Australia.

	Right whale	*Balaena glacialis* Müller
	Pygmy right whale	*Caperea marginata* (Gray)
	Blue whale	*Balaenoptera musculus* (Linnaeus)
*	Fin whale	*Balaenoptera physalus* (Linnaeus)
*	Minke whale	*Balaenoptera acutorostrata* Lacépède
*	Sei whale	*Balaenoptera borealis* Lesson
	Bryde's whale	*Balaenoptera edeni* Anderson
	Humpback whale	*Megaptera novaeangliae* (Borowski)
*	Sperm whale	*Physeter macrocephalus* Linnaeus
*	Pygmy sperm whale	*Kogia breviceps* (de Blainville)
*	Dwarf sperm whale	*Kogia simus* Owen
*	Southern bottle-nosed whale	*Hyperoodon planifrons* Flower
*	Cuvier's beaked whale	*Ziphius cavirostris* Cuvier
*	Gray's beaked whale	*Mesoplodon grayi* van Hast
*	Strap-toothed whale	*Mesoplodon layardii* (Gray)
*	Andrew's beaked whale	*Mesoplodon bowdoini* Andrews
*	Hector's beaked whale	*Mesoplodon hectori* (Gray)
*	Dense beaked whale	*Mesoplodon densirostris* (de Blainville)
*	True's beaked whale	*Mesoplodon mirus* True
*	Arnoux' beaked whale	*Berardius arnuxi* Duvernoy
*	Shepherd's beaked whale	*Tasmacetus shepherdi* Oliver
*	Killer whale	*Orcinus orca* (Linnaeus)
*	False killer whale	*Pseudorca crassidens* (Owen)
*	Pilot whale	*Globicephala melaena* (Traill)
*	Short-finned pilot whale	*Globicephala macrorhynchus* Gray
*	Risso's dolphin	*Grampus griseus* (Cuvier)
	Bottle-nosed dolphin	*Tursiops truncatus* (Montague)
*	Common dolphin	*Delphinus delphis* Linnaeus
*	Southern right whale dolphin	*Lissodelphis peroni* (Lacépède)
*	Frazer's dolphin	*Lagenodelphis hosei* Frazer

* Feeds on squid, usually in addition to fish

TABLE 2. Pinnipeds recorded in south-eastern Australia.

Resident species	
Australian fur seal	*Arctocephalus pusillus* (Schreber)
New Zealand fur seal	*Arctocephalus forsteri* (Lesson)
Australian sea lion	*Neophoca cinerea* (Peron)
Common visitors	
Southern elephant seal	*Mirounga leonina* (Linnaeus)
Leopard seal	*Hydrurga leptonyx* (de Blainville)
Extra-limital records	
Crabeater seal	*Lobodon carcinophagus* (Hombron & Jacquinot)
Weddell seal	*Leptonychotes weddelli* (Lesson)
Ross seal	*Ommatophoca rossi* Gray

The present distribution and abundance around south-eastern Australia of whales and dolphins is poorly known. Recent observations (e.g. Patterson 1982, Warneke *pers. comm.*) indicate that, for some species, numbers are recovering after extensive exploitation. For, example, up to nine southern right whales have been seen in nearshore waters of western Bass Strait during the 1982 winter. This is the third consecutive winter this species has returned to the area after an absence of almost 100 years.

Seabirds

There is no comprehensive survey of all colonies of seabirds for south-eastern Australia. A study of the distribution and status of 12 common species was undertaken by Harris and Norman (1981). The two most abundant species were short-tailed shearwaters *Puffinus tenuirostris* (1.45 million burrows in Victorian colonies) and little penguins *Eudyptula minor* (20,000 nest sites in Victorian colonies). The distribution of these colonies is shown in Fig. 10. Other species likely to be predators on squid are Australasian gannets *Morus serrator* and white-capped mollymawks *Diomedea cauta*. Gannets occur in small numbers (1500 occupied nests, c. 3000-4000 birds) in Victorian colonies, with a similar number around Tasmania. White-capped mollymawks breed in Bass Strait and off southern Tasmania (Serventy *et al.* 1971) with a population estimated to be about 5,500 breeding pairs (I. Skira, *pers. comm.*). White-capped mollymawks are commonly seen around shark vessels, when offal is being discarded (T. Walker *pers. comm.*).

Short-tailed shearwater colonies are found throughout south-eastern Australia from N.S.W. through Victoria to South Australia, and around Tasmania. Most of the colonies are on Tasmanian islands (c. 13 million burrows), while the 1.45 m. burrows in Victorian colonies are mainly around Wilsons Promontory and on Phillip Island (Fig. 10).

Little penguins occur and breed in south-eastern Australian colonies from north of Port Stephens (32.5^{o}S latitude) through Victoria, and South Australia and Tasmania. About 9% of the colonies are on the Victorian coast and the others mainly around Tasmania. The total of 82 colonies in south-east Australia (Serventy *et al.* 1971) probably contain about 150,000 burrows.

THE IMPORTANCE OF ARROW SQUID IN THE DIETS OF MAJOR PREDATORS

Arrow Squid

From an analysis of stomachs of approximately 1300 specimens of arrow squid *Nototodarus gouldi* collected by D. O'Sullivan (Monash University) from Japanese jigging vessels in Bass Strait from November 1979 to April 1980, it was found that crustaceans, fish and cephalopods predominated. Crustaceans were commoner in smaller squid and cephalopods in larger ones. The crustaceans which included several benthic species, were commoner in the diet at night than by day. In the diet, averaged over all sizes samples and including empty stomachs, fish occurred in 37 per cent, crustaceans in 32 per cent, and squid in 26 per cent of stomachs examined (Table 3). In terms of biomass, fish were considerably more important. Ninety per cent of the squid identified from stomachs were *Nototodarus gouldi*; That is, arrow squid are cannabilistic, a feature common for other species of cephalopod. Thus arrow squid provide 24% by frequency of occurrence, but 10-15% by weight of their own diet. From the size of the beaks of squid taken it could be shown that the mantle length of the prey was usually not more than half that of the predator. *N. gouldi* feeds primarily at night, probably moving up from the bottom into the watercolumn (O'Sullivan and Cullen *in press*).

TABLE 3. Number and frequency of occurrence of major food items in the diets of 1277 arrow squid (912 of which contained food) from Bass Strait (Data from O'Sullivan & Cullen *in press*).

Food Category	No.	% Total (n=1277)	% Feeding (n=912)
Crustacean	409	32.0	44.8
Fish	475	37.2	52.1
Cephalopod	344	26.9	37.7
Other	131	10.3	14.4
Empty	365	28.6	-

Commercial Fishes

The diets of fifty-two species of fish, taken from Bass Strait and adjacent areas of the Southern Ocean and the Tasman Sea, were investigated through examination of stomach contents (Coleman 1982 - report appended). Particular emphasis was placed on estimating the importance of arrow squid, *N. gouldi*, in the diets of the species investigated.

Cephalopods were found in the diets of twenty-one species. In general, octopus appeared to be a more significant item in the diet than did squid. By comparison with squid, octopus occurred with greater frequency, were proportionately better represented in the diet and gave higher values of the Index of Relative Importance.

Arrow squid was positively identified from the diets of eight species; gummy shark *Mustelus antarcticus*, whiskery shark *Furgaleus ventralis*, school shark *Galeorhinus australis*, saw shark *Pristiphorus* spp., John Dory *Zeus faber*, gemfish *Rexea solandri*, Yellowfin *Thunnus albacares* and southern bluefin tuna *Thunnus maccoyii*. A further seven species are at least potential consumers of arrow squid; toothed whiptail *Lepidorhynchus denticulatus*, toothy flathead *Neoplatycephalus speculator* and albacore *Thunnus alalunga* had stomach contents which could only be identified as squid or as ommastrephid squid; and endeavour dogfish *Centrophorus scalpratus*, piked dogfish *Squalus megalops*, elephant shark *Callorhynchus milii* and deepwater flathead *Platycephalus conatus* had stomach contents which could be identified only as cephalopods. In none of the species examined was arrow squid found to be a major component of the diet. In gummy and school sharks, which are probably the main predators, arrow squid accounted for an average of only 4 - 6% (by number, weight or volume) of the diet.

Marine Mammals

Whales and dolphins are known to be major consumers of squid. R. Warneke (*pers. comm.*) lists 24 species of cetaceans from south-eastern Australian waters which feed on squid usually in addition to fishes (Table 1). The most abundant marine mammal in this area, the Australian Fur Seal, is also known to eat squid.

Information on the diet of the Australian Fur Seal has been derived from reports from the fishing industry (FWD files, oral reports) and examination of the contents of stomachs (Lewis, 1929; Tubb and Brazenor, 1937; McNally and Lynch, 1951; R. Warneke, unpublished data). It is evident that a wide range of organisms are eaten, including surface, mid-water and bottom-dwelling species (Table 4). These data are essentially qualitative, as the few stomachs examined have been from animals shot on land, with the result that the contents, if any, are generally in an advanced state of digestion or merely the indigestible remnants of one or more feeding periods. No volumetric analysis of undigested or slightly digested contents is available.

Reports from fishermen indicate that shoaling species of fish such as snoek, salmon, pilchards and horse mackerel are commonly taken, depending on local and seasonal abundance. Other species, such as parrot fish, leatherjackets, rock cod and flathead appear to be frequently taken and probably are largely incidental in the diet. Of the deep water fishes, ling is said to be much favoured by seals.

Lewis (1929) presented data from 77 seals shot at Seal Rocks and Lady Julia Percy Island. Only 18 stomachs yielded identifiable food items, which provide a crude frequency of occurrency of fish, cephalopods, and crustaceans in the diet (Table 5).

TABLE 4. Prey of the Australian Fur Seal

Fish

Snoek	*Leionura*
Salmon	*Arripis*
Horse mackerel	*Trachurus*
Mackerel	*Scomber*
Ruff	*Arripis*
Yellow tail	*Seriola*
Hake	*Rexea*
Pilchard	*Sardinops*
Garfish	*Hemiramphus*
Parrot fish	*Pseudolabrus*
Whiting	*Sillaginodes*
Red mullet	*Upeneichthys*
Snapper	*Chrysophrys*
Ling	*Genypterus*
Rock Cod	*Physiculus*
Flathead	*Platycephalus*
Mullet	*Mugil*
Snook	*Australuzza*
Leatherjackets	F. Aluteridae
Gurnards	F. Trigilidae

Cephalopods

Squid	*Nototodarus, Sepiotheuthis*
Cuttlefish	*Sepia*
Octopus	*Octopus*

Crustaceans

Rock Lobster	*Jasus*
Crabs	

TABLE 5. Number and frequency of occurrence of fish, cephalopods and crustaceans in the diet of the Australian fur seal (Data from Lewis, 1929).

	Occurrence in stomachs	Percentage occurrence (in 18 stomachs)
Fish	16	89
Cephalopods	7	39
Crustaceans	2	11

These data suggest a major dependence on fish and a significant dependence on cephalopods (mainly squid), however the relative number of individual fish and cephalopods in 3 stomachs suggest that this analysis of such a small series has over-emphasised the importance of fish.

McNally and Lynch (1951) presented data from a sample of 241 seals shot between August 1948 and May 1949. 108 stomachs were empty and of the remaining 139, 126 contained identifiable food items. Unfortunately their data cannot be interpreted in a way comparable with that of Lewis (1929), however crude minimum frequencies of occurrence can be extracted (Table 6).

The relatively high proportion of crustacea (rock lobster) is due to the presence of remains in 37 of 68 stomachs containing food, from seals shot in November.

It is clear from a comparison of Tables 4 and 5 that, as for the fish study, it is difficult to draw conclusions about food preferences when quantitative measures of food items are lacking and when seasonal variation in food availability and selection cannot be assessed.

At the present time it can be said that the Australian fur seal is a catholic feeder, preying on surface, mid-water and bottom-dwelling organisms. Shoaling species of fish and cephalopods would appear to be most vulnerable to such a predator and appear to be staple in its diet.

Recoveries of seals from rock lobster pots, nets, lines and trawls reveal that this species frequently descends to a depth of 50 fathoms and may possibly hunt a depth of 150 fathoms or more.

Reference should be made to a larger and more satisfactory body of data on the diet of this species in South African waters (Rand, 1959). Although this population is geographically isolated from that in Australian waters

TABLE 6. Minimum number and frequency of occurrence of fish, cephalopods and crustaceans in the diet of the Australian fur seal (Data from McNally and Lynch, 1951).

	Occurrence in stomachs	Percentage occurrence (in 126 stomachs)
Fish	16	13
Cephalopods	27	8
Crustaceans	41	33

the two are virtually identical in most aspects of their natural history. Rand's data on diet indicates that the South African fur seal also feeds on a wide variety of surface, mid-water and bottom-dwelling organisms and in many cases the prey species are the same or similar to those recorded in the diet of the Australian fur seal.

Rand's analyses indicate that the diet of the South African fur seal, in terms of frequency of occurrence, is 50% fish, 37% cephalopods and 13% crustaceans. Volumetric analysis however gives a much more reliable measure of relative intake, which is 70% fish, 20% cephalopods and 2% crustaceans. To obtain comparative data on intake by the Australian fur seal would require extensive sampling of seals at sea, but this has never been done.

Seabirds

Short-tailed shearwaters migrate to the North Pacific Ocean in March-May, returning to the breeding rounds in September-October. The diet comprises crustacea (mainly euphausids *Nyctiphanes australis*), small pelagic fish such as anchovies *Engraulis australis* and small cephalopods (Serventy, *et al.* 1971). Stomach samples collected by Mr. I. Skira (Tasmania National Parks and Wildlife Service) contained some squid, about half of which were identified as juvenile *N. gouldi* (Mr. M. Imber, N.Z. Wildlife Division, *pers. comm.*). Squid occurred in 116 of 396 stomachs (i.e. 29.3%) examined by Skira (Table 7); 82 birds contained only one squid, 20 birds had 2 squid and the rest had 3 - 10 squid per stomach. The main food of the short-tailed shearwaters was the euphausid *N. australis*. The general impression given by Skira is that arrow squid comprise a regular but small proportion of their diet. No sampling was done in colonies of short-tailed sheartwaters in north-western Tasmania (where squid fishing has mainly occurred to date).

TABLE 7. Monthly variation in occurrence (numbers) of stomach samples and major food items in the diet of short-tailed shearwaters *P. tenuirostris* from Tasmania. (December 1978 - April 1980). (Data from Mr. I. Skira, Tasmanian National Parks & Wildlife Service.)

Month Totalled over period	No.	Occurrence (No.) Crustacea	Squid	Fish
January	52	34	11	10
February	60	21	22	19
March	49	22	17	9
April	29	23	10	9
September	39	33	8	0
October	78	69	21	0
November	-	-	-	-
December	89	20	27	6
TOTALS	396	222	116	53

The diet of the closely related New Zealand sooty shearwaters *P. griseus* also included a similar proportion of arrow squid *N. sloani*, in areas near one of the main New Zealand squid fishing grounds. (M. Imber, *pers. comm.*)

Studies undertaken at Monash University on the diet of little penguins from the colony on Phillip Island show that arrow squid occurred in about 30% of the regurgitations examined (Table 8).

The penguins main diet species were anchovies and pilchards, which occurred in 56% and 51% of stomachs respectively, and comprised the major portion of the diet by weight and numbers of individuals. The penguins held a maximum of ten arrow squid per stomach. The squids consumed were juveniles with a maximum dorsal mantle length of 5 cm. Although the squid were the third most frequently occurring species of prey taken, they comprised only 10-15% of the diet by weight. (T. Montague, Monash University, *pers. comm.*).

The diet of white-capped mollymawks at Australian colonies has not been examined in detail. On Albatross Island in Bass Strait fish and squid are recorded as being of approximately equal importance. Only one species of squid *N. gouldi* was identified, while cuttlefish are also eaten (Green, 1974). However, in New Zealand *Diomedea cauta* mollymawks eat juvenile and sub-adult arrow squids, but the proportion does not exceed 30% of squid eaten; that is, less than 10-20% of the total diet. (M. Imber, *pers. comm.*).

DISCUSSION

This review of existing information on the hydrology and circulation of Victorian coastal waters and the distribution and abundance of arrow squid and their potential predators is necessarily brief. A number of scientific studies on the physical, chemical and biological oceanography of Bass Strait are being co-ordinated by the Victorian Institute of Marine

TABLE 8. Monthly variation in occurrence (numbers) of stomach samples and major food items of little penguins *E. minor* from Phillip Island, Victoria (July 1979 - May 1981). (Data from Mr. T. Montague, Monash University, Melbourne).

Month totalled over period	No. of stomachs	No. with Food	No. with Fish	No. with Cephalopods	No. with Gould's Squid
January	63	37	37	5	3
February	68	46	46	14	9
March	60	51	49	8	7
April	88	59	59	23	16
May	81	64	64	24	22
June	38	22	19	8	3
July	30	18	13	10	9
August	59	25	24	8	6
September	50	38	38	12	10
October	81	67	66	23	17
November	46	29	29	23	19
December	157	80	80	59	43
TOTALS	821	536	524	217	164
AS PERCENTAGE OF STOMACHS WITH FOOD			97.8	40.5	30.6

Science (V.I.M.S.) and numerous reports are in preparation. It was not my wish to pre-empt the publication of the results of these studies.

However, it seems clear that biological processes are taking place at the western and eastern entrances to Bass Strait, which result in enhancement of nutrient levels and increased productivity of surface waters near and within the Strait. The circulation is not fully understood. Detailed examination of sea-surface phenomena from satellite-derived images is beginning to provide clear pictures of complex current systems. (See, for example, the tongues of cool, northward flowing subantarctic water (indicated by lighter shades) off the west coast of Tasmania on the frontispiece to this report.)

The known distribution of arrow squid indicates that this species is more abundant at the western approaches to Bass Strait, while demersal fisheries are mainly concentrated to the east of Bass Strait, south and east of Lakes Entrance. On the one hand there are indications that surface and mid-water feeding arrow squid are utilizing the enhanced production in the food chain from possible upwellings off north-west Tasmania, together with productive waters carried westward through Bass Strait in summer. Demersal fishes, on the other hand, are concentrated in areas where they would utilize production from upwellings at eastern Bass Strait carried to the bottom and over the edge of the continental shelf on the cascade postulated by Godfrey *et al.*

The major colonies of the two most abundant species of seabirds (short-tailed shearwaters and little penguins), and of Australian fur seals, are in Bass Strait, generally close to the north-western or north-eastern approaches to the Strait. Although their distributions are a function of cold-water adaptation and availability of suitable substrates there must also be an association with the distribution and regular occurrence of some enhanced productivity of these waters compared with other areas of Australia.

Although there is room for considerable expansion of the breeding population of the Australian fur seal in Bass Strait (traditional sites still vacant from the sealing era), the present population is remarkably stable and appears to have been in this state of static equilibruim for at least 30 years. The reasons for this stability are not known but some degree of equilibrium with its food resource may be involved.

The dietary studies, although limited, all indicate that arrow squid are not an item of major importance to any species of marine mammal, seabird or fish in Bass Strait. Arrow squid occur regularly in the diets of the more abundant species, but never comprise more than 20% of the diet by weight, and usually less than 10-15%. Apart from the diets of the larger predators (marine mammals and sharks) the arrow squid taken were usually juveniles less than 5 cm in dorsal mantle length. (Commercial jigging vessels catch squid of 14-35 cm dorsal mantle length). That is, they are taken at a time in their life history when natural mortality is high. The study by O'Sullivan and Cullen (*in press*) shows that because of their cannibalistic nature, arrow squid are perhaps their own major predator.

It is not possible nor advisable to speculate on the quantity of arrow squid required to maintain the diets of their predators. Coleman (report appended), has shown that in his extensive survey of fishes, the dietary diversity is so great for any consumer of squid, that the absence of squid would not inconvenience the predator because it could turn to numerous other food items. The details of the trophic interrelationships of squid and other species of the demersal, mid-water and pelagic food chains in Bass Strait are not yet delineated.

It is concluded that, because of the relatively low incidence of arrow squid in the diets of any species, it is unlikely that increased human exploitation of arrow squid will be detrimental to the populations of these predators in Bass Strait.

RECOMMENDATIONS FOR FUTURE RESEARCH

This desk study, although brief and very generalized, has highlighted the importance of Bass Strait in the biological productivity of south-eastern Australian waters. Enhanced productivity at eastern and western approaches to Bass Strait provide a food source for many marine mammals, seabirds, squid and fishes. There is a need for better definition of water masses in the area (such as the origin of "North Bass Strait Water"). There is also a need for studies on small-scale transient phenomena, at the shelf margins and in south central Bass Strait, which appear to be associated with nutrient enrichment. However, it would be unwise to proceed to further detailed scientific field studies of the area until the present collections from physical chemical and biological studies are published and evaluated.

The use of satellite imagery to locate and follow spring and summer upwellings in the area is a vital and essential step towards more comprehensive work on the productivity of Bass Strait and surface water of south-eastern Australia. Monitoring of sea-surface isotherms, surface chlorophyll, and perhaps surface fish shoals, will be a necessary prerequisite for a study on the fisheries potential of the area.

If exploitation of the arrow squid is to proceed, it will be necessary to make more detailed studies on the diets of species shown above to be predators of squid. The dietary analyses should investigate factors (e.g. relative sizes of predator and prey; locality of predator; vertical distribution; seasonal and diurnal behaviour) expected to influence the occurrence of squid in their diets, and should consider energetic as well as gravimetric, volumetric and frequency of occurrence parameters.

The Australian fur seal is one predator which might be affected by changes in squid abundance, because they are directly compete for the same size groups of squid as the commercial fleets. The major seal colonies should be monitored to allow early detection of changes in numbers.

Historical catch results by foreign jigging fleets have indicated that up to at least 6500 tonnes of arrow squid are available each year from south-east Australian waters. The distribution and abundance of arrow squid is known only from limited observations on commercial vessels during their fishing seasons. These observations suggest that arrow squid is the largest single-species fishery resource in south-east Australian waters. Utilization of this resource will largely be dependent on a carefully designed program aimed at determining the abundance and availability of arrow squid, and their vulnerability to various fishing methods. Such a program should include both research and industry components. As this study has indicated that squid are not of exclusive importance in the diets of the marine fauna, further human exploitation is possible.

ACKNOWLEDGEMENTS

The following people kindly made available much unpublished material. I am grateful for their co-operation and willingness in providing the data. For short-tailed shearwaters Mr. I. Skira of the Tasmanian National Parks & Wildlife Service provided basic summaries of stomach contents; for little penguins Professor M. Cullen and Mr. T. Montague of Monash University provided stomach sample analyses; Mr. M.J. Imber of the New Zealand Wildlife Service identified some stomach samples from Australian seabirds and provided comparative data from similar New Zealand species; for arrow squid

Professor M. Cullen and Mr. D. O'Sullivan, Monash University, provided unpublished data; for marine mammals Mr. R.M. Warneke provided unpublished distribution data, and the analysis of fur seal stomachs; Mr. E.P. Hyduke, Marine Science Laboratories, provided squid C.P.U.E. data; Mr. T.I. Walker, Victorian Fisheries & Wildlife Division, provided the map of marine fish distributions for Victoria; Dr. C.F. Gibbs, Marine Science Laboratories, provided physical and chemical data from Bass Strait; Mr. M. Dunning, C.S.I.R.O., Cronulla, provided the satellite image reproduced in the frontispiece.

I am indebted to the above and to Mr. J. Thompson and Mr. M. Marsden (V.I.M.S.) and Dr. D. Rochford (C.S.I.R.O., Cronulla) for invaluable advice, literature references and constructive comment.

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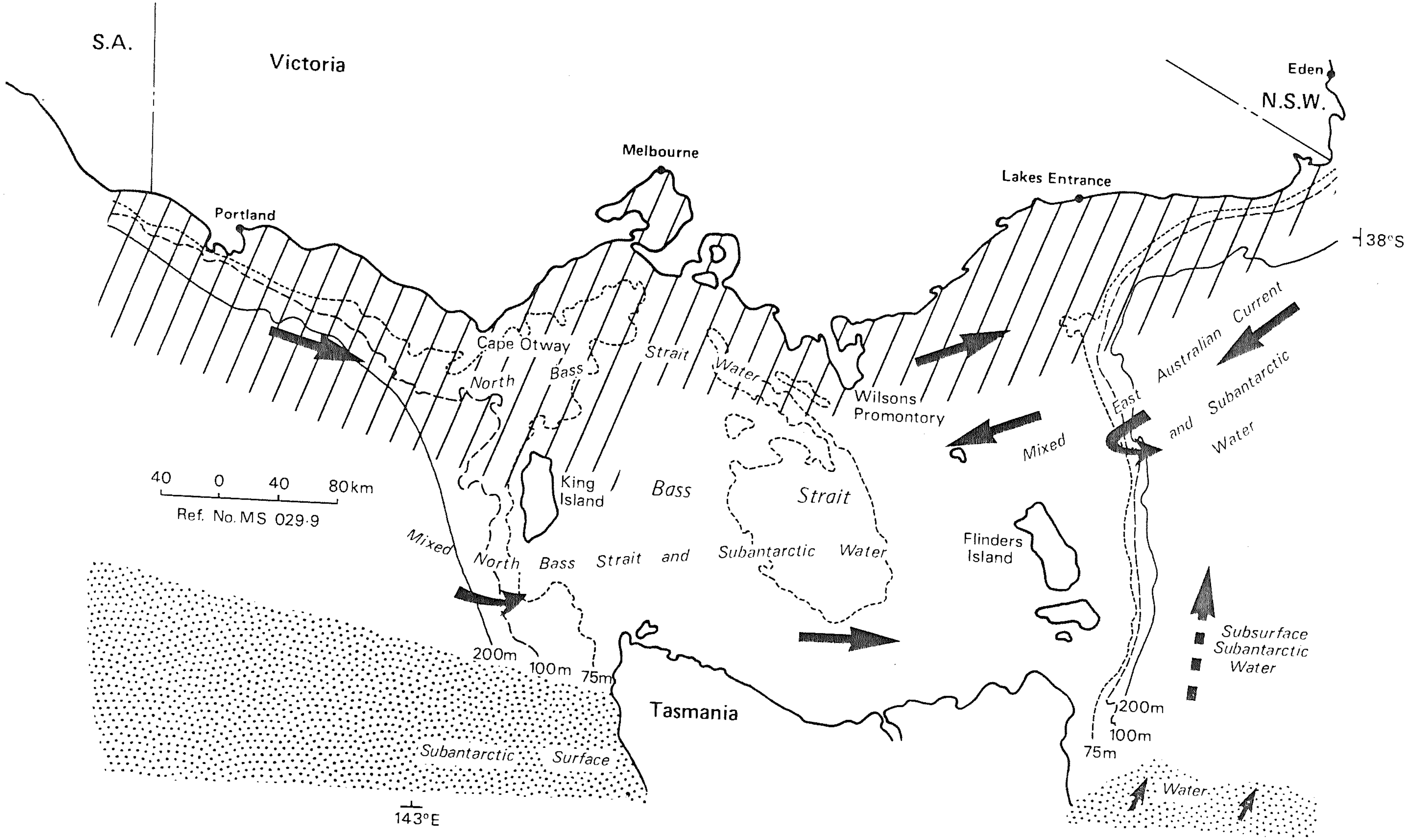

Fig. 1 Generalized winter surface circulation in Bass Strait, modified from Rochford 1975. Irregular small-scale variations may occur depending on wind and pressure stresses.

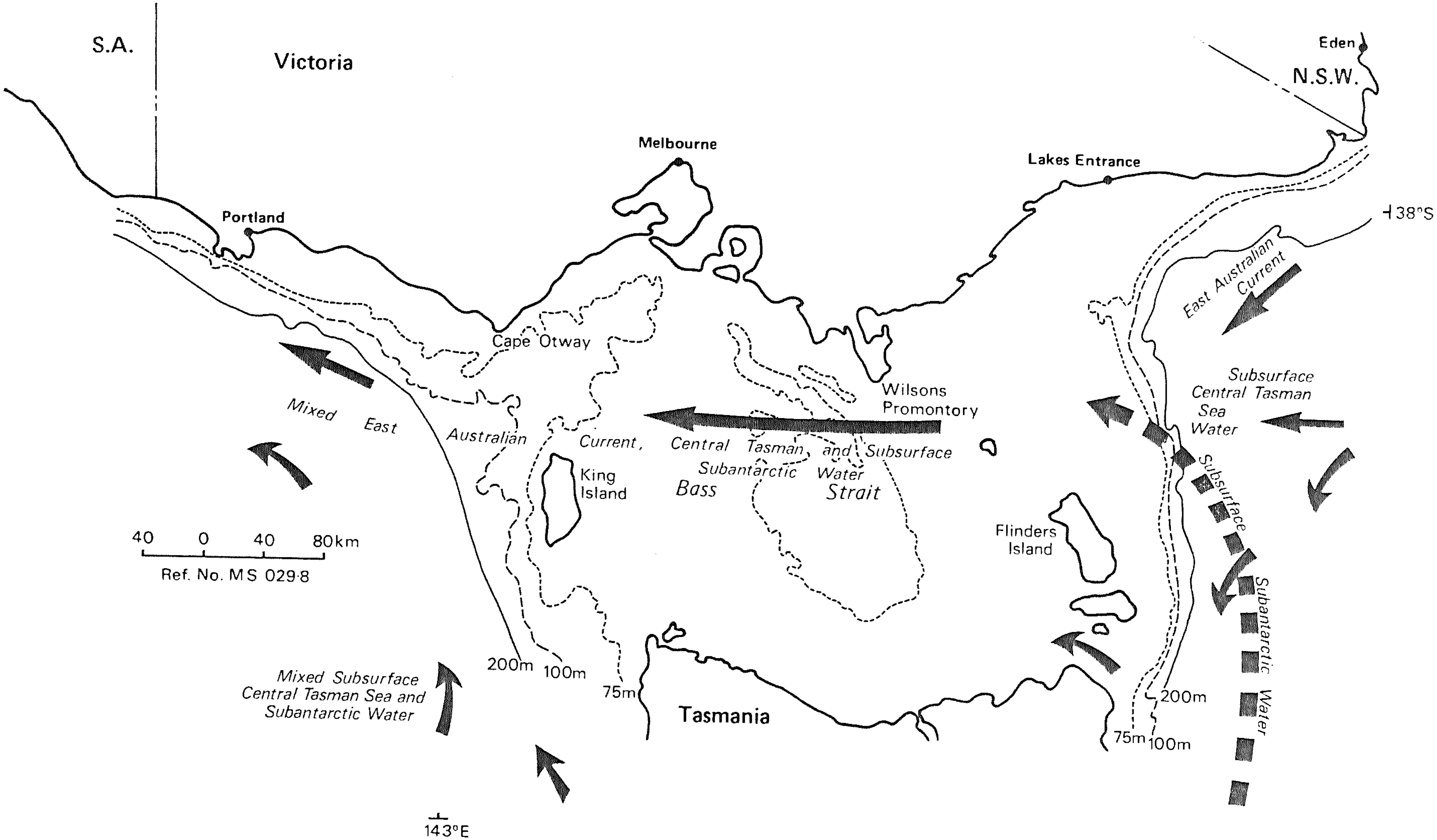

Fig. 2 Generalized summer surface circulation in Bass Strait, modified from Rochford 1975. Irregular small-scale variations may occur depending on wind and pressure stresses.

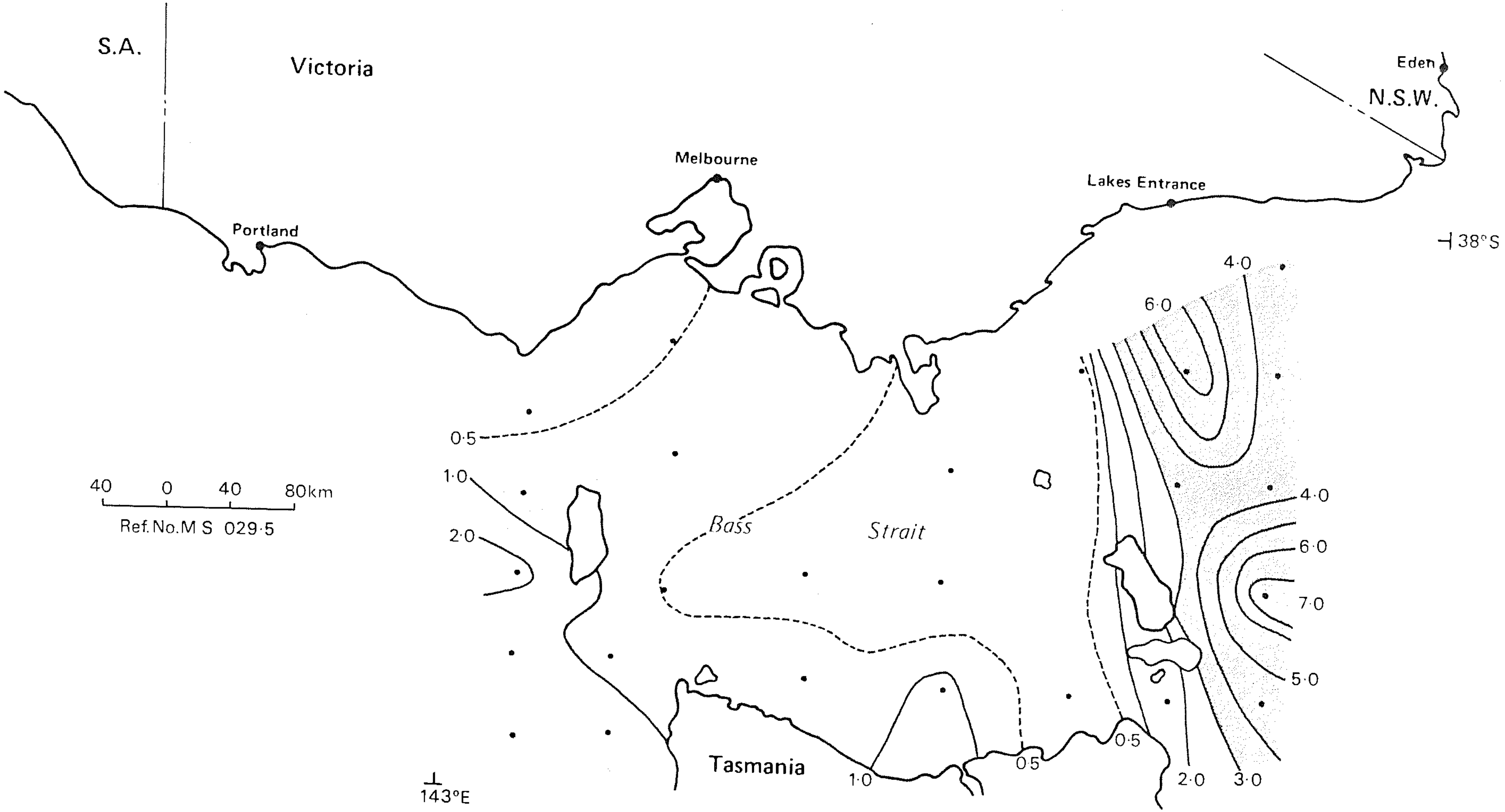

Fig. 3 Winter surface nitrate (μg at ℓ^{-1}) values in Bass Strait, July 1980. (C.F. Gibbs, *pers. comm.*)

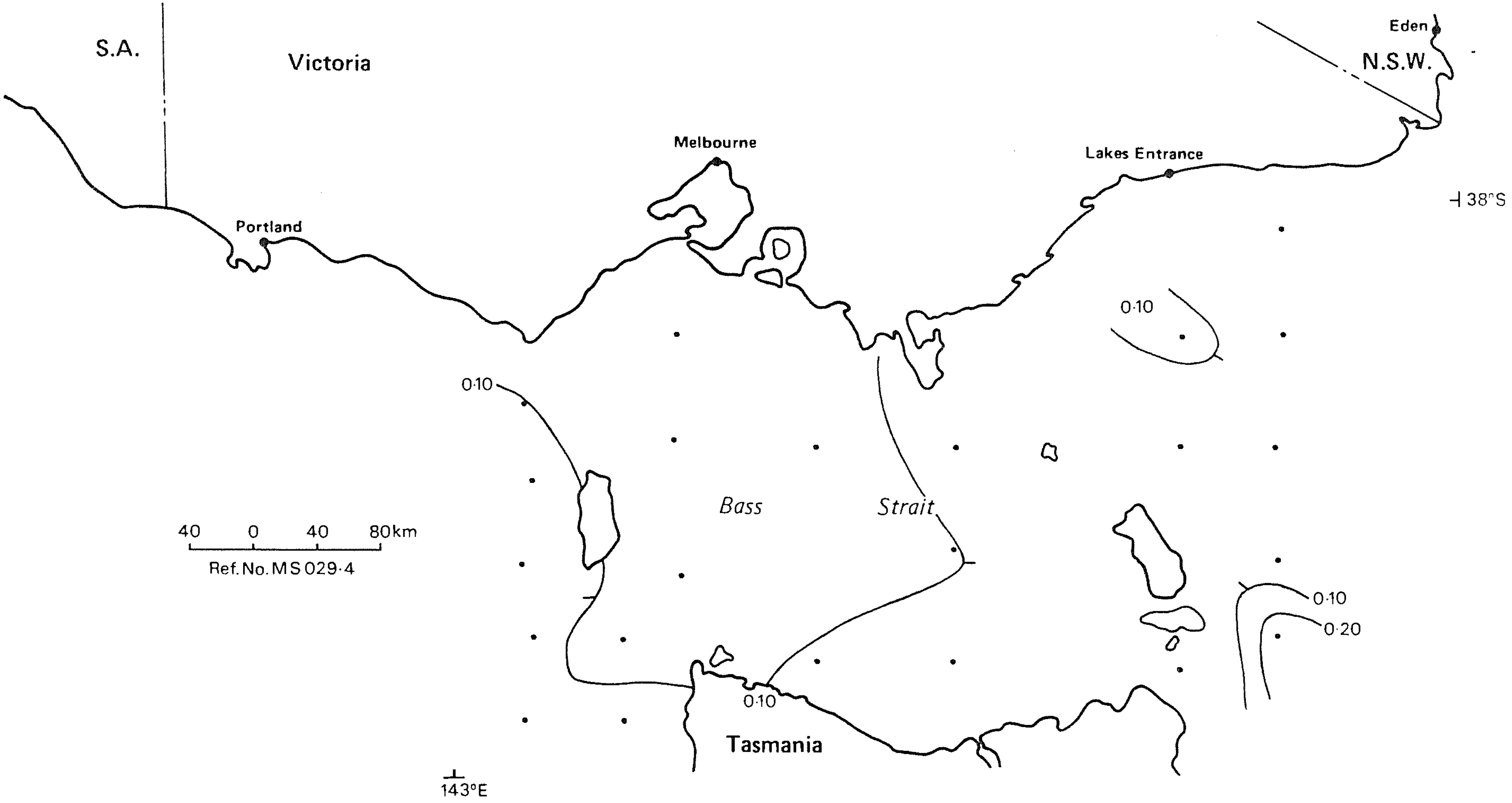

Fig. 4 Summer surface nitrate (μg at ℓ^{-1}) values in Bass Strait, January 1980. (C.F. Gibbs, *pers. comm.*)

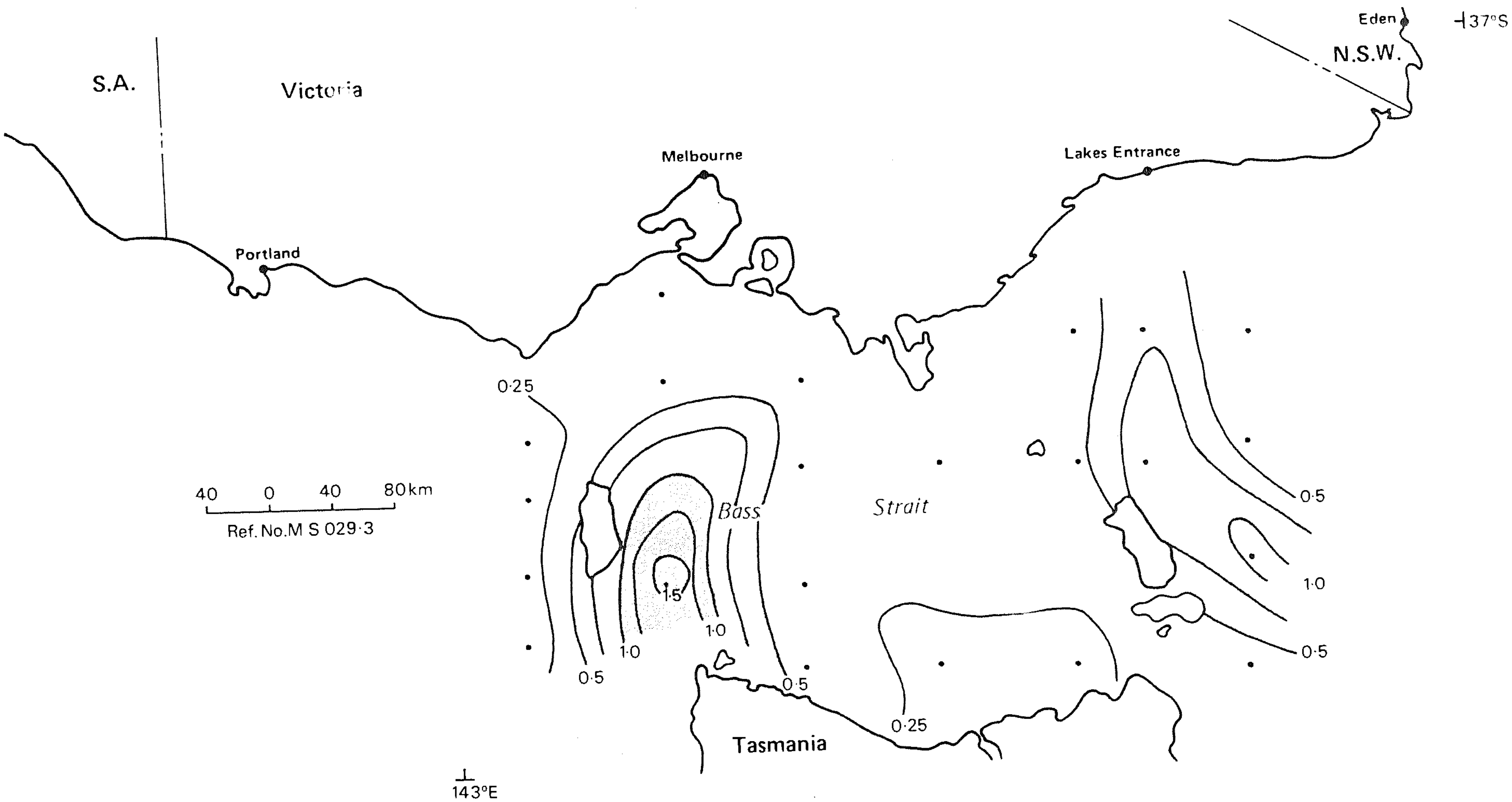

Fig. 5 Winter surface chlorophyll a (μg at ℓ^{-1}) values in Bass Strait, August 1980. (C.F. Gibbs, *pers. comm.*)

CHLOROPHYLL LEVELS – SUMMER

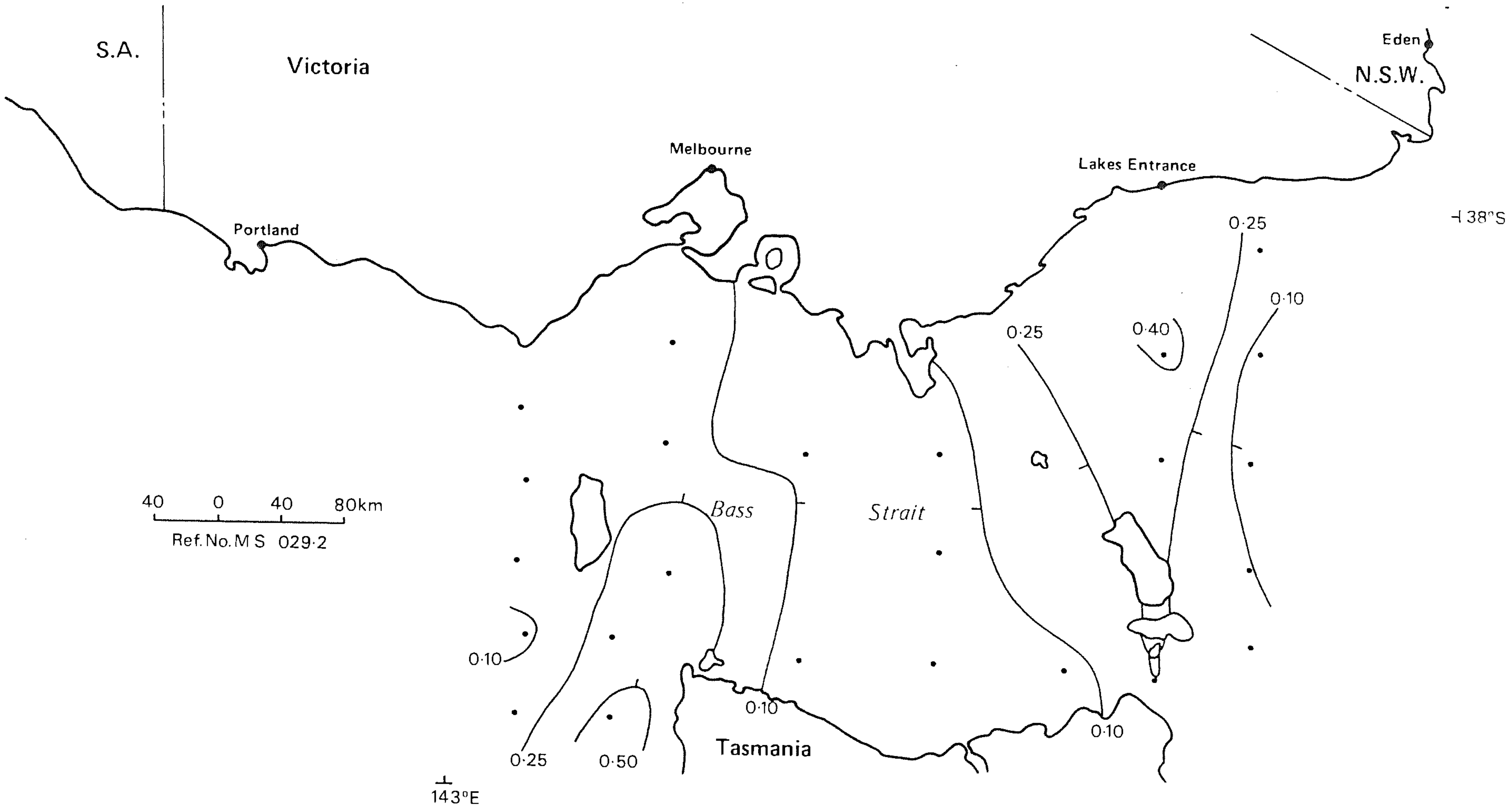

Fig. 6 Summer surface chlorophyll a (μg ℓ^{-1}) values in Bass Strait, January, 1980. (C.F. Gibbs, *pers. comm.*)

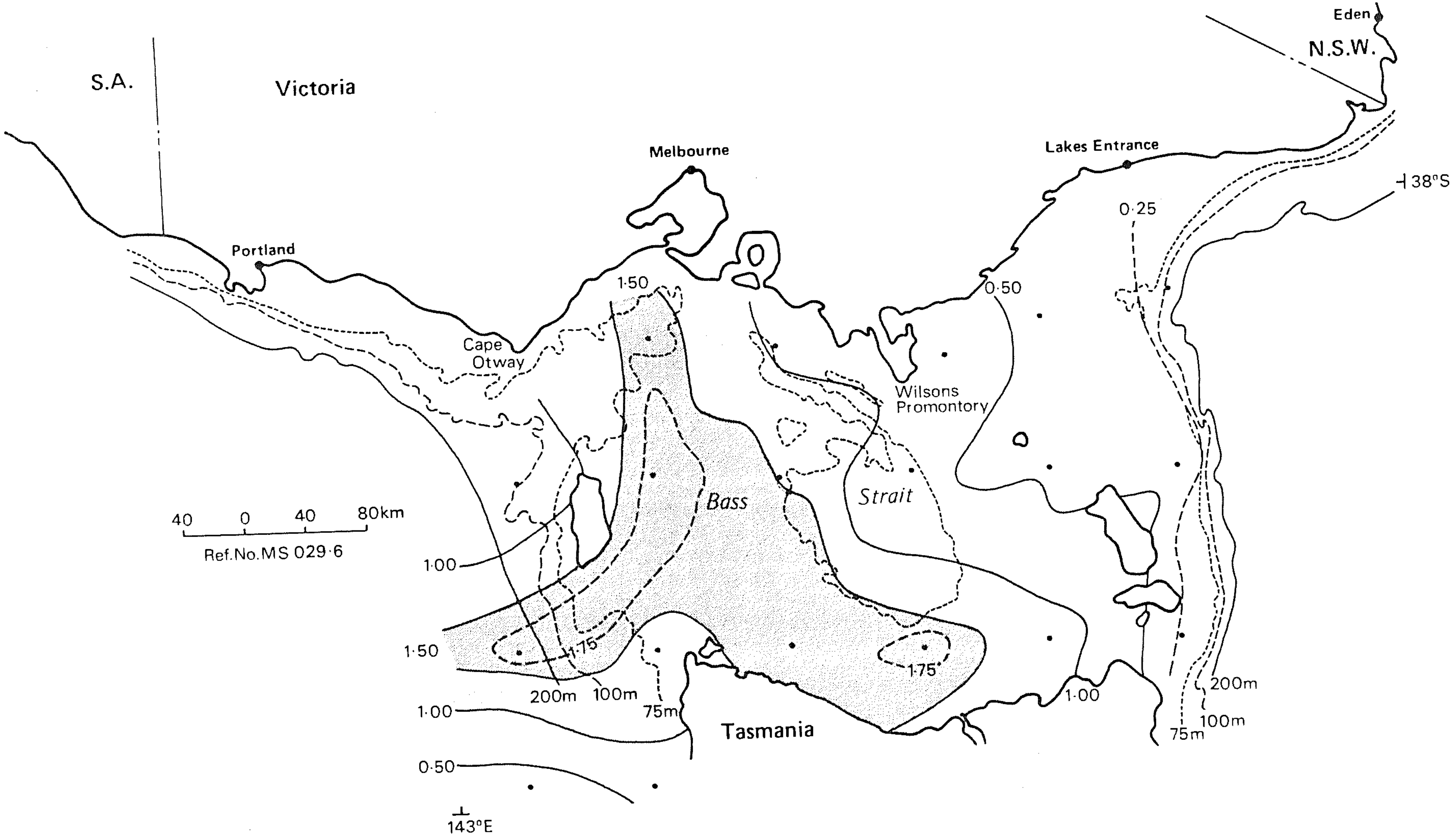

Fig. 7 Distribution and abundance (tonnes: vessel-day^{-1}) of arrow squid caught by the Japanese jig fleet during the 1979/80 season. Data are averaged by 1^{o} squares of latitude and longitude for the period 11/79 - 5/80. (Total catch 5405 tonnes, 3349 vessel-days, 1.6 tonnes-vessel-day^{-1}). (Analysed by E.P. Hyduke, Marine Science Laboratories, from data supplied by D.P.I., Canberra.)

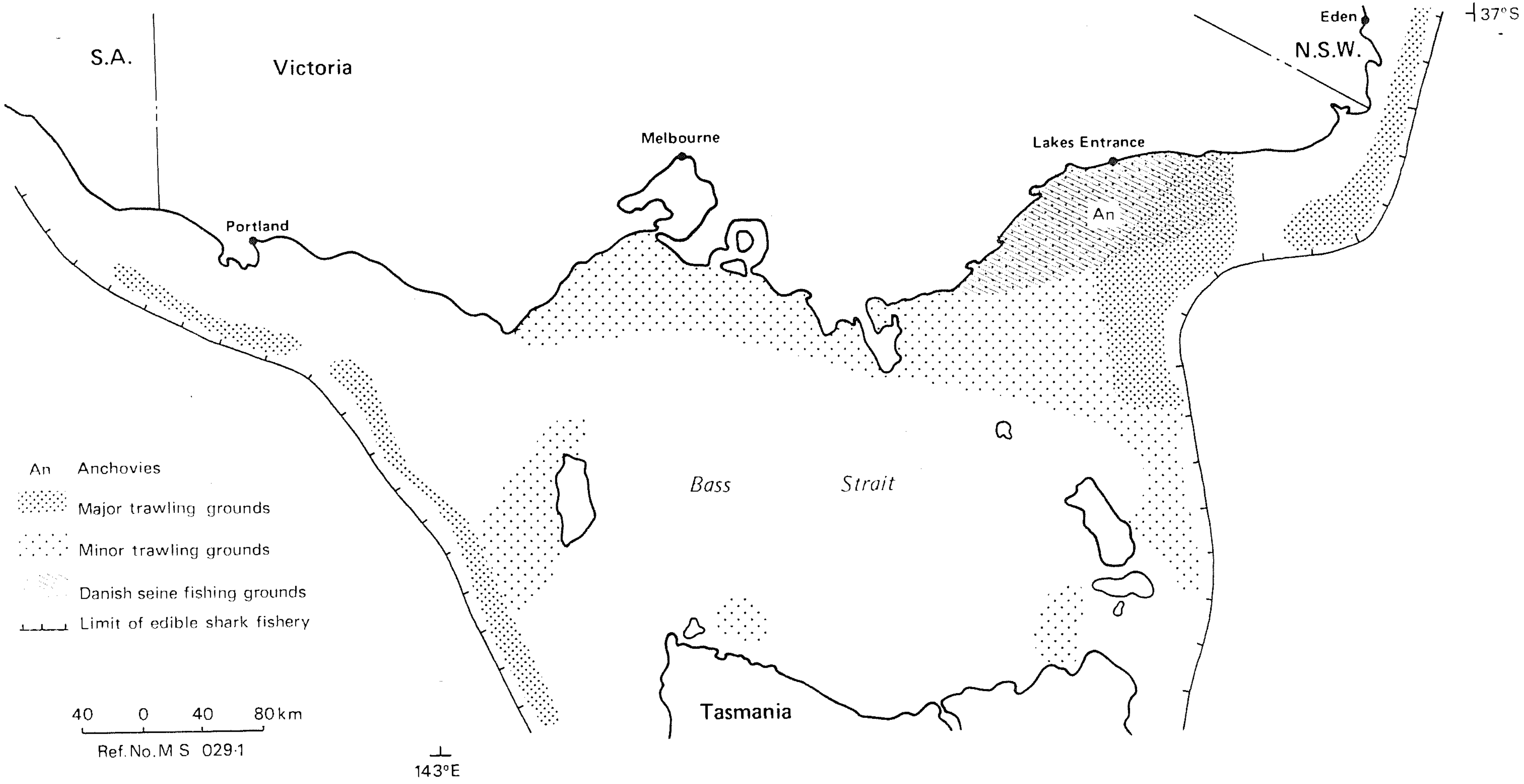

Fig. 8 Distribution of main Victorian trawling, Danish-seining and shark fishing grounds. Anchovy fishing ground off Lakes Entrance is also indicated. (From map supplied by T.I. Walker, Fisheries & Wildlife Division, Victoria.)

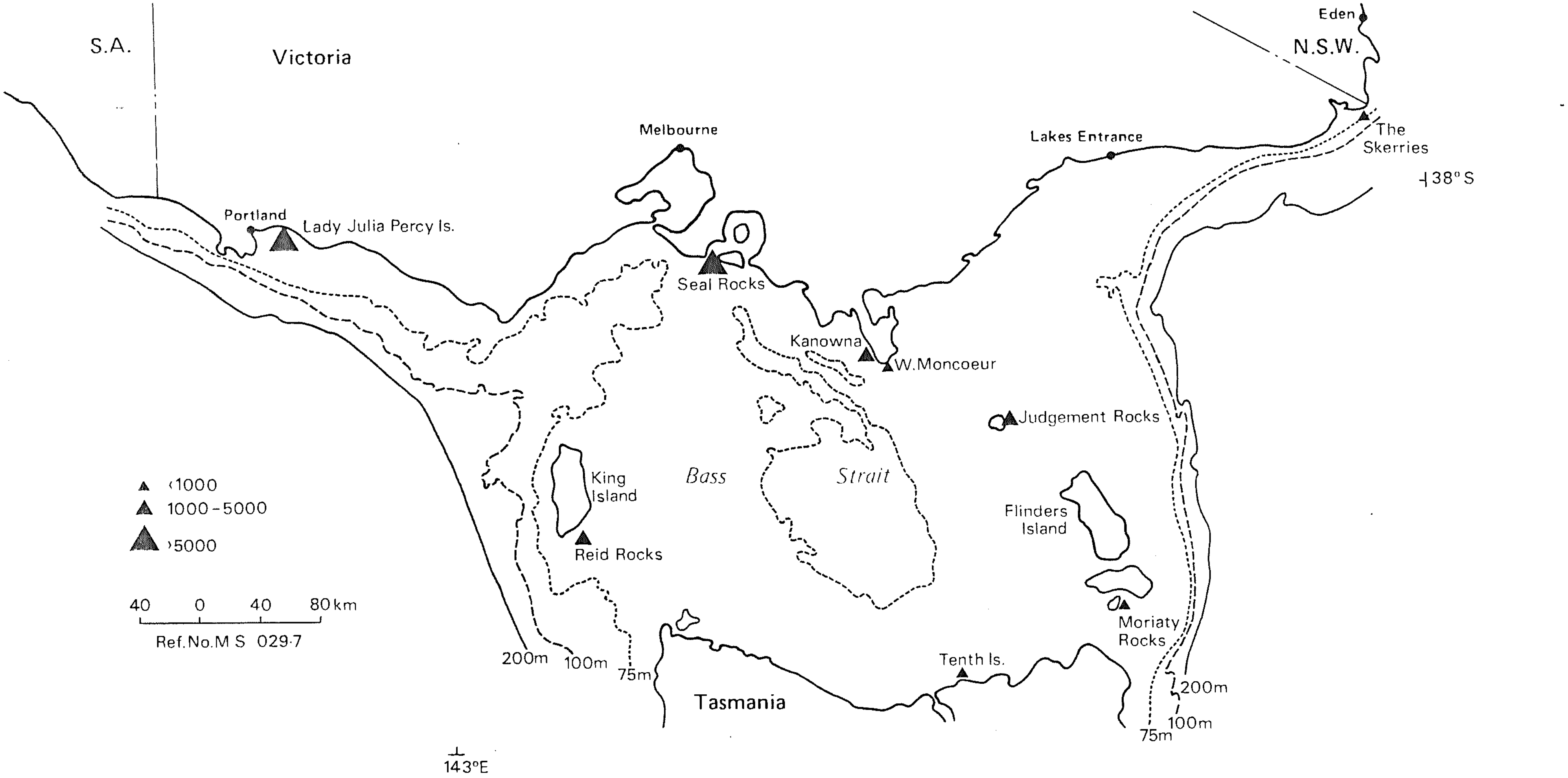

Fig. 9 Location of breeding colonies of Australian Fur Seals *Arctocephalus pusillus*. There are also colonies (not shown) of about 50 seals at Seal Rocks, N.S.W. (32° S) and 800-1000 at Maatsuyker Islands, South Tasmania (42° S). (From data supplied by R.M. Warneke, Fisheries & Wildlife Division, Victoria.)

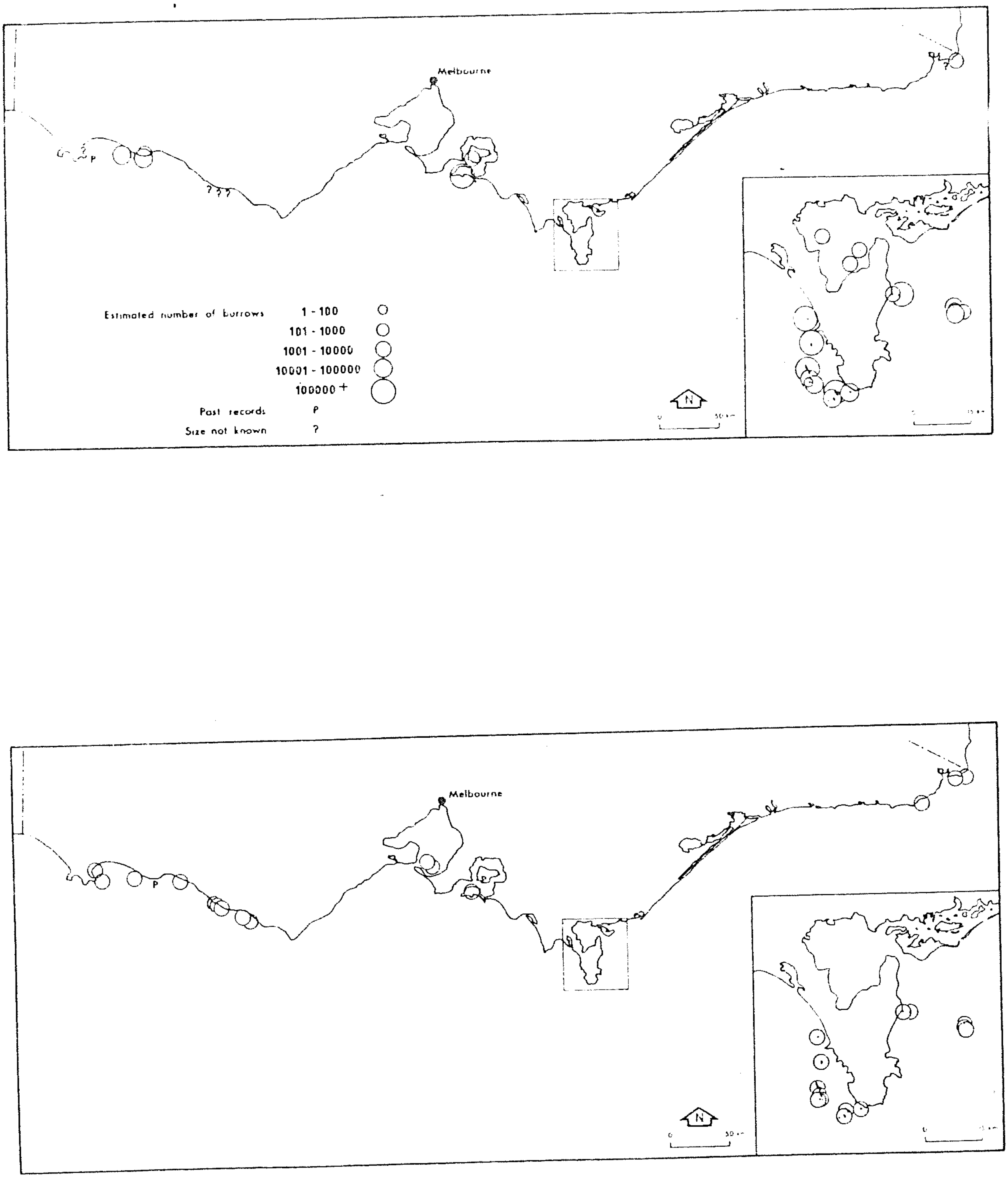

Fig. 10 Above: location of Victorian breeding colonies of short-tailed shearwaters, *Puffinus tenuirostris*. Size of colony is indicated by size of circle.

Below: location of Victorian breeding colonies of little penguins, *Eudyptula minus*. Size of colony not indicated. (From Harris & Norman, 1981, figs. 2 & 3.)

MINISTRY FOR CONSERVATION

SQUID ECOLOGY PILOT STUDY

N. COLEMAN

August 1982

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(Not for citation without permission)

MARINE SCIENCE LABORATORIES

SQUID ECOLOGY PILOT STUDY

THE OCCURRENCE OF ARROW SQUID *NOTOTODARUS GOULDI* (McCOY, 1888) IN THE DIETS OF COMMERCIALLY EXPLOITED FISH OFF THE COAST OF VICTORIA

REPORT TO THE FISHING INDUSTRY RESEARCH COMMITTEE

DEPARTMENT OF PRIMARY INDUSTRY, CANBERRA, A.C.T.

AUGUST 1982

by

N. Coleman

Marine Science Laboratories,

Ministry for Conservation

Queenscliff, Victoria.

ABSTRACT

Coleman, N. (1982). The occurrence of arrow squid *Nototodarus gouldi* (McCoy, 1888) in the diets of commercially exploited fish off the coast of Victoria.

The diets of fifty-two species of fish, taken from Bass Strait and adjacent areas of the Southern Ocean and the Tasman Sea, were investigated through examination of stomach contents. Particular emphasis was placed on estimating the importance of arrow squid, *Nototodarus gouldi*, in the diets of the species investigated.

Cephalopods were found in the diets of twenty-one species. In general, octopus appeared to be a more significant item in the diet than did squid. By comparison with squid, octopus occurred with greater frequency, were proportionately better represented in the diet and gave higher values of the Index of Relative Importance.

Arrow squid was positively identified from the diets of eight species: gummy shark (*Mustellus antarcticus*), whiskery shark (*Furgaleus ventralis*), school shark (*Galeorhinus australis*), saw shark (*Pristiphorus* spp.), John dory (*Zeus faber*), gemfish (*Rexea solandri*), yellowfin (*Thunnus albacares*) and southern bluefin tuna (*Thunnus thynnus maccoyii*). A further seven species are at least potential consumers of arrow squid: toothy flathead (*Neoplatycephalus speculator*) and albacore (*Thunnus alalunga germo*) had stomach contents which could only be identified as squid or as ommastrephid squid; and endeavour dogfish (*Centrophorus scalpratus*), piked dogfish (*Squalus megalops*), elephant shark (*Callorhynchus millii*), toothed whiptail (*Lepidorhynchus denticulatus*) and deepwater flathead (*Platycephalus conatus*) had stomach contents which could be identified only as cephalopods. In none of the species examined was arrow squid found to be a major component of the diet. In gummy and school sharks, which are probably the main predators, arrow squid accounted for an average of only 4 - 6% (by number, weight or volume) of the diet.

Because of the generally low incidence of arrow squid in the diets of fish along the coast of Victoria, it appears unlikely that increased fishing

for squid in the area will have any adverse affect on fin-fish populations that could be interpreted as due to the removal of an essental food resource.

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APPENDICES 1 – 4, referred to in the text, are bound in a separate volume and may be consulted at the Library of the Marine Science Laboratories, Queenscliff.

INTRODUCTION

Within the last two to three years there has been increased interest in joint-venture squid-fishing operations, particularly for the arrow squid *Nototodarus gouldi*, in south-eastern Australia. This interest has led to concern by some sectors of the fishing industry, and by the community at large, that increased fishing for squid will have a detrimental affect on fish stocks which (allegedly) depend largely on squid as a food resource (see Appendix 1).

Whether or not such concern is justified is difficult to assess, not least because of the lack of data on the diets of many of the fish species which are commercially exploited in Victoria; and where data are available, they are not necessarily derived from work carried out in Victoria or even in Australia. Olsen (1954) describes the diet of school shark (*Galeorhinus australis*); Thomson (1954) details the diets of several species of mullets; the diet of barracouta (*Leionura atun*) is described in Blackburn (1957); Thomson (1959) outlines the diets of nannygai (*Centroberyx affinis*), John dory (*Zeus faber*) and horse mackerel (*Trachurus declivis*); the diets of tiger (*Neoplatycephalus richardsoni*), sand (*Neoplatycephalus bassensis*), yank (*Platycephalus caeruleopunctatus*) and king (*Neoplatycephalus speculator*) flatheads are given in Colefax (1938), Fairbridge (1951) and Brown (1977); Winstanley (1978) provides a brief account of the diet of trevalla (*Hyperoglyphe porosa*); snapper (*Chrysophrys auratus*), Morwong (*Nemadactylus macropterus*) and whiting (*Sillaginodes punctatus*) diets are described in Godfriaux (1974a-c) and Robertson (1977); Serventy (1956) and Pinkas *et al* (1971) describe the diets of southern bluefin (*Thunnus thynnus maccoyii*) and bluefin (*Thunnus thynnus*) tuna and albacore (*Thunnus alalunga*); and Cotton (1942) lists cephalopods from the stomachs of fish, mainly tuna, caught off south-eastern Australia. Nevertheless, despite this apparently extensive list of references, details of the diets of the majority of commercially exploited fish species off the coast of Victoria are lacking. The purpose of the present work was therefore to carry out a preliminary investigation into the food of commercially important fish species from Bass Strait and adjacent areas of the Southern Ocean and the Tasman Sea.

Although a few commercially important species of fish are already known to consume squid, the study did not concentrate on these species.

Instead, as wide a range of species as practicable was examined. The reasons for conducting a wide-ranging study were twofold: to extend the knowledge of which species are eating squid, and to determine which species do not eat squid. Determination of both which species do and which species do not eat squid is necessary to indicate those species which are most and those species which are least likely to be affected by any depletion of squid stocks. Such knowledge will also provide a rational basis on which to select species for study in any future, more rigorous, investigation of the importance of squid in the diets of commercially exploited species of fish.

The demonstration that a particular species of fish eats squid, even as a major component of the diet, does not necessarily imply that a reduction in the fishery for that species will occur if squid abundance is reduced. The relationship between the abundance of squid and the abundance of squid-eating fish is complex, and one which it is largely beyond the scope of the present study to investigate. Nevertheless, an approach to investigating the relationship has been made. Two factors which may be of significance if the squid population is reduced are the competition amongst squid-eating fish for the remaining resource, and the ability of squid-eating fish to exploit alternative food sources. Estimates have therefore been made of the overlap in and diversity of the diets of the fish species examined.

MATERIALS AND METHODS

COLLECTION OF SAMPLES

No research vessel was available for use in the present study. Samples were therefore obtained, mainly from commercial sources, as follows.

(i) Staff from the Marine Science Laboratories accompanied commercial fishing cruises and sub-sampled the catch. Trips were made from Lakes Entrance, San Remo and Portland. In some cases whole fish were preserved in vapour-suppressed neutral formalin and brought back to the laboratory for measurement and for examination of the stomach contents. In other cases measurements on the fish were made at sea and the stomachs removed, preserved and brought back to the laboratory. Details of locality, depth of fishing and fishing method were noted.

(ii) By sampling from fishermens' co-operatives at Lakes Entrance and Port Albert. In some cases whole fish were made available for measurement and gutting. In other cases only stomachs were made available after the fish had been filleted at the co-op; where this was the case, the name supplied by the co-op was not always sufficient to allow specific identification of the fish providing the stomachs examined. Exact details of fishing locality (for the specimens examined) was generally unavailable.

(iii) By purchase from the Melbourne fish market. Exact details of fishing locality were not available with these samples, but the port of landing and thus a general indication of the area in which the fish were taken, was known.

(iv) Shark fishermen in Port Albert, San Remo and Apollo Bay were given drums of preservative and perforated plastic bags and asked to bring back stomachs individually bagged and preserved. Each bag was marked by the fisherman, using a water-proof marking pen, with the name of the kind of shark from which the stomach was taken and in some instances size data were also provided. In a few cases the labelling of the bags was insufficient to allow specific identification of the shark from which the stomachs were taken, and in all cases exact locality data were lacking.

(v) Tuna stomachs were obtained from SAFCOL in Melbourne.

(vi) A few stomachs were obtained from trawling by the Fisheries and Wildlife vessel 'Sarda'.

In the text and in the tables all the occasions on which samples were obtained are, for convenience, referred to as sampling cruises irrespective of the method by which the samples were actually obtained.

MEASUREMENT OF FISH

Where whole fish were available for examination, determinations were made of length, weight, sex and the condition of the gonad. Length was measured to the nearest centimetre. In most cases the dorsal normal length (i.e. from the mandibular symphesis to the tip of the normally expanded longest dorsal caudal fin ray) was measured; but where it was more appropriate (e.g. for ling and whiptail) the greatest total length was measured. Weight was measured to the nearest gram. The sex of the fish was determined and the gonad subjectively awarded a score of 0 for immature, 1 and 2 for developing, 3 for ripe and 4 for spent condition.

TREATMENT OF SAMPLES IN THE LABORATORY

Methods for studying the food of fishes have been reviewed by Hynes (1950), Pillay (1952), Berg (1979) and Hyslop (1980). The most commonly used methods for determining the importance of particular food items are by determining their frequencies of occurrence or proportions, by number, weight or volume, in the stomachs examined. All these methods of estimation have been used in the present study to offset the bias that results when only a single method of measurement is used (Hyslop 1980).

Each stomach was weighed and was subjectively awarded a score, ranging from 0 for an apparently empty stomach to 5 for a stomach which was greatly distended with food. The stomach was cut open and fullness assessed again on the basis of the observed stomach contents. The contents were removed and the empty stomach reweighed.

The stomach contents were sorted into individual food items. As far as possible the number, volume and weight of the individual items was determined; in some cases the amorphous nature of the contents, or their poor condition, made this impossible. (Some discrepancies occur in the text tables and the Appendices because it was not always possible to make complete measurements on the stomach contents.)

Where fragments of animals were present, certain parts of the body (e.g. the head) could be used to estimate the numbers of individuals represented. Where they could not be used to estimate numbers of individuals, fragments were, for the purpose of data analysis, counted as one individual. Volume estimates were made either by measuring the displacement of water in a measuring cylinder or by spreading the stomach contents to an even depth over a grid and counting the grid squares covered by the different food items. The second method was used where food items consisted of many small fragments or of relatively large amounts of amorphous or detrital material. Only one method of volume determination was applied to the contents of any one stomach.

Stomach contents were identified to the lowest possible taxonomic level, and specific identification, or separation into separate species, was possible for many of the polychaetes, crustaceans, molluscs and fishes removed from the stomachs. With the exception of that of the deep water flathead (Waite and McCulloch 1915) the scientific names applied to the fish encountered in the present study follow those in Scott *et al* (1980) and Maxwell (1980) although it is recognised that in some groups there is taxonomic confusion and uncertainty concerning the specific names to be applied to some species.

DATA ANALYSES

The following analyses were carried out for each species within each cruise. In addition, analyses of the frequency of occurrence, proportion of each prey in the diet and the diversity of the diet were carried out for samples of each species summed over all cruises; analyses of overlap between diets were carried out for cruise data aggregated according to locality and date of sampling.

FREQUENCY OF OCCURRENCE AND PROPORTION OF EACH PREY ITEM IN THE DIET

The numbers and percentages of fish with and without stomach contents were determined. The number of stomachs containing any specified food item was expressed as a percentage of all stomachs containing food. The proportion (by number, weight or volume) of each food item in each stomach with food contents was determined and the means and standard deviations of the proportions were determined. The food items considered were either generalised food categories (e.g. fish, cephalopods) or specifically identified prey species.

DIVERSITY OF FISH DIETS

The diversity of the stomach contents was estimated using Levins' index (Sale and Dybdahl 1975)

$$\frac{1}{\Sigma p^2}$$

where p is the proportion of each food item.

The index was calculated using proportion based on counts of prey items: it was determined for each stomach containing food and then averaged over all stomachs with food contents.

OVERLAP IN FISH DIETS

Overlap in diets was calculated as (Hunter 1978)

$$\frac{\sum_{k=1}^{190} P_{i,k} \cdot P_{j,k}}{\sqrt{\sum_{k=1}^{190} P_{i,k}^2 \cdot \sum_{k=1}^{190} P_{j,k}^2}}$$

where $P_{i,k}$ is the proportion of stomach contents belonging to category k for fish i; $P_{j,k}$ is the same for fish j; and 190 is the total number of prey categories. Counts of prey items were used in determining proportions.

Within each sampling cruise the overlap was calculated for every possible pair of species. For each pair, the overlap of each fish of one species with each fish of the other was determined and the average of these indices (i.e. the average overlap index) was calculated. An average value of 1 denotes identical diets and a value of 0 indicates no overlap between the diets of populations of the species compared.

Overlap indices were also calculated using the following aggregations of cruise data:

All samples from eastern Victoria (i.e. from Lakes Entrance, Port Albert, San Remo) taken between August and December 1980.

All samples from Eastern Victoria taken between January and March 1981.

All samples from Eastern Victoria taken between August and December 1981.

All samples from Western Victoria (i.e. from Apollo Bay and Portland) taken between January and March 1981.

All samples from Western Victoria taken between August and December 1981.

These aggregations of cruise data were used to overcome the fact that some species, because they are caught by different fishing methods, did not occur together on individual sampling cruises.

Values for the average overlap indices were generally low. Where values exceeded 0.2, the diets of the fish species concerned were examined to determine which prey items were common to both species.

INDEX OF RELATIVE IMPORTANCE

Pinkas *et al* (1971) developed the Index of Relative Importance as an index which combines measurement of food items in terms both of frequency of occurrence and of proportion in the diet. For any food item, the index as originally proposed is:

$$IRI = (N + V)F$$

where: IRI = Index of Relative Importance
N = Percentage by number of food item
V = Percentage by volume of food item
F = Percentage frequency of occurrence of food item

Pinkas *et al* (1971) only made volumetric measurements and counts of prey items. In the present study the weight of prey items has also been determined. The IRI has therefore been modified to include the weight of the food, the formula used being:

$$IRI = (N + V + W)F$$

where: IRI, N, V, F are as before

W = Percentage of food item by weight

Those food items which provide the highest values of the IRI are considered to be the most important in the diet and *vice versa*.

RESULTS

GENERAL ANALYSIS OF DIETS

Two thousand and forty-two stomachs taken from 52 species of fish were examined (Table 1). The majority of these stomachs came from fish landed at Victorian ports (Fig. 1) but the albacore were from New South Wales (port of landing unknown), the yellowfin tuna were from Port Lincoln in South Australia and the southern bluefin tuna came from both New South Wales and Port Lincoln.

The diets of all the species examined averaged over all cruises are shown in Table 2. Averaging the results of different cruises tends to obscure regional and temporal variations in diet. Nevertheless, the summary analyses (shown in Table 2) are in general agreement with the results of individual cruises irrespective of time or place; although the relative proportions of the different food items in the diet of any fish species may vary between cruises, generally the same one or two categories of food items constitute the bulk of the stomach contents. (A full listing of dietary analyses by cruise is given in Appendix 2.

Measurements of stomach contents (averaged over all cruises) by number, by weight and by volume all gave similar results; with only a few exceptions each method showed the same category of food items to be dominant (by proportion) in the diet (Table 3; Appendix 2). The most important food category was fish which, by one or other of the methods of measurement, was the major component of the diet in twenty five of the species examined. Next in importance were crustaceans which were the major component in the diets of fourteen species. Cephalopods, polychaetes and bivalves were the major items in the diets of six, five and two species respectively. Miscellaneous items, a category including nematodes, echinoderms, sipunculids and unidentifiable material, provided the bulk of the food in eleven species.

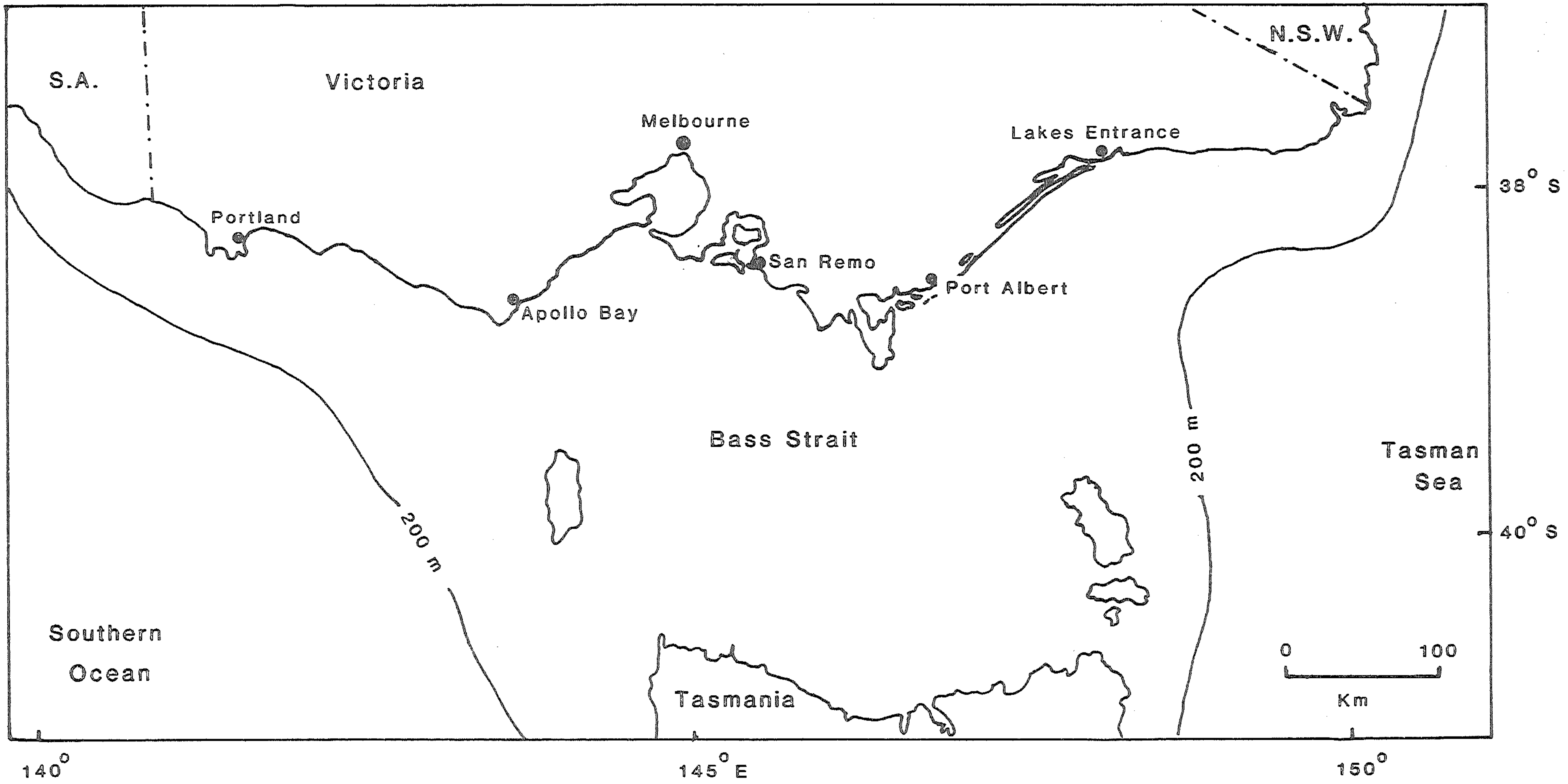

FIGURE 1. Sampling localities along the coast of Victoria.

THE OCCURRENCE OF CEPHALOPODS IN THE DIETS OF FISH

Cephalopods were found in the stomachs of twenty-one of the fish species examined. (Tables 2, 4; Appendix 3). These twenty-one species may be divided into three groups: those species in which cephalopods were a frequent and major constituent of the diet; those species in which cephalopods occurred with moderate frequency and in moderate proportions; and those species in which cephalopods, both by frequency and by bulk, were of minor occurrence.

In seven species, gummy shark, whiskery shark, school shark, endeavour dogfish, piked dogfish, toothy flathead, and yellowtail kingfish, cephalopods were clearly a major item in the diet. On average, cephalopods occurred in at least half of the individuals examined and formed at least a third of the stomach contents. The high values for the IRI (Table 5), which combines both frequency and quantitative measurements, also indicate the importance of cephalopods in the diets of these fish species.

The division of the remaining fourteen species into moderate and minor consumers of cephalopods is not clear-cut. If only the average stomach contents (by number, weight or volume) are considered, three species, toothed whiptail, John dory and deep water flathead, in which cephalopods constituted 11 - 21% of the diet, may be considered as moderate consumers. If frequency of occurrence is considered, six species, elephant shark, toothed whiptail, John dory, deep water flathead, albacore and yellowfin tuna, in which cephalopods were found in 11 - 28% of individuals, may be considered as moderate consumers. The IRI (Table 5) suggests that only the toothed whiptail, with a value for the index in excess of 1000, should be considered as a moderate consumer of cephalopods; and even in this species the value of the IRI for cephalopods appears small by comparison with the IRI for fish, which is the major type of food consumed by toothed whiptail.

Whatever criterion of importance is used, cephalopods appear to be of only very minor occurrence in the diets of eight species: saw shark, nannygai, gemfish, rock flathead, latchet, butterfly gurnard, morwong and southern bluefin tuna.

In four species, endeavour dogfish, elephant shark, piked dogfish and deep water flathead, no identification of cephalopod remains, beyond determining that they were cephalopod remains, was possible (Table 6). Thirteen species were found to contain squid, nine contained octopus and three contained cuttlefish. Occurrences of squid, octopus and cuttlefish were not mutually exclusive. Six species contained both squid and octopus, two species contained both squid and cuttlefish and one species, school shark, contained squid, octopus and cuttlefish.

Nototodarus gouldi, the arrow squid, was found in the diets of more fish species than were any other of the cephalopods which could be identified to species. In gummy shark *N. gouldi* was found in shark from eight of the eleven sampling cruises. Over all cruises, the average frequency of occurrence of *N. gouldi* was around 14% and the average contribution to the diet about 4 - 5%(Table 6). Amongst the individual sampling cruises, the frequency of occurrency ranged from 0 - 100% and the average proportion in the diet from 0 - 50% (Appendix 3). In school shark, the other shark species for which large samples were obtained, *N. gouldi* was found in shark from eight of the eleven sampling cruises; over all cruises the average frequency of occurrence was about 21% and the average contribution to the diet around 5 - 6%. Amongst individual cruises the frequency of occurrence of *N. gouldi* ranged from 0 - 67% and the average contribution to the diet from 0 - 26%. In saw shark *N. gouldi* was found in shark from one of the five sampling cruises: on that cruise it occurred with a frequency of 10% and contributed an average of about 10% to the diet. Over all cruises, the frequency of occurrence was 4% and the average contribution to the diet was about 4%. In John dory, obtained only on one sampling cruise, both the frequency of occurrence and the average contribution to the diet of *N. gouldi* were about 11%. For gemfish, *N. gouldi* were found in fish from two of the five sampling cruises and, over all, the frequency of occurrence and the average contribution to the diet were both about 5%. In southern bluefin tuna the frequency of occurrence of *N. gouldi* and its average contribution to the diet were both about 5%. In yellowfin tuna *N. gouldi* occurred in about 9% of individuals and contributed about 0.5% to the diet.

Several species of fish contained fragments of squid which could not be identified to species, but which could have been of *N. gouldi*. The actual incidence of *N. gouldi* in fish diets might therefore be higher than estimates based on identified fragments of *N. gouldi* would suggest. However, for those fish species in which both *N. gouldi* and unidentified squid fragments were found, values of the IRI for *N. gouldi* alone and for all squid present in the diet were both low (Table 7). That both values of the IRI are low indicates that any possible underestimates of the importance of *N. gouldi* are likely to be slight. For those fish species in which only unidentifiable squid remains were found, values of the IRI tend to be low, indicating that squid are not of great importance in the diet. The one exception is toothy flathead: the IRI for squid is high, suggesting that one or more species of squid may be important in the diet of toothy flathead, but the small number of specimens examined prevents any definite conclusions being reached.

After *Nototodarus gouldi* the most frequently occurring cephalopod that could be positively identified was *Octopus australis* which was found in gummy, whiskery and saw sharks. *O. australis* was a major item in the diet of the whiskery shark, but was of minor occurrence in the diets of the other two shark species (Table 6, 7). Other species of octopus which could be identified were *O. pallidus* from gummy and school sharks; *O. macropus*, *O. flindersi* and *O. superciliosus* from gummy shark, and *O. dofleini* from school shark.

Octopus remains which could not be specifically identified were found in nine species of fish. In four of these species, latchet, butterfly gurnard, jackass morwong and albacore, these unidentifiable remains were of infrequent and minor occurrence in the diet (average frequency and proportion in the diet both less than 5%, Table 6; Appendix 3) and values of the IRI for octopus are low (Table 7). In the remaining five species, gummy shark, whiskery shark, school shark, toothy flathead and yellowtail kingfish, unidentifiable octopus remains were of frequent occurrence (being found, on average, in 37 - 54% of the individuals) and constituted a relatively large proportion (17 - 50%) of the diet (Table 6; Appendix 3). Values of the IRI for all octopus were high for these species (Table 7).

DIVERSITY IN THE DIETS OF THE FISH SPECIES EXAMINED

Because it was not possible to identify all prey items to the species level, the estimates of dietary diversity are likely to be under-estimates. Nevertheless, it has been assumed that the values of Levins' index give a true picture of the relative diversities of the diets of the species studied.

Average values for Levins' Index ranged from 1.00 to 3.60 (Table 8) For the majority of species values were relatively low (< 1.5); ten species had values which were moderately high (1.50 - 2.50); and three species had values which were relatively high ($\gtrsim$ 3).

In four of the species in which cephalopods were dominant in the diet, gummy and school sharks and endeavour and piked dogfish, the diet was of moderate to high diversity. In the remaining three species, whiskery shark, toothy flathead and yellow-tail kingfish, the diet was of low diversity. Amongst those species in which cephalopods may be considered to be of moderate occurrence in the diet, elephant shark had a highly diverse diet and the remaining species had diets of low diversity. For those species in which cephalopods were of minor occurrence in the diet, jackass morwong had a moderately diverse diet and the remaining species had diets of low diversity.

DIETARY OVERLAP BETWEEN SPECIES

Values of the average overlap index were generally low (<0.2). The majority of moderate to high values which did occur generally resulted from the co-occurrences of prey items which had only been identified to a general level (e.g. as fish or as crustaceans). Even where dietary overlap resulted from co-occurrences of items which had only been generally indentified, instances in which the average overlap index could be considered as high ($\gtrsim$0.6) were in a minority.

Within individual cruises (Fig. 2), values of the average overlap index in excess of 0.2, and which could be related to the occurrence of specifically identified prey items, occurred most consistently for gummy school and saw sharks collected along the whole of the Victorian coast between November 1980 and April 1981. The prey contributing to the overlap were arrow squid and, to a lesser extent, various species of octopus. However, dietary overlap between the three shark species cannot be considered as great. Although arrow squid was found in both gummy and school shark from seven of the ten sampling cruises in which both shark species occurred, values of the average overlap index exceeded 0.2 on only five cruises and on no cruise did the value exceed 0.44.

~~After arrow squid, the species which could be identified as contributing most towards dietary overlap was the toothed whiptail. This species contributed to the overlap in diets of butterfly gurnard, gemfish~~, ~~and ling trawled off Portland in January 1981. Values for the average overlap indices calculated for these species were not great ranging from~~ 0.2 ~~for butterfly gurnard and ling to 0.36 for ling and Hapuku~~.

Using aggregated cruise data (Figs. 3 & 4), patterns of overlap were much as found from using data from individual cruises. In general, the degree of dietary overlap between species was not great, and the majority of overlaps were for fish whose diets had only been identified to a general level.

For species taken from the east coast of Victoria (Fig. 3), arrow squid *Octopus pallidus* and *O. australis* were common to the diets of gummy and school shark. Silverside (*Argentina elongata*) was common to the diets of several species of fish although its co-occurrences (in predator species) did not always lead to values of the average overlap index in excess of 0.2. Those pairs of species for which co-occurrences of silverside were associated with values of the average overlap index in excess of 0.2 were: saw shark and silver dory, saw shark and tiger flathead, saw shark and butterfly gurnard, butterfly gurnard and silver dory. Silverside and deepwater gurnard were both common to the diets of tiger flathead and butterfly gurnard; and silverside and cucumber fish were both common to the diets of tiger flathead and silver dory. Barred grubfish was common to the diets of butterfly gurnard and bearded cod, and latchet was common to silver dory and sand flathead. The crab *Halicarcinus rostratus* was found in the diets of several species and was associated with an average overlap index ≥ 0.2 in the following pairs of species: red gurnard and snapper, snapper and gurnard perch and gurnard perch and red gurnard.

	Toothy flathead	Jackass morwong	Blue grenadier	Gemfish	Ling	Silver dory
Jackass morwong	0					
Blue grenadier	0	0				
Gemfish	.08	0	.09			
Ling	.25	0	0	.10		
Silver dory	.35	0	0	.12	.35	
Mirror dory	.17	0	.67	.12	.17	.17

FIGURE 2. An example of overlap in diets between fish species from a single sampling cruise. Data are for fish trawled off Portland in March 1981 (further explanation in text).

	School whiting	Sand flathead	Tiger flathead	Butterfly gurnard	Red mullet	Cucumber fish	Velvet leatherjacket	Snapper	Trevally	Saw shark	Gummy shark	Barracouta	Nannygai	Warehou	School shark	John dory	Long snouted boarfish	Whiskery shark	Gurnard perch
Sand flathead	.06																		
Tiger flathead	.01	.42																	
Butterfly gurnard	0	.48	.87																
Red mullet	.15	.06	.08	.09															
Cucumber fish	0	0	0	0	0														
Velvet leatherjacket	0	.48	.87	1.0	.10	0													
Snapper	.14	.04	.02	0	0	.22	0												
Trevally	.16	.07	.09	.10	.51	0	.10	0											
Saw shark	0	.48	.87	1.0	.10	0	1.0	0	.10										
Gummy shark	.11	.04	.03	.04	.05	0	.04	.01	.05	.04									
Barracouta	0	.48	.87	1.0	1.0	0	1.0	0	.10	1.0	.04								
Nannygai	.43	.09	0	0	.18	0	0	0	.20	0	.23	0							
Warehou	.12	.06	.07	.08	.07	0	.08	.03	.07	.08	.06	.08	.23						
School shark	0	.06	.11	.12	.01	0	.12	0	.01	.12	.16	.12	0	.01					
John dory	0	.32	.57	.66	.06	0	.66	0	.07	.66	.03	.66	0	.05	.09				
Long snouted boarfish	.10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Whiskery shark	0	.10	.17	.20	.18	0	.20	0	.02	.20	.08	.20	0	.02	.14	.15	0		
Gurnard perch	0	0	0	0	0	1.0	0	.22	0	0	0	0	0	0	0	0	0	0	
Yellow-tail kingfish	0	.24	.43	.50	.05	0	.50	0	.05	.50	.16	.50	0	.04	.27	.33	0	.20	0

FIGURE 3. An example of overlap in diets between fish species determined using aggregated cruise data. Data are for all species collected on sampling cruises in eastern Victoria during March to January 1981 (further explanation in text).

	Sand flathead	Toothy flathead	Jackass morwong	Blue grenadier	Gemfish	Ling	Red ocean perch	Ribaldo	Saw shark	Gummy shark	School shark	Silver dory	Horse mackerel	Sandpaper fish	Mirror dory
Toothy flathead	.14														
Jackass morwong	0	0													
Blue grenadier	.10	.14	0												
Gemfish	.06	.11	0	.12											
Ling	.13	.20	0	.22	.19										
Red ocean perch	.18	.32	0	.20	.16	.28									
Ribaldo	.19	.09	0	.13	.06	.15	.11								
Saw shark	.14	.23	0	.13	.10	.19	.30	.12							
Gummy shark	.05	.21	0	.06	.04	.07	.09	.05	.07						
School shark	.05	.31	0	.05	.06	.07	.10	.05	.09	.22					
Silver dory	.05	.07	.08	.22	.07	.10	.13	.02	.07	.06	.02				
Horse mackerel	.03	.03	0	.03	.01	.03	.04	.01	.03	.01	.01	.04			
Sandpaper fish	.12	.10	0	.21	.06	.13	.15	.21	.10	.07	.04	.24	.05		
Mirror dory	.07	.13	0	.10	.08	.11	.16	.04	.11	.03	.04	.04	.01	.05	
Cucumber fish	0	0	0	0	.33	0	.08	0	0	0	0	.08	0	0	0

FIGURE 4. An example of overlap in diets between fish species determined using aggregated cruise data. Data are for all species collected on sampling cruises in Western Victoria during March to January 1981 (further explanation in text).

In the majority of cases values of the overlap index were not high (generally ≤0.35). The degree of overlap between red gurnard and gurnard perch was exceptional: in both species *Halicarcinus rostratus* was the only food item found and the average overlap index was therefore 1.

For species taken off the western coast of Victoria (Fig. 4) dietary overlap between gemfish and deepwater flathead was partly attributable to cucumber fish and three-spined cardinal fish; for gemfish and cucumber fish overlap was partly due to three-spined cardinal fish; for blue grenadier and ling overlap was partly due to toothed whiptail; and for gummy and school sharks, arrow squid and barracouta contributed to dietary overlap.

DISCUSSION

The present study has investigated the diets of the majority of commercially exploited fish species (Winstanley 1981) off the coast of Victoria. Because a wide range of fish species was investigated, the number of stomachs which could be examined for any one species was limited. In addition, some species are particularly poorly represented in the study because only a few individuals occurred on the sampling cruises which were made. Nevertheless, where comparable data are available the results of the present study are in agreement with those of previous investigations, the corollary being that where comparable data are not available the present study may be assumed to have presented an accurate picture of the diets of the species concerned.

Fish and crustaceans appear, generally, to be the most important food items for commercially exploited Victorian fish, being dominant in the diets of thirty-seven of the fifty-two species examined. Previous studies have shown fish and/or crustaceans to be important in the diets of school shark (Olsen 1954), barracouta (Blackburn 1957), deep sea trevella (Winstanley 1978), various species of flathead (Colefax 1938; Fairbridge 1951; Brown 1977), King George whiting (Robertson 1977), snapper and jackass morwong (Godfriaux 1954a, b), nannygai, John dory and horse mackerel (Thompson 1959), albacore (Pinkas *et al* 1971), bluefin (Dragovitch 1970; Pinkas *et al* 1971) and southern bluefin tuna (Serventy

1956). The present results agree with these findings and have shown that fish and/or crustaceans are also major dietary items in spotted catshark, gummy shark, saw shark, cucumber fish, toothed whiptail, blue grenadier, bearded cod, ribaldo, mirror dory, silver dory, sandpaper fish, sea mullet, gemfish, warehou, latchet, red gurnard, butterfly gurnard, red ocean perch, gurnard perch, ling, yellow-tail kingfish, long-finned pike and yellowfin tuna.

Cephalopods are found in the diets of a wide range of species fished off the coast of Victoria, but the number of species in which cephalopods are the major item in the diet is limited. School shark (Olsen 1954) albacore (Pinkas *et al* 1971) bluefin (Pinkas *et al* 1971) and southern bluefin tuna (Serventy 1956) are all reported to include cephalopods as a major item in the diet, and minor amounts of cephalopods are reported from the diets of deep sea trevalla (Winstanley 1978), sand, tiger and yank flathead (Colefax 1938; Fairbridge 1951; Brown 1977), snapper and morwong (Godfriaux 1954a, b).

The list of species known to consume cephalopods as a major part of the diet has been expanded, in the present study, to include gummy shark, whiskery shark, endeavour dogfish, toothy flathead and yellow-tail kingfish; and the list of species known to be moderate or minor consumers of cephalopods has been widened to include saw shark, elephant shark, toothed whiptail, John dory, nannygai, gemfish, rock flathead, deep water flathead, latchet, butterfly gurnard and yellowfin tuna.

In terms of the specific composition of cephalopods in fish diets, *Octopus* spp. seem to be most important. By comparison with squid, octopus occurred with greater frequency, were proportinately better represented in the diet and gave higher values for the IRI.

The most widely and frequently occurring squid species found in fish diets was the arrow squid, *Nototodarus gouldi*, and the major predators were found to be gummy, whiskery and school sharks, John dory and gemfish. In none of these species could arrow squid be considered as a major item in the diet. In whiskery shark and John dory, arrow squid contributed on average around 20% and 11% of the diet respectively; but in gummy and school shark and in gemfish, which are the most commercially important of these five predator species, arrow squid provided on average only about 4 - 6% of the diet. These findings are in agreement with unpublished data held by the Fisheries and Wildlife Division; these unpublished data show that arrow squid are not a major item in the diets of gummy and school sharks (Appendix 4).

One caution needs to be made in interpreting results averaged over all cruises. Fish from some cruises were found to contain a particularly high proportion of arrow squid. Similarly, Serventy (1956) reported that although tuna stomachs generally contained both fish and squid, on some occasions tuna stomachs were packed only with squid, which was the sole food item consumed. If, as Serventy (1956) suggests, the occasional high incidence of squid in the diet is purely fortuitous, results averaged over all cruises will be a true reflection of the importance of squid in fish diets. Conversely, if the high incidence of squid in the diet on some occasions results from some consistant, though as yet undefined, relationship between predator and prey, results averaged over all cruises will not be a true reflection of the importance of squid in the diet. The averaging of results will obscure the fact that under certain conditions squid may be of particular significant in the diet.

Many factors could lead to consistent changes in the relative importance of squid in fish diets. One factor might be seasonal changes in squid abundance associated with reproduction or migration patterns; such changes are reported to occur in Southern Australia (Wolfe 1973). The composition of fish diets and the intensity of feeding are known to be related to fish size, geographical location, position in the water column, season and time of day (Pillay 1953; Pinkas *et al* 1971; Tyler 1972; Godfriaux 1974a, b). None of these factors could be investigated in the present study because the facilities made available were not sufficient to allow a rigorously controlled sampling programme to be undertaken.

Irrespective of whether or not squid are of particular significance at certain times, data on dietary diversity and dietary overlap between species suggest that any reduction in the availability of squid for consumption could readily be compensated for by a transition to other food items.

Gummy and school sharks are commercially the most significant shark in Victoria and are probably also the major predators of arrow squid. Both species have relatively diverse diets and so it appears that they may be able to compensate for any reduction in the availability of squid. Of the remaining species found to eat squid, the most commercially significant are saw shark, nannygai, gemfish and morwong. The diets of these species ranged from relatively low in diversity to moderately diverse; but in all these species squid was only of minor occurrence in the diet; so even if the ability to transfer to other prey is limited, this is unlikely to be of any consequence with regard to a reduction in the squid component of the diet.

Although the majority of species examined are exploiting prey from three major groups, fishes, crustaceans and cephalopods, there appears to be relatively little overlap in diets. Many of the overlaps that were found are probably spurious: they arose because predator species had in common food items which could only be identified at a general level (e.g. as fishes or as crustaceans) not from co-occurrences of prey items known to be specifically identical. Even where overlap occurred because food had only been identified at a high taxonomic level, overlap indices tended to be low because of the number of food items which were not common to both predators.

A relatively low degree of overlap in diets is to be expected if food resources are being partitioned so as to reduce competition. Tyler (1972) notes that although fish may consume a wide range of prey, generally only three or four items constitute the bulk of the diet; there is relatively little overlap between predator species in those food items which provide the bulk of the diet; and co-occurrences of principal food items are likely to be greatest when food is super-abundant and least when food is limited. Godfriaux (1974c) has found that although morwong and snapper have in common many of the same categories of food organisms, the diverse diets of these two species combined with differences in food selectivity and time of feeding serve to reduce competition for food.

The generally low overlap indices found in the present study indicate that amongst fish populations in Victoria, as amongst fish populations elsewhere, trophic specialisation has occurred and has reduced interspecific competition for food. Only for gummy and school sharks could arrow squid be shown to contribute to dietary overlap. Average overlap indices for these shark species were not great (highest value 0.44) and were not consistent, failing to indicate even a moderate degree of dietary overlap between shark from some sampling cruises.

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All opinions expressed in the document are those of the author and must not be taken as the official views of the Ministry for Conservation.

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TABLE. 1. Numbers of stomachs examined for food content for each of the species of fish investigated.

Stomach samples are grouped by locality and date. East Coast columns indicate numbers of stomachs from fish landed at Lakes Entrance, Port Albert and San Remo and West Coast columns indicate stomachs from fish landed at Apollo Bay and Portland.

SPECIES	NUMBER OF STOMACHS EXAMINED												TOTAL
	East Coast						West Coast						
	1980		1981				1980		1981				
	JUL-SEP	OCT-DEC	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC	JUL-SEP	OCT-DEC	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC	
Spotted catshark *Halaelurus analis*	1												1
Gummy shark *Mustellus antarcticus*		10	24		41				51				126
Whiskery shark *Furgaleus ventralis*			5										5
School shark *Galeorhinus australis*	3	8	57		30				24				122
Endeavour dogfish *Centrophorus scalpratus*	1	1							1				3
Piked dogfish *Squalus megalops*	3	1											4
Saw shark *Pristiphorus sp*	1	7	1						31				40
Elephant shark *Callorhynchus milii*	3	3											6
Cucumber fish *Chlorophthalmus nigripinnis*									2				2
Garfish *Hemiramphus melanochir*		11											11
Toothed whiptail *Lepidorhynchus denticulatus*												19	19
Blue grenadier *Macruronus noveazelandiae*						1			34				35
Bearded cod *Lotella callarias*	12												12

TABLE. 1. (Contd.)

SPECIES	NUMBER OF STOMACHS EXAMINED												TOTAL
	East Coast						West Coast						
	1980		1981				1980		1981				
	JUL-SEP	OCT-DEC	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC	JUL-SEP	OCT-DEC	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC	
Ribaldo *Mora dannevigi*									36				36
John dory *Zeus faber*			12										12
Mirror dory *Zenopsis nebulosus*									4				4
Silver dory *Cyttus australis*	1	16				1			26			38	82
Nannygai *Centroberyx affinis*			15	126									141
Sandpaper fish *Paratrachichthys traill i*									6				6
Sea mullet *Mugil cephalus*		11											11
Barracouta *Leionura atun*	1	1	1										3
Gemfish *Rexea solandri*		1				1			65			61	128
Warehou *Seriolella brama*			1										1
Deep sea travalla *Hyperoglyphe porosa*		1							3				4
Toothy flathead *Neoplatycephalus speculator*		1	3						5				9
Sand flathead *Platycephalus bassensis*	7	26	43						12				88
Rock flathead *Platycephalus laevigatus*		19	1										20

TABLE. 1. (contd.)

SPECIES	NUMBER OF STOMACHS EXAMINED												TOTAL
	East Coast						West Coast						
	1980		1981				1980		1981				
	JUL-SEP	OCT-DEC	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC	JUL-SEP	OCT-DEC	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC	
Deep water flathead *Platycephalus conatus*												37	37
Tiger flathead *Neoplatycephalus richardsoni*	1	87	63			20							171
Yank flathead *Platycephalus caerolopunctatus*	1	3											4
Latchet *Pterygotrigla polyommata*	2	14										29	45
Red gurnard *Chelidonichthys kumu*	8	2	1										11
Butterfly gurnard *Paratrigla vanessa*	6	46	1										53
Red ocean perch *Helicolenus papillosus*		1							29			47	77
Gurnard perch *Neosebastes pandus*			1										1
Ling *Genypterus blacodes*						11			85			40	136
Horse mackerel *Trachurus declivis*		8										26	34
Yellowtail scad *Trachurus mccullochi*	4	48											52
Trevally *Usacaranx georgianus*	2	2		26		2							32
Yellow-tail kingfish *Seriola grandis*				3									3
Red mullet *Upeneichthys porosus*	4		13										17

TABLE. 1. (contd.)

SPECIES	NUMBER OF STOMACHS EXAMINED												TOTAL
	East Coast						West Coast						
	1980		1981				1980		1981				
	JUL-SEP	OCT-DEC	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC	JUL-SEP	OCT-DEC	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC	
Long-finned pike *Dinolestes lewini*		20											20
King George whiting *Sillaginodes punctatus*		20											20
School whiting *Sillago bassensis*	15	76	34										125
Snapper *Chrysophrys auratus*	5		5										10
Jackass morwong *Nemadactylus macropterus*	1	85				3			3			41	133
Long-snouted boarfish *Pentaceropsis recurvirostris*			3										3
Barred grubfish *Parapercis allporti*	3												3
Albacore *Thunnus alalunga germo*											(31)**		31
Southern bluefin tuna *Thunnus thynnus maccoyii*					(15)*						(26)**		41
Yellow-fin tuna *Thunnus albacares*					(36)**								36
Velvet leatherjacket *Navodon australis*	7	7	2										16

* Landed in N.S.W. (Port of landing unknown)

** Landed at Port Lincoln, South Australia

TABLE. 2. Summary analysis of fish diets averaged over all sampling cruises.

For each entry the three values denote, reading from top to bottom: the frequency of occurrence of the food item expressed as the percentage of all stomachs containing food in which that item occurred; the mean occurrence of the food item, expressed as the percentage contribution by volume of the item to the total stomach contents averaged over all stomachs containing food; and the standard deviation of the mean. spo.,sponges; Poly., polychaetes; Crust., crustaceans; Gast., gastropods; Biv., bivalves; ceph., cephalopods; Asc., ascidians; Misc., miscellaneous items comprising organisms of taxa not otherwise included in the table, and unidentifiable material.

Species	No. of Stomachs: Examined	With Food	% Stomachs With Food	Occurence of food items in stomachs: % Frequency, Mean, S.D. SPO.	POLY	CRUST	GAST	BIV	CEPH	ASC	FISH	MISC	WEED
Spotted catshark	1.	1.	100.0			100.0 10.5 0.0					100.0 5.3 0.0	100.0 84.2 0.0	
Gummy shark	126.	113.	89.7		9.7 1.1 5.3	72.6 39.6 40.2		3.5 0.3 3.1	69.9 43.0 42.4	0.9 0.1 1.3	30.1 10.3 22.6	10.6 3.2 13.4	
Whiskery shark	5.	5.	100.0			20.0 0.2 0.5			80.0 79.8 44.6		20.0 20.0 44.7		
School shark	122.	109.	89.3	0.9 0.0 0.2		2.8 1.0 9.6		1.8 0.5 4.8	90.8 67.3 38.7		51.4 28.0 37.8	0.9 0.0 0.0	
Endeavour dogfish	3.	1.	33.3			100.0 4.4 0.0			100.0 39.7 0.0		100.0 4.4 0.0	100.0 51.5 0.0	
Piked dogfish	4.	4.	100.0		25.0 7.7 15.4	25.0 15.0 30.0			50.0 42.0 50.4		50.0 35.0 47.3		
Saw shark	40.	28.	70.0			3.6 0.1 0.7			7.1 4.4 19.2		89.3 87.7 31.8	14.3 7.8 24.2	
Elephant shark	6.	6.	100.0			83.3 6.4 5.9	16.7 2.7 6.5	83.3 68.1 36.1	16.7 8.3 20.4		16.7 6.7 16.3	50.0 7.9 10.5	

TABLE. 2. (contd.)

Species	No. of Stomachs: Examined	With Food	% Stomachs With Food	Occurence of food items in stomachs: % Frequency, Mean, S.D. SPO.	POLY	CRUST	GAST	BIV	CEPH	ASC	FISH	MISC	WEED
Cucumber fish	2.	1.	50.0								100.0 100.0 0.0		
Garfish	11.	11.	100.0		9.1 2.8 9.4							63.6 42.9 53.5	36.4 33.5 47.3
Whip-tail (toothed)	19.	7.	36.8			28.6 23.8 41.8			28.6 17.3 37.3		71.4 58.8 46.6		
Blue grenadier	35.	17.	48.6			47.1 34.6 47.1					52.9 46.9 49.9	11.8 11.5 32.5	
Bearded cod	12.	11.	91.7			27.3 4.7 9.8	9.1 0.1 0.3				90.9 83.2 32.8	18.2 3.2 10.1	
Ribaldo	36.	11.	30.6								18.2 2.3 7.3	90.9 88.8 30.3	
John dory	12.	9.	75.0						11.1 11.1 33.3		88.9 88.9 33.3		
Mirror dory	4.	4.	100.0								100.0 100.0 0.0		
Silver dory	82.	53.	64.6		2.0 0.0 0.1	70.0 64.7 47.4					32.0 28.3 44.0	6.0 4.9 20.6	

TABLE. 2. (contd.)

Species	No. of Stomachs:		% Stomachs	Occurence of food items in stomachs: % Frequency, Mean, S.D.									
	Examined	With Food	With Food	SPO.	POLY	CRUST	GAST	BIV	CEPH	ASC	FISH	MISC	WEED
Redfish (nannygai)	141.	98.	69.5		1.0	87.6		1.0	1.0		11.3	6.2	
					1.0	82.7		0.0	1.0		8.5	4.2	
					10.2	36.4		0.0	10.2		26.2	19.3	
Sandpaper fish	6.	5.	83.3			60.0					40.0	20.0	
						56.7					23.3	20.0	
						52.2					43.5	44.7	
Sea mullet	11.	9.	81.8			100.0		22.2				66.7	
						68.1		0.6				27.8	
						34.0		1.6				33.4	
Barracouta	3.	2.	66.7								100.0		
											100.0		
											0.0		
Gemfish	128.	64.	50.0			1.6			9.4		89.1	1.6	
						1.6			7.9		89.1	1.6	
						12.5			27.2		31.5	12.5	
Warehou	1.	1.	100.0			100.0							
						100.0							
						0.0							
Deep-sea trevalla	4.	1.	25.0									100.0	
												100.0	
												0.0	
Toothy flathead	9.	5.	55.6						60.0		40.0		
									50.0		40.0		
									57.7		54.8		
Sand flathead	88.	43.	48.9		19.5	19.5	4.9			0.0	58.5	17.1	2.4
					14.0	14.0	3.8			0.0	50.9	12.1	0.6
					31.5	33.6	17.7			0.2	49.5	31.8	2.9

TABLE. 2. (contd)

Species	No. of Stomachs:		% Stomachs	Occurence of food items in stomachs:						% Frequency, Mean, S.D.			
	Examined	With Food	With Food	SPO.	POLY	CRUST	GAST	BIV	CEPH	ASC	FISH	MISC	WEED
Rock flathead	20.	12.	60.0			81.8		9.1	9.1		18.2	9.1	9.1
						76.2		1.3	9.1		13.6	0.0	4.5
						43.4		4.3	30.2		32.3	0.0	15.1
Deep water flathead	37.	13.	35.1						15.4		84.6	7.7	
									8.3		83.3	1.3	
									28.9		37.3	4.6	
Tiger flathead	171.	70.	40.9								91.4	8.6	
											91.4	8.6	
											28.2	28.2	
Yank flathead	4.	3.	75.0		33.3						33.3	66.7	
					0.0						33.3	50.0	
					0.0						57.7	70.7	
Latchet	45.	25.	55.6		4.8	61.9			4.8		71.4	9.5	
					0.9	35.8			0.2		54.9	0.5	
					4.1	40.5			0.8		42.5	2.1	
Red gurnard	11.	4.	36.4			100.0	25.0				50.0	25.0	
						65.7	0.3				34.1	0.0	
						41.1	0.5				40.7	0.0	
Butterfly gurnard	53.	43.	81.1		4.8	26.2		2.4	4.8		71.4	9.5	
					2.5	19.1		1.2	2.4		68.8	3.4	
					15.4	36.6		7.7	15.4		45.4	11.9	
Red ocean perch	77.	43.	55.8			43.9				34.1	58.5		
						28.4				28.0	43.7		
						42.2				41.7	46.5		
Gurnard perch	1.	1.	100.0			100.0							
						100.0							
						0.0							
Ling	136.	76.	55.9			21.6	1.4				83.8	12.2	
						12.9	0.0				77.3	5.0	
						29.6	0.0				39.1	19.3	

TABLE. 2. (contd)

Species	No. of Stomachs:		% Stomachs	Occurence of food items in stomachs: % Frequency, Mean, S.D.									
	Examined	With Food	With Food	SPO.	POLY	CRUST	GAST	BIV	CEPH	ASC	FISH	MISC	WEED
Mackerel horse	34.	26.	76.5			24.0 5.0 22.4					72.0 69.0 45.8	12.0 3.1 13.4	
Yellowtail scad	52.	29.	55.8			3.6 3.6 18.8	3.6 0.0 0.1					96.4 0.0 0.0	
Trevally	32.	17.	53.1		81.2 66.8 43.2	62.5 18.7 32.0					12.5 9.4 26.0	6.3 0.0 0.0	
Yellow-tail kingfish	3.	2.	66.7						50.0 50.0 70.7		50.0 50.0 70.7		
Red Mullet	17.	12.	70.6		75.0 53.6 47.1	58.3 24.0 38.7		8.3 0.5 1.8			8.3 8.3 28.9	16.7 3.8 12.6	
Long finned pike	20.	12.	60.0								100.0 100.0 0.0		
King george whiting	20.	9.	45.0		88.9 65.0 48.7	22.2 0.0 0.0						11.1 8.3 25.0	
School whiting	125.	46.	36.8		32.6 8.8 21.0	43.5 25.9 41.8					6.5 2.4 14.8	63.0 43.6 44.8	
Snapper	10.	3.	30.0			33.3 8.1 14.1		33.3 25.2 43.7				66.7 0.0 0.0	
Jackass morwong	133.	97.	72.9		56.4 32.1 38.0	39.4 17.4 31.0	4.3 1.3 10.6	4.3 0.3 2.3	1.1 1.1 10.3		8.5 4.2 17.3	61.7 39.8 41.0	5.3 2.2 14.7

TABLE. 2. (contd)

Species	No. of Stomachs: Examined	With Food	% Stomachs With Food	Occurence of food items in stomachs: % Frequency, Mean, S.D. SPO.	POLY	CRUST	GAST	BIV	CEPH	ASC	FISH	MISC	WEED
Boarfish (long snouted)	3.	1.	33.3									100.0	
												0.0	
												0.0	
Boarfish	1.	0.	0.0										
Hapuku	1.	0.	0.0										
Barred grubfish	3.	3.	100.0					100.0				100.0	
								0.0				0.0	
								0.0				0.0	
Albacore	31.	21.	67.7		4.8	71.4			14.3		19.0	4.8	4.8
					0.1	70.6			7.6		16.5	0.0	0.5
					0.5	45.8			24.1		36.4	0.0	2.1
Southern bluefin tuna	41.	38.	92.7			10.8			8.1		86.5	5.4	
						5.9			5.5		83.2	2.8	
						22.9			22.5		36.9	16.7	
Yellowfin tuna	36.	33.	91.7	3.0	3.0	45.5			15.2	12.1	69.7	6.1	
				0.0	3.0	37.9			1.2	0.5	57.2	0.1	
				0.2	17.4	45.6			4.2	1.6	47.3	0.5	
Velvet leatherjacket	16.	10.	62.5		10.0		10.0	10.0			20.0	80.0	
					1.3		0.6	4.4			20.0	34.2	
					4.1		1.8	14.1			42.2	42.3	

TABLE. 3. Dominant food items in fish diets averaged over all sampling cruises.

Crust., crustaceans; Ceph., cephalopods; Biv., bivalves; Poly., polychaetes; Misc., miscellaneous items as defined in caption to TABLE. 2.

SPECIES	DOMINANT FOOD ITEMS MEASURED BY:		
	NUMBER	WEIGHT	VOLUME
Spotted catshark	Crust/Fish	Misc	Misc.
Gummy shark	Crust	Ceph	Ceph
Whiskery shark	Ceph	Ceph	Ceph
School shark	Ceph	Ceph	Ceph
Endeavour dogfish	Crust/Ceph	Ceph	Ceph
Piked dogfish	Ceph/Fish	Ceph	Ceph
Saw shark	Fish	Fish	Fish
Elephant shark	Biv	Biv	Biv
Cucumber fish	Fish	Fish	Fish
Garfish	Poly	Misc	Misc
Toothed whiptail	Fish	Fish	Fish
Blue grenadier	Fish	Fish	Fish
Bearded cod	Fish	Fish	Fish
Ribaldo	Fish	Misc	Misc
John dory	Fish	Fish	Fish
Mirror dory	Fish	Fish	Fish
Silver dory	Crust	Crust	Crust
Nannygai	Crust	Crust	Crust
Sandpaper fish	Crust	Crust	Crust
Sea mullet	Crust	Crust	Crust
Barracouta	Fish	Fish	Fish
Gemfish	Fish	Fish	Fish

TABLE. 3. (contd)

SPECIES	DOMINANT FOOD ITEMS MEASURED BY:		
	NUMBER	WEIGHT	VOLUME
Warehou	Crust	Crust	Crust
Deep sea trevalla	-	Misc	Misc
Toothy flathead	Ceph	Ceph	Ceph
Sand flathead	Fish	Fish	Fish
Rock flathead	Crust	Crust	Crust
Deep water flathead	Fish	Fish	Fish
Tiger flathead	Fish	Fish	Fish
Yank flathead	Misc	Misc	Misc
Latchet	Fish	Fish	Fish
Red gurnard	Crust	Crust	Crust
Butterfly gurnard	Fish	Fish	Fish
Red ocean perch	Fish	Fish	Fish
Gurnard perch	Crust	Crust	Crust
Ling	Fish	Fish	Fish
Horse mackerel	Fish	Fish	Fish
Yellowtail scad	Misc	Misc	Crust
Trevally	Poly	Poly	Poly
Yellow-tail kingfish	Ceph/Fish	Ceph/Fish	Ceph/Fish
Red mullet	Poly	Poly	Poly
Long-finned pike	Fish	Fish	Fish
King George whiting	Poly	Poly	Poly
School whiting	Misc	Misc	Misc
Snapper	Crust	Biv	Biv
Jackass morwong	Poly	Misc	Misc
Long snouted boarfish	Misc	Misc	Misc

TABLE. 3. (contd)

SPECIES	DOMINANT FOOD ITEMS MEASURED BY:		
	NUMBER	WEIGHT	VOLUME
Barred grubfish	Misc	Biv/Misc	-
Albacore	Crust	Crust	Crust
Southern bluefin tuna	Fish	Fish	Fish
Yellow-fin tuna	Fish	Fish	Fish
Velvet leatherjacket	Fish	Misc	Misc

TABLE. 4. The occurrence of cephalopods in fish diets.

Frequency shows the percentage of all stomachs containing food in which cephalopods were found. Number, weight and volume columns show the proportion of cephalopods expressed as the percentage of the total stomach contents averaged over all cruises.

SPECIES	NUMBER OF STOMACHS		% OF STOMACHS	NUMBER OF	NUMBER OF SAMPLING CRUISES		OCCURRENCE OF CEPHALOPODS IN STOMACHS WITH FOOD AS			
					IN WHICH CEPHALOPODS:			PROPORTION OF FOOD ITEMS BY		
	EXAMINED	WITH FOOD	WITH FOOD	SAMPLING CRUISES	OCCURRED	WERE THE MAJOR ITEM IN THE DIET*	FREQUENCY	NUMBER (MEAN ± SD)	WEIGHT (MEAN ± SD)	VOLUME (MEAN ± SD)
Gummy shark	126	113	89.7	11	9	5	69.9	38.3 ± 37.0	42.2 ± 42.3	43.0 ± 42.4
Whiskery shark	5	5	100.0	1	1	1	80.0	70.0 ± 44.7	79.9 ± 44.7	79.8 ± 44.6
School shark	122	109	89.3	11	9	7	90.8	69.0 ± 32.9	67.0 ± 39.0	67.3 ± 38.7
Endeavour dogfish	3	1	33.3	3**	1	1	100.0	33.3 ± 0.0	25.9 ± 0.0	39.7 ± 0.0
Piked dogfish	4	4	100.0	2	1	1	50.0	37.5 ± 47.9	42.4 ± 50.5	42.3 ± 50.4
Saw shark	40	28	70.0	5	2	0	7.1	5.4 ± 20.8	4.4 ± 19.2	4.4 ± 19.2
Elephant shark	6	6	100.0	2	1	0	16.7	8.3 ± 20.4	6.2 ± 15.2	8.3 ± 20.4
Toothed whip-tail	19	7	36.8	1	1	0	28.6	21.4 ± 39.3	17.1 ± 37.3	17.3 ± 37.3
John dory	12	9	75.0	1	1	0	11.1	11.1 ± 33.3	11.1 ± 33.3	11.1 ± 33.3
Nannygai	141	98	69.5	2	1	0	1.0	1.0 ± 10.1	1.0 ± 10.1	1.0 ± 10.1
Gemfish	128	64	50.0	6**	3	0	9.4	8.2 ± 27.1	7.9 ± 27.0	7.9 ± 27.2
Toothy flathead	9	5	55.6	3***	2	2	60.0	60.0 ± 54.8	60.0 ± 54.8	50.0 ± 57.7
Rock flathead	20	12	60.0	2***	1	0	9.1	9.1 ± 30.2	9.1 ± 30.2	9.1 ± 30.2
Deep-water flathead	37	13	35.1	1	1	0	15.4	15.4 ± 37.6	15.4 ± 37.6	8.3 ± 28.9
Latchet	45	25	55.6	4	1	0	4.8	1.1 ± 4.8	0.1 ± 0.5	0.2 ± 0.8
Butterfly gurnard	53	43	81.1	4	2	0	4.8	3.0 ± 15.8	2.4 ± 15.4	2.4 ± 15.4
Yellow-tail kingfish	3	2	66.7	1	1	1	50.0	50.0 ± 70.7	50.0 ± 70.7	50.0 ± 70.7
Jackass morwong	133	98	73.7	8	1	0	1.1	1.1 ± 10.3	1.1 ± 10.3	1.1 ± 10.3
Albacore	31	21	67.7	1	1	0	14.3	5.2 ± 21.8	5.8 ± 21.8	7.6 ± 24.1
Southern bluefin tuna	41	38	92.7	2	1	0	8.1	4.2 ± 18.4	5.5 ± 22.5	5.5 ± 22.5
Yellowfin tuna	36	33	91.7	1	1	0	15.2	6.7 ± 24.2	1.3 ± 4.2	1.3 ± 4.2

* By number, weight or volume

** All fish without stomach contents in 2 of the sampling cruises

*** All fish without stomach contents in 1 of the sampling cruises

TABLE. 5. Values of the Index of Relative Importance (IRI), modified to include weight measurements, for cephalopods and for other food categories averaged over all cruises.

For those species in which cephalopods were the major item (by number, weight or volume) in the diet, the 'other' category is the second most important food category. Where cephalopods were not the major item, the 'other' category is the major item in the diet. Letters in the 'other' column denote the food category to which the IRI value refers: C, crustacea; F, fish; M, miscellaneous items as defined in caption to TABLE. 2.

SPECIES	IRI VALUE		
	CEPHALOPODS	OTHER	
Gummy shark	8633	8792	C
Whiskery shark	18376	1200	F
School shark	18460	4230	F
Endeavour dogfish	9860	13300	M
Piked dogfish	6110	5415	F
Saw shark	101	23218	F
Elephant shark	381	14136	B
Toothed whiptail	1596	12474	F
John dory	370	23710	F
Nannygai	3	21836	C
Gemfish	226	23745	F
Toothy flathead	10200	4800	F
Rock flathead	248	18111	C
Deep water flathead	602	20685	F
Latchet	7	10938	F
Butterfly gurnard	37	14723	F
Yellow-tail kingfish	7500	7500	F
Jackass morwong	4	6278	M
Albacore	266	15151	C
Southern bluefin tuna	123	21167	F
Yellowfin tuna	139	11229	F

TABLE. 6. The occurrence of cephalopod species in fish diets.

For each entry the three values denote, reading from top to bottom: the frequency of occurrence of the cephalopod species expressed as the percentage of all stomachs containing food in which that species occurred; the mean occurrence of the species expressed as the percentage contribution by volume to the total stomach contents averaged over all stomachs containing food; and the standard deviation of the mean.

SPECIES	NO. OF STOMACHS		% OF STOMACHS	OCCURRENCE OF CEPHALOPODS IN STOMACHS: % FREQUENCY, MEAN, S.D.																		
	EXAMINED	WITH FOOD	WITH FOOD	Unidentified Cephalopods	*Sepia rex*	*Sepia*	Cuttlefish	*Euprymna tasmanica*	*Sepioloidae*	*Nototodarus gouldi*	*Ommastrephidae*	*Pyroteuthis*	*Cheiroteuthis*	*Enoploteuthidae*	Unidentified squid	*Octopus australis*	*Octopus dofleini*	*Octopus flindersi*	*Octopus macropus*	*Octopus pallidus*	*Octopus superciliosus*	Unidentified octopus
Gummy shark	126	113	89.7	5.3 2.7 14.6						14.2 4.4 15.1	0.9 0.0* 0.0				3.5 3.5 18.3	2.7 1.6 12.3		2.7 2.2 13.6	0.9 0.7 7.7	11.5 7.9 24.9	0.9 0.2 1.8	37.2 17.3 31.4
Whiskery shark	5	5	100.0							20.0 20.0 44.7						40.0 39.8 54.5						20.0 20.0 44.7
School shark	122	109	89.3	5.5 2.9 14.5		2.8 0.8 5.8	0.9 0.1 1.2			21.1 6.0 17.6	1.8 0.8 5.7				5.5 2.6 14.7	1.8 1.5 11.1	1.8 1.7 12.3			22.0 17.4 35.0		54.1 27.3 37.5
Endeavour dogfish	3	1	33.3	100.0 39.7 0.0																		
Piked dogfish	4	4	100.0	50.0 42.3 50.4																		
Saw shark	40	28	70.0		7.1 4.1 16.1					3.6 3.6 18.9					3.6 0.8 4.2							
Elephant shark	6	6	100.0	16.7 8.3 20.4																		
Toothed whiptail	19	7	36.8	14.3 14.3 37.8																		14.3 3.1 8.1
John dory	12	9	75.0							11.1 11.1 33.3												
Nannygai	141	98	69.5			1.0 1.0 10.2																
Gemfish	128	64	50.0							4.7 4.7 21.3		1.6 0.0* 0.0			1.6 1.6 12.5							
Toothy flathead	9	5	55.6												20.0 20.0 44.7							40.0 25.0 50.0
Rock flathead	20	12	60.0					9.1 9.1 30.2														
Deepwater flathead	37	13	35.1	15.4 8.3 28.9																		
Latchet	45	25	55.6	4.8 0.0* 0.0																		4.8 0.2 0.8
Butterfly gurnard	53	43	81.1						2.4 2.4 15.3													2.4 0.0* 0.0
Yellowtail kingfish	3	2	66.7																			50.0 50.0 70.7
Jackass morwong	133	97	72.9																			1.1 1.1 10.3
Albacore	31	21	67.7	4.8 4.8 21.8							4.8 2.5 11.5										4.8 0.3 1.4
Southern bluefin tuna	41	38	92.7							5.4 5.3 22.5	2.7 0.2 1.1											
Yellowfin tuna	36	33	91.7							9.1 0.5 2.1			33.3 0.6 3.7	3.0 0.0* 0.0								

* <0.05

TABLE. 7. Values of the Index of Relative Importance, modified to include weight measurements, for squid and octopus consumed.

SPECIES	*Nototodarus gouldi*	All squid	*Octopus pallidus*	*Octopus macropus*	*Octopus australis*	*Octopus dofleini*	*Octopus flindersi*	*Octopus superciliosus*	All Octopus
Gummy shark	190	454	238	2	12		16	0.5	4612
Whiskery shark	1200	1200			4384				10183
School shark	443	899	1036		8	8			10615
Saw shark	38	100							
Toothed whiptail									187
John dory	370	370							
Gemfish	66	151							
Toothy flathead		1200							4200
Rock flathead		248							
Latchet									4
Butterfly gurnard		17							2
Jackass morwong									5
Yellowtail kingfish									7500
Albacore		17							4
Southern bluefin tuna	79	122							
Yellowfin tuna	39	139							

TABLE. 8. Diversity in the diets of fish species.

Values are for Levins' Index (mean ± S.D.) averaged over all stomachs containing food. Where fish were taken on more than one sampling cruise the range of average values per cruise is shown. Species of fish represented by less than five stomachs are omitted from the table.

SPECIES	NO. OF STOMACHS	LEVINS' INDEX	
		RANGE	MEAN ± S.D.
Gummy shark	113	1.24 - 3.00	1.97 ± 0.88
Whiskery shark	5	-	1.20 ± 0.45
School shark	109	1.18 - 2.13	1.69 ± 0.71
Saw shark	28	1.00 - 1.83	1.42 ± 0.68
Elephant shark	6	3.19 - 3.67	3.43 ± 2.00
Garfish	11	-	1.09 ± 0.30
Toothed whiptail	7	-	1.29 ± 0.49
Blue grenadier	17	1.00 - 1.13	1.12 ± 0.33
Bearded cod	11	-	1.41 ± 0.66
Ribaldo	11	-	1.07 ± 0.24
John dory	9	-	1.27 ± 0.41
Silver dory	50	1.00 - 2.00	1.09 ± 0.29
Nannygai	98	1.13 - 1.34	1.15 ± 0.35
Sandpaper fish	5	-	1.08 ± 0.19
Sea mullet	9	-	1.89 ± 1.05
Gemfish	64	1.00 - 1.16	1.07 ± 0.28
Toothy flathead	5	1.00	1.00 ± 0.00
Sand flathead	43	1.17 - 1.50	1.23 ± 0.43
Rock flathead	11	-	1.33 ± 0.75
Deep water flathead	13	-	1.14 ± 0.34
Tiger flathead	70	1.00 - 1.03	1.01 ± 0.10
Latchet	21	1.00 - 1.65	1.48 ± 0.67
Butterfly gurnard	42	1.00 - 1.30	1.21 ± 0.41
Red ocean perch	41	1.00 - 1.54	1.40 ± 0.69
Ling	74	1.16 - 1.50	1.19 ± 0.41
Horse mackeral	25	1.00 - 2.00	1.08 ± 0.28
Yellowtail scad	28	1.00 - 1.19	1.01 ± 0.07
Trevally	16	1.00 - 1.64	1.60 ± 0.67
Red mullet	12	1.31 - 4.00	1.53 ± 0.92
Long-finned pike	12	-	1.00 ± 0.00
King George whiting	9	-	1.22 ± 0.44
School whiting	46	1.14 - 1.51	1.43 ± 0.75
Jackass morwong	95	1.00 - 1.78	1.54 ± 0.67
Albacore	21	-	1.01 ± 0.05
Southern bluefin tuna	37	1.00 - 1.08	1.06 ± 0.19
Yellow-fin tuna	33	-	1.28 ± 0.68
Velvet leatherjacket	10	1.00 - 1.14	1.10 ± 0.32

RECOMMENDATIONS FOR FUTURE RESEARCH

Although the evidence from the present study is that arrow squid do not form a major item in the diet of any of the fish species investigated the usefulness of the study has been limited by the lack of facilities with which to conduct a controlled sampling programme. Because of this lack, it has not been possible to examine any of those factors which might be expected to influence the importance of squid, or the accessability of squid, to those fish which do consume them. In addition, where only small samples of a species were obtained, the importance of squid in the diets of these species may be underestimated. For example, fishermen report that yellowtail kingfish consume large amounts of arrow squid, but this was not obvious from the very small sample of yellowtail kingfish obtained in the present study.

Prerequisites for future work are that fewer species should be investigated and that a more controlled sampling programme should be undertaken. Controlled sampling is necessary to provide data from which may be derived a greater understanding of the factors which influence the importance of squid in fish diets. Factors which need to be investigated include the relative sizes of predator and prey and the feeding of fish in relation to: locality of fish, position of fish in the water column, time of day and season.

Besides studies on fish, some investigation of the biology and behaviour of the squid themselves seems necessary. There is some evidence that squid undergo seasonal migration, and there is also evidence for daily vertical migrations through the water column; both kinds of migration might be expected to influence the availability of squid as a food for fish and therefore require investigation. Similarly, a knowledge of the breeding cycle of squid and of growth rates, particularly in relation to the size ranges of squid available to predatory fish, seems desireable. Irrespective of any considerations regarding squid as an item in fish diets, these studies would also provide data of use in the management of a squid fishery.

In selecting those fish species for which further study seems necessary, emphasis obviously needs to be given to species which are both major consumers of cephalopods and of commercial importance. For other species, because they are not major consumers of cephalopods or because they are not of great commercial significance, the need for further study seems less obvious. However, it should be borne in mind that sampling for those species most obviously in need of further study will also produce those species which are less obviously so; the cost of sampling for these latter species should therefore not be a major consideration in deciding whether or not they merit further study.

Gummy and school shark, and to a lesser extent saw shark, are the most obvious species for further study because they are major consumers of cephalopods, have been shown to eat arrow squid and are of considerable commercial importance. John dory and toothed whiptail should also receive further study; they are not species of great commercial significance, and appear only to be moderate consumers of squid, but only small samples of these species were obtained and so some amplification of the present work seems necessary. Gemfish, a species of commercial importance, also requires further study. The present study found gemfish to be only a minor consumer of squid, but fishermen report considerable variation in the incidence of squid in the diet of this species. Albacore, yellowfin tuna and southern bluefin tuna were not found to be major consumers of squid but they nevertheless merit further study. Various studies have shown that the incidence of squid in the diets of these species may vary considerably and some indication of the extent of this variation seems desirable (cf 'Australian Fisheries' 1982 41(4) p.10 which reports that almost 50% of southern bluefin tuna examined off Tasmania had squid remains in the gut). Yellowtail kingfish also requires further study since the very small sample obtained precluded a proper assessment of the reported status of this species as a major consumer of arrow squid.

In addition to more detailed studies of the kind described in the present report, it would also be useful to obtain estimates of the energy content of the prey items consumed by those species which include squid in the diet. The present study has estimated the importance of prey items in terms of number, weight, volume and frequency of occurrence. However, such estimates ignore the fact that the importance of items is also related to their energy content and dominance by number, weight or volume does not necessarily imply dominance in terms of energy content. Items such as gastropods, bivalves and crustaceans, in which there is a large proportion of skeletal