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Marine aggregate proposal : marine ecological investigations

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METROMIX PTY LIMITED

MARINE AGGREGATE PROPOSAL:
MARINE ECOLOGICAL INVESTIGATIONS

VOLUME 1

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Summary

General Introduction

State planning authorities have identified the need for finding alternative sources of sand for use in Sydney's construction industry. This study investigates potential effects on the marine environment of the extraction of sand ("marine aggregate") from deposits distributed off the coastline adjacent to Sydney.

The marine ecological investigations for this proposal and the preparation of this report were done by The Ecology Lab Pty. Ltd. The information presented is based on field studies, a review of the scientific literature and discussions with scientists, managers and current users of the areas where extraction is proposed.

Description of the Proposal and Review of Potential Effects

Metromix Pty. Limited (the "Applicant") proposes to extract marine aggregate from two offshore areas south of Sydney - Cape Banks and Providential Head - and to deliver it to a berth in Port Jackson. The marine aggregate targeted for extraction is contained within one of a number of shelf sand bodies found on the coast of New South Wales. Proposals for both areas were prepared individually. If both are approved, the period of extraction would be increased and there would be an increase in the return interval (i.e. the number of months before a previously extracted area on the seafloor is disturbed again).

Extraction of marine aggregate would be by a trailer suction vessel and marine aggregate would be stowed in the vessel until offloading. Excess water would be released into the sea via diffuser ports at a depth of about 15 m below the ocean surface. A return trip for the extraction operation would be about 12 h. During each trip, the operation would disturb about 1 ha of seabed. At the end of the 25 y life of the project (or 50 y, if approval is given for both extraction areas), the 30-55 m isobaths would have moved shoreward by distances of 0.1-0.5 km.

No extraction would be done within at least 250 m of any rocky reefs or shipwrecks. The extraction operation would have a set of management rules, including the avoidance of any reefs or previously undiscovered shipwrecks.

Three major categories of potential impact associated with the extraction of marine aggregate were identified: disturbance to the seafloor resulting from removal of aggregate; disturbance of the water column resulting from the release of fines in the excess water; and disturbance caused by the operation of, or accidents happening to, the extraction vessel.

Particular issues of local significance include the effect of the proposal on the marine organisms of habitats in and around the proposed extraction areas; potential for recolonisation and replenishment of disturbed areas; effects of extraction on patterns of migration of marine animals; the compatibility of the extraction proposal with fishing and diving, scientific research, the operation Sydney's sewage outfalls and existing and proposed marine parks and reserves.

Description of the Environment

The coastline adjacent to the proposed extraction areas has steep sandstone cliffs, pocket beaches, a large embayment at Bate Bay and two estuaries, Botany Bay/Georges River and Port Hacking. Sandstone blocks commonly form subtidal talus slopes at the base of the cliffs and intertidal rock platforms are common. There are also several pocket beaches.

The areas of interest are large accumulations of sediment which are typically tens of metres thick and extend tens of kilometres along the coast. Shelf sand bodies are relatively common on the coastline of NSW, they occur off Montague Island, Jervis Bay, Bass Point and from Newcastle to Sugarloaf Point.

Planktonic and Pelagic Communities

Planktonic and pelagic organisms are those organisms residing in the water water column (either parmanently or as part of their life cycle). Phytoplankton (i.e. microscopic planktonic plants) growth is driven by additions of nutrients. Nutrients may come from a variety of sources, such as upwelling and/or intrusions of waters from the continental slope, terrestrial runoff after rain and, close to urban centres, from sewage outfalls. Seasonal successions in species of phytoplankton have also been observed off Port Hacking. In many cases, however, phytoplankton blooms were observed to be most pronounced following input of nutrients.

Zooplankton (i.e. planktonic animals) may consist of permanent residents (e.g. jellyfish and copepods) or temporary residents (e.g. fish eggs and larvae). The production and biomass of both permanent and temporary components of the zooplankton varies considerably in time and space. Recent surveys have shown that many fish larvae seem to prefer water depths of between 20 and 30 m, compared to surface waters. Large populations of pelagic fishes, such as tunas and sharks, and squid occur in NSW coastal waters. Many are seasonally abundant while others occur year-round.

Benthic Macrofauna

Soft sediments constitute the habitat likely to be disturbed most by the proposal to extract marine aggregate. As part of the marine ecological research, five studies were done on benthic macrofauna: 1) a survey of the macrofauna of the proposed extraction areas compared with reference areas; 2) an analysis of sediment grain size and benthic macrofauna; 3) a survey of benthic macrofauna before and after disturbance by a large storm event; 4) an experiment in which plots on the seafloor were defaunated by simulated dredging and the recolonisation by macrofauna monitored through time; and 5) a survey of benthic scavengers.

Benthic samples were collected from up to 5 locations on four occasions: Providential Head (PH), Bate Bay (BB), Bass Point (BP), Illawarra (IL) and Cape Banks (CB) between January 1990 and January 1991. PH and CB are the proposed extraction areas; the others were used as reference areas.

During the main study, a total of 115,545 individuals from three major groups of macrofauna were collected. Crustaceans constituted 53% of individuals, followed by polychaetes (39%) and molluscs (7%). Other taxa, including bryzoans, pycnogonids and ophiuroids were collected in small numbers.

The most abundant crustaceans were amphipods (58% of crustaceans), tanaidaceans (22%), isopods (7%), ostracods (3%), cumaceans (6%) and decapods (2%). The most common decapods collected were small hermit crabs. Representatives of 41 families of polychaetes were collected. The most abundant families were the Maldanidae, Spionidae, Chaetopteridae, Syllidae and Sabellidae, which made up >70% of all polychaetes collected.

Assemblages of macrofauna showed distinctive variability with depth, but no consistent variation among the locations sampled. In other words, the proposed extraction areas had assemblages of macrofauna which were similar to those at the reference locations, and depth was an important influence on the structure of assemblages at all locations.

It was concluded that taxonomically-rich assemblages of polychaetes, crustaceans and molluscs occurred in the sand bodies. The number of animals is comparable with the few other studies done in the nearshore marine habitats off NSW. Patterns of variation among depths may have important consequences for the assessment of impact of extraction of marine aggregate. Extraction from shallower areas would remove fewer animals and taxa than extraction from deeper water.

The study also showed that significant variation occurred at small spatial scales (i.e. over several hundred metres) and at temporal scales of 2 to 6 months or less. Short term temporal variation may imply short life cycles and turnover times of benthic fauna. If so, physical disturbance may not have long-term effects as recolonisation of disturbed patches would be of the order of months or less.

Part of the study of macrofauna sought to determine if the distribution of macrofauna was correlated with characteristics of the sediment. Surface sediments were mainly fine to medium-fine sands (median grain size: 100-300 µm). Sediments tended to become slightly finer with increasing depth. There were weak, negative correlations between grain size and abundance of a number of taxa of macrofauna.

Soon after completion of the second survey for the main study, two large storms occurred off Sydney. The wave conditions at the peak of the first storm would have affected the seabed to depths of at least 65-70 m. We sampled macrofauna at 4 depths at 2 sites one week after the second storm and just over two weeks after the second main survey. In shallow areas, there was no change in the macrofauna that could be attributed to the storm. In deep water (65-70 m), however, there was evidence that the storm caused significant changes to macrofauna.

As part of the studies, an experiment was done to measure the rate of recolonisation of denuded areas of similar width and depth to those that would be formed during extraction. Macrofauna rapidly recolonised the experimentally dredged patches, within 1-2 months. Recolonisation appeared to be mainly by immigration of adult animals from surrounding, undisturbed patches.

Benthic scavengers (including several groups of crustaceans) appeared to be poorly sampled using the grab device used in the main study. A study was done in which small, baited traps were deployed overnight at several sites and depths. Large numbers of scavengers were collected.

Demersal Fishes and Mobile Invertebrates

Demersal fishes and mobile invertebrates (e.g. squid and prawns) were sampled up to 4 times over a year at the proposed extraction areas and at reference locations. In all, 132 215 fish were collected from about 150 species and 64 families. Also, 2 692 invertebrates from 35 species were collected. Most of the species are relatively common and widespread on the NSW coast; none is considered rare or endangered. Although many of the species are subject to fishing bag limits, size limits or catch quotas, none is protected under existing legislation.

Species which were numerically dominant varied among depths and times and to a lesser extent among locations. In 20-30 m depth, catches were dominated by gurnards (*Lepidotrigla* spp.), long-spined flathead, stingarees and box fish. Balmain bugs, octopus and calamari squid were the most common invertebrates.

In 40-50 m, the catch was again dominated by *Lepidotrigla* spp. and long-spined flathead, but crested flounder and school whiting were also abundant. Invertebrates were dominated by cuttlefish and hermit crabs.

In 60-70 m, dominant species included school whiting, tiger flathead, crested flounder, Lepidotrigla spp. and, john dory. Cuttlefish were again the dominant invertebrates.

The numbers of fish species of economic importance tended to increase with depth.

Assemblages of fishes varied among depths over all surveys. Assemblages were similar at all locations, indicating that the assemblages at the proposed extraction areas were not distinctive compared to the reference locations. Also, little variation occurred among survey times within each depth range, particularly at 20-30 m and 40-50 m. At 60-70 m, the assemblages sampled during survey 4 differed from those at other times. This difference appears due to larger numbers of some species in the catch during survey 4, including john dory, bellowsfish, school whiting, yellowtail scad and crested flounder.

Populations of individual species often showed significant spatial and temporal variation, but this was often inconsistent among locations, depths or sites within locations through time.

Length frequency data were compiled for 20 species of economic value. Most, such as angel sharks, tiger flathead and school whiting, were present at all locations throughout their life cycle. Others, such as yellowfin bream and dusky flathead, occurred only as adults. There was no evidence (either from the field study or the literature) that the proposed extraction areas are major spawning or nursery grounds.

Rocky Shores, Reefs and Shipwrecks

Rocky shores, reefs and shipwrecks support very different assemblages of marine organisms to those of sandy substrata. There is much information on intertidal communities at Cape Banks as a result of research done there by the University of Sydney, but less is known of the intertidal communities near Providential Head. It is likely that many of the same processes structuring communities at Cape Banks would also apply there.

Shallow rocky reefs have been described as a mosaic of kelp stands, diverse foliose and turfing algae and thin, encrusting coralline algae or "barrens". Assemblages of fishes on reefs in the Sydney region are dominated in terms of numbers of species by wrasses and leatherjackets. Abundant species include mado, sweep, hulas, bullseyes, one spot pullers, white ear and red morwong. These species tend to reside on rocky reefs all or most of their life. In contrast, there are many other species which occur on local rocky reefs only as transients. Some of these, such as luderick and bream, recruit to estuarine habitats and make their way to shallow rocky reefs as adults. Other species, such as yellowtail scad, may use several habitats, including rocky reefs, estuaries and coastal waters.

The ecology of deep rocky reefs is poorly understood largely because of difficulties associated with sampling this habitat. Surveys done in water depths of 45-55 m indicate that the sessile fauna is dominated by sponges and there are no large areas of macroalgae. Photographic data also suggest that parts of the deep reefs are frequently covered by sediment.

Little is known of the biota of shipwrecks in the Sydney region. There is no doubt that large numbers of fish are associated with shipwrecks, such as the s.s. Tuggerah. No macroalgae such as kelp occur on these deep shipwrecks, but they are covered with a mosaic of sessile organisms, such as hydroids, anemones, sponges and corals.

Sandy Beaches

The surf-zones of exposed, sandy beaches have been described as harsh, structurally homogeneous environments for marine organisms. Beaches between Maroubra and Wattamolla occur in the vicinity of the proposed extractions areas. Those near to the proposed Cape Banks extraction area include Maroubra and Southern Bate Bay (Wanda, Elouera and Cronulla). Beaches of low to moderate energy occur at Long Bay, Little Bay and on the northern shore of the entrance to Botany Bay (Congwong Bay, Frenchmans Bay and Yarra Bay). Near the proposed Providential Head extraction area there are small pocket beaches, including Marley, Little Marley and Wattamolla Beaches. Studies of the fauna of local beaches suggest that the structure of these assemblages may be related to the degree of exposure of the beach to ocean waves.

Seabirds, Shorebirds, Marine Mammals and Marine Reptiles

Seabirds and marine mammals are often a conspicuous feature of the coastal environment. Some are resident on particular areas of coastline, while others undergo long migrations. Most are protected by legislation ranging from state laws to international agreements. Marine reptiles, which include turtles and sea snakes occur in our waters generally as vagrants from warmer areas. Many are also protected by law. Several species of birds occurring in the study region are listed in the Japan-Australia (JAMBA) and China-Australia (CHAMBA) Migratory Bird Treaties and are included in the Endangered Species Schedules of the National Parks and Wildlife Act, 1974.

The occurrence of many seabirds on the mid NSW coast is related closely to changes in ocean currents and other seasonal factors. Many seabirds congregate to feed at the edge of the continental shelf about 35 km offshore and hence are found mainly beyond the proposed extraction areas. Rocky shores, tidal reefs and ocean beaches are used by many species of birds, including gulls, waders and cormorants. Many feed along the edge of the intertidal others feed in adjacent waters. Boat Harbour, in Bate Bay is an important area for shorebirds. The Five Islands Nature Reserve, off Port Kembla, is a major seabird habitat. Of the 25 species of shorebirds found in the region, 19 are non-breeding migrants from the northern hemisphere. The others breed in Australia and are considered sedentary, with some movement between wetlands.

In NSW waters, cetaceans, pinnipeds, and dugongs are protected under the National Parks and Wildlife Act, 1974 and the National Parks and Wildlife (Marine Mammals Protection) Amendment Act, 1986. All marine mammals are considered to be of special importance in NSW legislation because they are rare or vulnerable to exploitation. They are also protected under commonwealth law and several international agreements.

Twenty-two species of marine mammals have been recorded in and around the study region. Most of the species recorded in the region are inhabitants of temperate to cool temperate waters (e.g. bottlenose dolphins). Some are of tropical or sub-tropical origin (e.g. dugongs, striped dolphins, dense beaked whales, whilst others are migrants (southern right whales, humpback whales) or vagrants (crabeater seals) from Antarctic waters.

Marine Reptiles likely to be recorded in the study region include five species of sea turtles and about five species of sea snakes. All marine reptiles are protected in NSW waters under Section 98(1) of the NSW National Parks and Wildlife Act, 1974. The luth turtle is listed as endangered fauna of special concern. Up to five species of sea snake may occur within the study region, mainly during the summer months. The Yellow-bellied Sea Snake is the most likely to occur.

Contamination of Coastal Fish and Invertebrates

Levels of trace metal and organochlorine contaminants in the water from the extraction areas were typical of those from coastal waters in the vicinity of large cities, but were above the levels that might be expected in pristine coastal waters. This was attributed to low-level pollution from a variety of sources, such as atmospheric fallout, ocean outfalls and movement of water from bays and estuaries to the sea.

Samples of sediment from both study areas had no organochlorines (OCs) at the level of detection for the analyses. Concentrations of trace elements were small and typical of sandy sediments on the NSW inner shelf. At Cape Banks, trace elements, particularly mercury, were generally more common in mid-shelf sediments (not the proposed extraction area) opposite Botany Bay, than in samples obtained to the north and south. The sediments from both areas had no detectable levels of hydrocarbons and very low levels of nutrients.

Elutriate testing showed no OC's or hydrocarbons being released from samples from either of the proposed extraction areas. Some cadmium was released in excess of the background levels, but the elutriate concentrations were still below water quality criteria.

Studies of contamination in fish and invertebrates have shown that there was significant contamination in some marine biota off Sydney and that the cliff-face outfalls were major sources of these contaminants prior to their decommissioning in the last 3 years. The commissioning of the deepwater ocean outfalls brings the potential source of contaminants closer to the proposed extraction area at Cape Banks. Thus, assessments of the impacts of the proposed aggregate extraction need to be considered, among other things, in relation to the outfalls.

Commercial Fishing, Angling and Diving

The waters off Providential Head and Cape Banks are utilised by a number of groups of people. Commercial fishing occurs in oceanic, coastal and estuarine waters along the length of NSW. It is regulated by both state and commonwealth agencies. With respect to the proposal to extract marine aggregate, fisheries which were considered include pelagic fishing, demersal fisheries using otter trawl, and reef fisheries using traps and lines for fish and crayfish, or diving to collect abalone.

Pelagic fisheries are not important in the proposed extraction areas. There are believed to be about 4 trawlers which exploit demersal fisheries in the proposed extraction areas (among other areas fished). Prawn trawling within Botany Bay does not extend out to the Cape Banks extraction area. Reef fisheries are done by linefishing and trapping. No reefs are within 250 m of the proposed extraction areas. Abalone are collected by diving along rocky reefs, usually in depths of 10 m or less. The fishery is centred in southern NSW, but 2-3 divers collect abalone commercially between Botany Bay and Wollongong.

Data compiled on the commercial catch of fish and prawns from various zones along the NSW coast were provided by FRI. In terms of fishing effort, the areas in which the proposed extraction would occur show a similar amount of effort to most other zones, when all methods are combined. Looking at specific methods, the Sydney region was subject to similar or slightly lower levels of effort to many of the other zones (e.g. linefishing, prawn trawling, fish trawling). The effort expended in fish trapping and fish trolling was relatively large, however.

Records of the fisheries catches often showed distinctive trends in the catch along the NSW coastline for selected species, but rarely, if ever, did the Sydney region stand out in comparison with other zones.

For recreational fishers, the main categories of fishing include gamefishing and fishing for pelagic fishes, reef fishes and fishes on soft substrata. Much of the gamefishing done off the Sydney coastline occurs towards the edge of the continental shelf.

Fishing for demersal or ground fishes is one of the most popular forms of recreational fishing. Fishing on reefs may be done either by anchoring on a reef or drifting over one or more reefs. There are productive reefs in waters off Cape Banks, beyond the outer limit proposed for extraction. The reefs inshore of the area are also good for reef fish. Similarly, the reefs fringing the proposed Providential Head extraction area provide good reef fishing. Angling over shipwrecks also yields good catches of reef fish.

Fishing for groundfish on sandy substrata is usually done by drifting. The proposed extraction area off Cape Banks is a popular area for flathead, particularly during the winter and early spring, when westerly winds provide a good "drift" across the sand body.

Angling from rocky shores and beaches is also very popular in the Sydney region. Anglers also gather bait from rocky shores and beaches.

There are numerous popular diving sites for SCUBA and snorkelling between Botany Bay and Wattamolla. In addition to diving on rocky reefs, diving on shipwrecks is popular with experienced divers. The s.s. Tuggerah and s.s. Undola, lying to the south of the proposed extraction area at Providential Head, are at depths of around 45-48 m. There are at least 6 charter boats which take divers to these wrecks and, when the weather is good, it is likely that there will be divers at the wreck on most days, especially during weekends and holidays.

All the coastline fringing Royal National Park is considered to be good for spearfishing, although there are a number of outstanding locations, such as Jibbon Bombora.

Research, Education and Conservation

There is extensive scientific research being done along the coastline of Sydney. In particular, the University of Sydney administers the Cape Banks Scientific Marine Research Area, located at the northern entrance to Botany Bay. It fringes the shoreline adjacent to the proposed extraction area at Cape Banks, lying about 1.25 km from the eastern boundary of the proposed extraction area. The research area is known as a major area for scientific research on the ecology of rocky shores. It also provides one of the few areas for long term ecological research within Australia.

Marine ecological studies being done for the deepwater ocean outfalls environmental monitoring program (EMP) include research on ichthyoplankton, demersal fish of soft substrata and reefs, macroinvertebrates of soft substrata and algae and invertebrates of rocky substrata. In addition, research is being done on bioaccumulation in marine organisms. Most of the studies commenced one or two years before commissioning of the deepwater outfalls. These studies, along with the use of control or reference sites, provide a baseline against which any effects of relocating the outfalls are being measured. Field work for these studies is scheduled to end in 1993 and a decision is yet to be made regarding future monitoring.

There are three existing aquatic reserves in the vicinity of the proposed extraction areas. Towra Point Aquatic Reserve occurs at Towra Point in Botany Bay, Shiprock Aquatic Reserve occurs at the entrance to Burraneer Bay, Port Hacking and Cabbage Tree Basin Reserve occurs on the southern side of the Port. The NSW National Parks Association (NPA) has proposed the declaration of a marine and estuarine protected area (MEPA) at sites adjoining Royal National Park. The limits of the proposed MEPA were divided into three areas: the Port Hacking estuary, the open ocean and the area within Bate Bay joining these two areas together. Much of the proposed MEPA is incorporated within Port Hacking Thus, many of the criteria apply only to the estuarine portion of the proposal. However, the MEPA would have as its eastern (i.e. seaward) boundary the 50 m bathymetric contour, which would also incorporate virtually all of the proposed extraction area at Providential Head. The proposed extraction area fringes less than 25% of the shoreline of Royal National Park.

Assessment of Impacts

Disturbance of Marine Biota in Relation to the Seabed and Coastline

It is predicted that impacts to macrobenthos would be extreme but highly localised in space and time. Most of the living benthic organisms would initially be removed from under the track of the extraction head (i.e. up to about 1.7 m wide)on each pass. Given the powerful suction generated at the extraction head, some benthic organisms (e.g. meiofauna) which may occur within a floc just above the seabed, would be sucked into the extraction head from the sides of the head.

More long term, or spatially widespread, impacts are not predicted because:

1) A large proportion (i.e. > 75%) of the area of the seabed within the proposed extraction areas would not be disturbed at any one time.

2) The extraction operation would have an equal or longer return time than recolonisation rates of macrobenthic invertebrates. Rates of recolonisation are predicted to be of the order of 2-3 months.

3) The sediments exposed during the extraction process would, minus the living organisms, be the same as, or very similar to, those presently occurring on the surface of the sand body.

4) Resettlement of any fines in the excess water returned to the sea would be < 1 mm per year. Thus, the potential for mortality of organisms due to smothering would be minimal.

At the end of the project, the seafloor would be 5 m deeper than at the start. Because the sand body is about 30 m deep in the areas proposed for extraction, no bedrock would be exposed by extraction. The remaining sediment would consist of material similar to that present before extraction. An increase in depth in the proposed extraction areas may cause a change in the structure of benthic assemblages, but the benthic assemblages in deeper of the proposed extraction areas tended to be taxonomically richer, and contain more animals, than shallower waters.

Most fish and mobile invertebrates would be able to avoid being sucked into the extraction head. The extent of impact to fish assemblages would therefore depend upon whether the benthic food source became limiting as a result of the loss of benthic macrofauna which was removed by the extraction operation, and by the behavioural responses of fish to the extraction operation. Given the relatively small area of the seabed that would be disturbed at any one time, and was therefore being recolonised, a reduction in food supply would probably not be limiting to fishes within the extraction area.

There was no evidence to suggest that the proposed extraction areas were significant spawning or nursery areas for fishes.

In the long-term, an increase in the depth of the seabed of up to 5 m may lead to assemblages of fish in the shallow areas becoming more similar to those sampled in deeper parts of the proposed extraction areas. As these assemblages included species of economic value, such changes may benefit local fisheries.

No extraction would occur within a 250 m buffer zone of any known rocky reefs or shipwrecks. A large part of the study done on behalf of the Applicant considered the effects of the proposal on the coastline and on movement of sediment on the seabed. These studies concluded that there would be no measurable increase in coastal erosion (or indeed, any measurable changes to beaches) as a result of the proposal. It is therefore concluded that, if the physical environment of the coastline is unlikely to change as a result of the proposal, it is highly unlikely that any measurable effects on biota of beaches or rocky shores would occur.

Sediment Plumes

The return of excess water and fine sediments from the extraction operation would form a plume in the receiving waters. Due to the relatively rapid dispersal of the plume over a large area and the size of the coastal water body compared with that of the plume, it is unlikely that there would be detectable differences in primary productivity as a result of the extraction operation, except possibly on very small spatial and temporal scales. Moreover, subsurface release of the plumes would expose less of the water column to turbid water, further reducing the potential for impacts to the plankton.

There would be no significant release of contaminants from the plume into the water column. Moreover, clogging of sensitive feeding and breathing organs by fine particles of sediment would not occur, except possibly at very small spatial scales, due to rapid dispersion of the plume.

Due the small scale and rapid dispersal of plumes associated with release of excess water, it is predicted that migrations of aquatic organisms would be unaffected by extraction of aggregate. Changes to water clarity as a result of suspended solids are unlikely to affect bird feeding, due to the relatively small size of the plume and subsurface release of excess water, which is below the depths at which most birds occurring in Sydney's coastal waters feed.

Disturbance from Operations or Potential Accidents Associated with the Extraction Operation

No seismic testing or blasting in the marine environment is planned should approval for the project be given. Specialist consultants engaged by the Applicant investigated potential noise associated with the extraction proposal. It was predicted that in the Sydney region, which has extensive shipping, the noise of dredging machinery may be attenuated by the background of other shipping noises. Moreover, it was predicted that the noise of an extraction vessel steaming to and from the extraction area each day would be unlikely to cause any significant change in existing ambient underwater noise levels.

As with any seafaring vessel, it is possible that there could be an accident or loss of the vessel. The discarding of wastes, occurrence of spillages, etc. all have the potential to cause impacts. The extent to which they are likely to occur, however, can be moderated by management practice.

Effects on other Users of the Area

While there is some commercial fishing within or near the proposed extraction areas, much of this is minor compared with fishing in deeper water or elsewhere on the coast. Possible exceptions to this may be trap fishing for fish and crayfish and diving for abalone. Otter trawling has the greatest potential for being disrupted by the extraction operation, yet is rarely done at Providential Head and Cape Banks.

Potential conflicts between anglers and divers, and the extraction operation would be minimised by not extracting aggregate during weekends and public holidays.

The level of enjoyment associated with diving relies largely on the clarity of the water. Creation of a turbid plume from extraction of marine aggregate could reduce the pleasure and safety of diving. The extraction operation has, however, been developed so that effects to divers visiting shipwrecks should be eliminated in most cases, and minimal in the rare event of divers passing through a plume. The plumes are expected to impinge rarely upon shallow rocky reefs, and turbulence and other processes associated with the nearshore zone should ensure that the plume is rapidly diluted.

The development of the extraction plan and the modelling of the physical impacts of the proposal has, in part, been done to assess and minimise any effects on the Cape Banks Marine Research Area. On this basis, it is considered that this area would not be affected by the extraction proposal.

Some of the research being done as part of the environmental monitoring programme for the deepwater ocean outfalls is close to or within the proposed extraction areas. If the monitoring ends in 1993 with the current contract (or even if it were extended up to the time the extraction began), there would be no conflict between the EMP studies and the extraction proposals. If, however, monitoring of the effects of the outfalls continued beyond the commencement of extraction, results of the monitoring could be affected.

The outer boundary specified by the draft proposal for a marine extension of Royal National Park currently includes most of the proposed extraction area at Providential Head. Given that the habitat and assemblages within the proposed extraction area at Providential Head are similar to other areas; that the effects of extraction should not extend significantly beyond the extraction area; and that the extraction area itself fulfils few of the criteria adopted for the proposed park extension, it is likely that the marine aggregate proposal could be accommodated within a proposal to extend Royal National Park to adjacent marine waters.

Ecologically Sustainable Development

The effects of the proposed development on marine ecology and other users were assessed in terms of principles of ecologically sustainable development (ESD). The six main principles of ESD were addressed: intergenerational equity, intragenerational equity, conservation of biodiversity, dealing cautiously with risk, global issues and economic diversity/resilience. In particular, it was concluded that the project would maintain equity within and among generations, that biodiversity would be conserved on small and large scales and that acceptable approaches ("anticipatory" and "precautionary") to risk had been followed.

Monitoring

Monitoring of selected habitats, processes or assemblages should have, as a minimum requirement, the use of spatial and temporal controls. That is, sampling should be done before, during and, if necessary after extraction, both within the proposed extraction area(s) and at reference areas which would not be affected by extraction. Furthermore, monitoring to detect the effects of sand extraction would be more rigorous if extraction occurred in both Cape Banks and Providential Head, because the effects of extraction would be replicated at the scale of the extraction areas.

Monitoring of the plumes created by return of excess water should focus on monitoring of physical and chemical characteristics of the water (e.g. light attenuation, suspended solids, nutrients, contaminants), compared with at least two areas near to, but not within, the plume. Concentrations of chlorophyll should also be measured inside and outside the plume.

The effects of the extraction operation on benthic macrofauna could occur at three spatial scales: the small-scale tracks along which the extraction head passes; the medium-scale portion of the extraction area being targeted at any one time; and the large-scale of the entire extraction area. Monitoring should be designed to examine effects of extraction at each of these scales.

Due to the mobility of fish and mobile macroinvertebrates of soft substrata, it may be practical to sample this component of the fauna only at scale of disturbance over the whole extraction area.

For biota of rocky shores, a two year study should be done prior to commencement of extraction. This baseline could then be used as a temporal control to compare against similar surveys done at any time during the life of the extraction operation. For example, it may be advisable to repeat the survey at 5 or 10 yearly intervals, or if monitoring of physical processes (e.g. sand transport) varies from the predicted effects.

Shallow rocky reefs (< 20 m) are accessible by divers. Monitoring should be done on rocky reefs in relation to the possible movement of silt onto reefs associated with the return of excess water. Also, surveys of sessile biota (e.g. kelp and sponges), mobile invertebrates (e.g. abalone and sea urchins) and fish should be done.

Deeper rocky reefs (to about 45 m depth) and shipwrecks are far less accessible to divers. Deep reefs may be sampled remotely by using photoquadrats for sessile biota and by traps, gill nets and/or longlines for fish and some mobile invertebrates. Sampling the biota associated with shipwrecks is problematic, because of the depths involved, the relatively small size of the wrecks and the lack of suitable control locations. It is recommended that monitoring be limited to investigating physical matters, such as the frequency (if at all) that plumes impinge on shipwrecks and the stability of the seabed surrounding the wrecks.

Sandy beaches would be monitored as part of the physical studies, but no recommendation is made for monitoring the biota of sandy beaches.

No specific monitoring studies are recommended for marine mammals and reptiles. It is, however, recommended that contact with specialist scientists be maintained as part of the monitoring programme to allow the Applicant to alter the extraction plan in response to changed migration paths, changes in abundance and so forth. Also, as part of the vessel's operating practice, any incident involving marine mammals should be reported to the Applicant and NSW NPWS. In particular, if southern right whales are observed with calves in areas such as Bate Bay, observations should be made of any interaction between the extraction vessel and the whales. Such interactions should be minimised. Monitoring of seabirds is not warranted given the very small potential for impact. It is recommended, however, that close liaison be maintained with NSW NPWS, the Royal Ornithological Society and the Australian Museum to identify any trends in populations of seabirds that should be accounted for in the extraction plan.

Testing for contaminants in the marine aggregate and in the water column should be done routinely. Testing biota should only be considered if contaminants are found in the aggregate or water column, or if testing of biota as part of the deepwater ocean outfalls monitoring programme ceases.

If the extraction operation is approved, close liaison should be established with groups of users of the waters of the extraction areas. Codes of practice should seek to minimise any conflict between the operation and other users. Monitoring of plumes associated with release of excess water, and of biota, should indicate how other users of the area(s) might be affected, if at all. Surveys should also be considered for monitoring changes in fish catches (compared with control locations) for at least the early part of the project. Liaison with other researchers in the area should be maintained.

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STUDY TEAM AND ACKNOWLEDGEMENTS

STUDY TEAM

The work for this project was done by The Ecology Lab Pty. Limited, with the assistance of others.

The report was written by Marcus Lincoln Smith and Rodney James, with contributions from Dr Aldo Steffe (Chapter 7), Philip Hawes (Chapter 12), Adam Smith (Sections 14.3.3 and 14.3.4) and Roberta Dixon (Section 14.3.2) from The Ecology Lab; Dr Jim Lowry (Section 8.5) from the Australian Museum; and Professor Tony Underwood (Appendix C and E) and Karen Astles (Appendix C) from The Institute of Marine Ecology at the University of Sydney. Dr Graeme Inglis from The Ecology Lab provided editorial comment.

Production of the report was done by M. Lincoln Smith, R. James and P. Hawes, with assistance from other members of The Ecology Lab, particularly R. Dixon and Adam Pope.

Field work was done by P. Hawes, Carl Alvars, M. Lincoln Smith, R. James, Francisco Duque-Portugal, R. Dixon, A. Steffe, A. Smith, Tim Park, Nick Skelton, Steve Keable and J. Lowry. Vessels were chartered from and skippered by Gratz Lammachia ("Christa"), Vic Blaslov ("Winkels") and Graham Pebmerton. Diving assistance was provided by Alan MacLennan, John Black, Andrew West and Ian Puckeridge.

Laboratory work was done by R. Dixon, C. Alvars, R. James, Anna Salih and P. Hawes. Max Davies (Metromix) analysed grain size of sediment samples.

The Australian Museum was contracted to identify benthic macrofauna and demersal fish. In particular, Dr Alan Jones and Dr Hal Cogger conducted initial negotiations, Penny Berents co-ordinated identification and archiving of specimens and Dr Ian Locke, Anna Murray and Roger Springthorpe identified molluscs, polychaetes and crustaceans, respectively. Workers from the Department of Fish, including Dr John Paxton, Mark McGruther and Sally Reader identified some of the fish collected.

Dr Peter Fairweather (Macquarie University) was engaged as peer reviewer for the marine ecological studies and assisted with development of study designs and review of the report. A. Underwood and specialists visiting from overseas, including Professor Pete Peterson, Dr Dick Clark and Dr Richard Warwick were also engaged to attend a workshop and provide comment on the marine ecological studies.

ACKNOWLEDGEMENTS

Editorial comment was provided P. Fairweather, Rob Corkery (R.W. Corkery and Co) and Bob Home. Comments were also provided by John Hann (Metromix), A. Underwood and reviewers from NSW Fisheries (particularly Jenny Burchmore and Dr Nick Otway), the NSW Environment Protection Authority (EPA) (particularly Gary Henry) and the Water Board.

Dr Bruce Pease (NSW Fisheries Research Institute, FRI) prepared and supplied data on commercial fishing in NSW, Dr Steve Kennelly (FRI) and Steve Montgomery (FRI) provided information on prawn trawling, and Alan Campbell provided information on abalone collecting. The Fisheries inspectors at Sydney Harbour and Sans Souci also provided information on commercial fishing activities off Sydney. N. Otway, Rob Williams, Ron West of FRI and J. Burchmore and Barbara Richardson of the Habitat Management Section at NSW Fisheries provided information on issues of concern to Fisheries and on the studies being done for the Deepwater Ocean Outfalls environmental monitoring programme (EMP). N. Otway and G. Henry provided trawling data from the EMP.

Max Gleeson provided information on shipwrecks off Sydney and organised a meeting with local divers. Bruce Schumacher (RFAC) provided laison with recreation fishers and Duncan Leadbitter (Ocean Watch) provided liaison with commercial fishers.

Finally, we would like to acknowledge the contributions made by other members of the Metromix study team, including John Hann (Metromix), Rob Corkery (R.W. Corkery and Co.), Lex Neilsen and Doug Lord (Geomarine), Doug Treloar (Lawson and Treloar), Ted Ambler (MTM), John Hudson, Darren Skene, Ian Irvine (Pollution Research) and Bob Home who provided information, comments and advice throughout the project.

Abbreviations and Some Common Terms

ANOVA	Analysis of Variance (statistical)
The Applicant	Metromix Pty. Limited
cm	centimetre(s)
DOP	Department of Planning
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EPA	NSW Environmental Protection Authority, formerly known as the State Pollution Control Commission (SPCC).
Fines	Component of marine aggregate not retained following extraction (usually released at sea)
FRI	Fisheries Research Institute
ICES	The International Council for the Exploration of the Sea
ISLW	Indian Spring Low Water
kg	kilogram(s)
km	kilometre(s)
l	litre(s)
m^2	square metre(s)
Mm^3	million cubic metre(s)
mm	millimetre(s)
MDS	Multidimensional scaling (statistical)
MEPA	Marine and estuarine protected area
Mt	million tonne(s)
NPWS	NSW National Parks and Wildlife Service
NPA	National Parks Association
PWD	NSW Public Works Department
SPCC	State Pollution Control Commission, now known as the Environmental Protection Authority.
TEC	Total Environment Centre
TEL	The Ecology Lab Pty. Ltd.

μg	micrograms
$>$	greater than
$\geq$	greater than or equal to
$<$	less than
$\leq$	less than or equal to
$\approx$	approximately equal to
σ	significance criterion, i.e. the probabilty at or below which the statistical null hypothesis is rejected, by convention, σ is usually set at 0.05.

PART II: DESCRIPTION OF THE PROPOSAL AND REVIEW OF POTENTIAL EFFECTS

CHAPTER 3. BRIEF DESCRIPTION OF THE PROPOSAL

The Applicant proposes to extract marine aggregate (fine sand) from two offshore areas south of Sydney and deliver it to a berth and adjoining terminal at Pyrmont for distribution by truck principally to markets east of Parramatta (Fig. 3.1). Fine sand will be needed to replace existing sources in the Kurnell dunes, due to close before the end of this decade (Corkery and Co. 1993).

The marine aggregate targeted for extraction is contained within one of a number of shelf sand bodies that have accumulated on the inner continental shelf along the NSW coast. A "shelf sand body" is a convex upward feature on the seafloor (Ferland 1990). Such bodies have also been termed "sand bulges" to distinguish them from drowned embayments and beach wedges that are also common near Sydney. The sand body targeted for extraction is approximately 20-30 m thick, comprises mainly well sorted quartzose sands. The shelf sand body is not connected directly to sand on nearby beaches (Geomarine 1993).

The aggregate resources within the shelf sand body of interest have been divided into three grades, all of which have been found at the surface of the seafloor:

* Grade 1: medium quartzose sand that is well sorted, contains 3-18% shell. This grade occurs only at Cape Banks, where it varies in thickness from 0.5 m to more than 4 m.

* Grade 2: fine to medium grained quartzose sand, finer than Grade 1. It is generally fawn-brown, moderately well to well sorted, containing 4-15% shell. This grade becomes finer to the south of Providential Head. It varies in thickness from 0.5 m to more than 6 m, and typically overlies the Grade 3 marine aggregate.

* Grade 3: fine grained quartzose sand, finer than Grade 2. It is fawn-grey to grey, well sorted, with less than 10% shell. The thickness of this grade is commonly more than 20 m.

The Grade 1 and Grade 2 resources are suited commercially for a range of applications in the building and construction industries and are referred to collectively as concrete grade resources. The uses of Grade 3 resources are limited to general construction purposes, such as filling. Emphasis is to be placed upon extraction of concrete grade resources.

The extraction proposal is described in detail in the EIS (Corkery and Co. 1993). A brief description of it is provided here to focus the reader on aspects that may have a direct bearing on marine ecological issues.

The proposals for Cape Banks and Providential Head have been prepared on a stand alone basis, that is, in isolation from the proposal to extract marine aggregate from the other extraction area. It is the Applicant's intention to extract sand from both areas simultaneously. This approach is considered appropriate should it be established that for some reason that extraction is not approved or is delayed within the other extraction area.

3.1 PROVIDENTIAL HEAD

3.1.1 Extraction Area, Amount and Duration of Extraction

The proposal for extraction of marine aggregate at Providential Head would involve extraction of two concrete grades of aggregate in water depths of between 25 m and 55 m, an area of 7.4 km^2 off the NSW coast between The Cobblers in the north and Providential Head in the south (Fig. 3.1). This proposal would yield up to 30.6 million tonnes of concrete grade sand over approximately 25 years. A further 19 million tonnes of fine grained material (Grade 3) could also be extracted for general construction purposes, should the need arise and there is a capacity in the extraction schedules to extract the material after the concrete grade requirements. Extraction of this additional material forms part of the present proposal, however, its rate of extraction would be limited to 1.5 $Mt.y^{-1}$ together with the concrete grade marine aggregate. Any future proposal involving extraction of a greater quantity of material would be subject to further applications (Corkery and Co. 1993).

Extraction would probably be concentrated in water depths of 25-35 m during the early years of operation and would then extend to 55 m for the remainder of the operation. No extraction would occur within 500 m of any part of the coastline, or less than 25 m depth (whichever is the farthest from the coast), or within 250 m of any rocky reef or shipwreck. Moreover, no extraction would occur in depths of less than 35 m and within 1.5 km of the extremities of Marley Beach and Little Marley Beach.

The seaward limit of extraction or the 55 m isobath lies between 2.0 and 2.5 km off the coast. This limit coincides with the seaward extent of the aggregate resource. In other words, extraction of aggregate beyond 55 m depth would not occur because no sand of value to the Applicant occurs there.

The annual requirements for marine aggregate would vary throughout the life of the proposal. Initially, 0.6 Mt would be required annually in the first five years of operation. This would increase to 1.0 $Mt.y^{-1}$ in years 6 to 10, and up to 1.5 Mt annually thereafter. The exact quantity produced, however, would be market-dependant. Grades 2 and 3 of marine aggregate would be blended (ratio 4:1, respectively) to provide a product acceptable to the current market. This blend would be known as target grade material. Given the large volume of Grade 3 marine aggregate, not all this grade would be extracted to be combined for target blend. Some additional Grade 3 marine aggregate could be extracted for general construction purposes.

The life of the extraction proposal at Providential Head for concrete grade marine aggregate is estimated to be approximately 25 years. This has been determined, however, in isolation, without reference to the Cape Banks proposal. Should that proposal also proceed, the continued operative life of both resources would be in the order of 50 years. The ongoing extraction of Grade 3 material would increase the life of the operation beyong 50 years.

3.1.2 Extraction Procedures

Extraction of marine aggregate would be done by a trailer suction vessel in which marine aggregate would be stored in a hopper within the extraction vessel. The Applicant proposes first to extract all the target grade marine aggregate within the extraction area and, secondly (subject to market requirements), to extract whatever Grade 3 material can be used for filling or other general construction projects throughout the life of the operation.

The selection of the extraction track within the extraction area would be undertaken both on a long term basis and on a trip by trip basis. Annual planning of the area for extraction would be done, with the intent that the area selected would enable the extraction vessel to traverse any part of that area in that year, provided the extraction tracks were haphazardly spaced, with relatively large areas of undisturbed sediment between (see Part IV for further discussion of this).

The Master of the vessel would select the extraction track for each trip based on 1) occurrence of previous extraction tracks; 2) Navigation conditions; and 3) the desired blend of marine aggregate. The track would need to cover about 4.5 km of Grade 2 marine aggregate and 1.2 km of Grade 3 aggregate to achieve the 4:1 target blend.

The extraction vessel would steam directly from the berth at Pyrmont to the extraction area. The vessel's hopper (≈ 2000 m^3 capacity) would be filled with water ballast drawn from Sydney Harbour. Upon arrival at the Extraction Area, the extraction arm would be lowered to the sea bed and pumping would commence. The suction head would skim a path along the seabed about 1.7 m wide and about 0.2 m deep. The speed of the Vessel during extraction would be 1.0-1.5 knots. The vessel would need to travel 5.7 km over a period of about 2 hours to fill its hopper.

The cargo of marine aggregate would be loaded into the vessel's hopper as a slurry comprising approximately 90% seawater and 10% aggregate. After the aggregate settled in the hopper, about 30% of the seawater would be retained with the aggregate, while the remainder would need to be released from the vessel. This water would be released from a series of diffuser ports at an average depth of about 15 m below the ocean surface (Corkery and Co. 1993). About 40-50% of the water then remaining in the aggregate would be discharged into the ocean en route to the terminal. This return water would be effectively filtered through the aggregate and returned "clean" to the sea, via a series of outlets in the base of the vessel's hull.

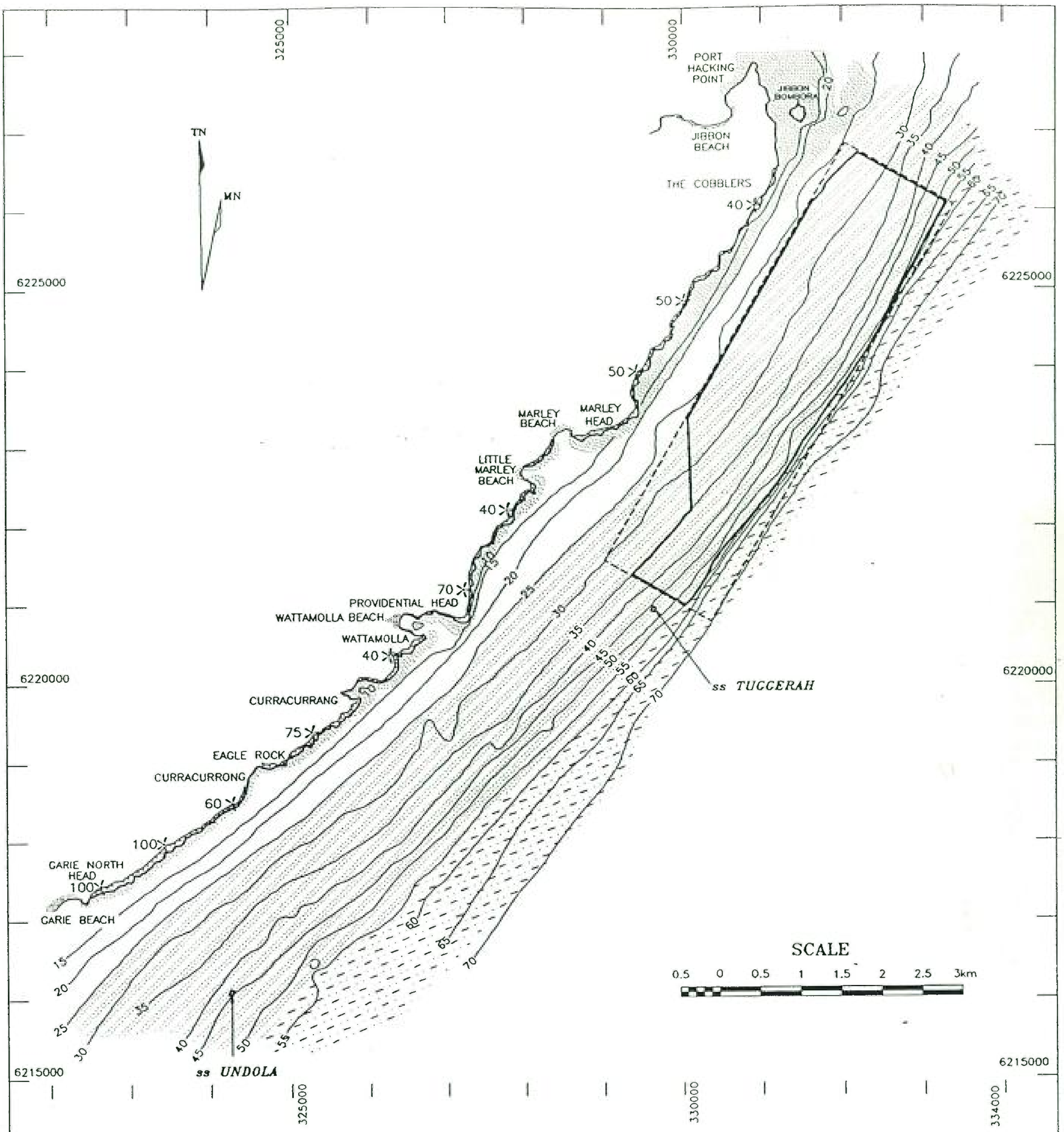
When fully operational, the cycle time for the extraction operation and unloading would be about 12.5 hours at Providential Head.

The sequence of extraction throughout the life of the proposal is shown in Figure 3.3. This is based on the depth limit of the extraction vessel, the occurrence of the resource, ecological considerations, sea conditions and the location of shipwrecks, such as the s.s.Tuggerah. It is proposed that extraction would generally be confined to water depths of less than 35 m in at least the first 5 years of operation, thus there will be an opportunity to monitor adopted criteria at distances up to 0.5 km from the wreck during that time. Consideration of those results should confirm or otherwise the suitability of the proposed 250 m buffer around the wreck.

At the end of the 25 years proposed for extraction of concrete grade marine aggregate, the 30-55 m isobaths would have moved shoreward by distances of 0.1-0.5 km. This assumes extraction of Grade 3 material for general construction purposes.

During each trip, the extraction operation would cause direct disturbance to about one hectare of the seabed. The total area disturbed per year would vary depending on the total amount of marine aggregate extracted (Table 3.1). Consequently, the return interval, defined as the number of months before a previously extracted area is disturbed again (not including the crossing of previous extraction tracks) would be initially 30-40 months, but would be reduced to 14-30 months after the first 5 years (Table 3.1). Over the remaining life of the project, the return interval would decrease to a minimum of 3 months as the availability of the resource decreased. If additional material were required for general construction purposes at any time during the life of the project, the rate of extraction would be determined such that return intervals were never shorter than 3 months and that a maximum of 1.5 Mt of aggregate would be removed in any year. Any proposed changes to these criteria would be subject to separate applications (Corkery 1993).

The description of the proposal provides for monitoring of effects, and for annual reporting on the operations. These reports would incorporate the ongoing results of ecological and physical monitoring.

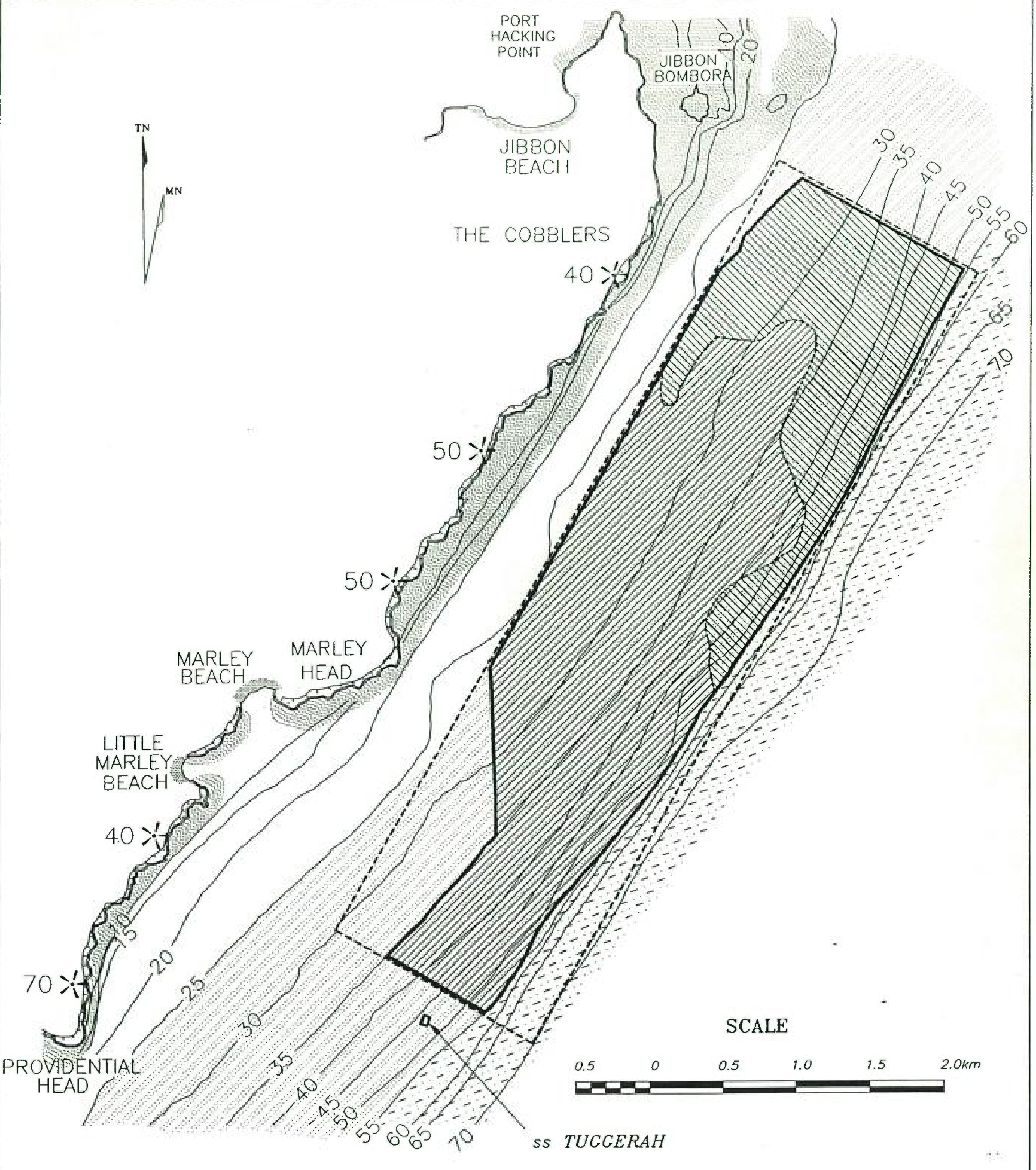


REFERENCE

- ▨ Beach
- ⌒ Cliffed and/or Rocky Shoreline
- ▨ Approximate Extent of Rock Reef
- ▨ Inner Continental Shelf Sand Unit (Marine Aggregate Resource)
- ▨ Mid Continental Shelf Muddy Sand Unit
- ~ Zero Metres Indian Spring Low Water (ISLW)
- ~ Bathymetric Contour (Metres below ISLW, Interval = 5m as shown)
- --- Boundary of Proposed Application Area
- ⌒ Boundary of Extraction Area
- ▫ Shipwreck Location
- 25 ✣ Onshore Spot Height (m, AHD)

Source : R.W.CORKERY & Co. PTY. LTD.

Figure 3.1
STUDY REGION



REFERENCE

▒ Beach
⌒ Cliffed and/or Rocky Shoreline
▓ Approximate Extent of Rock Reef
░ Inner Continental Shelf Sand Unit (Marine Aggregate Resource)
⋰ Mid Continental Shelf Muddy Sand Unit
▫ Shipwreck Location
∼ Bathymetric Contour (Metres below ISLW, Interval = 5m)
25✳ Onshore Spot Height (m, AHD)

Marine Aggregate Resource

⌒ Boundary of Resource Proposed for Extraction
▩ Resource Grade 1 (Absent on this Plan)
▨ Resource Grade 2
▧ Resource Grade 3
⌒ Boundary between Resource Grades

Source : R.W.CORKERY & Co. PTY. LTD.

Figure 3.2
EXTRACTION AREA

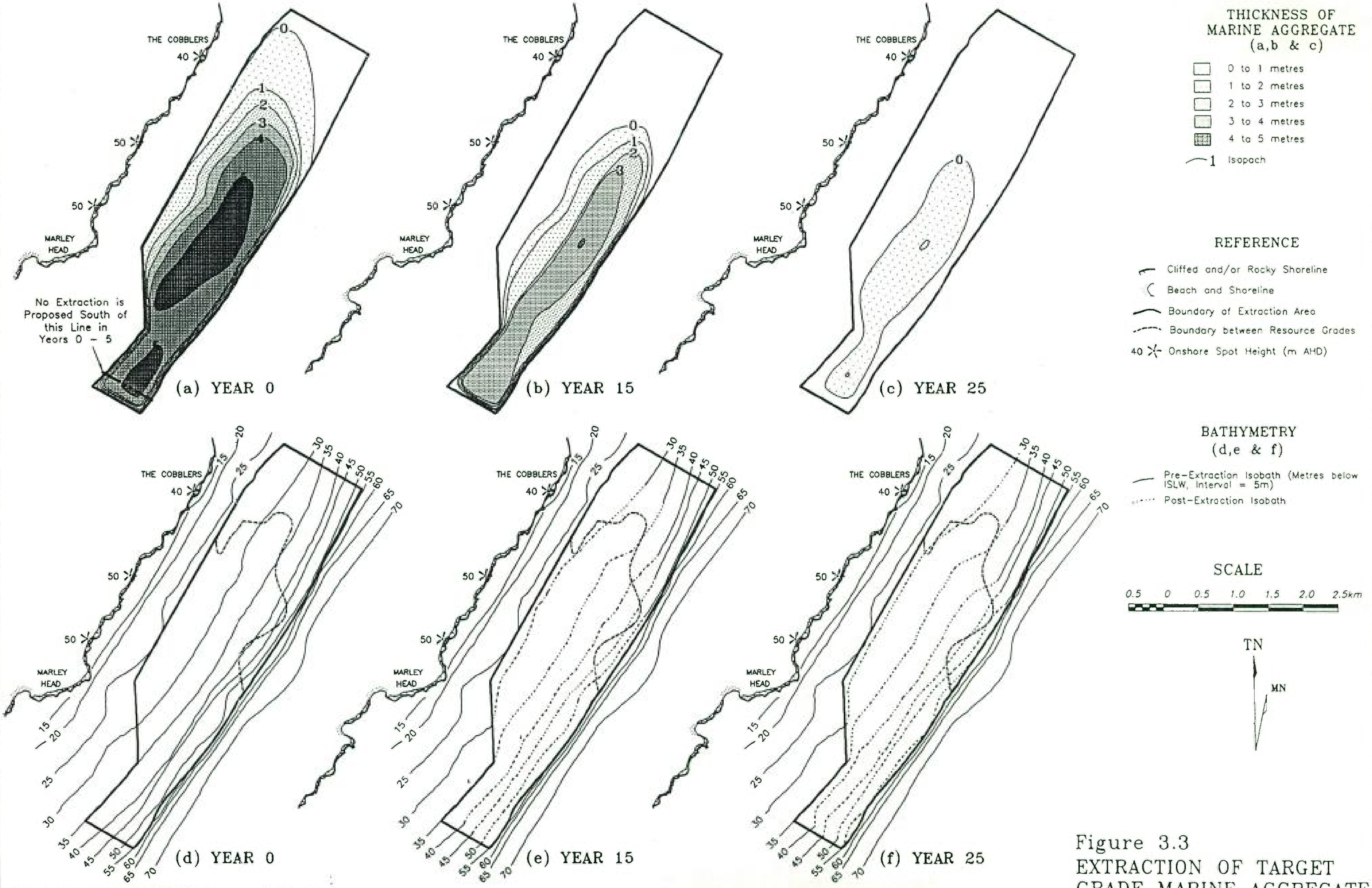


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Figure 3.3
EXTRACTION OF TARGET GRADE MARINE AGGREGATE

Table 3.1 Proposed frequency of extraction trips and area of disturbance at Providential Head (sources: Mining Tenement Management 1993; Corkery 1993).

Annual production level (Mt)	Years of Operation	Trips per year	Annual area (km^2) of disturbance	Return interval (months)
0.6	1- 5	170-200	2.0	30-40
1.0	6-10	285-330	3.3	14-30
1.2 to	11+	340-400	4.0	3-14
1.5		430-450	5.0	3-14

3.2 CAPE BANKS

3.2.1 Extraction Area, Amount and Volume of Extraction

The sand body at Cape Banks is part of the same feature as that at Providential Head. The proposal for extraction of marine aggregate at Cape Banks would involve extraction of three grades of aggregate in water depths of between 43 m and 65 m, in an 8.2 km^2 area off the coast, near the entrance to Botany Bay (Fig. 3.4). The landward side of the sand body lies against rocky reef, except at the entrance to Botany Bay, where the sand body lies on fluvial and estuarine sediments. The seaward side of the sand body merges in water depths of 55 m to 65 m with a finer grained, muddy sand on the mid-shelf plain.

The proposal to extract marine aggregate from Cape Banks would yield almost 27 Mt of concrete grade sand, extracted over approximately 24 years. A further 24 Mt of fine grained material could also be extracted for general construction purposes. As with the Providential Head proposal, the 24-year life proposed for Cape Banks has been determined in isolation. If both proposals proceed, the total operative life would be about 50 years.

3.2.2 Extraction Procedures

Many of the procedures described for the Providential Head proposal (Section 3.1.2) apply to that at Cape Banks. As with Providential Head, extraction would be done using a trailer suction vessel in which aggregate would be stored in a hopper. The Applicant proposes first to extract all the Grade 1 and Grade 2 marine aggregate within the extraction area and to extract whatever Grade 3 material can be removed for filling or other general construction projects during the life of the operation. There would be no blending of the Grade 2 and Grade 3 materials as at Providential Head.

The selection of the extraction track would be as described in Section 3.1.2. The Master of the vessel would make his/her selection based on previous extraction tracks and navigation conditions.

During extraction, the vessel would traverse about 5.7 km of the seabed to fill its hopper. It would be necessary to undertake several passes across the resource to obtain a full hopper load of marine aggregate, particularly for the Grade 1 material. Subject to the prevailing sea and atmospheric conditions, the Master would establish whether it was necessary to raise the extraction head during the tighter turns. The extraction head would be lifted 5 m to 10 m above the seabed and lowered at the end of each turn. The hopper would be filled in about 2-5 hours. Excess water would be released as described in Section 3.1.2 (see also Corkery 1993).

The cycle time for the extraction operation at Cape Banks would be about 11 hours.

The sequence of extraction at Cape Banks is shown in Figure 3.6. This is based on the same factors as described in Section 3.1.2. At Cape Banks, no extraction would occur 250 m of two ship wrecks, the <u>s.s.Woniora</u>, beyond the eastern limit of the extraction area, and the <u>s.s.Kelloe</u>. beyond the northwestern limit. In fact, it is proposed that no extraction would occur within a radius of 500 m around these wrecks during the first five years of extraction, during which time monitoring would be used to confirm the suitability or otherwise of the proposed 250 m buffer zone around the wrecks.

Because the Grade 1 resource occupies a small area, the extraction runs for this would be much shorter than for Grade 2 (Fig. 3.6). Further, as the Grade 1 resource diminishes, more of the Grade 2 resource would be exposed at the surface of the seabed. The Grade 1 marine aggregate would be extracted fully within about 20 years. At the end of Year 25, which virtually coincides with the completion of extraction of the Grade 2 marine aggregate, the 50 m and 65 m isobaths would have moved inshore by 0.1-0.5 km (Fig. 3.6f).

As at Providential Head, about 1 ha of the sea bed would be disturbed on each trip to Cape Banks. Also, the total area disturbed annually would vary, depending upon the production level (Table 3.2).

It is important to emphasise that the return intervals have been considered in isolation from the extraction in the Providential Head extraction area. Should both areas be approved, the return time for extraction of target grade material at Providential Head and Grade 2 at Cape Banks would essentially double.

Table 3.2 Proposed frequency of extraction trips and area of disturbance at Cape Banks (source: Mining Tenement Management 1993; Corkery 1993).

Annual production level (Mt)	Years of Operation	Trips per year	Annual area (km^2) of disturbance	Return interval (months)	
				Grade 1	Grade 2
0.6	1- 5	170-200	2.0	>22	>55
1.0	6-10	285-330	3.3	13-22	15-55
1.2 to	11+	340-400	4.0	3-13	3-15
1.5		430-450	5.0	3-13	3-15

3.3 UNLOADING FACILITIES

According to the EIS, unloading facilities would be located initially at an approved site within Port Jackson (Corkery 1993). This part of the proposal is not addressed further in this report.

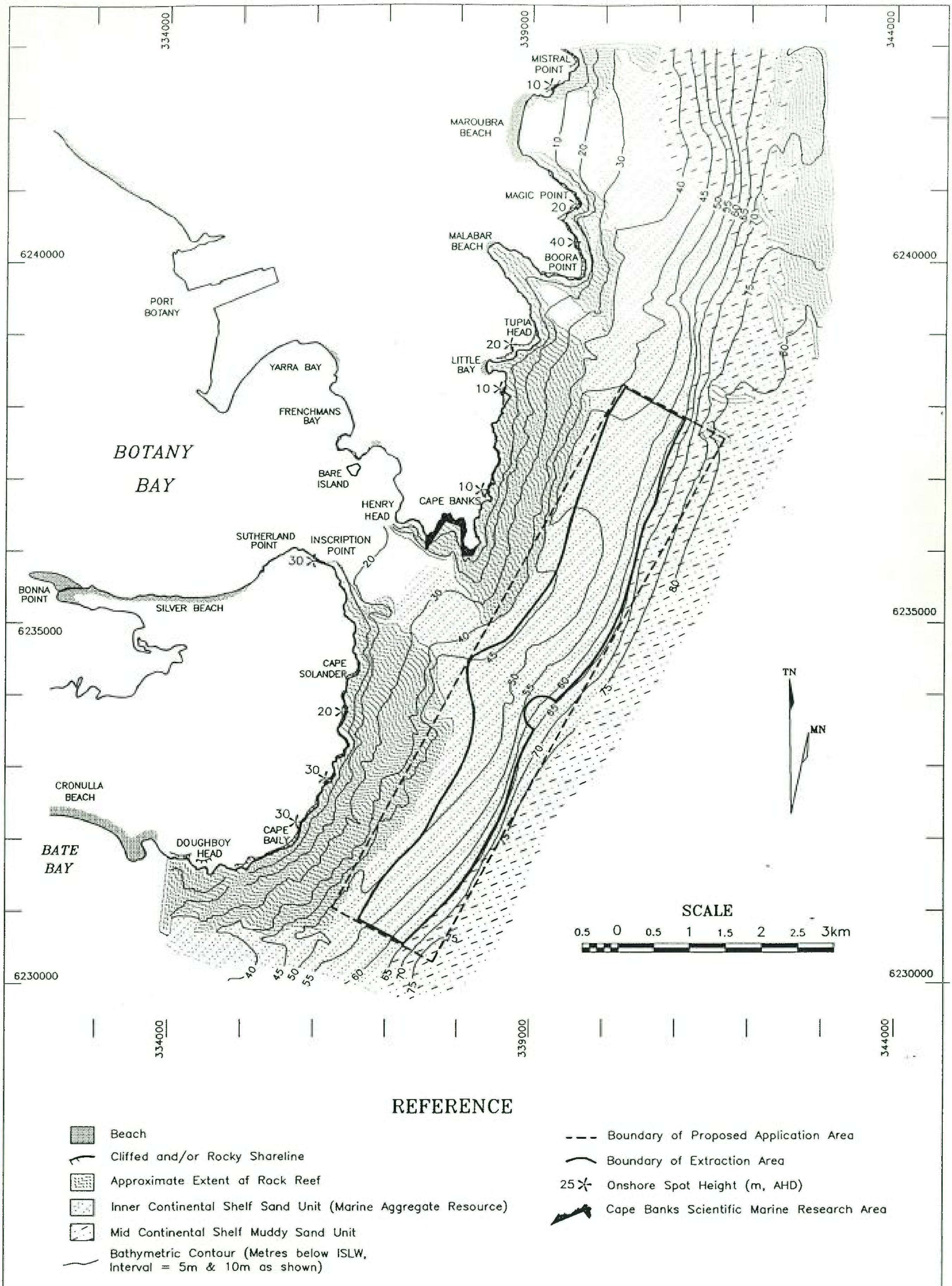

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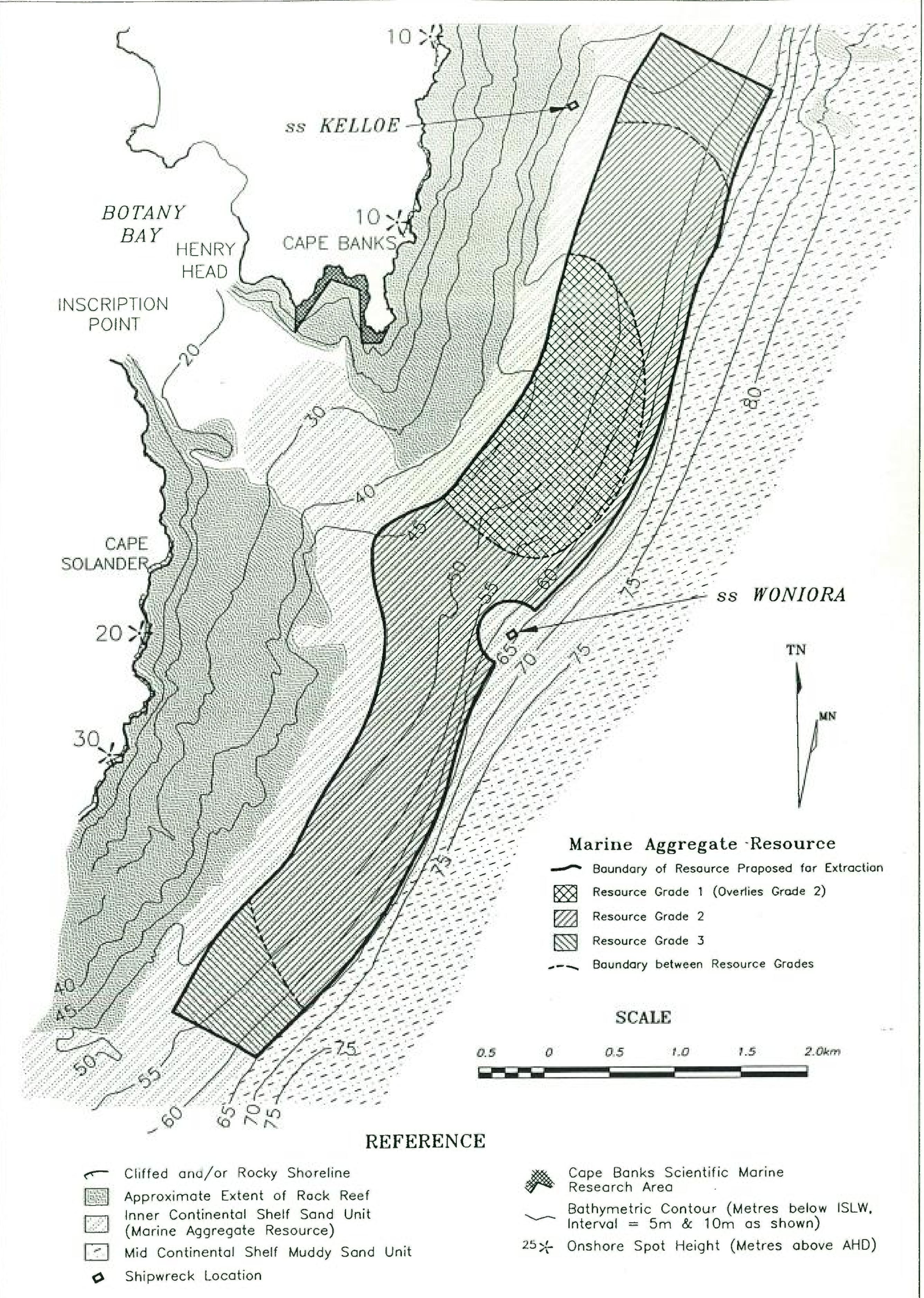
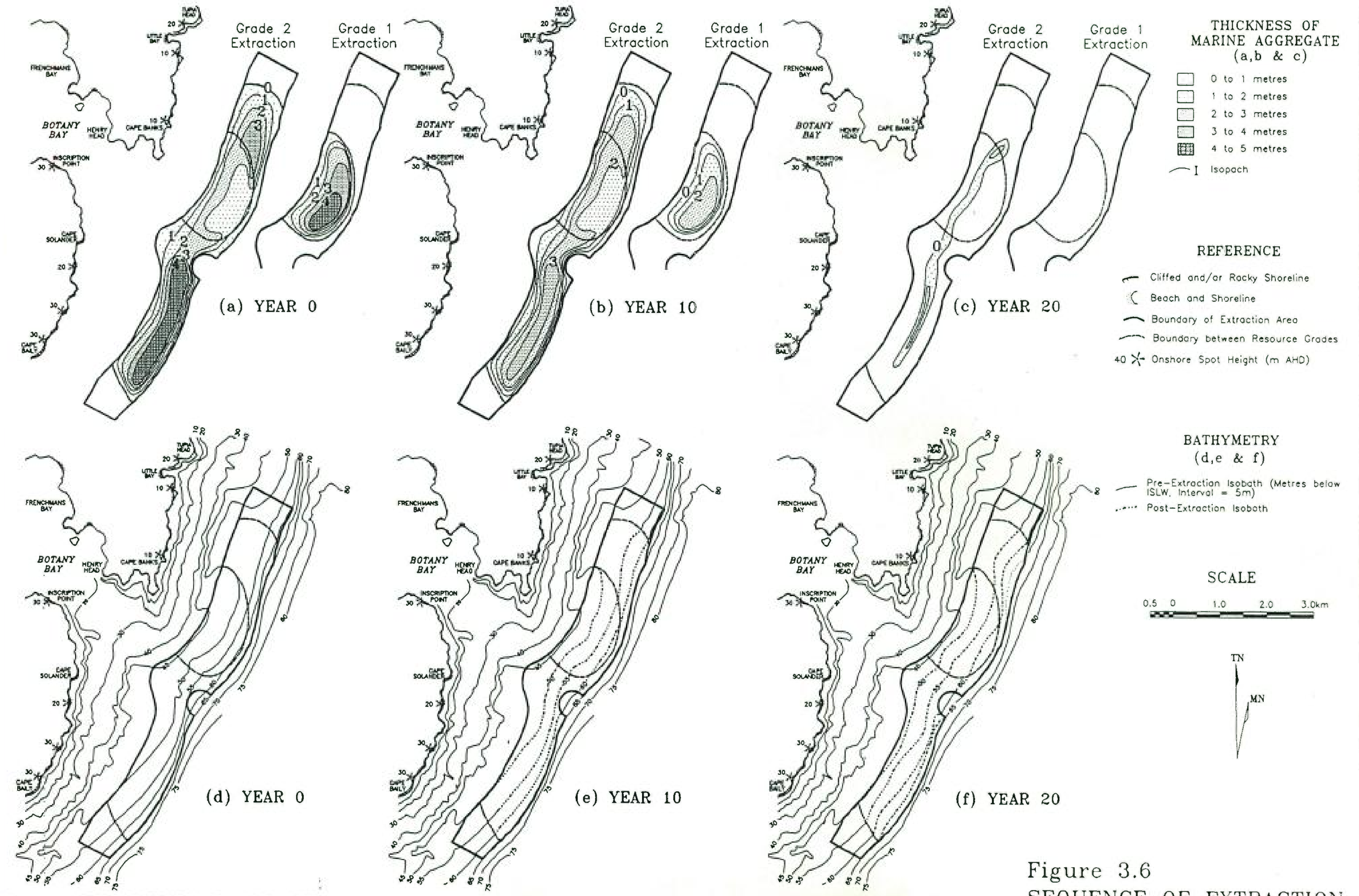
Figure 3.4
STUDY REGION



Source : R.W.CORKERY & Co. PTY. LTD.

Figure 3.5
EXTRACTION AREA



Source : R.W.CORKERY & Co. PTY. LTD.

Figure 3.6
SEQUENCE OF EXTRACTION

CHAPTER 4. REVIEW OF POTENTIAL EFFECTS

There have been few proposals to extract marine aggregate from the continental shelf of Australia (Carey and Talbot 1980; Nielsen et al. 1991). Moreover, like much of the aquatic environment of Australia, little is known of the ecosystems of the continental shelf. There is therefore, a need to identify properly the issues of concern so that the most important parts of the ecosystem can be described, assessed with respect to the proposal and monitored should the proposal proceed. There are several available sources of background information, including the scientific literature and responses from government departments to the notification by the Applicant of its intent to prepare an EIS on aggregate extraction. Information also came from local resident groups, clubs and citizens, who provided input during the public consultation programme undertaken by the Applicant. In this Chapter, issues of concern are described.

4.1 REVIEW OF THE SCIENTIFIC LITERATURE

4.1.1 Extraction Versus Dredging and Other Forms of Marine Mining

Dredging is a common term used to describe an activity where unconsolidated material is pumped from the bed of a waterway principally to deepen specified areas to permit the safe passage of vessels. The term is also used for the recovery of unconsolidated materials to reclaim adjoining areas for uses such as airports, etc. For the purposes of this report, extraction is a similar activity, however, the emphasis is placed upon the recovery of the materials recognised to have value as a resource.

There are numerous sources of information which help us to identify the potential impacts of extraction of marine aggregate. In fact, as there has never been extraction of marine aggregate on the open coast of NSW, we must rely on other sources of information to assist in the prediction of impacts. Clearly, it is an advantage to draw on as many relevant studies as possible. Such studies have been done on extraction of marine aggregate from other countries, dredging and spoil disposal, other forms of marine mining, and other forms of disturbance to the seabed. It is important to be aware, however, that there are significant limitations to extrapolating from other countries or other types of seabed disturbance to the proposal being considered in this report. These other sources of information and their limitations with respect to the current proposal are discussed in the next four sections.

4.1.1.1 Extraction of Marine Aggregate in Other Countries

Extraction of marine aggregate for the construction industry has been undertaken in many countries for several decades (Nielsen et al. 1991). In particular, marine aggregate is used widely in the United Kingdom and many of the countries fringing the North and Baltic Seas (ICES 1991a). It is also important in Japan (Tsurasaki et al. 1988) and to a lesser extent the United States (Bokuniewicz 1988). Research done on the effects of extraction of marine aggregate in these countries is very useful to this study, but there are several major limitations. First, the marine environments and the organisms inhabiting these environments are very different in other countries. In the North Atlantic, for example, a major concern associated with aggregate extraction is the impact on stocks of herring (Clupea harengus, Clupeidae), which lay their eggs directly onto the substratum, where they become attached to objects such as gravel and algae (ICES 1975; Oulasvirta and Lehtonen 1988). This species does not occur in Australia and there is no known species of economic value occurring on the sand bodies proposed for extraction under the present proposal (see Chapters 9 and 14).

Second, the types of aggregate obtained from the seafloor may be different to that proposed for extraction off Sydney. In particular, gravel is a major constituent of the marine aggregate obtained in the North Atlantic (ICES 1975). There are major differences in the types of impact associated with extraction of gravel compared with sand. For example, the furrows left following extraction of gravel remain evident for many years (Millner et al. 1977; ICES 1991b), whereas extraction of sand in areas of high energy may be barely evident over a scale of hours or days (Carey and Talbot 1980). The biota associated with gravel varies markedly from that associated with sand (Cressard 1975). Also, the turbidity plume associated with extraction of gravel can be very intense, as the gravel is normally screened from the sand and the latter returned to the sea - up to 40% of the material may be returned to the sea.

Third, different methods of extraction may be used. There are basically two alternative procedures: a static method in which the vessel is anchored and removes the aggregate to form a depression or pit in the seabed; and a mobile method in which the vessel moves over the seabed removing the aggregate in narrow, shallow furrows. The extent of impacts associated with each method can be quite different (Packer 1987). The static method is employed in the North Sea (ICES 1975) and New York Harbor (Bokuniewicz 1988); the mobile method is also employed in the North Sea and in Japan (Tsurasaki et al. 1988). Under the current proposal, the mobile method of extraction would be used (Sections 3.1.2 and 3.2.2).

4.1.1.2 A Comparison of the General Effects of Extraction and Dredging

There are many scientific papers on the effects of dredging on marine ecosystems. These are of limited use for the present study, which entails long-term extraction of sand, for four reasons. First, dredging occurs normally in relatively shallow, sheltered waterways such as estuaries and embayments and, therefore, the results of studies of this type of dredging do not apply directly to deeper and more exposed waters off the coast. A good example of this is the concern often raised with proposals for dredging that oxygen depletion will occur in deep, poorly mixed dredged holes in estuaries (e.g. Pollard et al. 1991). In relatively shallow, ocean environments which are very well mixed, oxygen depletion is extremely unlikely to occur (Packer 1987).

Second, dredging is usually done over a relatively short time span - the main aims often being to remove sediments to improve navigation or to provide fill for reclamation. One example of this is the construction of the Brisbane airport (Poiner and Kennedy 1984). For that project, a total of approximately 21 Mt (i.e. 14 Mm^3) of sand were dredged from a 5 km^2 area in Moreton Bay over two years to provide fill. Removal of an equivalent amount of sand under the extraction proposal for Providential Head would take more than 18 years! Another example is the dredging of sand on Queensland's Gold Coast for beach nourishment (Nielsen et al. 1991). There were several periods of dredging for this project, but over an eight month period from October 1989 to May 1990, approximately 5.4 Mt of sand were dredged to nourish adjacent beaches (Nielsen et al. 1991). This is the equivalent of extracting sand over a period of 7.5 years under the Providential Head extraction proposal. On the one hand, disturbance associated with dredging often occurs intensively over a short time period, but on the other hand, disturbance associated with extraction would continue over a much longer time period, but less intensely.

Third, dredging is often done in very fine sands and muds (e.g. Jones 1986), which are very different from marine aggregate . In particular, there may be severe impacts associated with dredging of muds, such as very turbid plumes, release of toxins adsorbed onto fine particles and increased biological and chemical oxygen demand, which are less severe for dredged sands (Kiorboe and Mohlenberg 1981; Packer 1987).

Fourth, the machinery used and methods of dredging are often very different for aggregate extraction. Dredging employs a variety of techniques, such as cutter suction dredges, bucket dredges and clam shell dredges which have different environmental effects (e.g. Pennekamp and Quaak 1990). Only trailer suction dredges are similar to the method that would be employed under the present proposal. Also, dredging operations rarely leave undisturbed areas within the dredged area, unless by accident (e.g. McCauley et al. 1977). The present extraction proposal would leave large areas of seabed between the extracted furrows.

This has significant consequences for recolonisation of the seabed following disturbance (Part IV).

Given these differences between marine dredging and aggregate extraction, it is considered that issues associated with dredging may be of value in identifying general issues of concern with respect to marine aggregate, but that large differences between techniques allow only limited comparisons. Two possible exceptions are 1) the disposal of dredge spoil at sea, where marine organisms can be affected by smothering, spoil plumes or toxins released from contaminated sediments (e.g. SPCC 1986); and 2) the recolonisation of soft substrata following dredging (e.g. Poiner and Kennedy 1984).

4.1.1.3 Other Mining Activities

There are numerous other forms of marine mining, such as drilling for oil and natural gas, mining of manganese nodules, placer deposits (e.g. gold and tin) and mineral sands. Studies of these provide some information on impacts to aquatic ecosystems which may be relevant to the proposal. For example, work has been done on the effects to larval fishes of turbidity associated with mining of deep ocean floors, such as manganese nodules (Matsumoto 1984; Jokiel 1989).

Again, important differences lie in the nature of these other mining activities and the relative magnitude of associated impacts. For example, the mining of placer deposits often requires the removal of a large amount of overburden (i.e. sediment overlying the target resource). This overburden is often dumped back in the sea, leading to very turbid waters (Packer 1987). Similarly, mining of mineral sands requires the removal of a large volume of sand for a relatively small yield of minerals, hence most of the sand is returned to the sea. By comparison, some 98% of the aggregate extracted for the present proposal would be retained, with about 2%, consisting of fine-grained material ("fines") returned to the sea (Chapter 3).

4.1.1.4 Other Forms of Disturbance

4.1.1.4.1 Effects of Fishing

In addition to mining and dredging activities, there are other types of disturbance to the sea floor which should be considered in relation to the proposal. Like dredging and other forms of mining, making direct comparisons with the present proposal is limited and caution is required in interpretation of effects. One of the most widely reported forms of disturbance to the seabed is that associated with commercial fishing activities (Caddy 1973; de Groot 1984; Fowler 1989; Hall et al. 1990; Hutchings 1990; ICES 1991b; Riemann and Hoffmann 1991). Otter trawling may have five types of impact:

1) Removal of fish, crustaceans and molluscs for sale, which could change the structure of fish populations and assemblages (Rowling 1990; ICES 1991b).

2) Removal of unwanted species ('by-catch') which are then discarded. Some of these species die as a result of being caught in the net and removed from the water. Other species may be returned to the water alive, but are very vulnerable to predation in the water column and on the seafloor (Hill and Wassenberg 1990; Wassenberg and Hill 1990).

3) Disturbance of the seabed from the passage of otter boards and ropes, wires or chains along the base of the net (ICES 1991b). Otter boards have been reported to dig into soft (unspecified) substrata by about 8-10 cm, while chains dig into a silty soft bottom by up to 3 cm (ICES 1991b).

Caddy (1973) observed scallop dredges cutting grooves several centimetres through surficial gravel, exposing underlying sand. Caddy calculated that 2.3 m long otter trawl boards should leave a track 1.3 m wide if in contact with the bottom along their whole length. This track width is similar to that of the track which would be created during aggregate extraction under the present proposal (Chapter 3).

4) Creation of a turbid plume in the wake of the trawl net (ICES 1991b, Riemann and Hoffmann 1991). The latter authors reported up to 14-fold increases in the amount of particulates in the path of a trawler immediately after the trawl gear had passed by. No significant reductions in oxygen or nutrients were reported for the trawl gear, although a significant reduction in oxygen was noted following the passage of a mussel dredge. Unfortunately, Riemann and Hoffman (1991) did not indicate whether the seabed was predominantly sand or finer material.

5) Initiation of behavioural responses by organisms. Marine organisms may be attracted or frightened by the passage of fishing gear. Caddy (1973) reported that fish and crabs were attracted to the tracks of scallop dredges within one hour of fishing. Densities of these species were three to thirty times those recorded outside the tracks.

The types of impacts just described are very similar to those potentially associated with sand extraction (see next section), but there are clearly differences in the scale and methods of both activities which need to be considered when assessing potential impacts of either activity. One important point that ICES (1991b) make is that the relative degree of seabed disturbance associated with fishing tends to be much larger than with aggregate extraction. In the North Sea, marine aggregate extraction has been estimated to disturb 0.03% of the seabed annually while fishing disturbs about 55% of the seabed (ICES 1991b).

4.1.1.4.2 Natural or Experimentally-simulated Disturbances

Apart from disturbances caused to the seabed from human activities, there are numerous studies on the effects of natural disturbances to the seabed (Thistle 1981). These disturbances can be caused by animals (e.g. marine mammals - Oliver and Slattery 1985, Oliver et al. 1985; and fishes - Van Blaricom 1982, Thrush et al. 1991), or by physical and chemical factors such as storms and flooding (e.g. Boesch et al. 1976; Van Blaricom 1982; Dobbs and Vozarik 1983; Flint 1985). There have also been several studies which examine the effects on benthic organisms of simulated natural disturbance (e.g. Zajac and Whitlach 1982a,b; Turner and Miller 1991).

These studies provide useful information on the responses of marine organisms to disturbance, particularly with respect to rates of recolonisation following mortality induced by disturbance. Limitations include the location of many of these studies (often on intertidal sand flats) and, apart from large scale physical events such as storms, they are often limited in scale compared with activities associated with human disturbances.

4.1.2 Potential Effects of Aggregate Extraction Described in the Scientific Literature

Notwithstanding the limitations described above, research into the effects of aggregate extraction in other countries, dredging and other forms of marine mining provide us with a basis for identifying the potential impacts associated with the proposal for extraction of marine aggregate off Sydney. There are numerous literature reviews of the potential effects of aggregate extraction (Cressard 1975; ICES 1975; Owen 1977; Padan 1977; de Groot 1979a,b; Ellis 1987; Packer 1987; Hurme and Pullen 1988; ICES 1991b). There is, however, much less accessible information on the observed effects of the extraction of marine aggregate (e.g. Cressard 1975; Millner et al. 1977; Conover et al. 1985; Oulasvirta and Lehtonen 1988; Lees et al. 1990). In this section, the potential impacts are simply identified as they are described in the literature. They will be discussed in more detail in relation to the proposal in Part IV of the report.

Three major sources of potential impact associated with extraction of marine aggregate have been identified:

1) disturbance to the seafloor resulting from the removal of aggregate;

2) disturbance of the water column resulting from the rejection of fines suspended in the slurry water which is drawn into the hopper of the extraction vessel; and

3) disturbance caused by the operation of, or accidents

happening to, the extraction vessel.

For each of these major sources of impact there may be resultant effects on marine organisms or other users of the area, such as commercial and recreational fishers, and divers. These effects are discussed in the following three sections.

4.1.2.1 Disturbance to Seafloor from Removal of Marine Aggregate

Disturbance of the seabed is seen generally as the most severe impact associated with aggregate extraction (e.g. ICES 1975; de Groot 1979a,b; Packer 1987). The following potential impacts have been identified:

1) Direct loss of organisms destroyed by the suction head, leading to reduction in productivity hence reduction in fish stocks (Cressard 1975; Owen 1977; de Groot 1979a; 1986). As the suction head passes over the substratum, a furrow is created which is up to 2 m wide and about 20 cm deep. The literature generally suggests that most, if not all, of the benthic infauna (animals living within the sediment, e.g. marine worms) will be destroyed by this activity (ICES 1975). The benthic infauna would be sucked up in the slurry, and some of it would be returned to the water with the overflow of fines.

ICES (1991b) suggested that some of the benthos, for example small, hard-shelled molluscs, may be returned to the seabed alive. ANON (1978) reported that most fish appear to able to avoid the extraction device. There are also reports that fish aggregate to feed behind the extraction vessel, attracted by the benthos in the water column (ANON 1978). Uren (1988) reported that commercial fishing vessels off England are often observed trawling behind extraction vessels, to catch aggregating fish.

There is considerable discussion about the duration and nature of recolonisation of the seabed following extraction. It appears from the literature that, if the substratum after extraction is similar to that before, there will be recolonisation by similar organisms (de Groot 1986; Packer 1987). Many of the estimates of recolonisation by benthic organisms are derived from studies of dredging (e.g. Kaplan _et_ _al_. 1975; McCauley _et_ _al_. 1977) and it is not clear how relevant they are (see Section 4.1.1.2).

de Groot (1986) asserted that, if the nature and structure of the substratum do not differ substantially after dredging, the bottom fauna will recover from the effects of extraction. First, recovery starts within months, with full recovery within two to three years (de Groot 1986). Also, Packer (1987) suggested that as long as a layer of the original substratum remains, the same type of bottom-dwelling organisms may be able to return. Packer (1987) reported rates varying from one to five months in temperate waters to up to 12 years in arctic waters, but that recolonisation is generally of the order of one to two years. ICES (1991b) described recolonisation as follows: "Classically, this proceeds with an influx of 'opportunistic' species and then, assuming no further dredging occurs, succession proceeds towards a more diverse and stable community dominated by larger, long-lived species. If, however, dredging continues periodically, succession may be impeded so that opportunistic species continue to predominate" (ICES 1991b, page 25). ICES (1991b) presented no substantiation of this "classic" situation, and there is emerging in the literature evidence to suggest that this type of successional pattern is not particularly widespread (Chapter 8).

2) Destruction of spawning grounds and other important habitats for species of economic value. In the North Sea, valuable spawing grounds have been identified for species of economic value. Herring lay their eggs on gravel or algae; sandeels (e.g. Ammodytes marinus) live in sand and lay their eggs onto it; and edible crabs (Cancer pagurus) overwinter on sandy substrata (Oulasvirta and Lehtonen 1988; ICES 1991). Extraction of marine aggregate has been suggested as a potential threat to fisheries based on these species.

3) Alteration of the sediment type following extraction of marine aggregate. It has been argued that extraction of marine aggregate can cause changes to the substratum by three mechanisms (de Groot 1986; Packer 1987, ICES 1991b). First, removal of the aggregate could lead to exposure of a different type of substratum. In particular, removal of gravel in the North Sea may lead to exposure of fine grained material beneath (e.g. Millner et al. 1977). Second, settlement of the overflow fines from the vessel hopper could alter the seabed (Packer 1987). Third, increasing the depth of the seafloor by removal of sediment may alter the current patterns in the area. In particular, the energy regime may diminish, allowing greater natural settlement of fines to occur. This is most relevant in the static or pit method of extraction, where relatively deep holes are created (Conover et al. 1985; de Groot 1986; see also Jones 1981 for an example associated with dredging in Botany Bay, NSW).

Alteration of the sediment type could in turn lead to alteration of assemblages of benthic organisms inhabiting an extraction area. The most obvious examples are from the North Sea where gravel is replaced by sand (e.g. Millner et al. 1977) or where sand is removed to leave a layer of exposed gravel (Cressard 1975).

4) Alteration of seabed shape, leading to disruption of fishing methods (de Groot 1979a; 1986; Conover et al. 1985; Ellis 1987; Packer 1987; ICES 1991b). Many forms of commercial fishing require a fairly even seabed over which to operate. The creation of deep furrows or pits can prevent the proper operation of trawl nets and bottom-set longlines and hence may impair fishing. It has been suggested that pit dredging can have very severe effects on fishing operations, while mobile dredging usually has little effect (de Groot 1986; Ellis 1987; Uren 1988; ICES 1991b).

Extraction of marine aggregate may also lead to the exposure of obstructions which may foul fishing gear, such as rocky reefs or shipwrecks (Packer 1987).

5) Alteration of seabed shape, leading to changes in patterns of migration of fishes, marine mammals, movement of larvae, etc. ICES (1991b) referred to the possible significance of specific spawning grounds to herring stocks, suggesting that the herring may cue to the noise 'signal' emitted from gravel as it is moved by currents.

6) Coastal erosion caused by alteration of the seabed (Owen 1988, Nielsen et al. 1991). Removal of marine aggregate from the seabed may cause a number of changes to coastal processes. These include beach erosion during storms which is not replenished during calm periods (i.e. "beach drawdown"), removal of offshore banks, changes to the movement of bed material, etc. In turn, such physical changes may affect habitats and associated organisms by, for example, removal of beach habitat, or increasing the wave energy striking the coastline.

7) Mobilisation of sediments at the seabed, leading to reduction in the concentration of oxygen and the release of toxins and nutrients. It has been suggested that chemical changes may occur as a result of aggregate extraction (Padan 1977; de Groot 1986; Packer 1887). In particular, disturbance of sediments containing metal sulphides can increase chemical oxygen demand on the overlying water, while disturbance of nutrient rich particles may increase biological oxygen demand. These impacts are considered relatively minor in the context of marine aggregate extraction (Packer 1987; ICES 1991b).

4.1.2.2 Disturbance of the Water Column from Rejection of Fine-grained Material

Part of the operation of extracting marine aggregate requires that a slurry of aggregate and water be pumped from the seabed to the surface vessel and the return of excess water to the sea. The literature suggests that the effects associated with this disturbance can vary greatly, depending on the type of aggregate, the proportion (and absolute amount) of fines, the local oceanographic conditions (e.g. the presence of storms) and the method of extraction. All these factors should be considered when predicting the effects of the present proposal. Some of the general impacts reported include the following:

1) Creation of a turbid plume may cause a number of potential impacts. These can be divided into the following categories:

a) Reduction in light levels and changes to spectral quality (Owen 1977; de Groot 1979a). Reduction in light levels could affect the photosynthetic productivity of plankton and bottom flora. Moreover, changes to the spectral quality of the water may occur as a result of fines being suspended in the water column - shorter wavelength radiation becomes attenuated more rapidly in turbid water than longer wavelengths (de Groot 1979a).

b) Floccule formation leading to mechanical removal of plankton from the photic zone (Owen 1977).

c) Release of nutrients into surface waters (de Groot 1979a). It has been argued that this effect may balance the effects of reduction in light levels associated with the turbid plume (de Groot 1979a).

d) Changes to the efficiency of fishing gear. Murphy (1956) found that catches of tunas by trolling decreased in turbid waters, but catches using gill nets increased.

e) Disruption of migratory patterns of fish (Hurme and Pullen 1988; de Groot 1979b).

f) Clogging of the gills of fish and suspension feeders (Moore 1977; Owen 1977).

2) Thermal shock associated with pumping cold, bottom water to the surface of the sea (Packer 1987). This author argues that this impact may be of most concern during deep ocean mining, when very cold water is brought to the surface; in shallow coastal waters this impact would probably be minimal (Packer 1987).

3) Smothering of fauna as fines settle back onto the seabed (Packer 1987; Hurme and Pullen 1988; ICES 1991a; see Peterson 1985 and Peterson and Black 1988 for experimental studies of smothering effects on bivalves).

4.1.2.3 Disturbance from Operation/Accidents Associated with Extraction Vessel

The impacts of the regular presence of extraction vessels in the coastal zone are not referred to often in the literature. Several authors do, however, note possible impacts associated with the operation of the extraction vessel. Packer (1987) discussed the possible effect of noise associated with extraction of marine aggregate on marine animals. There is very little information on this, although Packer suggests that the impacts are relatively minor.

There is a little more information on the effects of vessel noise associated with oil drilling operations on cetaceans in the arctic (e.g. Hazard 1988). Unfortunately, much of this literature is difficult to obtain, as it is often confined to reports of government departments or mining companies.

Packer (1987) and Strudwick (1990) also noted that there may be impacts associated with accidental spillages and dumping of wastes from extraction vessels. No actual cases were documented.

4.1.3 The Broken Bay Extraction Proposal, 1980

The previous section described potential concerns about extraction of marine aggregate from operations overseas. The next three sections focus on local issues associated with aggregate extraction by looking at an earlier proposal for extraction in the Sydney region and then looking at issues raised by government departments, interest groups and private citizens about the current proposals to extract aggregate off Providential Head and Cape Banks.

An EIS was submitted in 1980 applying for a permit to extract marine aggregate from the seabed off Broken Bay, NSW (Consolidated Goldfields Limited and ARC Ltd 1980). It represents the first published proposal to extract marine aggregate from the NSW continental shelf. The assessment of impacts to marine organisms and to commercial and recreational fishing was made by workers at Macquarie University (Carey and Talbot 1980).

Three possible sources of impact were identified by the study (Carey and Talbot 1980):

1) Disturbance to and removal of the substratum;

2) discharge at the ocean surface of water with suspended solids drawn from the seafloor;

3) settlement of sediments and subsequent alteration of the substratum.

Sources of potential impact were identified as first order effects. These were translated into successive orders until an assessment of a given impact was made as either beneficial, deletarious or both (Carey and Talbot 1980). Impacts considered significant (Carey and Talbot 1980) are summarised in Table 4.1.

Carey and Talbot (1980) summarised their assessment of impacts of trailer extraction on the offshore biota of Broken Bay as follows (Carey and Talbot 1980, pp 64-66):

> "1. Trailer dredging in shifting sands will remove, destroy or adversely affect part of the benthic invertebrate fauna, but will have minimal overall effect on diversity and biomass provided that a substantial area which has not been dredged for the previous 3-5 years, on average, is retained between dredged strips.
>
> 2. The benthic fauna is adapted to substrate instability and periodic high loads of suspended solids. Although it may disrupt breeding populations and delay larval settlement, increased substrate disturbance in semi-stable areas is expected to be of minor significance

> overall, since a very small area will be affected in any one year.
>
> 3. Temporary local reductions in phytoplankton productivity may occur, but being very limited in area and duration will have little overall significance, if any.
>
> 4. Direct physiological effects of re-suspension of bottom sediments by the suction head may occur, particularly to sessile bottom fauna, but because settling will be rapid, and the affected area small, should be of minor significance, if any.
>
> 5. Demersal fishes will not be affected directly by substrate removal or suspended solids because of their mobility; their food supply (i.e. mainly benthic invertebrates) will not be significantly depleted providing dredge strip management is as described.
>
> 6. The rocky reef fauna and flora is unlikely to be affected providing the dredge operates at sufficient distance to avoid raising the suspended solid load in the reef environs.
>
> 7. Only minor changes in benthic community structure and composition are anticipated provided no large dredged area is reworked within three years. Any such change is not necesarily deletarious.
>
> 8. No permanent change in the nature of the substrate is anticipated because of the substantial depth of sand of uniform characteristics; hence the biota of any area that was heavily utilised would rapidly revert to the condition of the surrounding areas when dredging ceased.
>
> 9. Commercial fisheries are unlikely to be affected.
>
> 10. Very little is known of the cumulative results of seemingly minor or sub-lethal impacts. Study of these and other aspects during a carefully designed program of biological monitoring could provide a valuable contribution to marine environmental management."

A response to the EIS was prepared by the Department of Planning and Environment (DOP 1981). The response raised the issue of possible impacts to the Bouddi National Park Marine Extension, located just to the north of Broken Bay. The response did not raise any further issues of concern which had not been identified by Carey and Talbot (1980), although it did question conclusions presented in the EIS, particularly in relation to commercial and recreational fisheries.

Table 4.1 Identification of the possible impacts on biota from marine aggregate mining by trailer extraction in Broken Bay, NSW (source: Carey and Talbot 1980).

1st Order	2nd Order	3rd Order	4th Order	Beneficial or Deleterious
Disturbance of substratum	Changes in bottom topography	Area traversed by linear furrows & shallow depressions	Sand mobility initiated more frequently in semi-stable areas	+ or -
			Migration patterns of some species changed	+ or -
	Exposure of rocky areas; mud strata	Bottom trawls, lines, etc, snagged	Fishing hazards increased	-
		Attachment surfaces provided for epifauna, shelter for fish	Food supply increased fishing improved	+
		Anoxic sediments remain at interface	BOD raised, dissolved oxygen depleted	-
	Removal of substratum	Benthic fauna destroyed	Food supply reduced fishery affected	-
		Spawning grounds & settling stimuli destroyed	Repopulation inhibited	-
Resuspension of sediments	Sea surface discharge of bottom water & sediment	Direct effects on biota	Respiratory surfaces clogged, feeding efficiency reduced	-
		Water column light levels reduced	Photosynthetic activity of phytoplankton reduced	-
		Heavy metals or pollutants released	Organisms harmed	-
		Nutrients released	Productivity enhanced	+
		Opportunistic feeders attracted	Growth rates & populations increased	+
	Sediment settling	Fines interfere with feeding, respiration & locomotion	Reproduction rates reduced	-
		Benthic algae blanketed	Productivity reduced	-
		Changes in benthic larval settlement & metamorphosis	Benthic community composition changed	+ or -

4.2 Issues Identified by Government Departments Regarding the Present Proposal

There is a considerable amount of government legislation which may apply to the present proposal. Also, as part of the EIS process for the present proposal, the Applicant sought details of those issues of concern to government departments (Corkery and Co 1993). The following sections summarise issues related to marine ecology.

4.2.1 Department of Planning

The Department of Planning is the determining authority for the proposal, under Part V of the NSW Environmental Planning and Assessment Act (1979). The Director of the Department of Planning provided the following specific requirements related to ecological issues (correspondance, references R91/00430/001 & R91/00431/001, 20/3/91):

1) To describe the biological populations, habitats and resources which may be affected by offshore extraction of aggregate within the exploration licence areas.

2) To consider the impact of offshore extraction on the marine ecosystem (including marine mammals and avifauna). This should include an assessment of impacts on ecologically important episodic phenomena (e.g. breeding behaviour) affecting this ecosystem.

3) To formulate proposals for on-going environmental monitoring of effects on physical and biological resources, processes and potential for pollution.

4) Consultations should be undertaken with relevant government authorities, including NSW Fisheries, NSW National Parks and Wildlife Service, the State Pollution Control Commission, the Water Board, etc.

A related issue also required that known and potential wreck locations should be identified and the likely effects of destabilisation or scouring of a wreck by extraction in the vicinity be identified. Buffer areas should be calculated to avoid destabilisation.

In addition to the specific issues raised by the Director, attachments, which are not project-specific, were also supplied pertaining to the preparation of EISs in general and to the preparation of EISs for projects related to dredging and to the extractive industries (see Corkery and Co 1993).

4.2.2 Environmental Protection Authority (formerly SPCC)

The (then) SPCC required access to data on a wide range of issues, including the marine biological environment. Emphasis was placed on the potential extent of contamination in the aggregate and slurry water, and the extent of noise associated with the extraction procedure.

4.2.3 NSW Fisheries

Several general matters of relevance to the present proposal are specified in the Fisheries and Oyster Farms Act (1979), under which much of the legislation applying to fisheries in NSW occurs. The Act distinguishes between dredging and mining (Section 90F), as it specifies that the Act does not apply where dredging work is carried out "for the purpose of removing material under the laws relating to mining". Sections where the Act may be relevant include the following:

a. Placing obstructions on recognised fishing grounds. Under Section 32, any person who obstructs the use of a fishing net by any fisherman on any recognised fishing ground and who refuses to remove the obstruction without reasonable or lawful excuse, is guilty of an offense. This obstruction may be caused by placing or mooring any boat or buoy, or by placement of "any stake, post or thing".

Under Subsection 4(1) of the Act, a recognised fishing ground is defined as: "any area of Crown lands whereon fishermen use or operate their fishing nets, daily or intermittently throughout the year or at a certain period thereof, but does not include an area of Crown lands only occasionally used for such purpose; nor any area which can be staked or cultivated by lessees without prejudicing the fishing operations of fishermen".

The Fisheries and Oyster Farms Act defines "Crown lands" as:

a) land submerged by water, not being land vested in a person other than the Crown, a public authority or trustees for public recreation or for any other public purpose;

b) any foreshore; and

c) a training wall, breakwater, retaining wall or guide-bank the property in which is vested in the Crown, a public authority or trustees for public recreation or any other public purpose,

but does not include the subject of a lease under the Act and land of which a person has exclusive possession under a lease under any other act.

b. Interference with fishing operations. Section 32A of the

Act establishes an offence if a person:

a) uses a boat, surfboard, waterski, aquaplane or similar equipment in any waters on a recognised fishing ground in such as way (and in such proximity) that is likely to disperse fish travelling in a school or shoal; or

b) uses a boat, surfboard, etc, in any waters in such a way that it unreasonably interferes with the operations of a fisherman lawfully fishing, or waiting to carry on lawful fishing, in those waters, and that person does not desist on request by an inspector.

c. Poisonous materials, chemicals, waste products and explosives. Under the Act (Subsection 34(2)), it is an offence to permit to flow into any waters, any liquid or solid matter which is injurious to fish, their spawning grounds, their spawn or food. Subsection 34(1) states that it is an offense if any person puts poison, lime or noxious materials in any waters with intent to take or destroy fish.

Matters to be addressed which have arisen during discussions with NSW Fisheries and the Fisheries Research Institute (FRI) include the following:

1) An assessment of the impact of the proposed extraction on commercial and recreational fishing.

2) An assessment of the impact of the proposed extraction on aquatic reserves.

3) An assessment of the risk of release of contaminants from disturbed sediments and subsequent bioaccumulation in fish and invertebrates of economic value. In particular, concern was raised about the proximity of the deepwater ocean outfall off Malabar to the Cape Banks exploration licence area.

4) An assessment of the impact of the proposed extrtaction on monitoring programmes which are evaluating the impacts of Sydney's three deepwater ocean outfalls (North Head, Bondi and Malabar). In particular, concern was raised about the possible effects of aggregate extraction on surveys being done off Cape Banks, Port Hacking and Marley Beach, which are all close to, or within, the areas of the exploration licences being considered in this proposal.

4.2.4 NSW National Parks and Wildlife Service

Matters to be addressed in the EIS which are of relevance to the Service include the following:

1) Marine mammals, including annual cetacean migrations.

2) Marine reptiles.

3) Avifauna, with particular reference to migratory birds covered by international agreements.

4) Sediment deposition, wave action and beach erosion at Royal and Botany Bay National Parks, and at Towra Point Nature Reserve.

5) The general ecology of the area, including any increases in water turbidity at Royal and Botany Bay National Parks, and at Towra Point Nature Reserve.

6) Fauna in the area where release and dispersion of sediments from the extraction vessel occurs.

Legislation which applies to the protection of birds, marine mammals and marine reptiles is described in Chapter 12.

4.2.5 The Water Board

The Water Board raised a number of issues concerning the potential impact of the proposal on existing and planned sewerage works. The Water Board raised the following issues:

1) That any extraction proposal does not have an adverse impact on the existing Malabar extended ocean outfall by alteration of current patterns, etc.

2) That any extraction proposal does not affect existing control sites for environmental monitoring of Sydney's deepwater ocean outfalls.

3) That the total area of potential impact is discussed, including the area where dewatering of aggregate would occur on the way to the terminal.

4.2.6 Department of Mineral Resources

This department suggested that the following ecological issues be addressed:

1) The bottom-dwelling communities of the exploration licence areas

2) The fish communities. Here the non-migratory and migratory species should be distinguished, and times at which migratory species occur within the exploration licence areas should be identified.

3) Communities of marine plants should be identified and

their capacity for regeneration should be discussed. The question was asked whether there would be any need for replanting or regeneration of marine plants.

4) Communities of mobile crustaceans (i.e. prawns, crabs and crayfish) should be described. Liaison with fishing co-operatives was recommended.

4.3 ISSUES IDENTIFIED FROM OTHER SOURCES

In addition to the required consultation with government departments, the Applicant also sought comments from several other sources. These included a workshop held at Macquarie University (ANON 1990) and meetings held with local groups throughout the period of studies for the EIS.

4.3.1 Macquarie University Workshop, June 1990

The Graduate School of the Environment at Macquarie University conducted a workshop on 9/6/90 on behalf of the Applicant. The objective of the workshop was to identify possible environmental issues and impacts associated with offshore and continuing onshore sand extraction. The report contains a checklist of potential issues and impacts and a brief discussion of critical factors (Table 4.2)

4.3.2 Proposed Curracurrong Marine and Estuarine Protected Area

National Parks Association of NSW Inc (NPA) has proposed the establishment of Curracurrong Marine National Park (NPA 1991). The NPA has raised concerns that extraction of marine aggregate from the area proposed off Providential Head posed a "threat to a pristine oceanic temperate water ecosystem" (NPA 1991, page 3). In particular, NPA suggests that:

1) The extraction of marine aggregate would pose a threat to the "naturalness" of the area.

2) The usefulness of the area as a scientific reference area for monitoring Sydney's deepwater ocean outfalls would be destroyed.

3) The nature of the substratum over a large area would be changed as the top 2-5 m of sand would be removed with unknown consequences for fish feeding behaviour and survival of filter feeders and benthic microfauna.

4) Even with staged dredging of strips of sand over a large

area, the long term consequences of this form of extraction in ecosystems different to those where this technique is used overseas, is unknown.

5) Australia has international obligations to ensure that the water column off the coast is not altered in ways that might affect the migration of whales such as humpback and southern right whales. The potential threat of the constant noise could contribute to the disturbance of the sonar mechanisms of whales and dolphins used for navigation and communication.

The actual boundaries of the proposed marine park and allowable activities are described in NPA (1991). These are discussed further in Parts III and IV of this report.

4.3.3 Public Consultation

During the studies for the marine aggregate EIS, a series of meetings and workshops were held with various scientists, interest groups and citizens (Corkery and Co 1993). In particular, discussions were held with commercial and recreational fishers and with divers to identify their concerns regarding the proposal. Many of the issues already raised were expressed during public consultation. Major issues which were raised include the following:

1) Effects of turbidity and settlement of sediments on nearby rocky reefs and wrecks.

2) Effects of any increased turbidity on water clarity and subsequent effects on SCUBA and skindiving.

3) Navigational conflict between the extraction vessel and small craft, particularly fishers who may be anchored on reefs or wrecks, or drift fishing over reefs and sand.

4) Effects of changes to the seafloor on:

a) efficiency of fishing gear
b) large-scale currents or eddies which may concentrate fish at certain times.

5) The rate of recolonisation of disturbed areas.

6) Effects of changed wave patterns to the ecology of rocky shore organisms, and in particular to the scientific research being conducted at the Cape Banks Scientific Marine Research Area.

In addition to the public consultation, there have been various articles about aggregate extraction on the east coast of Australia. In southern Queensland, Ness (1992) suggested that the

Table 4.2. Issues relevant to marine ecology and current users of the proposed extraction areas, as identified during a workshop at Macquarie University, 1990 (ANON 1990a).

Primary issue	Related issues
1) Location	
	a) relationship to estuaries
	b) relationship to other maritime uses:
	* existing and former ocean dumping sites and the nature of the material dumped
	* major sewage outfalls
	* sewage discharge monitoring sites
	* commercial and recreational fishing sites
	* marine research and research areas
2) Beach Erosion	
3) Recreational Activities	
	a) diving on reefs and shipwrecks
	b) recreational fishing
	c) whale watching
4) Commercial and recreational fishing	
	a) economic evaluation of these activities
	b) migration of fish
5) Marine park proposals and existing reserves	
6) The marine ecosystem	
	a) change in water depth
	b) change in bottom topography
	c) changes in the character of the substratum
	* exposure of rock, mud or clay
	* removal of substrata
	* seasonal changes in substratum stability
	* post-dredging changes in substratum stability
	d) effects in mobile and semi-stable sands
	e) effects of sediment disturbance and removal of organisms
	* microorganisms, phytoplankton, zooplankton, meiofauna, macrophyptes, macroinvertebrates
	f) effects of resuspension of sediments
	* microorganisms, phytoplankton, zooplankton, meiofauna, macrophyptes, macroinvertebrates
	g) effects of changes in physicochemical characteristics
	* pH, dissolved oxygen, chemical and biological oxygen demand, temperature, salinity
	* release of pollutants/toxins and effects
	* nutrient release and effects on productivity
	h) effects on eddy/water mass boundaries
	i) effects on migratory fishes and spawning of fishes
	j) effects on marine mammals
	k) effects on birds, including those covered by international agreements
	l) threats to any species endangered species
	m) long term effects

loss of one trawling area may lead to increased pressure of fishing in other areas, as more fishers would be forced to use areas where no extraction occurred. One conservation group, the Total Environment Centre (TEC), identified the following impacts of marine aggregate extraction to marine ecology (ANON 1991): damage to fisheries from turbid sea water produced during extraction, oil spills, migration of nearshore sand into the extraction area possibly threatening beaches (e.g. Marley and Maroubra Beach), migration of the borrow cavity created by extraction along the coast causing other long term effects remote from the extraction area. The TEC also asserted that, "unlike land based mining where it is theoretically possible to contain environmental damage on mine sites, offshore sand mining must have environmental impacts beyond the mine site. Consequently, marine mining activities have greater potential of environmental damage." (ANON, 1991, page 7). Unfortunately, this assertion overlooks potential impacts from land based mining such as alteration of ground and surface water, which can ultimately affect catchment management well beyond the mine site.

4.4 SUMMARY OF ISSUES

Clearly, there are many issues and potential concerns related to extraction of marine aggregate in general and to the present proposal in particular. The three major potential sources of impact identified at the beginning of this chapter provide a useful framework for the prediction of impacts, namely: the effects of disturbance and removal of material from the seabed (and the possible consequences arising from altered coastal processes); the effects of turbidity associated with the overflow of slurry water; and any impacts associated with operation of the extraction vessel or possible accidents which might occur.

Within the framework of general impacts which may be associated with aggregate extraction, there are other, more specific effects which have been identified from Carey and Talbot (1980), matters raised by government departments and by interest groups and citizens. Some of the major issues include:

1) the effect of the proposal on the marine organisms inhabiting the water column, the seabed, sandy beaches, rocky reefs, rocky shores and shipwrecks;

2) potential for recolonisation and replenishment of disturbed areas;

3) potential impact of extraction on patterns of migration of marine mammals, marine reptiles, avifauna, fish and invertebrates; and

4) the compatibility of the extraction proposal with fishing and diving interests, scientific monitoring for the deepwater ocean outfalls, the operation of the outfalls themselves, and

existing and proposed marine parks and reserves.

Having identified the major issues which need to be addressed, the next chapter discusses the study approach taken to describe the natural environment and its present users.

CHAPTER 5. STUDY APPROACH

In formulating a study approach to the extraction proposal, it is important to consider what the key issues are that need to be addressed and the time frame over which studies need to be considered.

5.1 KEY ISSUES

It would be logistically impossible to describe every conceivable aspect of the environment that could be affected by the extraction proposal. Given that the sand bodies themselves are the habitat most likely to be affected, field studies focused on describing some of the important communities of that habitat. The DOP (1981) review of the Broken Bay extraction proposal (Carey and Talbot 1980) criticised the lack of comparative data from "baseline sites", where there would be no dredging. This type of approach is now accepted generally as being critical in EIA (e.g. Green 1979; Bernstein and Zalinski 1983; Hurlbert 1984; Underwood 1991) and this approach was adopted in the present studies for the proposed extraction areas.

The field studies of the sand bodies within the proposed extraction areas which were done for the EIS were implemented to address the following questions:

1. How do the diversity and abundance of the communities within areas proposed for extraction compare with those of other sand bodies which will not be affected by aggregate extraction under the proposal?

2. How do the diversity and abundance of the communites within the areas proposed for extraction vary through time, and is this variation consistent among several sand bodies? In other words, do communities of the sand bodies vary in the same way through time at different places?

3. What changes in community structure occur at different water depths over the sand bodies, and is this variability consistent among sand bodies and over time?

4. What might the effect of natural disturbances, such as storms, be on the diversity and abundance of communities inhabiting the sand bodies?

5. What rate of recolonisation by benthic organisms might be expected in areas which are disturbed by removal of sand?

Communities which were chosen for detailed study included macroinvertebates (Chapter 8) and demersal fishes (Chapter 9). Following discussions with the Australian Museum, we also initiated a small study of benthic scavengers, which were highly mobile macroinvertebrates that may avoid the sampling device used originally for macroinvertebrates.

Information was also obtained on other habitats within or adjacent to the exploration licence areas. It was decided at the outset that rocky and sandy shores, reefs and shipwrecks, which may be indirectly affected by the proposal, were very important components of the ecosystem (see Part III). On this basis, it was considered that existing information would enable a sufficient description for the EIS. Assessment of impact for these habitats has been based on the extent of physical and chemical impacts associated with extraction and mitigation of impacts based on management practice (Part IV). A similar approach was adopted for marine mammals, marine reptiles and avifauna.

5.2 TIME FRAME OF STUDIES

Ellis (1987) suggested that studies of the environmental effects of marine mining should be considered in the context of a "mine lifetime concept", especially where the mining is proposed to take place over a time scale of decades. In this context, the studies done now would constitute only part of the work associated with the proposal (Table 5.1). At each stage of the extraction operation, environmental studies would have different goals and their own individual time frames.

The current phase of the operation represents the pre-approval period, which, in terms of the ecological studies, has been underway for over three years (Table 5.1). The actual field studies encompassed four survey periods over about a year.

There is considerable debate about how long research should be in order to allow a proper assessment of impacts. Most EISs in NSW rely on only one sampling period (Fairweather 1989; Lincoln Smith 1991) and therefore provide no indication of temporal variability in communities likely to be affected. Several recent large-scale studies in NSW spanned two to three years. For example, a study of fish in Botany Bay spanned two years (SPCC 1981), pre-commissioning studies of fish, benthos and bioaccumulation for Sydney's deepwater ocean outfalls spanned two years (FRI 1991; SPCC 1991), and a large study of the marine ecology of Jervis Bay commissioned by the Australian Navy spanned two to three years (e.g. Lincoln Smith et al. 1992). None of these studies was commissioned directly for an EIS (although parts of the studies have been incorporated into EISs). In particular, the studies associated with the deepwater ocean outfalls were commenced after approvals were given and in this sense they are analogous to the pre-extraction phase described in Table 5.1.

Westoby (1991) argued that field experiments of three to six years will detect mainly the effects of manipulation on species already present and their interactions, while studies over 10 to 50 years might also hope to detect effects involving other species arriving subsequently. He argued that studies with this time frame do not provide enough replicate years to reliably detect any but the strongest correlations between variables at one site, nor do they estimate the frequency of rare events well. To achieve these objectives, paleobiological records at least 100 - 1000 years should be pursued. This suggests that some of the questions we might wish to answer can, in practical terms, never be answered, regardless of the type of development proposal.

In this phase of the operation it is important that predictions about impact are formulated in such a way that they can be tested as part of a subsequent monitoring programme (Buckley 1989). Unlike many EISs, the biological investigations were initiated at a relatively early stage in the studies. In this respect, the specialist studies interacted over much of the study period. Thus, changes to the extraction plans were able to be incorporated into the proposal on the basis of the biological investigations.

The second phase of the operation would (if approval to proceed is given), involve a refinement of the monitoring programme formulated in this report. This includes finalisation of the levels of replication and of the appropriate temporal and spatial scales of sampling. It also includes commencement of the monitoring programme for the sand bodies, rocky reefs, etc., prior to any impacts occurring (e.g. Bernstein and Zalinski 1983; Stewart-Oaten et al. 1986; Underwood 1991). The duration of this period should ideally span at least two years, but this would need to be considered in the context of other aspects of the project.

The extraction phase would encompass the main period of monitoring. Disturbance of the seabed can be considered to occur potentially at three spatial scales. The first scale is at the level of furrows created by the extraction head. This level of disturbance was simulated as part of the pre-extraction studies (Chapter 8). An intermediate scale of disturbance could occur because the extraction plan would lead to disturbance of only relatively small parts of the extraction area in any one year. Thus, there is an opportunity to monitor in such a way that the effects of extraction are assessed as part of a series of investigations or large-scale expriments. If one area is targeted for extraction, other nearby areas could be used as controls, with monitoring aimed at that specific area before, during and after extraction. This experiment could be repeated when the next area is targeted for extraction, and so forth (see Part IV). During this phase the extraction plan would be evaluated constantly in the context of the results of monitoring and any changes to the mine plan that were suggested by the results of monitoring would be accommodated.

The third and largest scale of putative disturbance is over the whole extraction area. The baseline for monitoring at this scale has been initiated as part of the pre-approval studies and includes comparisons of the putative impact locations with control locations.

The final phase of the operation would involve any monitoring required after the extraction is complete. The extent of such monitoring would be decided on the basis of any effects detected during the life of the extraction.

Having defined a framework in which ecological studies for the proposal should be done, the next part of this report presents a description of the environment and current users of the proposed extraction areas.

Table 5.1. Establishing an appropriate research framework within the context of the lifetime of the extraction operation.

Phase of the operation	Goals	Time frame
Pre-approval (EIS)	* description of the environment & determination of the significance of areas likely to be affected * prediction of impacts * development of measures to mitigate impacts * development of a monitoring programme	3 years (includes 1y of field sampling)
Pre-extraction (following approval)	* refinement and implementation of the monitoring programme	1-2 years
Extraction	* monitoring of extraction * environmental audit (testing predictions) * revision of extraction plan in accordance with monitoring results	≥3 years
Post-extraction	* monitoring of 'recovery', if necessary	?

PART III: DESCRIPTION OF THE ENVIRONMENT

CHAPTER 6. GENERAL DESCRIPTION OF THE ENVIRONMENT

6.1 INTRODUCTION

The aim of this chapter is to provide a general description of the study region, with emphasis on the habitats which may be affected by the proposed aggregate extraction. The information provided here is drawn largely from studies done by other specialist consultants engaged for the project (e.g. Bower 1993; Geomarine 1993; Mining Tenement Management 1993) and those reports should be read for more details.

6.2 PHYSIOGRAPHIC SETTING

The following description is derived largely from Geomarine (1993). The coastline adjacent to the proposed extraction areas is characterised by steep sandstone cliffs, pocket beaches, a large embayment at Bate Bay and two estuaries, Botany Bay/Georges River and Port Hacking (Fig 6.1). Massive sandstone blocks commonly form subaqueous talus slopes at the base of the cliffs (Geomarine 1993). Rock platforms are common, although in many places the intertidal zone consists of a vertical wall or is undercut. Geologically, the cliffs along much of the coastline from Port Jackson to Garie consist predominantly of Triassic Hawkesbury Sandstone underlain by Narrabeen Group sediments, which comprise interbedded quartzose and quartz-lithic sandstones, siltstones and shales (Geomarine 1993). These latter sediments form cliffed outcrops along the Garie to Scarborough coastline. Wave and rain action on these outcrops can lead to the formation of turbid plumes; these have been noted in the waters south of Garie Beach (Corkery, unpublished data). According to Geomarine (1993), however, it is unlikely that cliff erosion is a major source of sediment to coastal sands in the region.

Water depths around headlands and along cliffed sections are such that the beaches are comparted and isolated, with little or no alongshore littoral sand supply or loss. On local beaches, a depth of 12 m (± 4 m) represents the subaqueous limit of the active beachface on an annual basis, whereas a depth of 22 m (± 4 m) is the absolute limit of offshore sand transport under extreme storm events (Geomarine 1993). According to Geomarine (1993), sand transport alongshore through the study region would only occur from wave stirring combined with longshore currents in deeper water, as there is no transport or littoral drift by breaking waves at the shoreline from one embayment to another.

Kurnell Isthmus, between Bate Bay and Botany Bay, comprises a massive dune modified by sand extraction (Geomarine 1993). While there has, in the past, been some aeolian transport of sand landward, no offshore losses or supplies of sand have been identified. In summarising available information, Geomarine (1993) reported that there is no conclusive evidence of any significant sand transport along the continental shelf and into Bate Bay or the entrance to the estuary at Port Hacking and concluded that sediment infeed from the ocean into the estuary was negligible. Similarly, rates of longshore transport in the proposed extraction area at Cape Banks are virtually negligible and that rates of shore-normal transport were even smaller (Geomarine 1993).

Apart from soft substrata on the continental shelf off Sydney, there are large outcrops of rocky reef (Geomarine 1993) and a number of shipwrecks (Bower 1993). Major reef systems occur off Long Reef, North Head, Port Jackson and Maroubra (Fig. 6.2). A large, patchy reef also occurs off Bondi. At the proposed Cape Banks extraction area, a large reef system extends from the shoreline to about 43 m depth. Near Providential Head, a reef system is associated with Jibbon Bombora and extends to 25-30 m depth. Other reefs occur at Marley Head, Little Marley Beach and Wattamolla (Chapter 10). However, most of the reef adjacent to the proposed Providential Head extraction area occurs as talus at the base of shoreline cliffs.

No rocky reefs have been found inside or within 250 m of either of the proposed extraction areas. There are, however, shipwrecks present nearby (Figs. 3.1 and 3.4). Some of these, such as the s.s.Hilda and s.s.Kelloe rest on reef. Others, such as the s.s. Woniora, off Cape Banks, which sank in 1882, the s.s.Tuggerah, off Marley (sank in 1919) and the s.s.Undola, off Garie (sank in 1918) are on sandy substrata (Bower 1993). Several other vessels have reportedly sunk in the vicinity of the study region but have never been located.

6.3 THE FORMATION AND STRUCTURE OF SHELF SAND BODIES

The continental shelf of NSW can be divided into three broad morphological zones (Mining Tenement Management 1993):

1. The Inner Shelf, which extends to about 60 m water depth and consists of a relatively steep and concave-up inshore zone, grading to a more gentle slope at its seaward limit. Sediments are generally well sorted quartzose sands with minor amounts of skeletal carbonate. Commonly there are outcrops of rocky reef.

2. The Mid Shelf, which extends approximately from about 60 m to 90 m and has a gentle slope. It is mantled discontinuously by muddy sands to muds.

3. The Outer Shelf, which occurs from about 90 m to the edge of the shelf. Sediments consist typically of poorly sorted calcarious sands and gravels.

Within the inner shelf, there are notable exceptions to the

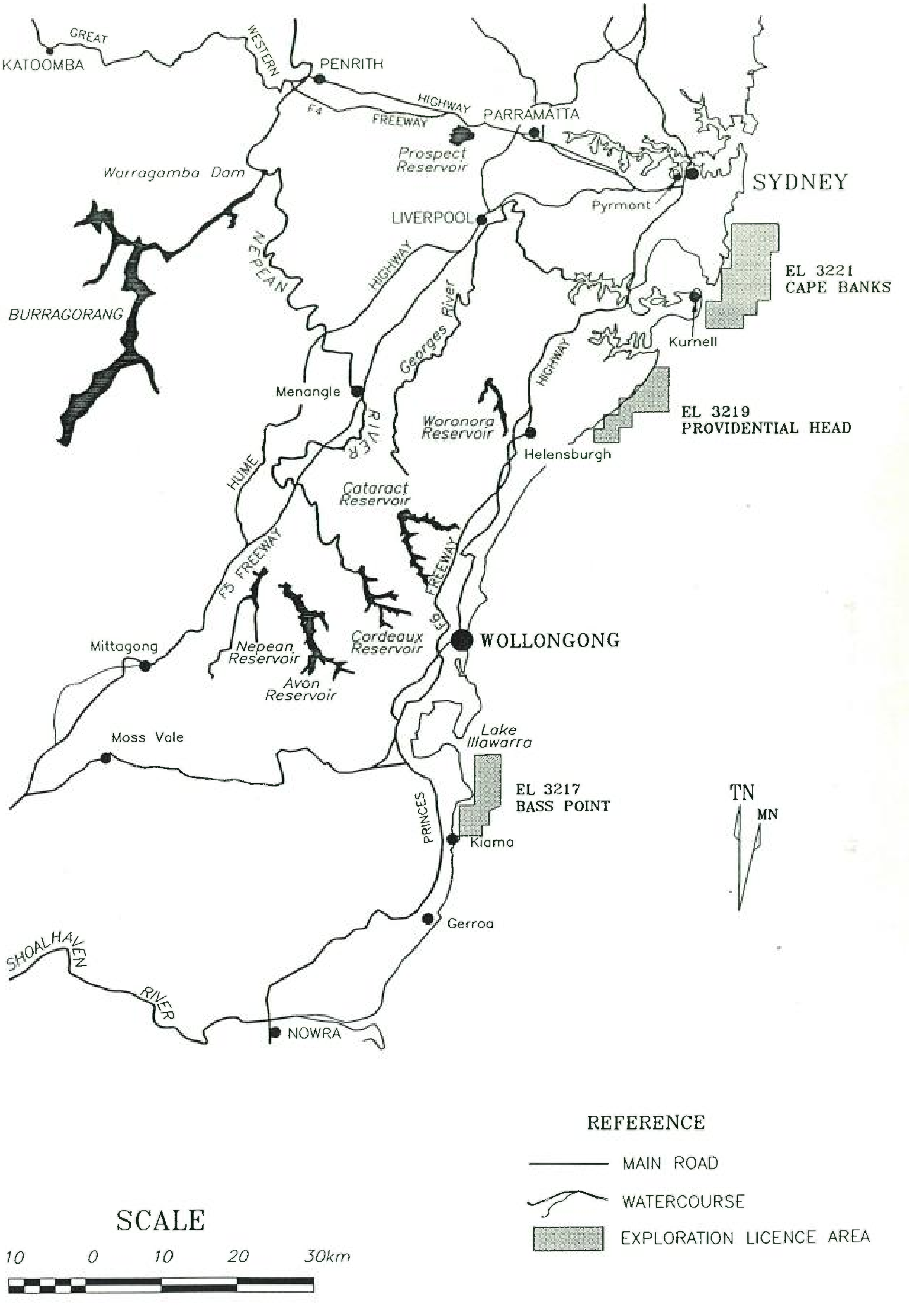


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Figure 6.1
THE STUDY REGION

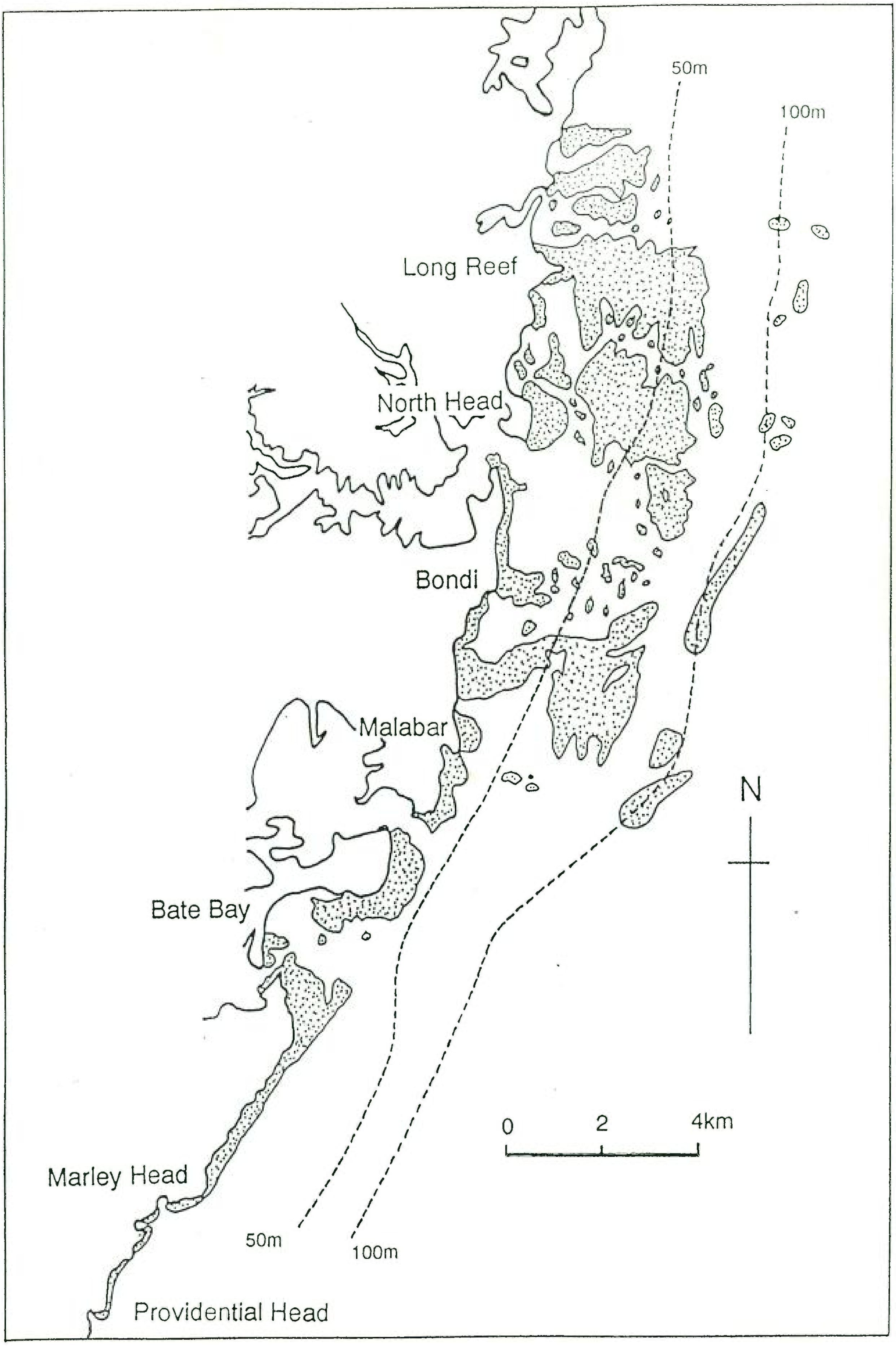


Figure 6.2 Approximate depth of rocky reef to 100m water depth in the Sydney Region (after Gibbs 1987 & Geomarine 1993).

general morphology and sedimentology described (Mining Tenement Management 1993). These include large accumulations of sediment termed "shelf sand bodies", which are typically tens of metres thick and extend over tens of kilometres along the coast. They are generally within about 3 km of the coast. The sediment in shelf sand bodies is comprised mainly of well sorted quartzose sands. The proposed extraction areas occur within a single large shelf sand body extending from Port Jackson to Garie Head North.

Shelf sand bodies are relatively common along the NSW shelf (Ferland 1990). Shelf sand bodies also occur, among other places, off Cape Howe, Montague Island, Jervis Bay, Bass Point and from Newcastle to Sugarloaf Point. Thus, the broad habitat provided by the shelf sand bodies is relatively common on the NSW coast.

The shelf sand body of interest to the Applicant is typically 20-30 m thick, consists of a surficial fine to medium grained quartzose sand which is absent in places and varies in thickness to over 6 m (Fig. 6.3). Beneath this, and also sometimes occurring at the surface (where the upper layer is absent), is a relatively thick (> 10 m) fine grained sand which merges offshore, in water depths of 60-65 m, with a more fine grained, muddy sand (Mining Tenement Management 1992).

In summary, the sand of interest for aggregate extraction occurs at the surface of the shelf sand bodies. It overlays a thick layer of slightly finer sand, although no approval to extract sand is being sought at depths below 5 m from the surface of the sand bodies. The finer sand type does, however, already occur at the surface in some parts of the shelf sand body.

6.4 ATMOSPHERIC AND OCEANOGRAPHIC CONDITIONS

6.4.1 Processes

Sydney has a relatively high energy coastline, due to the shape of the continental shelf, which is narrow and deep, and to its exposure to rough seas and swells generated both locally and remotely. Geomarine (1993) summarised the climate of the region, which is briefly described here. The coast experiences a complex wind regime, although, in general, offshore winds dominate in winter and diurnal seabreezes and landbreezes dominate in summer. Storm winds tend to approach from the south to southeast. These are generated from several sources: cyclones off the east coast, tropical cyclones off the Queensland coast and southerly busters associated with the eastward migration of fronts.

The average yearly rainfall for the Sydney region is about 1230 mm, but variability among years can be very high. There is a tendency for similar years, wet or dry, to occur consecutively (Geomarine 1993). Heavy rainfall associated with thunderstorms or cyclonic depressions is common, with daily totals over 120 mm occurring in all months. This can lead to rapid and extensive runoff into coastal waters from estuaries, hence marked episodic variability in water quality. Lawson and Treloar (1993) estimated that the amount of suspended solids discharged from the Hunter River into Stockton Bight over a 40 year period (i.e. the same time period as the proposed extraction operation) would be about 2.5 Mm^3. Examination of the seabed sediments in the bight showed very little evidence of this fine material, suggesting that the suspended solids were transported away to settle in deep, less disturbed water.

Variability in water quality on the NSW coast was monitored as part of a visual survey of reef fish (Lincoln Smith et al. in 1993). Near the entrances to large estuaries, such as the Georges River/Botany Bay estuary and at Batemans Bay, water visibility was typically quite low (e.g. 3-6 m horizontal visibility). Reefs near smaller estuaries, such as Jervis Bay and Port Hacking often had much better visibility (8-12 m horizontal visibility - Lincoln Smith, unpubl. data). Comments by divers interviewed during the present study supported this - they believed that the waters off Royal National Park were the clearest in the Sydney region.

The wave climate of the Sydney region consists of a persistent moderate swell and wind wave climate (Geomarine 1993). A significant wave height of 1.5 m is exceeded 50% of the time and storms with a significant wave height of 6 m occur about once a year (Geomarine 1993).

There are several processes which can cause water level variations on the shelf (Geomarine 1993), including:

1. the astronomical tide (maximum ≈2 m above Indian Spring Low Water);

2. continental shelf waves (maximum ≈0.2 m);

3. storm surge (maximum ≈0.5 m);

4. ocean currents (maximum ≈0.2 m);

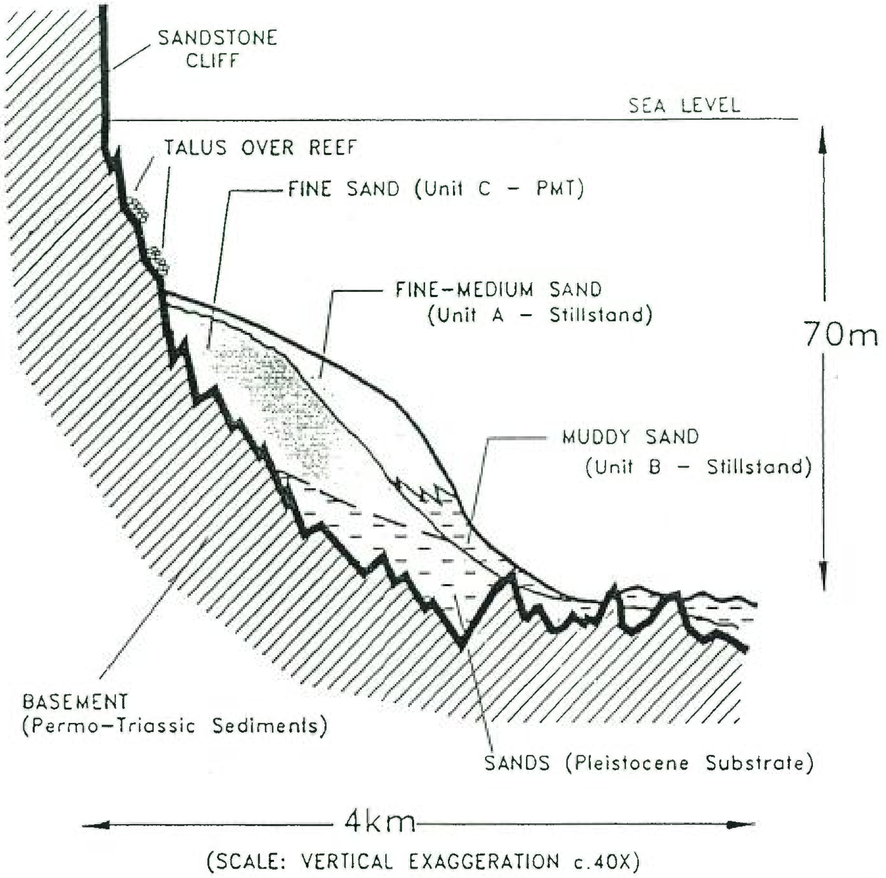
5. El Niño Southern Oscillation (≈0.1 m);

6. tsunamis (maximum ≈1.1 m);

7. eustatic changes, e.g. the Greenhouse Effect.

The last three processes are global in nature. The Greenhouse Effect is forecast to cause a rise in the sea level of 0.13-0.32 m by the year 2036 (National Research Council USA, 1987). It is also predicted that the severity and frequency of storms may increase (Geomarine 1993).

There are several sources and causes of currents on the NSW coast (Geomarine 1993), the most significant of these being



Late Pleistocene to Holocene Sea Level Trends

Postglacial marine transgression (PMT): 18,000 to 6,500 years ago

Stable sea level (Stillstand) : 6,500 years ago to Present

Figure 6.3 Idealised stratigraphic section of inner shelf sediment bodies.
Source: Geomarine 1993, after Roy 1985.

currents induced by local wind conditions, tides, the East Australia Current, coastal trapped waves and internal waves. These currents are of varying importance for determining regional and local water quality and water temperature, mobilisation and transport of sediments and transport of propagules (e.g. eggs, larvae, seeds, spores) from one habitat or location to another (e.g. Kingsford 1990).

Studies reported by Geomarine (1993) showed that changes in local currents may be related to changes in observed wind fields. Moreover, sustained winds (e.g. persistent southerlies or northeasterlies) can initiate the Ekman Spiral, the propagation of currents at an angle to the wind direction. Off Sydney, persistent northeasterlies may cause an Ekman Spiral with currents tending offshore. This, in turn, can lead to upwelling of deeper, nutrient-rich waters from the continental slope (Chapter 7).

Research by Lawson and Treloar (Geomarine 1993) showed negligible effects of tidal currents from Port Hacking on the proposed Providential Head extraction area. At Cape Banks, there was a minor influence of tides from Botany Bay adjacent to the entrance to the bay. The northern and southern parts of the proposed extraction area were virtually unaffected by tidal currents.

The East Australia Current (EAC) is a large-scale oceanic density current formed by the flow of warm, relatively low density Coral Sea water south along the eastern coastline of Australia (Geomarine 1993). The extent of southward penetration increases in summer, possibly as far as Jervis Bay. As the current turns east, portions may be pinched off to form counter clockwise warm core eddies. On the western side of the EAC, smaller, less intense eddies may form, which can cause northerly currents on the shelf. The EAC can also cause formation of cold core eddies through lateral shear and momentum dispersion (Geomarine 1993). These generally form in large coastal embayments. Thus, the EAC can have highly variable effects, even over small spatial scales. It is one of the major oceanographic features on the NSW coast.

Coastal trapped waves (CTW) are believed to occur as a result of changes in high and low pressure systems which propagate from west to east across southern Australia (Geomarine 1993). They originate in eastern Bass Strait and travel up the NSW coast.

Internal waves are caused by stratification in the ocean. They occur typically in NSW when a stratified layer occurs on the coast, broadly from October to April (Geomarine 1993). Upon arriving at the coast, internal waves may reflect off the shore or break in shallow water.

The studies done for the proposed aggegrate extraction found that currents near the sea bed were dominated by remote winds (e.g. CTW), local winds and, to a less frequent extent, by internal waves (Geomarine 1993). Effects of the EAC are common near the water surface, but their effects are reduced at the seabed, probably because the EAC tends to occur on the edge of the shelf and it contains less dense water that usually found overlaying the shelf. Tidal currents flowing into and out of estuaries had negligible effect at Providential Head and little effect at Cape Banks.

6.4.2 Natural Processes of Physical Disturbance to Habitats

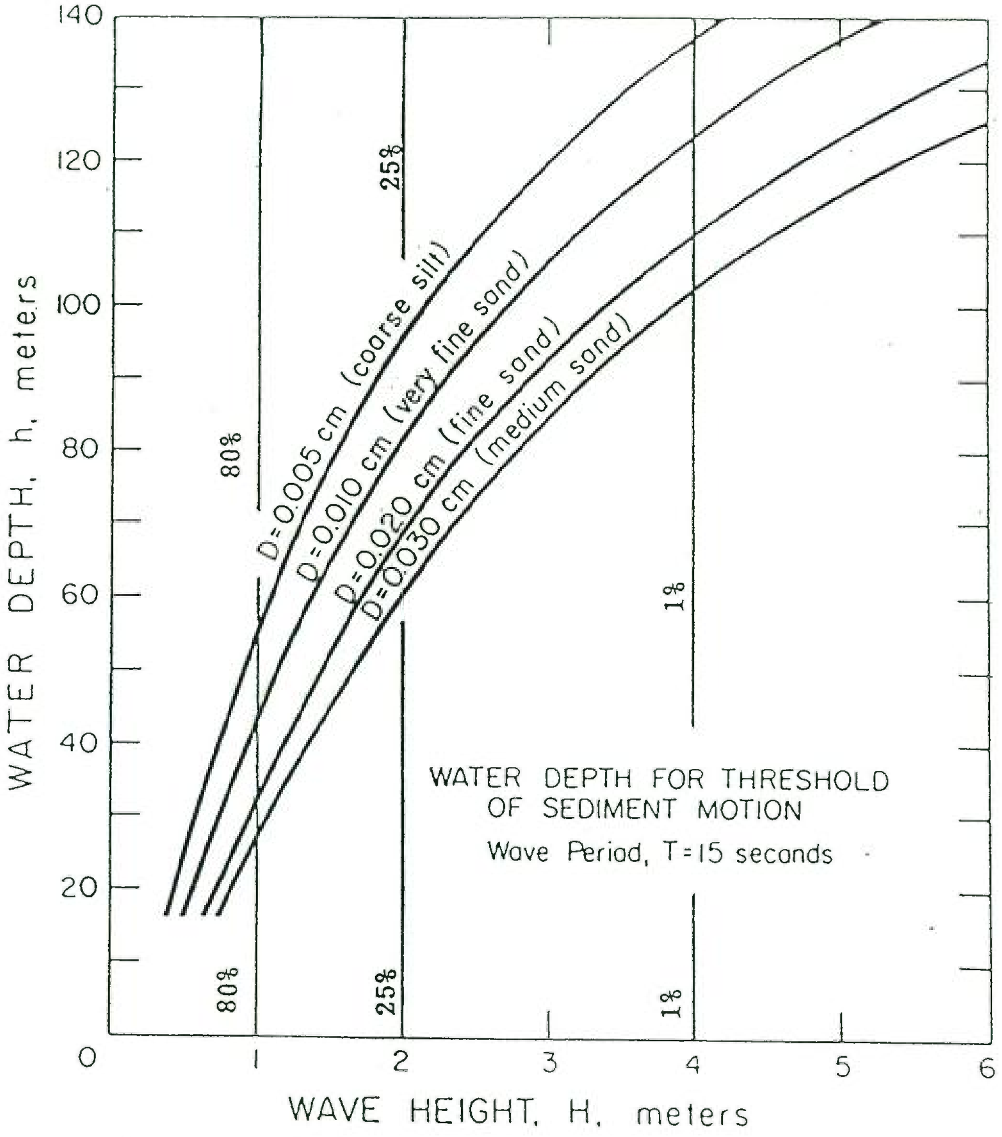
Irrespective of the proposed extraction of marine aggregate, there are numerous potential sources of disturbance to habitats on the NSW continental shelf. Some include anthropogenic sources, such as the effects of fishing and contamination from runoff out of estuaries, sewer outfalls and dumping grounds (Chapters 9, 10, 13 and 14). Natural processes, such as storms and large-scale oceanographic events also have the potential to cause disturbance to habitats (e.g. McGuinness 1987a,b). Russell (1975) reported that an artificial reef constructed of tyres and deployed on sand in 20 m water depth was broken up by a storm with wave heights of up to about 4.5 m.

One major question of interest is the extent to which ocean waves may cause disturbance to the sediments of the shelf sand bodies. Figure 6.4 shows the approximate depth to which waves of a given height and frequency can mobilise sediments to a depth in the substratum of 0.2 m (see Geomarine 1993). It also shows the the probabilities of significant wave height exceedance for the Sydney coastline. At depths of 25-30 m, sediments off Sydney are mobilised by wave action about 80% of the time. Even at depths of 60 m, mobilisation of sediment by waves occurs about 25% of the time. Thus, mobilisation of those sediments which would be subject to extraction already occurs frequently under natural conditions.

Carey and Talbot (1980) distinguished between mobile and semi-stable sands in the area off Broken Bay considered for extraction of marine aggregate. On the basis of the oceanographic studies done at the time, they concluded that the seafloor within the (then) proposed extraction area was disturbed naturally between 5% and 25% of the time (see Fig. 2 in Carey and Talbot 1980). As described above, these parameters have been estimated to be much larger (i.e. 25-80%) for the current marine aggregate extraction proposal. Since the work that Carey and Talbot (1980) relied upon was done, a large data base has been developed for the Sydney shelf which indicates that there is a higher level of wave activity with depth than was considered previously (L. Nielsen, pers. comm.)

6.5 CONCLUSIONS

The study region contains several major types of habitat, including the waters overlaying the shelf, the shelf sand bodies, rocky shores, reefs and wrecks, sandy shores and adjacent estuaries. All of these are subject to a numerous natural processes as well as anthropogenic processes. In particular, turbid plumes may occur as a result of erosion of siltstones, outflow from estuaries, urban runoff and discharge of sewage. Also, natural disturbance of the seabed as a result of wave action occurs over the depth range of interest for extraction of marine aggregate. The remainder of Part III of this report describes our existing understanding of the assemblages of plants and animals which occur in the habitats which may be affected by the proposal to extract marine aggregate.



(annotated with significant wave height exceedance after Youll 1981)

Figure 6.4 Sediment mobility under wave action Sydney shelf.
Source: Geomarine 1993.

CHAPTER 7. PLANKTONIC AND PELAGIC COMMUNITIES

Many of the factors affecting planktonic and pelagic communities in coastal waters are determined by relatively large-scale processes. Thus, much of the information presented here applies to both Providential Head and to Cape Banks and will be discussed in the same sections. A brief comparison of the two areas - particularly with respect to their proximity to estuaries - is discussed toward the end of this chapter.

7.1 PLANKTONIC COMMUNITIES

7.1.1 Introduction

By strict definition the term 'plankton' is used to describe those organisms which are carried about passively by water movements, but many organisms regarded historically as plankton are able to swim strongly enough to overcome passive transport by prevailing currents. Even so, 'plankton' remains a convenient term for categorising a myriad of phylogenetically diverse and ecologically important pelagic organisms.

Plankton may be divided into phytoplankton (plants) and zooplankton (animals). The phytoplankton contains many diverse floral groups, for example, diatoms, dinoflagellates, coccolithophorids, and microflagellates. The phytoplankton is often conveniently divided according to size, for example, nanoplankton are that fraction of the community less than 15 μm. In contrast, the zooplankton are usually divided, using life cycle criteria, into the holoplankton (permanent plankton) and the meroplankton (temporary plankton). The holoplankton contains organisms whose entire life span is planktonic, such as, copepods, arrow-worms, salps and krill. The meroplankton contains organisms which reside in the plankton for only part of their life cycle, such as, the eggs and larval stages of fishes, prawns, crayfish, mussels, scallops and some benthic worms.

Any attempt to understand the ecology of planktonic assemblages requires a detailed knowledge of current systems and the physical processes that drive them. Large-scale physical processes that may influence the distribution and abundance of planktonic assemblages in both the horizontal and vertical planes include seasonal wind-induced transport (Nelson et al. 1977; Pietrafesa et al. 1986; Taggart and Leggett 1987), estuarine fronts (Govoni et al. 1989; Kingsford 1990), convergences associated with internal waves (Shanks 1983, 1985, 1988; Kingsford and Choat 1989; Shanks and Wright 1987), coastally trapped waves (Church et al. 1986), and the vagaries of offshore eddy movements in the East Australian Current (Boland and Church 1981; Cresswell et al. 1983; Tranter et al. 1986; Louis 1989).

7.1.2 Phytoplankton

Growth of phytoplankton is driven by additions of nutrients to the euphotic zone (Jeffrey 1981). Input of nutrients into the euphotic zone may come from a variety of sources, such as, upwelling and/or intrusions of continental slope waters onto the shelf, terrestrial runoff following heavy rain and, adjacent to coastal cities, domestic sewage. Surface waters (0-100 m depth) in Australian coastal areas are generally low in nutrients (Jeffrey 1981) thus increasing the importance of nutrient recycling processes associated with animal excretion and microbial decomposition (McCarthy and Goldman 1979; Jeffrey 1981). The rapid physiological responses (i.e. detection and uptake of nutrients) of many phytoplankters to episodic, small-scale patches of nutrients in their micro-environment suggests that high growth rates can be achieved in seemingly "nutrient poor" environments (McCarthy and Goldman 1979; Holligan 1979; Jeffrey 1981). Thus, low levels of measured nutrients in the water do not imply low levels of phytoplankton production (Eppley et al. 1979; Jeffrey 1981).

Phytoplankton ecology within Australian waters is poorly understood (Jeffrey 1981). The only station in Australian coastal waters that has been sampled regularly over many years (weekly since early 1953) is known as the Port Hacking 100 m station, located about 12 km east of Port Hacking, along the 100 m depth contour (Jeffrey 1981). Another station at 55 m depth has also been sampled less regularly (Scott 1979). High chlorophyll peaks indicative of large phytoplankton biomass have been recorded at the 100 m station (Jeffrey 1981). These high chlorophyll peaks coincided with localized intrusions of nutrient rich slope waters onto the continental shelf (Humphrey 1963; Jeffrey 1981).

Scott (1979) collected data on nutrients at various depths through the water column at the 55 m station (and therefore within the depth range of the proposed extraction areas). Pulses of nutrients which were found in greatest concentrations near the seabed were attributed to intrusions of slope waters. Typically, these slope intrusions last about three days (Rochford 1975, cited in Scott 1979). Nutrients in rainwater runoff from land were also detected at the 55 m station, as increased concentrations of silicate and nitrate in surface waters (Scott 1979). Scott (1979) was unsure whether these runoff effects were due to water from the Port Hacking catchment or the Georges River-Botany Bay catchment.

Seasonal successions of phytoplankton species have also been documented from the coastal waters of the Sydney region (Dakin and Colefax 1933, 1940; Grant and Kerr 1970; Jeffrey and Carpenter 1974; Hallegraeff 1981; Hallegraeff and Reid 1986). The seasonal patterns of phytoplankton succession described at the Port Hacking 50 m and 100 m station are similar to those of coastal waters in other parts of the world (Jeffrey 1981).

Hallegraeff and Reid (1986) identified three major phytoplankton categories during their three year (1978-1981) study of phytoplankton populations at the Port Hacking 100 m station. They concluded that short term species successions following episodic nutrient enrichments were more pronounced than seasonal species changes. These episodic events, which were dominated by increases in nitrate nitrogen (NO_3-N > 3 μg-at l^{-1}), were most evident in the periods September-October and February-March. Slope water intrusions were identified as the mechanism for this nutrient input into the upper 40 m of the water column. The major groups of phytoplankton identified by Hallegraeff and Reid (1986) were:

1) Species which were present throughout the year. This group included most of the nanoplankton.

2) Diatom species which bloomed following episodic nutrient enrichments.

3) Warm water species which were typically associated with tropical water masses.

Hallegraeff and Reid (1986) also documented short-term (4-14 weeks) species successions within the spring and summer diatom blooms. These began with small diatom species, followed by large diatom species, and then by large dinoflagellates (Hallegraeff and Reid 1986). Hallegraeff and Jeffrey (1993) reported that spring blooms of phytoplankton occur over very large spatial scales - extending over much of the length of the NSW coast.

One question arising in relation to the extraction proposal is the possible effect of plumes containing fine sediment on phytoplankton (Section 4.1.1.2). Some information on the depth to which phytoplankton occur naturally may assist in addressing this question. Jeffrey and Hallegraeff (1990) presented data from the 100 m station off Port Hacking showing that coastal phytoplankton blooms can have chlorophyll maxima at depths of 15-30 m. In the example they discuss, the depth of the maxima decreases in intensity but increases in depth as the bloom declines over a two week period. This situation contrasts with chlorophyll concentrations associated with the open ocean and a warm core eddy from the East Australia Current, where the maxima ranged from 120 m to about 50 m; or a dinoflagellate bloom in a freshwater lake, where the maxima were very close to the water surface (Jeffrey and Hallegraeff 1990).

Recent data obtained by the EPA as part of the deepwater ocean outfalls monitoring programme showed less consistency with depth (EPA 1992a). While there appeared to be a trend to decreasing chlorophyll a with depth, this was not consistent among sites sampled.

Near the proposed extraction areas, phytoplankton communities have also been described for marine-dominated estuarine systems such as Port Jackson (Revelante and Gilmartin 1978) and Port Hacking (Wood 1964; Scott 1983). Prevailing offshore oceanographic events were found to strongly influence phytoplankton species composition and abundance in the lower reaches of these estuaries, with a group of cosmopolitan neritic species being recorded commonly (Revelante and Gilmartin 1978; Scott 1983). Similarities in phytoplankton species composition and abundance recorded in comparisons between the Port Hacking 100 m station and the lower reaches of two nearby marine-dominated estuaries suggest that the floras there may also be similar to that of inshore coastal waters (0-50 m depth).

7.1.3 Zooplankton

The zooplankton fauna of Australian coastal waters and marine embayments is better known than the phytoplankton, but the ecology of these zooplankton populations is not. This is true for assemblages of both holoplankton and meroplankton.

7.1.3.1 Holoplankton

Holoplanktonic populations from the coastal waters around Sydney have been studied (Dakin and Colefax 1940, Tranter 1962). Weekly sampling at the Port Hacking 100 m (depth) station was conducted over several years (Tranter 1962). A characteristic feature of the coastal holoplankton was the common occurrence of large, short-term (weekly), fluctuations in zooplankton biomass (Tranter 1962).

More recently, a one year study of spatial and seasonal patterns of zooplankton abundance was conducted in two marine-dominated embayments, Port Phillip and Westernport Bays, in Victoria (Kimmerer and McKinnon 1985). Both bays had a resident fauna distinct from that of adjacent Bass Strait waters. The resident holoplanktonic communities within each bay shared many common species but the patterns of abundance and dominance were different (Kimmerer and McKinnon 1985). Within Westernport Bay, vertical profiles of the most abundant copepod species _Acartia tranteri_, showed that adults migrated vertically in synchrony with the tides, and in a direction that reduced transport out of the bay (Kimmerer and McKinnon 1987). None of the non-resident zooplankton species migrated in synchrony with the tides. Thus, the dominance of the copepod _A. tranteri_ in Westernport Bay can be explained, in part, by the behavioural response of this species to tides (Kimmerer and McKinnon 1987). Further work has demonstrated that selective predation by planktivorous fishes was also important in structuring copepod populations in Westernport Bay (Kimmerer and McKinnon 1989). Planktivorous fishes have been shown to locally decrease the density of zooplankton on both temperate rocky reefs (Kingsford and MacDiarmid 1988) and tropical coral reefs (Hamner _et_ _al_. 1988).

7.1.3.2 Meroplankton

Very little is known about the relative distribution and abundance of most meroplanktonic assemblages from Sydney coastal waters, including the areas proposed for aggregate extraction. This is particularly so for most invertebrate meroplankton, including those of economic importance such as prawns, crabs and scallops. In contrast, there has been a recent increase in studies which seek to describe patterns of distribution and abundance in assemblages of fish larvae from NSW waters (Bruce 1982; Steffe 1982, 1991; Marsden 1986; Ramm 1986; Miskiewicz 1987; Gibbs 1987; FRI, 1992).

To date, all distributional and ecological studies of larval fish assemblages in Australian waters have been limited by the taxonomic problems associated with identifications of larval fish (Leis and Goldman 1987; Williams _et al_. 1988; Steffe 1991). Although recent advances in larval identification (e.g. Leis and Rennis 1983; Moser _et al_. 1984; Leis and Trnski 1989) have enabled researchers to identify most fish larvae to a family level, it is still the case that relatively few taxa can be identified to species.

Several studies have focused on describing patterns of distribution and abundance in assemblages of nearshore fish larvae from NSW waters (Bruce 1982; Miskiewicz 1987; Gibbs 1987). A brief summary of these studies follows.

Bruce (1982) described seasonal variations in the numbers of fish eggs and larvae at the Port Hacking 50 m and 100 m stations during 1981. Horizontal surface and vertical drop samples were collected at both stations. Numbers of ichthyoplankton were often highly variable (Bruce 1982). Large catches of larval fishes were often made in the vertical drop samples thus suggesting that a large proportion of the larval population may be present in subsurface layers (Bruce 1982).

Miskiewicz (1987) collected larval fishes from four stations located along a transect which extended seaward from the entrance of Lake Macquarie, on ten dates between January 1984 and January 1985. One station was located within Swansea Channel at the mouth of Lake Macquarie, whilst the others were located at the 30 m, 40 m, and 50 m depth contours opposite the entrance to the Lake. Sampling was restricted to surface waters during daylight. Two distinct larval assemblages which had different nearshore distributions were recognized (Miskiewicz 1987). An 'estuarine' assemblage consisting of species such as bream _Acanthopagrus australis_, silver biddy _Gerres ovatus_, and the perchlet _Ambassis jacksoniensis_, which were recorded occasionally at the 40 m and 50 m depth contour stations, were most abundant closer to shore, within Lake Macquarie and at the 30 m station (Miskiewicz 1987). In contrast, a 'marine' assemblage comprising taxa such as the beaked salmon, _Gonorhynchus greyi_, yellowtails and trevallies

(Family Carangidae), bellowsfish (Macroramphosidae), goatfish (Mullidae), and morwongs (Cheilodactylidae), which were rarely found entering the Lake, were most abundant at the two stations furthest from the shoreline (Miskiewicz 1987).

Miskiewicz (1987) also reported patterns of distribution and abundance for many larval fish taxa collected during three CSIRO 'Sprightly' cruises, conducted during January, March and May of 1983, along the NSW coast. During each cruise, 7 transects, each separated by one degree of latitude, and ranging from 28° to 34° were visited. Each transect commenced off the continental shelf and extended in towards the coastline, sampling stations being located over the 2000 m, 1000 m, 400 m, 200 m, 100 m, and 50 m depth contours (weather permitting). One surface and one oblique (200 m-0 m where possible) sample were collected at each station during the night. Some larval taxa, such as pilchards, Sardinops neopilchardus, anchovy, Engraulis australis and maray, Etrumeus teres, had widespread distributions, extending across the shelf (Miskiewicz 1987). Conversely, other larval taxa, such as luderick, Girella tricuspidata, snapper, Pagrus auratus and sand whiting, Sillago ciliata, had restricted inshore distributions (Miskiewicz 1987). The cross-shelf patterns of distribution described by Miskiewicz (1987) should be viewed with caution as they are based on very limited numbers of samples per station, derived from only three cruises. Clearly, seasonal patterns of distribution and abundance cannot be assessed adequately using these data.

Gibbs (1987) collected a combined total of 48 oblique plankton samples (38 day, 10 night) from stations at both the 30 m and 100 m depth contour at Long Reef, North Head, Malabar and Port Hacking. The sampling program, which formed part of the environmental monitoring program pilot study for the Sydney deepwater sewage outfalls, yielded 9200 individuals from 197 taxa (Gibbs 1987). The species composition was different at the 30 m and 100 m depth contour stations indicating the presence of distinct 'inshore' and 'offshore' larval assemblages (Gibbs 1988). The inshore assemblage consisted predominantly of estuarine species while the offshore assemblage included many species trawled in nearshore waters (Gibbs 1987). Unfortunately, Gibbs gives no sampling dates.

FRI (1992) has continued sampling of larval fishes as part of the ongoing deepwater ocean outfalls environmental monitoring program. The sampling design has been modified from that used in the pilot study of Gibbs (1987) and it involves the collection of three replicate tows at each of two depths (surface and deep) at Long Reef, Port Hacking, Marley, North Head, Bondi, and Malabar (FRI 1992). Surface samples are restricted to the top 2 m layer of the water column at each station. Deep samples are collected with an opening/closing net at depths of about 20 m at the 30 m depth contour stations, and at depths of about 30 m at both the 60 m and 100 m depth contour stations (FRI 1992).

In analysing their data, FRI (1992) compared sites and sampling depths over time within each depth contour (viz., 30, 60 or 100 m). Thus, no cross-shelf comparisons were made. The results of the survey showed that there was considerable variation in abundance of ichthyoplankton among sites and seasons and between depths (FRI 1992). The number of fish larvae was often greatest at depths of 20 or 30 m compared with those from the surface (i.e. 0-2 m) samples.

The broad patterns of distribution and abundance that have been described for assemblages of nearshore larval fishes from NSW coastal waters, although limited, suggest that distinct assemblages occur at different distances from the shoreline. However, the temporal and spatial persistence, or variability, of these patterns cannot be assessed because of the paucity of available data.

7.2 PROVIDENTIAL HEAD AND CAPE BANKS

Apart from the long term sample stations off Port Hacking, there is little information on the plankton of the two areas proposed for aggregate extraction. An important consideration with respect to the meroplankton may be the relative proximity of each proposed extraction area to estuaries. Providential Head is several kilometres to the south of Port Hacking, while are considered at Cape Banks is directly off the entrance to Botany Bay.

Several studies of larval fish have been done in Botany Bay, a large marine-dominated embayment. During these studies 158 taxa of larval fishes were recorded and the assemblage was dominated numerically by taxa which have demersal reproductive strategies, such as, gobies, blennies and syngnathids (Steffe 1982, 1991; Steffe and Pease 1988). Steffe (1991) assessed variation in concentrations of larval fish due to vertical position in the water column, age (developmental stage), tide and diel factors at two sites adjacent to the Bay entrance but which were characterised by different current regimes. A null model which assumes larvae act as passive particles was a poor predictor of larval distributions. At both sites most of the observed larval distributions contradicted the predictions of the passive particle null model. Thus, Steffe (1991) argued that orientated larval behaviours interacting with localised current patterns structure larval distributions and determine ultimately the distribution of larvae competent to settle. These interpretations suggest that any changes to the prevailing current regimes near the entrance of Botany Bay could affect the recruitment of fishes that spawn at sea and subsequently occupy nursery habitats within the Bay. This group of fishes contains many species of economic importance, such as, bream Acanthopagrus australis, tarwhine Rhabdosargus sarba, leatherjackets Meuschenia spp., and mulloway Argyrosomus hololepidotus.

7.3 PELAGIC FISHES AND SQUID

Many species of bony fishes and sharks frequent the surface waters of the continental shelf off NSW. The distributions and abundances of these pelagic species often varies seasonally. The occurrence of predominantly tropical species along the southern NSW coast coincides with the southward transport of warm Coral Sea water by the East Australia Current. At these times species such as black marlin, Maikara indica, and tiger sharks, Galeocerdo cuvieri, may be encountered in NSW waters. Large, migratory sharks that are seasonally abundant at other times in NSW shelf waters include blue sharks, Prionace glauca, mako sharks, Isurus oxyrhinchus, and the hammerheads, Sphyrna lewini and S. zygaena (Stevens 1984). Many species of pelagic fishes are found in NSW shelf waters, either as permanent residents or as migrants (Thomson 1960; Maclean 1974). These include yellowfin tuna, Thunnus albacares, southern bluefin tuna, Thunnus maccoyii, kingfish, Seriola lalandi, tailor, Pomatomus saltator, Australian salmon, Arripis trutta, sea garfish, Hyporhamphus australis, and many species of baitfish such as pilchards, Sardinops neopilchardus, blue mackerel, Scomber australasicus and yellowtail, Trachurus novaezelandiae. Large schools of sea mullet, Mugil cephalus, which spend much their life cycle in estuaries, migrate northward to spawn through the shallow coastal waters of NSW, usually in autumn (Thomson 1960; Maclean 1974). Many of these species, both sharks and bony fishes, support important recreational and/or commercial fisheries in NSW.

The assemblage of pelagic fishs off Sydney has been sampled in depths ranging from 60 m to 600 m by midwater trawling techniques (Paxton and Fitzgerald 1973; Gorman and Graham 1973, 1974, 1978, 1980). These limited surveys have recorded large, patchy, aggregations of baitfish species, e.g. anchovy, Engraulis australis, pilchard and yellowtail. Other species collected frequently included skipjack tuna, Katsuwonis pelamis and several lanternfishes (Family Myctophidae). In contrast, attempts to sample populations of pelagic fishes with pelagic gillnets off Sydney have yielded poor catches, possibly due to the sampling methodology (Gibbs 1987).

Exploratory fishing surveys which target pelagic squid have been conducted in NSW coastal waters (Gorman and Graham 1982a,b; 1983). These surveys extended from Crowdy Head to Bass Strait and fishing was mainly restricted to shelf waters. Variable catch rates of Gould's squid Nototodarus gouldi, the most common species recorded during all three surveys were reported (Gorman and Graham 1982a,b; 1983).

7.4 CONCLUSIONS

Planktonic assemblages form the basis of many if not all of the ecosystems in the sea. They are vital for supplying food, while planktonic dispersal is the mechanism by which many organisms move to new areas, or by which adult stocks are maintained within an area. Phytoplankton undergo blooms which appear to be driven primarily by intrusions of nutrient-rich slope waters, a large-scale process on the coast. In relation to the current proposal, subsurface release of excess water may simulate, on a regular but minute scale, this mechanism. There is, however, some evidence that increased nutrient levels can occur up to several kilometres offshore as a result of runoff (Scott 1979).

The limited data available on zooplanktonic communities suggests that the coastal waters encompassing the proposed extraction areas are transitional between the nearshore/estuarine communities and those offshore. Thus, there is likely to be a mixture of larval fishes belonging to estuarine and shallow coastal habitats (e.g. bream, tarwhine, leatherjackets) and fishes more common offshore (e.g. lanternfishes, redfish).

Much research effort is being directed at describing the general patterns of distribution and abundance of phytoplanktonic, holoplanktonic and meroplanktonic communities from the coastal waters of NSW. An apparent feature of all these planktonic systems is the common occurrence of large, short-term, fluctuations in abundance. The physical and biological processes which cause these patterns are not well understood. Also, the relative importance of surf-zone, rocky reef and epibenthic habitats to planktonic communities, especially the meroplankton, have not been ascertained, and these questions merit further investigation.

Large populations of pelagic fishes (including bony fishes and sharks) and squid occur in NSW coastal waters. Many species are abundant seasonally while many others occur year round. The migratory patterns of many of our pelagic fishes are poorly understood (although some others, such as sea mullet, are better known). Many of these species, however, support important recreational and/or commercial fisheries in NSW coastal waters (see Chapter 14).

There are four main constraints of the planktonic and pelagic communities which are relevant to the proposal:

1) Release of nutrients associated with any excess water released as a result of sand extraction could potentially cause localised plankton blooms.

2) Release of contaminants associated any excess water could become mobilised within planktonic and pelagic communities.

3) Changes to patterns of water movement as a result of changes to the seabed could affect the dispersal of eggs and larvae. Within the proposed areas, normal movement of eggs and larvae just above the seabed could be disrupted by the dredging operation and the changes to seabed topography. There may also be

significant implications in the proximity of the proposed extraction area off Cape Banks to Botany Bay: changes to the seabed off the entrance to the estuary may affect recruitment processes within the bay. This is probably of less concern at Providential Head, which is well to the south of Port Hacking. Fairweather (1991) discusses the ways in which disruption of larval transport or nursery areas may have consequences for adult stocks.

4) The presence of a turbid plume may affect the movements, including migrations, of pelagic fishes and squids.

The extent to which these potential effects are likely to occur as a result of the proposal would be dependent upon the nutrient and contaminant levels within the sand body, the extent to which hydrological processes would be altered, and the scale of the proposal. These issues are being addressed by other researchers involved in the preparation of the EIS and are examined in Part IV of this report.

CHAPTER 8. BENTHIC MACROFAUNA

8.1 THE DISTRIBUTION AND ABUNDANCE OF BENTHIC MACROFAUNA

8.1.1 Introduction

Benthic organisms (or "benthos") are defined here as those plants and animals living in or on the soft-sediments of the seafloor. Benthic organisms are usually classified into three size-classes: micro-, meio-, and macrobenthos. Micro- and meiobenthos usually live attached to grains of sand or in the spaces between grains and include flora (e.g. diatoms) and fauna (e.g. bacteria, protozoans, nematodes and copepods). The macrobenthos usually only includes animals ("macrofauna") retained on a 0.5 mm or 1 mm mesh. Given the paucity of ecological and taxonomic information on micro- and meio-benthos, we decided to focus on benthic macrofauna. Information on micro- and meiobenthos is reviewed in Section 8.1.1.2.7.

Benthic macrofauna may form taxonomically rich and numerically dense groups of animals ("assemblages"). Most benthic macrofauna are relatively sedentary and changes in populations or assemblages are useful indicators of human disturbance (Warwick 1993). Further, benthic macrofauna are an important source of food for fish and larger invertebrates (Chapter 9).

Benthos would be removed and the soft-sediment habitat disturbed by the proposed extraction of marine aggregate. In this study, the distribution, abundance and taxonomic richness of benthic macrofauna were investigated at the proposed extraction areas and at reference areas. In this phase of the project, the reference areas provided a regional context for assessing the significance of the macrofauna of the proposed extraction areas. If extraction is approved, the reference areas would be critical in monitoring the effects of extraction.

This chapter has five major sections. Section 8.1 reviews existing information on benthos of soft-sediments and presents the methods, results and conclusions of a large-scale study by the Ecology Lab of benthic macrofauna. Subsequent sections describe the distribution and nature of surface sediments, which can affect the distribution of macrobenthic assemblages and populations (Section 8.2); the effects of a storm on macrofauna (Section 8.3); the recolonisation of macrobenthic assemblages and populations to patches disturbed experimentally (Section 8.4); and a study of benthic scavengers (Section 8.5).

8.1.1.1 Aims of the Study

The aims of this component of the study were:

1. to provide a review of the literature on benthos of soft-sediments relevant to the proposal;

2. to describe existing assemblages and populations ofmacrofauna by analysing patterns of spatial and temporal variation in the areas proposed for extraction of marine aggregate extraction and in reference areas;

3. to predict the effects of the proposed extraction on benthos of soft-sediments (Part IV); and

4. to formulate a proposal for monitoring the effects of the proposed extraction on benthos of soft-sediments (Part IV).

8.1.1.2 Existing Information

The benthos of soft-sediments has been studied in many countries, leading to a good description of assemblages in these areas. Our understanding of the processes structuring these assemblages is, however, still relatively poor (Peterson 1979; Butman 1987; Wilson 1991). This is because most studies have sought to describe the patterns of distribution and abundance of benthos of soft-sediments, but have not examined the processes causing these patterns.

In Australia, the only offshore extraction of marine aggregate has been for beach replenishment projects on the Gold Coast. No biological studies accompanied these projects. In general, offshore macrofauna have not received much study in Australia. Most offshore work has been done for environmental impact assessment (EIA) of sewage outfalls and sand extraction (e.g. Carey and Talbot 1980) and has been descriptive. There are, however, a number of studies of the macrofauna inhabiting Australian estuaries, including work on spatial and temporal variation of macrofauna in the Hawkesbury River (Jones et al. 1986; Jones 1987) and the effects of dredging in Botany Bay (Jones and Candy 1981), but these were descriptive.

This reviews the four main studies dealing with coastal and offshore macrofauna on the east coast of Australia, including:

- two studies of macrofauna for monitoring Sydney's deepwater ocean outfalls (Jones 1977; Fisheries Research Institute (FRI) 1992);

- the Broken Bay Marine Aggregate Project (Carey and Talbot 1980); and

- studies of the macrofauna in Moreton Bay, Queensland as part of an EIA of a large dredging programme (QLD Department of

Transport and Communication (QDTC) 1987).

Relevant estuarine work from Australia and the current understanding of the processes which structure soft-sediment benthos are also reviewed.

8.1.1.2.1 Early Studies for Sydney's Deepwater Ocean Outfalls

One of the first marine ecological studies associated with construction of Sydney's deepwater ocean outfalls was the Shelf Benthic Study done by the Australian Museum (Jones 1977). Surveys of macrofauna were done off Malabar, NSW to obtain quantitative baseline information prior to installation of the deepwater ocean outfalls. Data from these surveys are, however, of only limited use for the present study. Jones (1977) sampled macrofauna using a small sand dredge fitted with a 3 mm mesh bag and, therefore, only retained the largest components of the macrofauna. Replicate dredge hauls were combined, however, and subsampled. Comparisons among sites could not be interpreted as no estimates were made of spatial and temporal variability within sites (Hurlbert 1984).

Crustaceans, polychaetes and molluscs were the most abundant animals collected, including 148 crustacean taxa made up of 15 families of amphipods, 4 families of isopods and 23 families of decapods. The large mesh used by Jones (1977) may have biased the results towards collection of the larger, decapod crustaceans at the expense of smaller forms such as amphipods and isopods.

Difficulties with the taxonomy of polychaetes and crustaceans meant that molluscs were the only animals considered in detail. Approximately 215 species of molluscs were identified. Of these, 52 species from 23 families were bivalves, 148 species from 36 families were gastropods and 3 species were scaphopods. It is not clear what groups the remaining species belonged to.

Overall, the Shelf Benthic Study described qualitatively the larger macrofauna occurring off Malabar, NSW, but presented little useful quantitative information on the spatial and temporal variation of these animals.

8.1.1.2.2 Broken Bay Marine Aggregate Proposal

Studies for an EIS on proposed trailer dredging off Broken Bay included a sampling programme designed to provide data on the distribution and abundance of macrofauna (Carey and Talbot 1980). Four sites in different depths of water off Broken Bay and one previously dredged site in Botany Bay were sampled. Sampling was repeated at these sites, but not all sites were sampled at similar times. The data were used to compile a list of the most abundant species in the area and to provide some crude comparisons among sites and over time. Unfortunately, any differences among sites may have been due to depth, time, position or many other variables and hence this study provides relatively little information other than a list of taxa.

Carey and Talbot (1980) used a 0.5 mm mesh sieve. The archiannelid Polygordius sp. was the most abundant organism collected, followed by filter-feeding sabellid polychaetes. Cumaceans and tanaidaceans were the most abundant crustaceans. Polychaetes were often the most abundant taxa at any given site, followed by crustaceans, which were particularly abundant during some sampling periods, and molluscs and echinoderms (mainly heart urchins Echinocardium cordatum). The number of individuals and species varied over both time and space.

Carey and Talbot (1980 p.27) considered that "the most important characteristic of the benthic macro-invertebrate fauna is its extreme variability, both in numbers of species and individuals, in dominant species and in biomass". Further they suggested that "this variability, resulting mainly from the patchiness of larval settlement, is related to the length of time that the substrate has been in a semi-stabilised condition, or more simply to the physical variability of the location sampled" (Carey and Talbot 1980, p.27). They postulated that larval settlement and physical disturbance of the substrate were the most important processes structuring the benthic assemblages in the study area.

Carey and Talbot (1980) attempted experimental dredging to assess the effects of sand extraction on the substratum and macrofauna. An area of 2 x 6 m was marked in 25 m of water off the mouth off Broken Bay. Divers removed sediment within the marked area to a depth of 0.5 m with an airlift. The area was sampled before dredging and was to have been sampled afterwards, but three separate attempts to remove the sediment were unsuccessful due to reworking of the sand. It was concluded that, because the rate of natural disturbance in these mobile sands was great and the benthic infauna in the area would be adapted to frequent disturbance, the extra disturbance to assemblages caused by the proposed trailer dredging would be negligible and animals would rapidly recolonise the disturbed areas.

The diets of several species of fish, including flounders, stingarees, gurnards and flathead that were common off Broken Bay were also studied. Macrofauna constituted the most common food eaten by fish. Crustaceans (including shrimps) and polychaetes were important items of food (see Chapter 9).

8.1.1.2.3 Recent Studies for Sydney's Deepwater Ocean Outfalls

The Deepwater Ocean Outfalls Environmental Monitoring Programme (FRI 1992) sampled macrofauna at the 3 deep-water ocean outfall sites off Sydney (North Head, Bondi, Malabar) and at 3 reference sites (Long Reef, Port Hacking, Marley) for 1-2 years prior to the commissioning of the deep-water ocean outfalls in

1990. Sampling was done at three depths: 30 m, 60 m and 100 m at each site. The aim was to describe the soft-bottom assemblages of macrofauna off the coast of Sydney and relate this to the history of sewage disposal via cliff-face ocean outfalls (FRI 1992).

Components of the macrofauna were identified to different taxonomic levels. Polychaetes were identified to family (although some were identified to species), molluscs to class (bivalves, gastropods and scaphopods) and crustaceans mainly to order (amphipods, isopods, etc.). About 33 families of polychaetes were collected. The most common polychaetes were spionids, maldanids, syllids, owenids and ampharetids, although different families predominated at each depth. Amphipods were the most abundant crustaceans collected, followed by tanaidaceans, isopods and cumaceans.

Syllids were very common at 30 m; owenids, ampharetids and maldanids were common at 60 m and spionids were very abundant at 100 m. Gastropods and bivalves were abundant at all depths but larger numbers of molluscs occurred at 30 m and 60 m than at 100 m. Amphipods were very abundant at both 30 m and 60 m, but there were few amphipods at 100 m. Similarly, tanaidaceans were very abundant at 30 m and 60 m but less common at 100 m. Isopods were also relatively common in shallow water and less common in deeper water.

Abundant taxa were analysed using analysis of variance to distinguish variation among the times sampled (Winter 1989, Summer 1990 and Autumn 1990) and within and among reference and outfall sites. Significant spatial and temporal variation occurred for most taxa. Variation among sites was rarely consistent over time.

Crustaceans dominated the macrofauna at sewage outfall sites while polychaetes dominated the macrofauna at reference sites in 30 m of water. At 60 m, polychaetes both dominated reference and outfall sites. A trend towards more polychaetes and fewer crustaceans with increasing depth was also noted. Generally, molluscs were less abundant than polychaetes and crustaceans.

This study highlighted the enormous natural variability of macrofauna in soft-sediments off Sydney and, therefore, the need for properly replicated sampling programmes in both space and time to describe adequately these populations. This approach contrasts with Jones (1977) and Carey and Talbot (1980).

8.1.1.2.4 Dredging of Fill for Brisbane Airport

A summary of the marine biological investigations and monitoring connected with the EIS for Brisbane Airport were presented in a report to the Queensland Department of Transport and Communications (QDTC 1987; see also Stephenson et al. 1978; Stephenson 1980; Poiner and Kennedy 1984). These studies surveyed macrofauna to assess the likely effects of the airport development. Follow-up work to confirm the validity of assessments was done by QDTC (1987).

Studies of the Middle Banks, an ocean-influenced sandy area of Moreton Bay just west of Moreton Island, are probably the most useful in the context of the current proposal, although the area is not strictly an offshore habitat. Approximately 14 Mm^3 of fine sand were dredged over two years from a 5 km^2 section of the Middle Banks, to be used as fill for the Brisbane Airport (Poiner and Kennedy 1984). The macrofauna of the Middle Banks area was sampled every three months for two years. It was considered that spatial patterns were identified adequately by the study but that a longer study would have been required to describe temporal patterns (QDTC 1987).

Collections of macrofauna were made using a Smith-McIntyre grab that sampled an area of 0.1 m^2. Fifty-seven sites were sampled, ranging from about 10 m to 30 m depth (Stephenson et al. 1978). All animals were identified to species. In all, 463 taxa were identified, of which 32% were polychaetes, 28% were crustaceans (11% decapods, 7% amphipods), 24% were molluscs (11% gastropods, 13% bivalves) and 6% were echinoderms. A spionid polychaete, Prionospio sp., was the most abundant animal collected (Stephenson et al. 1978).

Stephenson et al. (1978) considered spatial and temporal patterns of assemblages separately by classification analyses. They recognised 11 site-groups, characterised by hydrographic features. Temporal patterns were variable and inaccurate relocation of sites caused problems in separating spatial changes from temporal changes as only one sample was taken per site. About 10% of species had recurrent seasonal patterns, 40% had sequential patterns and about 45% had no distinct temporal patterns (Stephenson et al. 1978). Seasonally, large densities of macrofauna occurred in September of both years.

Stephenson et al. (1978) suggested that assemblages of macrofauna on the Middle Banks area were in a continual state of flux. Most species were considered to be annuals or 'subannuals' with few attaining sexual maturity in the area and it was suggested that the population was dependent on continual recruitment (Stephenson et al. 1978). Stephenson et al. (1978) suggested that a temporary human disturbance (i.e. removal of all animals from a large area) would have only short-term (less than one year) effects on assemblages of macrofauna. This argument was based on the removal of all animals from a large area as a result of dredging.

Poiner and Kennedy (1984) examined the impact of dredging that took place in the Middle Banks area between 1981 and 1983 by comparing some of the pre-dredging data obtained by Stephenson et al. (1978) between 1972 and 1974, with their post-dredging data collected in late 1982 (Poiner and Kennedy 1984). They found significant decreases in the mean number of species (from an average of 33 to 17 species per site) and the mean total abundance of individuals (from an average of 118 to 48 individuals per site) in dredged areas at the Middle Banks (Poiner and Kennedy 1984). At adjacent undredged areas there had been a significant increase in the average mean number of species (32 vs 68) and mean total abundance (118 vs 752) between the studies (Poiner and Kennedy 1984). They suggested that these increases were due to an increase in the nutrients available to macrofauna in areas adjacent to dredging. Nutrients were thought to be liberated from the sediments by dredging and transported to the adjacent areas in the sediment plume from the dredge (Poiner and Kennedy 1984).

A major problem with this study is that the single survey conducted after the dredging operation may not be representative of the assemblages of macrofauna of the Middle Banks following dredging. It may be that the time that Poiner and Kennedy (1984) sampled was an unusual period with large or small abundances of macrofauna. Sampling at one time after a disturbance also tells us little about the patterns of temporal variation in benthic populations at the Middle Banks after dredging nor of any changes in the temporal variation of macrofauna that may have been caused by the dredging (e.g. Underwood 1991). Consequently, their conclusions must be treated with caution.

8.1.1.2.5 Local Estuarine Studies

Jones et al. (1986) and Jones (1987) described long-term variation in the structure of assemblages of macrofauna in the Hawkesbury estuary. Although assemblages varied significantly in space, time and depth, the two most seaward areas sampled (located in Broken Bay) had consistently more species of macrofauna than the three sites furthest upstream. The number of species collected was positively correlated with salinity and there were also major differences in the structure of assemblages that were related closely to salinity (Jones et al. 1986). Changes in salinity in estuaries are likely to be a major factor in structuring estuarine assemblages (e.g. Flint 1985) but changes in salinity are much smaller in offshore areas and are, thus, unlikely to affect marine assemblages. Patterns of temporal change in assemblages of macrofauna in the Hawkesbury varied among the sites sampled and differences in the structure of assemblages were not seasonal (Jones 1987).

Jones and Candy (1981) compared dredged and undredged areas of Botany Bay and concluded that assemblages of macrofauna in dredged areas differed from those in undredged areas nearby. No sampling was done before dredging took place, however, so a comparison between the assemblages that occupied the dredged areas prior to dredging and after dredging was not possible. Such a comparison is clearly important for any proper assessment of the effects of the dredging on macrofauna.

Nevertheless, the number of species collected by Jones and Candy (1981) was strongly correlated with the type of sediment.

More species were collected from sand than mud. Jones (1981) suggested that the sediment had been altered from clean sand to muddy sand in areas of Botany Bay where dredging had taken place. Jones and Candy (1981) concluded that assemblages of macrofauna in dredged areas of Botany Bay were different to assemblages in undredged areas and that the change in sedimentary characteristics in dredged areas had caused this change. In the marine-dominated mouth of Botany Bay, the deeply dredged entrance channel (19-21 m deep) had slightly muddy sand and a particularly rich assemblage and large populations of benthic macrofauna. The authors postulated that this was due to an increase in the food available in this area.

8.1.1.2.6 Processes Structuring Assemblages of Macrofauna

The processes determining the distribution and abundance of populations of organisms are the supply of food, dispersal, habitat selection, recruitment, interrelations with other organisms (including predation, competition and mutualism), physical and chemical factors and physical disturbance (Krebs 1985). Most experiments which have led to the current views of how marine benthic assemblages are structured have been carried out in rocky-reef habitats (Peterson 1979; Wilson 1991). Relatively few experiments have been carried out in soft-bottom habitats and of these, most have been done on sand and mud flats or shallow subtidal areas in estuaries.

Supply of Food

Benthic biomass and activity in all latitudes are closely related to food supply (Alongi 1990). The supply of food to benthic organisms comes from the overlying water column (Alongi 1990). Benthic macrofauna have many feeding habits, including filter-feeders, deposit-feeders, carnivores, omnivores, herbivores, scavengers and browsers (Fauchald and Jumars 1979; Barnes 1980). Individual taxa may display several modes of feeding and many taxa are opportunists (Barnes 1980).

Large-scale variation in abundance of benthos may be associated with changes in primary production (Alongi 1990). Large numbers of benthic organisms tend to inhabit regions where primary production is large, such as areas of upwelling (Cushing 1988 cited in Alongi 1990). Rich demersal fisheries may also occur in these areas and many species of demersal fishes and crustaceans eat benthic organisms (SPCC 1981b; Alongi 1990). Alongi (1990) suggested that the dynamics of fish and benthos are related more to total water-column production than to each other.

Dispersal

The dispersal of organisms is a major factor producing patchiness in the distribution and abundance of marine invertebrates in time and space (Underwood and Fairweather 1989). Many benthic animals have a planktonic larval stage and patterns of recruitment from the plankton may determine the subsequent distribution of adult populations on large and small scales. On a large scale (e.g. along the coast of NSW), areas may not receive recruits of some taxa in any given year because of variations in oceanographic processes such as currents. As a consequence, populations and assemblages of organisms vary widely in time and space (Caffey 1985). On a smaller scale, the distribution of benthic animals is often correlated with characteristics of the sediment and it has been postulated that this is due to active habitat selection (see Butman 1987). This correlation may be more simply explained, however, by hydrodynamic processes that act on both sediment and larvae thus causing similar distributions (Butman 1987).

Macrofauna are often thought to be relatively sessile after recruitment (e.g. Jones 1977). At least some macrofauna, however, influence their own distribution by active migration or redispersal via currents. Animals such as cumaceans, amphipods, isopods, ostracods and some polychaetes are known to be active swimmers and may disperse into the water column at night and resettle the next day (DeWitt 1987; Hughes 1988). Even relatively sessile forms such as sabellid fanworms are capable of moving at least short distances. Dobbs and Vozarik (1983) found increased numbers of adult benthic animals in the water column following a storm and suggested this may be a mechanism of adult dispersal. A consequence of this behaviour could be rapid recolonisation of disturbed patches.

Interrelations with other Organisms

Interrelations among animals, including conspecifics, may influence the distribution and abundance of populations. Predation may limit the distribution, abundance and size-distribution of populations of benthic infauna. Most studies of the effects of predation on benthic infaunal populations have concentrated on large epibenthic predators such as crabs (Wilson 1991; Thrush et al. 1991). Experiments done on intertidal sandflats and shallow soft-sediment have used cages to exclude or contain epibenthic predators (e.g. Thrush 1986). Caging experiments have shown that various predators such as gastropods, crabs, decapods, fish and shorebirds (in intertidal areas) may negatively affect the distribution and abundance of benthic infauna (Peterson 1979, Wilson 1991) by inducing emigration in response to predators (Ambrose 1984) or actual predation. Note that the results of caging studies are open to serious debate for many reasons (see Peterson 1979; Frid 1989; Wilson 1991).

Predation may also interact with other processes. Kent and Day (1983) showed that predation by fish and birds removed adult nereid worms from an intertidal mud flat. They found significantly more recruitment of juveniles to treatments where predators were not excluded compared to areas where predators were excluded and the density of adult worms was large. Thus, increases in the density of adults may decrease recruitment and may compensate for losses due to predation (Kent and Day 1983).

Overall, predation is thought to be important in structuring soft-sediment assemblages but results are unclear and the effects of predation in offshore, relatively deep, marine benthic assemblages has not been studied. Many demersal fish eat benthos (e.g. Carey and Talbot 1980) and offshore populations and assemblages may be affected by predation from demersal fish.

Some authors have postulated that competitive exclusion is unlikely to occur in benthic assemblages as predation would limit the density of macrofauna so there would never be a shortage of resources such as space and food (e.g. Woodin 1978). Further, density-dependent emigration of mobile macrofauna may be a mechanism that prevents adult populations reaching a density where competition for resources is necessary (e.g. Ambrose 1986). Other authors have suggested that populations of benthic infauna are limited by the availability of food (e.g. Peterson 1982) and, thus, there should be competition for this scarce resource. There is a evidence that competition, particularly for food, occurs in infaunal assemblages, but it rarely has an impact on patterns of abundance (see Peterson 1979, 1980; Peterson and Andre 1980; Black and Peterson 1988).

Interference competition occurs when organisms seeking a resource harm one another in the process, even if the resource is not in short supply (Birch 1957). Interference competition among adults (e.g. Levin 1982) and between adults and larvae or juveniles (e.g. Woodin 1976) may be an important process structuring assemblages of macrofauna. Interference competition among adult tube-dwelling spionid polychaetes in dense assemblages has been observed to reduce the feeding time of the loser of interactions (Levin 1982). Reduced feeding time could result eventually in mortality (Levin 1982). Woodin (1976) proposed that dense patches of macrofauna may maintain their assemblages by preventing the recruitment of other animals. This conclusion was based partly on a study that showed burrowing species on an intertidal mudflat responded to space vacated by tube-builders by increased success of settlement (Woodin 1974). On the other hand, large animals such as bivalves and structures such as the tubes of polychaete worms may facilitate recruitment and offer shelter or a range of habitats to smaller animals, thus influencing the distribution, abundance and structure of assemblages in some areas (e.g. Gallagher et al. 1983, Woodin 1978).

Overall, competition may be an important process structuring marine benthic assemblages but the extent of mortality induced by competition has not been quantified and it may only cause small changes in abundance (Wilson 1991) but may affect distributions via the emigration of infauna (Ambrose 1986).

Other interactions among benthic macrofauna may be indirect and the result of modifications of the habitat. Rhoads and Young (1970) noted that sandy substrata were dominated by suspension-feeders (animals that filter their food from the water), but muddy substrata were dominated by deposit-feeders (animals that get their food from the sediment or the organic layer at the surface of the sediment). They concluded that bioturbation of muddy sediments by deposit feeders rendered them inhospitable to suspension feeders. Butman (1987) suggested that these differences may be caused by differential larval settlement (possibly due to hydrodynamic processes that control the distribution of mud and sand) rather than differential post-settlement mortality or active habitat selection.

Jones (1977) found that assemblages of molluscs in muddy, fine sands at three, 66 m stations off Malabar were dominated by deposit-feeders. Deposit-feeders made up about 80% of the total abundance of molluscs, whereas suspension-feeding and carnivorous molluscs each made up about 10% of the total abundance of molluscs at these stations. It is not known if this sediment was similar to the marine aggregate examined in the current proposal, but it is possible that the sediments in 66 m off Malabar consist of mid-shelf muds, not sand suitable as marine aggregate (Chapters 3 and 6).

Physical and Chemical Factors

The distribution and abundance of macrofauna may be affected by many physical and chemical factors including, water temperature, salinity, characteristics of the sediment, wave action and depth. Wildish and Kristmanson (1977) hypothesised that current velocity and roughness at the sediment-water interface controlled the number, biomass and growth of suspension feeding macrofauna in estuaries. In swift currents sediment would be eroded and physical conditions would be unsuitable for deposit or suspension feeders (Wildish and Kristmanson 1977). Where currents were weak, however, the deposition of sediment would favour deposit feeders, resulting in bioturbation of sediment, making it less suitable for suspension feeders (Wildish and Kristmanson 1977). Under this hypothesis, a mixed assemblage of deposit feeders and suspension feeders would result when only appropriate regimes of current velocity, food supply and sediment characteristics were met (Wildish and Kristmanson 1977).

Long-term monitoring in estuaries has shown that benthic macrofauna can undergo massive variations. This may be due to episodic environmental disturbances (e.g. fluctuations in estuarine salinity, Flint 1985). In fact, disturbances may be responsible for sustaining long-term productivity in these systems (Flint 1985). Similarly, assemblages and populations of macrofauna in marine areas are dynamic and non-equilibrial, with disturbance playing an important role in structuring them (Van Blaricom 1982).

Physical Disturbance

Natural physical disturbances, such as storms and the feeding activities of animals, and man-made physical disturbances, such as sand extraction and trawling, can create space in soft-sediment habitats. Disturbance by feeding activities of stingrays (Van Blaricom 1982), gray whales (Oliver and Slattery 1985) and crabs (Thrush 1986); and by trawling (Caddy 1973), can create patches of free space which may be colonised by migrating adults or by the settlement and recruitment of larvae. Pits created by natural or man-made disturbances contain resources, such as accumulated detritus (Van Blaricom 1982) or damaged animals (Oliver and Slattery 1985) which are attractive to opportunistic scavengers that persist as long as the food supply lasts. Fauna may also be washed passively into pits (Savidge and Taghon 1988) or use pits for shelter (Caddy 1973).

Two main models have been proposed to explain the effect of disturbance on the structure of assemblages of macrofauna. Johnson (1973) hypothesised that patches generated disturbance are recolonised in a prescribed sequence by the addition of species rather than the displacement of species that are already present. Thus, a given location is a mosaic of differently aged patches with assemblages depending on the state of recovery. Grassle and Sanders (1973) also proposed that disturbance creates a spatial and temporal mosaic of assemblages but that in any one patch there is succession with the replacement of the initially colonising opportunistic species by better competitors which invade later. A species will persist because patches exist in time and space that are in the appropriate state for the species to colonise either by migration or larval recruitment (Grassle and Sanders 1973).

Thistle (1981) concluded that both the models of Johnson (1973) and Grassle and Sanders (1973) could apply. It was not clear, however, whether inital colonisers were responding to the resources of space and food created by a disturbance or whether they were also responding to the absence of competitors (Thistle 1981). Thus, although disturbance is capable of producing patchiness in assemblages and populations both in time and space, the mechanism by which this occurs is unknown (Thistle 1981).

Connell (1978) suggested that diversity will be maximal at intermediate scales of disturbance. Immediately after a severe disturbance, few species will be present as the time for colonisation is short. With continued, frequent disturbance, assemblages will consist of only those few species capable of reaching maturity quickly (Connell 1978). Under this hypothesis, diversity would also increase as the interval between disturbances increases as more time is available for the invasion of more species (Connell 1978). If the frequency of disturbance is low, however, diversity will decline because the best competitor(s) will eliminate the rest or, if all species had similar competitive abilities, the one that is least prone to mortality from other sources, such as predation and physical factors, will eventually dominate the available space (Connell 1978). That this model relies on competitive exclusion, which is probably rare in benthic assemblages (see above).

Similarly, diversity is predicted to be greatest when disturbances are of an intermediate intensity or size (Connell 1978). If a disturbance kills all animals over a very large area, recolonisation in the centre of this area can only be by propagules that can travel large distances and become established in open, exposed conditions (Connell 1978). If species with such propagules are a small subset of the total pool of species then diversity will be low (Connell 1978). In very small openings, recolonising propagules are more likely to come from organisms adjacent to the opening so that colonisers will again be a small subset of the available pool of species and diversity will tend to be low (Connell 1978). When openings created by disturbances are intermediate in size, species adjacent to the opening and propagules from other areas can colonise and diversity should be higher than for very small or very large openings (Connell 1978). If a disturbance were of intermediate intensity such that some residents were damaged and not killed, diversity in a large area would be greater than if the disturbance was large and all residents were killed (Connell 1978). This is predicted because recolonisation may come from both propagules and regeneration of survivors in the first case and only propagules in the second (Connell 1978).

This model differs from the equilibrial view of recolonisation discussed by ICES (1991b, see section 4.1.2.1). ICES consider that if "dredging continues periodically, succession may be impeded so that opportunistic species continue to predominate" (ICES 1991b, page 25). Under the intermediate disturbance hypothesis (Connell 1978), this would only be the case if the time period between dredging were small and/or the spatial scale of dredging was large. At intermediate scales of dredging (in time and space), the intermediate disturbance hypothesis (Connell 1978) predicts that diversity will be high <u>if</u> competitive exclusion actually occurs.

In summary, many explanations of the structure of benthic assemblages propose that the distribution and abundance of benthos are the result of larval dispersal and recruitment, followed by mortality or emigration caused by predation, competition and disturbance and interactions among these processes. Although the mechanisms of particular processes may be understood, biologists still lack the ability to present unifying theories for the structure of assemblages of soft-sediment macrofauna or, ultimately, to predict the effects of these processes on marine assemblages (Wilson 1991).

8.1.1.2.7 Interstitial Flora and Fauna

Interstitial flora and fauna are those organisms that live in the spaces between grains of sand, including bacteria, diatoms, protozoans and meiofauna. Bacteria are usually attached to sand grains and they are responsible for the decomposition and recycling of nutrients (Mann 1982). Diatoms and other microscopic algae may also be present in sediments. Algal production decreases with increasing depth as light penetration falls (Mann

1982). Ciliates and foraminiferans are typically the most abundant protozoans. They may feed on bacteria, diatoms, other protozoans, meiofauna and small macrofauna (Brown and McLachlan 1990).

Meiofauna are the best studied component of the interstitial fauna. They are often defined as those animals that pass through 0.5 mm meshes but are trapped on 30 to 100 μm meshes (Brown and McLachlan 1990). Nematodes are usually the most abundant members of marine meiofaunal assemblages followed by harpacticoid copepods (Coull 1988; Palmer 1988). Other common groups include ciliates, tardigrades, turbellarians, gastrotrichs, oligochaetes, archiannelids and ostracods. Juvenile forms of macrofauna are also sampled with meiofauna but are regarded generally as temporary meiofauna. Meiofauna generally have shorter generation times than macrofauna. Due to small body size, usually only a small number of gametes are produced, fertilization is often internal, brood protection is common and pelagic larvae are absent (Brown and McLachlan 1990). Meiofaunal food items are suspected to be diatoms, bacteria, detritus and perhaps protozoans and dissolved organic matter (Coull 1988).

Few studies have been done on meiofauna in Australia. Alongi (1988a,b cited in Alongi 1990) studied microbial and meiofaunal assemblages on intertidal mangrove and sandflat habitats in north Queensland. He found that the abundance of most microbial and meiofaunal groups fluctuated significantly over time in both habitats with no obvious seasonal changes. Alongi (1990) reported that the turnover time of bacteria on sediments in the Great Barrier Reef was greater than 4 days in most subtidal areas.

Most work on assemblages of meiofauna has been done on intertidal sandflats or mudflats and has concentrated on recolonisation of disturbed areas (e.g. Sherman and Coull 1980; Chandler and Fleeger 1983). There is a usually a decrease in the abundance and diversity of the meiofauna after disturbance but this is followed by recolonisation (Coull 1988). Rates of recolonisation vary from hours to months (Coull 1988). Copepods are often the taxa affected most quickly by a perturbation and nematodes are often affected least (Coull 1988).

Studies in intertidal habitats have shown that meiofauna may rapidly recolonise disturbed areas by transport in the fluidized, flocculent upper layer of the sediment. Sherman and Coull (1980) found that recolonisation of a 9 m^2 disturbed area on an estuarine mudflat took only one tidal cycle. They concluded that most recolonisation was from nearby areas via transport with the tide because it was unlikely that small meiofaunal animals could crawl large distances within one tidal cycle.

Chandler and Fleeger (1983) suggested that copepods colonise defaunated sediments rapidly via transport in suspended sediments whereas the dispersal of nematodes may occur via both suspended transport or movement within the sediment. Copepods reside typically in the upper layers of the sediment (0-20 mm) and many are good swimmers (Palmer 1988). Walters (1988) found that harpacticoid copepods and copepod nauplii larvae migrated actively from sediments at night. Many nematodes reside deeper in the sediments than copepods and most are poor swimmers (Palmer 1988). Nematodes may respond to fast surface current speeds by moving deeper into the sediment (Fegley 1987). Thus, copepods are likely to recolonise disturbed areas more rapidly than nematodes via the water-column or suspended sediment.

Reidenauer and Thistle (1981) and Sherman et al. (1983) studied the effects of feeding by stingrays (Dasyatis sabina) on populations of harpacticoid copepods and nematodes, respectively. These studies were done on fine sand at 2 m depth which was intensely disturbed by stingrays which made small (about 0.7 m^2) feeding excavations in search of macrofauna. Reidenauer and Thistle (1981) showed that the number of harpacticoid copepods in the pits 29 hours after disturbance was similar to numbers in undisturbed areas. Nematodes took longer than 3 days to recolonise the pits to levels in undisturbed areas (Sherman et al. 1983). Sherman et al. (1983) concluded that recolonisation of these patches by nematodes and copepods probably occurred by different methods. Further, transport of sediment and meiofauna that are thought to be responsible for rapid recolonisation of disturbed sediment in intertidal areas may be less important in subtidal areas (Sherman et al. 1983).

Palmer (1988) considered that 4 factors interacted to determine whether active emergence of meiofauna from sediments or passive transport of meiofauna in sediments would occur in a given habitat: (1) the taxonomic composition of assemblages; (2) hydrodynamics of the habitat; (3) the presence of above ground structure in the habitat; and (4) the amount of disturbance occurring in the habitat. She considered that passive dispersal of meiofauna modified by behaviour which influenced transport and settlement would dominate in areas free of above ground structure where hydrodynamic processes were active. In areas that were hydrodynamically benign (e.g. seagrass beds), dispersal of actively swimming adults may be more prevalent. Disturbance may lead to suspension of meiofauna and sediment and possibly active emergence of the meiofauna from the sediment (Palmer 1988).

Macrofauna may affect assemblages of meiofauna on a local scale. 'Olafsson et al. (1990) studied the effects of feeding and faecal casts of a tube-dwelling polychaete on the surrounding assemblages of meiofauna. They found that the number of nematodes collected did not vary between faecal casts, feeding areas and areas unaffected by polychaetes. Copepods, however, were more abundant in unaffected areas than in faecal casts and feeding areas. Polychaetes feed at the top of the sediment and therefore affect copepods but not nematodes, which generally live deeper in the sediment ('Olafsson et al. 1990).

Warwick et al. (1990a) studied the effects of disturbance by soldier crabs (Mictyris platycheles) on assemblages of meiofauna on a sand-flat in Tasmania. They showed that the structure of assemblages of meiofauna (mainly nematodes and copepods) in areas disturbed by soldier crabs was different to those in undisturbed areas. This was likely to be due to disturbance by the crab, rather than predation, because soldier crabs are thought to be deposit feeders.

Predation may also affect the structure of assemblages of meiofauna and the size of populations. Reise (1985) showed that predation by crabs could affect the size of meiofaunal populations. Woods and Coull (1992) studied the effect of predation on populations of a species of harpacticoid copepod (Amphiascus tenuiremis) in the laboratory. The reproductive potential of this copepod was large under laboratory conditions and it was concluded that changes in population size and composition from predation would be short-term. Predation would, therefore, only play a small role in determining the population structure of this copepod (Woods and Coull 1992). Other studies have shown that the removal of harpacticoid copepods by predators ranged from 0.01 to 3.45% of the local population per day and the authors concluded that predation at these rates would not significantly alter populations of copepods (references in Woods and Coull 1992). Indirect effects of predation may, however, be important (e.g. Fairweather 1990a) as may predation by different predators on the same populations.

Assemblages of macrofauna and meiofauna may be affected differently by disturbance. Warwick et al. (1990b) compared changes in the structure of assemblages of macrofauna and meiofauna (mainly nematodes) among sites in Hamilton Harbour, Bermuda. Physical instability of the sediment was a possible cause for differences in the structure of assemblages of macrofauna in different sites of the harbour (Warwick et al. 1990b). The structure of assemblages of meiofauna were, however, less variable among sites indicating that they may be less affected by disturbance.

Meiofauna may play an important role in making detritus available to macroconsumers (Coull 1988). Meiofauna, however, are thought to play a more significant role in benthic energetics in extremely shallow water (mudflats, estuaries) and in the deep sea than in other benthic habitats (Coull 1988). The presence of meiofaunal prey in the stomachs of fish and invertebrate predators has been well documented and benthic copepods are common food even though they are rarely the most abundant taxon (Coull 1988). Copepods may be preyed on selectively because they dwell typically on the sediment surface and presumably are easier to catch than subsurface dwellers (Coull 1988).

Meiofauna inhabiting mud appear to be more heavily preyed upon by organisms from higher trophic levels than meiofauna inhabiting sand (Coull 1988). Meiofauna inhabiting sand may live deeper in the sediment than meiofauna inhabiting mud and thus may not be as susceptible to browsing predation (Coull 1988). Meiofauna that live near the surface of sand are, however, susceptible to predation (Coull 1988).

In conclusion, little work has been done on Australian interstitial organisms and most studies have been done in intertidal habitats. The information available suggests that interstitial organisms are an important component of the assemblages of sediments and that they are capable of rapid recolonisation of disturbed areas.

8.1.2 Methods

8.1.2.1 Study Sites and Survey Times

Benthic samples were collected from five locations on the coast of NSW (Fig 8.1a,b): Providential Head (PH), Bate Bay (BB), Bass Point (BP), Illawarra (IL) and Cape Banks (CB) between January 1990 and January 1991. During survey 1 (11/1/90 - 1/2/90) samples were collected from PH, BB, IL and BP in 25-30 m, 35-40 m and 45-50 m of water. At that time, the Applicant was considering extraction of marine aggregate from BP and PH, and the sampling design included IL and BB as reference locations. These reference locations were used because they had similar habitats to the proposed extraction locations.

During survey 2 (25/6/90 - 26/7/90), an additional depth, 65-70 m, was sampled at PH, BB, IL and BP because advice to the Applicant suggested that the resource extended into deeper water than thought previously and that extraction to a water depth of about 65 m was possible (J. Hann, Metromix, pers. comm.).

Following survey 2, the Applicant decided to seek approval to extract marine aggregate from CB but not from BP. Sampling was continued at BP which was now considered as a reference location but IL was not sampled further and the samples collected from IL were not sorted or used.

During surveys 3 and 4 (29/10/90 - 14/11/90 & 3/1/91 - 18/1/91, respectively), samples were collected from CB, PH, BB and BP in 25-30 m, 35-40 m, 45-50 m and 65-70 m. Throughout this report PH and CB are considered as the proposed extraction locations whereas BB and BP are used as reference locations (Fig. 8.1). Locations were not sampled in any specific order during each survey period.

It should be noted that the southern-most site in BB is actually within the PH area (Fig. 8.1a). This occurred because the study sites were selected and sampled from the beginning of the EIS studies, hence before the final boundary was defined.

Three sites within each location were sampled where possible. Samples could be taken only at 25-30 m and 35-40 m at one site (site 11) at CB because of the distribution of rocky reefs at this location (Fig. 6.2). Samples from 65-70 m at BP, site 5, were actually taken from 60 m of water because there was a reef in 65-70 m of water. The locations, sites and depths sampled during each survey are shown in Figure 8.2a.

Variations in the original sampling design meant that various subsets of the data had to be used for statistical analyses (see below).

8.1.2.2 Sampling and Laboratory Procedures

All samples were collected from commercial fishing trawlers which were chartered for the study. The trawlers were equipped with radar and depth sounders.

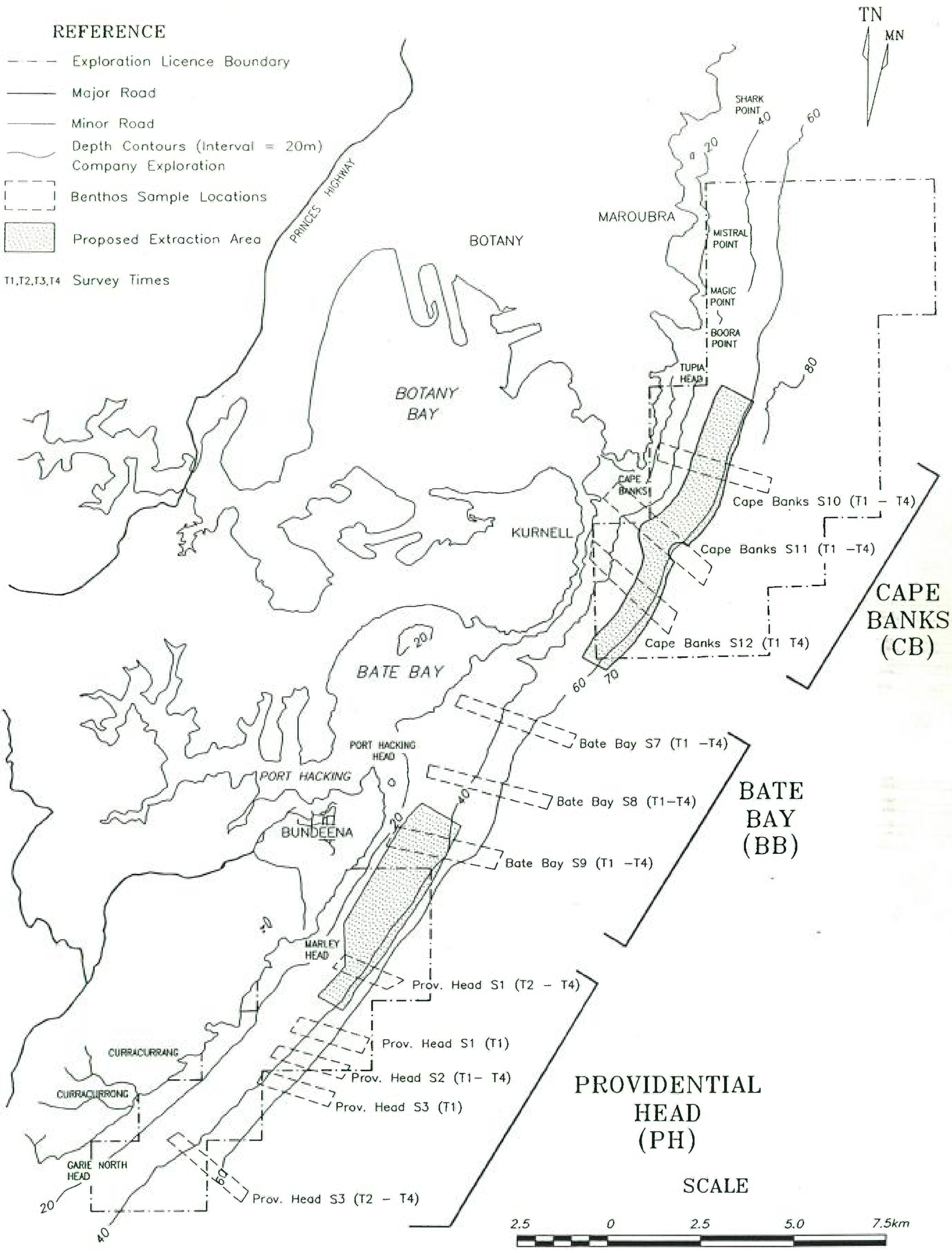
Sites were identified using landmarks and depth soundings. The east-west boundaries of each site were determined by depth, whereas north-south boundaries were determined by aligning landmarks (by eye, compass and radar). Radar images, compass bearings and radar distances to landmarks were recorded for each depth range at each site to help in the relocation of sites. In practice, each site covered a north-south distance of approximately 500 m.

The northern (S1) and southern sites (S3) at PH were situated approximately 500 m from the middle site at PH (S2) during survey 1. In later surveys these sites were sampled approximately 2km north and south of the middle site at PH to avoid any overlap of the sites and because of new information provided by the Applicant on the location of the aggregate resource. These sites are merely considered to have covered a larger geographic area than most other sites (Fig. 8.1a).

Five replicate grab-samples were collected from each depth and site during each survey. A modified Smith-MacIntyre grab which sampled an 0.05 m^2 area of seafloor to a depth of approximately 100 mm was used. The cable connected to the grab was marked at lengths corresponding to each depth to ensure that excess wire was not paid out during operation of the grab. Samples from the grab were washed into a large plastic tub, sieved through a 1 mm mesh and the residue preserved in 10% formalin and seawater.

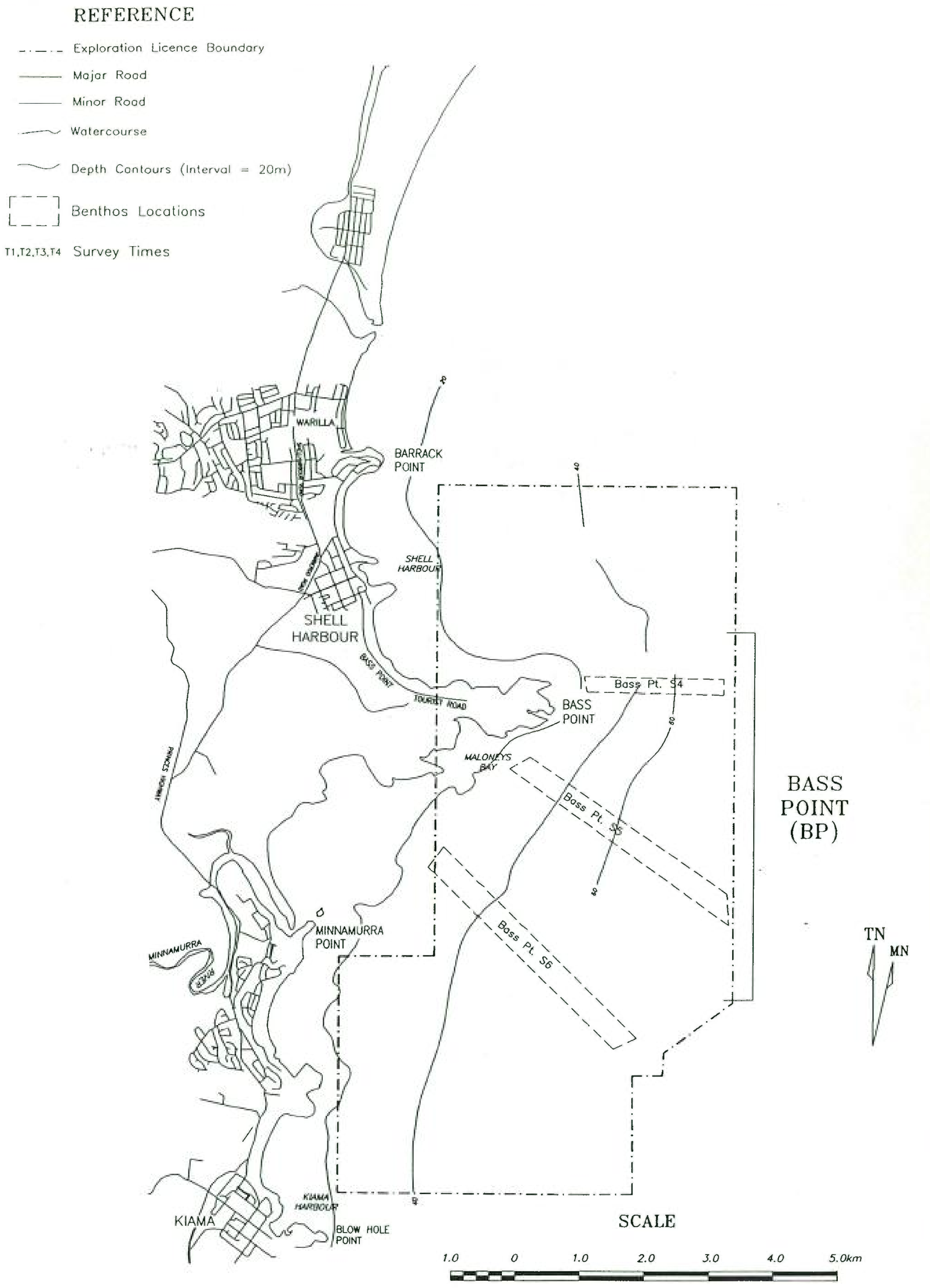
During survey 1, two extra replicates were taken at 25-30 m, 35-40 m and 45-50 m at each site. Two extra replicates were taken at the 65-70 m sites during survey 2 and two extra replicates were taken at each site and depth at CB during survey 3. These were sent unsieved to Metromix Laboratories for analysis of grain size (see Section 8.2).

In the laboratory, four replicate samples from each survey, depth and site were randomly chosen from the five collected. They were stained using Biebrich Scarlet, washed over a 1 mm mesh with freshwater to remove excess formalin and stain, and hand-sorted from shallow white enamel trays under magnifying lamps (approx. 2X). Polychaetes, molluscs, crustaceans and ophiuroids were



SOURCE : R.W.CORKERY & CO. PTY. LIMITED
3rd September, 1993

Figure 8.1 (a)
BENTHOS SAMPLING LOCATIONS CAPE BANKS, BATE BAY AND PROVIDENTIAL HEAD



SOURCE : R.W.CORKERY & CO. PTY. LIMITED
3rd September, 1993

Figure 8.1 (b)
BENTHOS SAMPLING LOCATIONS
BASS POINT

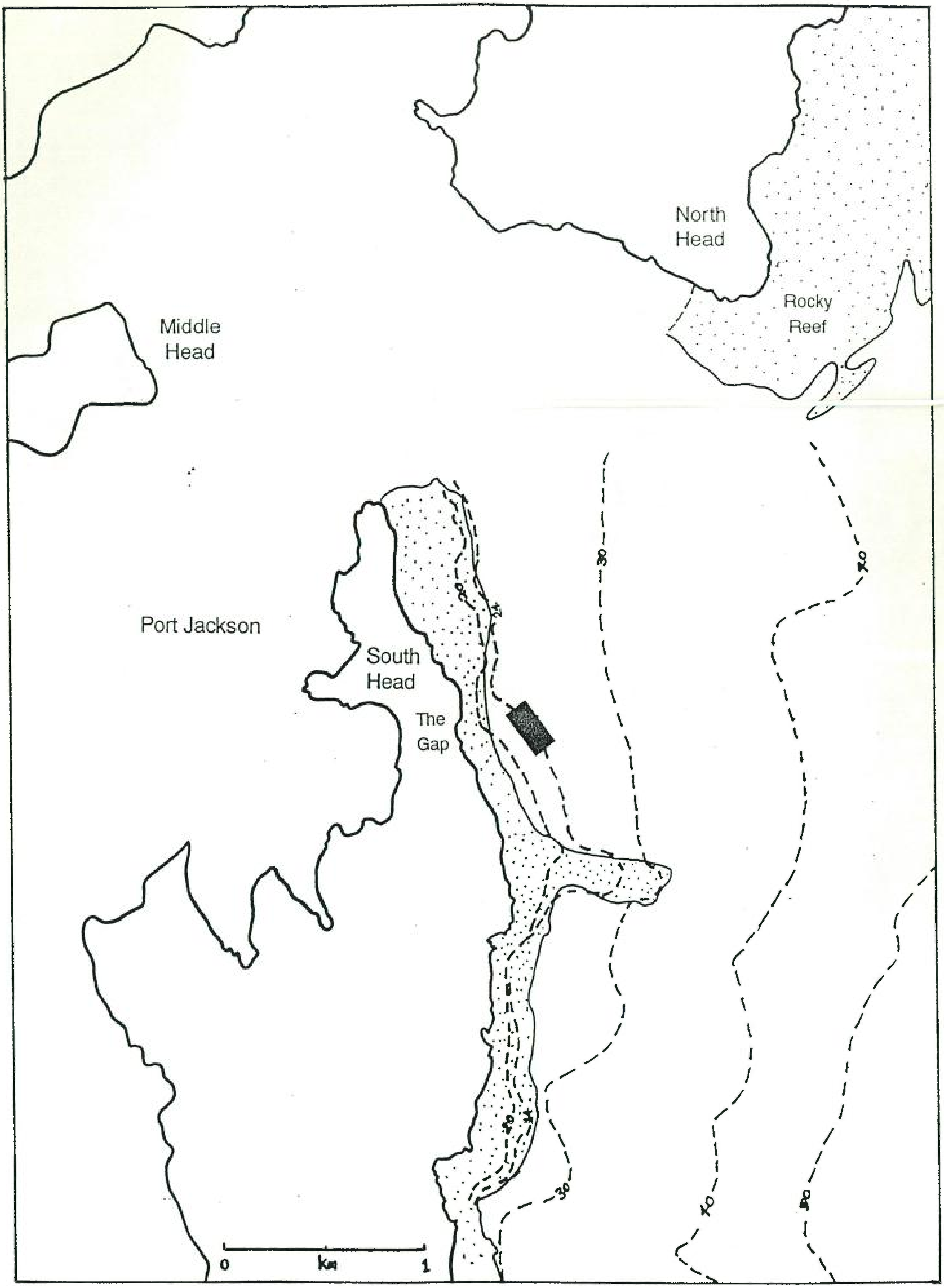
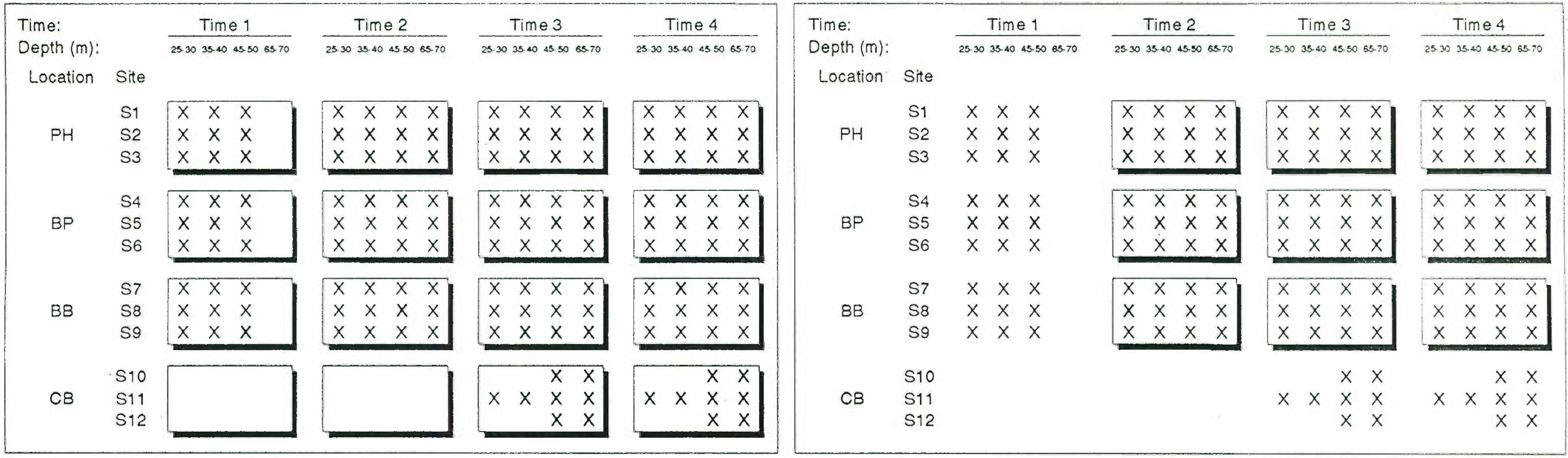
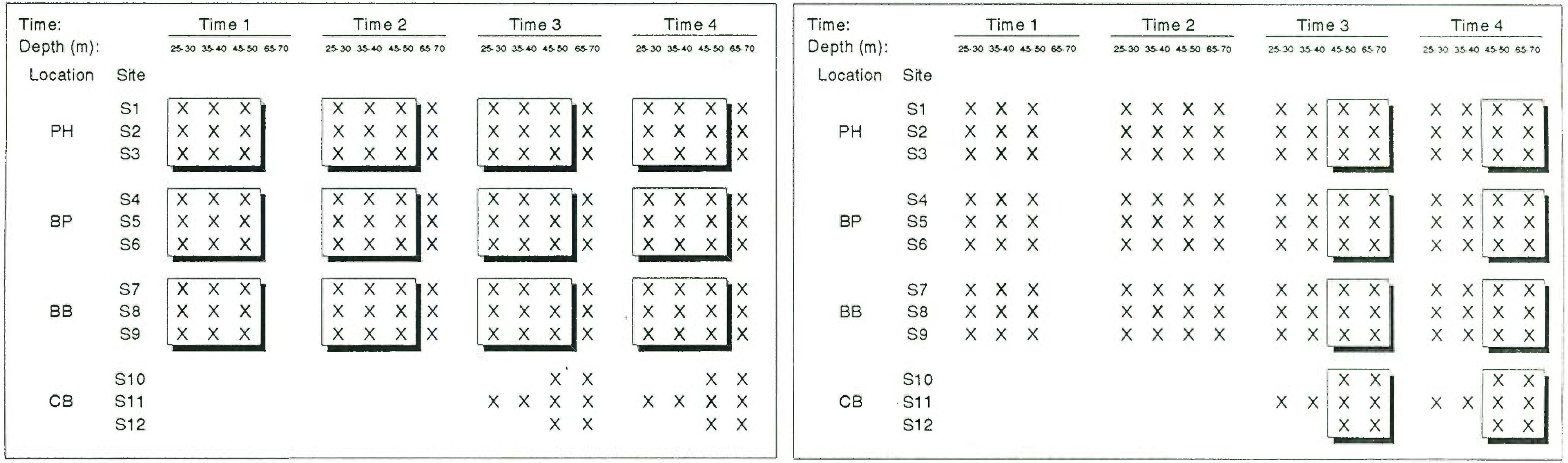


Figure 8.1c. Study site for the physical disturbance experiment.


(a) Distribution of all samples

(c) Design 2 - Providential Head


(b) Design 1 - Providential Head

(d) Design 3 - Cape Banks

Figure 8.2. The distribution of benthic samples and analytical designs comparing balanced subsets of these samples by ANOVA.
The boxes represent balanced sets of data (X = 4 replicates).

identified to family, counted and stored in 70% alcohol by staff at the Australian Museum, Sydney. Except for discrete, colonial bryozoans and pycnogonids (sea spiders), other taxa were not fully identified but have been stored in 70% alcohol by the Ecology Lab, should further examination be warranted. These other taxa made up <1% of the macrofauna.

8.1.2.3 Pilot Study

As part of the first survey, we examined the effects of mesh-size and taxonomic resolution on the interpretation of spatial patterns in assemblages and populations of macrofauna (Appendix A1). The mesh-size through which samples of sediment containing benthic macrofauna are sieved to separate the animals from the sediment and the level of identification of the animals are important variables to consider when describing patterns of variation in macrofauna. Sieve mesh-size has been set traditionally at either 0.5 mm or 1 mm (Eleftheriou and Holme 1984; Kingston and Riddle 1989). Spatial patterns detected using these mesh-sizes were compared in the pilot study. Identification of animals is done using a hierarchical series of categories (Table 8.1). The effects of identifying the benthic macrofauna to species or to the broader grouping of family was examined in the pilot study.

Table 8.1. The seven hierarchical levels of classification listed from broadest (Kingdom) to finest (Species). An example of the classification of an amphipod is shown (N.B. intermediate categories such as superorder are also used but are not shown here).

Level	Example
Kingdom:	Animalia
Phylum:	Crustacea
Class:	Malacostraca
Order:	Amphipoda
Family:	Corophiidae
Genus:	Photis
Species:	Photis dolichommata

Sorting samples sieved through a 0.5 mm mesh took up to twice as long as sorting samples sieved through a 1 mm mesh. Many juvenile macrofauna were collected in 0.5 mm sieved samples and these were difficult to identify (R. Springthorpe, Aust. Museum, pers. comm.), thus adding to the overall time taken to process samples sieved through a 0.5 mm mesh.

Sieving samples through a 1 mm mesh rather than a 0.5 mm mesh and identifying them to the level of family rather than species had little effect on the interpretation of patterns of spatial variation in assemblages of macrofauna. Similar conclusions have been reached by other workers studying the effects of pollution on assemblages of macrofauna (e.g. Warwick 1988; Ferraro and Cole 1990). To date, no studies of assemblages of macrofauna have shown that spatial or temporal patterns at the species level of identification not apparent at the family level (R.M. Warwick, pers. comm.).

The absolute abundance of some populations of polychaetes and crustaceans was underestimated using a 1 mm mesh to sieve samples but the spatial patterns of distribution of most families were similar for both mesh-sizes. There were often 3 to 4 species per family and spatial patterns of the distribution of the most abundant species in each family should be similar to patterns detected at the family level. Some families, however, contained many species (e.g. Corophiidae) and the patterns of distribution of the less abundant species may differ to that detected for the species' family. These rarer species are usually ignored in analyses of populations anyway, so there is little loss of information by analysing family level data.

It was decided to use a 1 mm mesh to sieve samples and identify animals to family in this study so that a larger number of samples could be processed and we could better investigate spatial and temporal variation in macrobenthic assemblages.

8.1.2.4 Statistical Analyses

Statistical analyses were done to describe temporal and spatial variation of the macrobenthic assemblages and populations sampled. Both univariate and multivariate statistical analyses were used to describe the variation of benthic fauna among times, depths, locations and sites within each location.

8.1.2.4.1 Analyses of Assemblages

Multivariate analyses were used to examine spatial and temporal patterns of assemblages. Both classification and ordination techniques were used. The procedures used were those outlined in Clarke (1993).

Classification analysis is a technique for the assignment of objects to groups using a similarity measure and then a grouping algorithm (Gauch 1982; James and McCulloch 1990). Classification summarizes the data so that the number of groups is less than the number of objects that were classified into them. Group average clustering was used to classify assemblages in this study.

Ordination is a representation of ecological data in fewer dimensions than the total data set (James and McCulloch 1990). It may be more appropriate for continuous data than classification, which is most appropriate for categorical data and will impose discrete groups on data even if they do not actually exist (Burd et al. 1990; James and McCulloch 1990). The ordination technique used was non-metric multidimensional scaling (NMDS) (Kenkel and Orloci 1986; Field et al. 1982; Clarke 1993). Each site is represented as a point on the plot of an ordination and the distance between any two points can be considered the relative degree of similarity of the assemblages at these sites.

Data from all surveys, depths, locations (PH, BP, BB and CB) and sites within each location were used in the multivariate analyses. Data were split into depths (including all locations and surveys sampled at each depth) and times (including all locations and depths sampled during each survey) for analyses. These subsets were analysed separately to examine, (1) variation among times and locations at each depth, and (2) variation among depths and locations during each survey. Only the abundances of polychaetes, molluscs and crustaceans were used in the analyses as they were the most common animals. Replicates were pooled to give the total abundance of each taxon per site for analysis.

The Bray-Curtis similarity measure and fourth-root transformation were used for classification and ordination of sites (Field et al. 1982; Clarke 1993). A fourth-root transformation was used so that most families, not just the most abundant ones, contributed to the results of these analyses.

Groups of similar assemblages were identified from classification and ordination plots and were usually all the assemblages from a single depth or survey. We then identified those families that were characteristic of these groups of assemblages. Those families that were most responsible for differences among groups were also identified. This was done using similarity analyses described by Clarke (1993).

Similarity analyses were used to determine both the contribution of each taxon to the average similarity among assemblages in a defined group and the contribution of each taxon to the average dissimilarity between different groups of assemblages. This information allowed us to determine which taxa were typical of groups of assemblages (i.e. widespread but not necessarily very abundant) and which taxa were abundant but less typical of assemblages, i.e. had a patchy distribution (collected in some samples in large numbers but not in other samples). Note that these analyses show only the relative contribution of taxa to the average similarity or dissimilarity of groups of assemblages. Differences in the average abundance of taxa are discussed but may not be significant due to the large amount of variability associated with the means. Such differences in the abundance of benthic populations are examined in Section 8.1.3.3.

The Bray-Curtis similarity measure and fourth-root transformed data were used in similarity analyses for the reasons outlined above. Only taxa with greater than 5% of the total abundance of each set of data analysed were used in the corresponding similarity analysis.

8.1.2.4.2 Analyses of Populations

Multivariate analyses have limited use in testing hypotheses about assemblages and cannot determine if differences among samples are merely due to chance (but see Clarke 1993). Univariate analyses, however, test specific hypotheses about the distribution and abundance of populations and determine whether differences occur at a given probability.

Selected populations of macrobenthic animals, which may prove to be good indicators of changes to assemblages, were analysed separately. Families were chosen for statistical analysis on the basis of similarity analyses and *a priori* predictions of their importance. This strategy was designed to limit the number of analyses performed to minimize type I error. Abundant taxa from groups other than polychaetes, molluscs and crustaceans were ophiuroids, bryozoans and pycnogonids. Data on these taxa and the number of taxa per sample were also analysed. Data on taxa not analysed are available should the need arise.

The only commercially important macrobenthic animals collected were a few individuals each of the scallop *Pecten fumata* (Pectinidae) and penaeid prawns. These were not studied further. Other small molluscs from the family Pectinidae were collected in relatively large numbers. These small molluscs are not commercially important but are considered (as part of the Pectinidae) below.

Four-factor analyses of variance (ANOVAs) were used to detect significant sources of variation in the selected populations. Sources of variation were times of sampling, depths, locations and sites nested within locations (Table 8.1). Thus, variation in the selected populations was examined at three spatial scales: among replicate samples (metres apart), among sites and depths (100's of metres) and among locations (10's of kilometres). Temporal changes were examined over one year at selected intervals and space-time interactions were also examined.

Time of sampling, depth and location were treated as fixed factors, whereas sites nested within locations was considered as a random factor. All the *F*-tests were relatively powerful (large df, Table 8.2) and therefore post-hoc pooling of non-significant terms (Winer 1971; Underwood 1981a) was not done. Because not all stations were sampled during each survey, three different sets of analyses were done (Fig. 8.2). All analyses were based on balanced sets of data which provide more reliable results from ANOVA than unbalanced sets of data (Underwood 1981a).

Each analytical design answered a different question. Designs 1 and 2 compared data from three locations: PH, BP and BB. Design 1 covered all four surveys at three depths (25-30 m, 35-40 m, 45-50 m) (Fig. 8.2b). Design 2 included all depths (25-30 m, 35-40 m, 45-50 m, 65-70 m) at these locations, for surveys 2, 3 and 4 (Fig. 8.2c). Design 3 included all locations but only 45-50 m and 65-70 m and surveys 3 and 4 (Fig. 8.2d). It compared Cape

Banks with the other locations. In all three designs, one or two of the proposed extraction areas (PH and/or CB) were compared with the two reference areas (BP and BB).

Table 8.2. General ANOVA model. "F vs" indicates the denominator in each F-ratio, and the degrees of freedom are presented for the three ANOVA designs.

Source	Expected Mean Square	F vs	df: Design 1	Design 2	Design 3
Time [T]	$\sigma^2_e + an\sigma^2_{TS(L)} + acdn\sigma^2_T$	TxS(L)	3,18	2,12	1,8
Depth [D]	$\sigma^2_e + bn\sigma^2_{DS(L)} + bcdn\sigma^2_D$	DxS(L)	2,12	3,18	1,8
Location [L]	$\sigma^2_e + abn\sigma^2_{S(L)} + abdn\sigma^2_L$	S(L)	2,6	2,6	3,8
Site(Loc) [S(L)]	$\sigma^2_e + abn\sigma^2_{S(L)}$	Residual	6,324	6,324	8,144
T x D	$\sigma^2_e + n\sigma^2_{TDS(L)} + cdn\sigma^2_{TD}$	TxDxS(L)	6,36	6,36	1,8
T x L	$\sigma^2_e + an\sigma^2_{TS(L)} + adn\sigma^2_{TL}$	TxS(L)	6,18	4,12	3,8
T x S(L)	$\sigma^2_e + an\sigma^2_{TS(L)}$	Residual	18,324	12,324	8,144
D x L	$\sigma^2_e + bn\sigma^2_{DS(L)} + bdn\sigma^2_{DL}$	DxS(L)	4,12	6,18	3,8
D x S(L)	$\sigma^2_e + bn\sigma^2_{DS(L)}$	Residual	12,324	18,324	8,144
T x D x L	$\sigma^2_e + n\sigma^2_{TDS(L)} + dn\sigma^2_{TDL}$	TxDxS(L)	12,36	12,36	3,8
T x D x S(L)	$\sigma^2_e + n\sigma^2_{TDS(L)}$	Residual	36,324	36,324	8,144
Residual	σ^2_e				

Perhaps the most important assumptions of the ANOVA technique are that the error variances of the data are homogeneous and the data are normally distributed (Underwood 1981a). Since the distribution of macrofauna is often aggregated (Elliot 1977; Downing 1979; Stephenson and Cook 1977) and abundance data were positively skewed, routine transformations to $\log_{10}(X+1)$ were done to help satisfy assumptions of normality and homogeneity of variances. Species richness data were only transformed where error variances were heterogeneous. All graphs show untransformed data. Total abundances at higher taxonomic groupings were calculated prior to data transformations.

Cochran's Test was used to test the assumption of homogeneous variances (Underwood 1981a). The Type I error rate (α) was set at 0.05 in the ANOVA if variates had homogeneous variances at $P>0.05$. If variances were heterogeneous at $P\leq0.05$ but homogeneous at $P>0.01$ then α was set at 0.01 in the subsequent ANOVA. Since the data set was large, Cochran's Test often detected very small differences among cell variances and many variates did not have homogeneous variances at $\alpha=0.05$ or 0.01. The size of differences among variances that are important in ANOVA is not known and thus the small differences among variances detected by such a powerful Cochran's Test may not necessarily be important for ANOVA. Therefore, where variances were heterogeneous at $P\leq0.01$, ANOVAs were interpreted at $\alpha=0.005$ as we thought it better to detect small differences and to examine these rather than disregard possible significant factors. The interpretation of non-significant terms in an ANOVA is not affected by violation of the assumption of homogeneous error variances. The effect of violating this assumption is to inflate the Type I error rate, so that terms may be interpreted as significant when, in fact, they are not (Underwood 1981a).

A general interpretation of significant factors and interactions in the ANOVAs is shown in Table 8.3. Many significant factors and interactions are also presented graphically to highlight trends. In some cases, multiple comparison tests were used to identify significantly different levels within factors. Student-Newman-Keuls (SNK) tests were done to compare 2 or 3 means, whereas Ryan's test was done to compare 4 or more means (see Day and Quinn 1989). Multiple comparison tests were not done for most 3-way interactions, here trends were interpreted graphically.

8.1.3 Results

Results of the analyses are presented in three sections: general findings, analyses of assemblages of macrobenthic infauna and analyses of selected populations. Most of the tables referred to are in Appendices A1-A20, Volume II. Figures 8.3-8.68 are in Appendix A21.

8.1.3.1 General Findings

A total of 115,545 individuals from three major taxonomic groups of macrofauna, crustaceans (53% of individuals), polychaetes (39%) and molluscs (7%), were enumerated from the 604 samples collected during the study (Table 8.4). Other taxa, including mobile bryozoans, pycnogonids (sea-spiders) and ophiuroids (brittle stars) were collected in small numbers.

The most abundant crustaceans were amphipods (58% of crustaceans), tanaidaceans (22%), isopods (7%), ostracods (3%), cumaceans (6%) and decapods (2%). The most common decapods collected were small hermit crabs, Diogenidae and Paguridae, which constituted nearly 50% of the decapods (Table 8.4)

Representatives of 41 families of polychaetes were collected. The most abundant families were the Maldanidae, Spionidae, Chaetopteridae, Syllidae and Sabellidae which made up over 70% of all polychaetes collected (Table 8.4).

The order Mollusca is divided into six classes. Of these, gastropods, bivalves, amphineurans and scaphopods were collected in this study (Table 8.4). Bivalves and gastropods were the most abundant molluscs but molluscs generally were less abundant than crustaceans or polychaetes.

Table 8.3. General interpretations of significant factors in ANOVAs. NB: where a factor or interaction is significant as part of a larger-order interaction, no interpretation of that factor or interaction is made. An interaction indicates that the effects of one factor vary from level to level of the other factor(s) of the interaction (and vice versa).

Factor	Symbol	Interpretation
Times	T	The mean abundance of the variate differs among times and these differences are consistent among depths, locations and sites
Depths	D	The mean abundance of the variate differs among depths and these differences are consistent among times, locations and sites
Locations	L	The mean abundance of the variate differs among locations and these differences are consistent among times and depths
Sites (within locations)	S(L)	The mean abundance of the variate differs among sites within locations and these differences are consistent over times and depths
Time by Depth interaction	TxD	Differences in the mean abundance of the variate among times vary inconsistently among depths (and vice versa) but are consistent over locations and sites
Time by Location interaction	TxL	Differences in the mean abundance of the variate among times vary inconsistently among locations (and vice versa) but are consistent over depths
Time by Site (within location) interaction	TxS(L)	Differences in the mean abundance of the variate among times vary inconsistently among sites (and vice versa) but are consistent over depths
Depth by Location interaction	DxL	Differences in the mean abundance of the variate among depths vary inconsistently among locations (and vice versa) but are consistent over times
Depth by Site (within location) interaction	DxS(L)	Differences in the mean abundance of the variate among depths vary inconsistently among sites (and vice versa) but are consistent over times
Time by Depth by Location interaction	TxDxL	Differences in the mean abundance of the variate among times vary inconsistently among depths and locations (and vice versa)
Time by Depth by Site (within location) interaction	TxDxS(L)	Differences in the mean abundance of the variate among times vary inconsistently among depths and sites (and vice versa)

Table 8.4. The most abundant taxa in each major group (Phyla are in boldface). The number of taxa listed refer to families unless otherwise indicated. The % of group refers to the % abundance of that taxon to its group (e.g. the Corophiidae comprise 25% of the Amphipoda). The totals are calculated from 604 samples.

Group	Number of Taxa	Total Abundance	Abundant Taxa	% of Group
Annelida:				
Polychaeta	41	45585	Maldanidae	28
			Spionidae	17
			Chaetopteridae	10
			Syllidae	10
			Sabellidae	6
Mollusca:	71	8502		
Amphineura	2	255	Chaetodermatidae	99
			Prochaetodermatidae	1
Scaphopoda	2	168	Dentaliidae	91
			Siphodentaliidae	9
Bivalvia	30	4636	Pectinidae	21
			Nuculanidae	14
			Tellinidae	10
			Diplodontidae	9
			Veneridae	9
Gastropoda	37	3438	Rissoidae	30
			Nassariidae	21
			Marginellidae	13
			Trochidae	8
			Turritellidae	5
Crustacea:		61458		
Amphipoda	32	35441	Corophiidae	25
			Aoridae	15
			Ampelisicdae	11
			Phoxocephalidae	10
			Podoceridae	9
Tanaidacea	2 sub-orders	13637	Tanaidomorpha	68
			Apseudomorpha	32
Isopoda	10 + 1 sub-order	4164	Paranthuridae	25
			Anthuridae	22
			Arcturidae	17
			Cirolanidae	12
			Sphaeromatidae	12

Table 8.4, continued.

Group	Number of Taxa	Total Abundance	Abundant Taxa	% of Group
Cumacea	6	3967	Bodotriidae	33
			Diastylidae	30
			Gynodiastylidae	27
			Nannastacidae	5
			Lampropidae	3
Ostracoda	5	1760	Cylindroleberidae	34
			Philomedidae	34
			Cypridinidae	22
			Sarsiellidae	5
			Rutidermatidae	5
Decapoda	20	1520	Diogenidae (Anomura)	25
			Paguridae (Anomura)	23
			Callianassidae (Anomura)	19
			Pasiphaeidae (Caridea)	13
			Processidae (Caridea)	4
Leptostraca	1	371	Nebaliidae	100
Copepoda	3 orders	255	Calanoida	53
			Harpacticoida	47
			Siphonostomatoida	0.4
Mysidacea	1	170	Mysidae	100
Euphausiacea	1	33	Euphausiidae	100
Cirripedia	2 sub-orders	18	Lepadomorpha	89
			Balanomorpha	11
Echinodermata: Ophiuroidea	–	853	–	
Bryozoa:	–	2166	–	
Chelicerata: Pycnogonida	–	297	–	

Samples were usually clean sand, but those from 65-70 m tended to be more muddy than those from shallower depths. Some samples from the deeper areas, 45-50 m and 65-70 m, also contained many tubes constructed by polychaetes or crustaceans.

8.1.3.2 Analyses of Assemblages of Macrofauna

8.1.3.2.1 Spatial Variation of Assemblages during each Survey

Classification, ordination and similarity analyses were used to examine data on assemblages of macrofauna from each survey. Assemblages varied relatively consistently among depths during all surveys but there was no consistent variation among locations. Polychaetes such as spionids and syllids and amphipods such as corophiids and phoxocephalids were common members of assemblages at all depths and surveys. Other taxa were typical of assemblages at particular depths during some surveys but not others. These included diastylid cumaceans, isopods and cirratulid polychaetes. This section describes the variation of assemblages among depths, locations and sites during each of the four surveys.

Survey 1 - January 1990

Classification and ordination analyses both showed that macrobenthic assemblages differed among 25-30 m, 35-40 m and 45-50 m during survey 1 (Fig. 8.3a,b). Assemblages at the three depths were not totally distinct, as shown by the overlap of sites in the classification and ordination diagrams, but there were differences in assemblages among depths (Fig. 8.3a,b). The greatest difference was between assemblages at 25-30 m and 45-50 m. Assemblages at 35-40 m and 45-50 m were more similar to each other than they were to assemblages at 25-30 m (Fig. 8.3a,b). There were no consistent differences among locations during survey 1 (Fig. 8.3a,c).

A large number of families occurred at all depths. Appendix A3 shows the contribution of each taxon to the average similarity of macrobenthic assemblages collected from each depth during each survey and hence which taxa were typical of assemblages at each depth during survey 1 (see Section 8.1.2.4 and Clarke 1993). For example, tanaidomorph tanaidaceans were very abundant, on average, assemblages in 35-40 m during survey 1 (Appendix A3a), but the distribution of these crustaceans was very patchy (standard deviation (SD) >> mean). Taxa typical of assemblages at 35-40 m during survey 1, such as corophiid amphipods, were abundant with a relatively small SD and contributed greatly to the similarity of samples collected from 35-40 m during survey 1 (Appendix A3).

Amphipods and polychaetes dominated assemblages at 25-30 m. Corophiids and spionid polychaetes were the two most abundant taxa at this depth during survey 1 (Appendix A3a). Spionid and syllid polychaetes and phoxocephalid, corophiid and urohaustorid amphipods were typical members of assemblages at 25-30 m during survey 1.

Amphipods and polychaetes also dominated assemblages at 35-40 m (Appendix A3a). Tanaidaceans and maldanid polychaetes were abundant in patches and were not considered typical of assemblages at this depth during survey 1. Taxa that were typical of 35-40 m assemblages during survey 1 were corophiid, phoxocephalid, ampeliscid and lysianassid amphipods.

Corophiids were also very abundant at 45-50 m and, with apseudomorph tanaidaceans, phoxocephalid amphipods and sabellid fanworms, were typical of assemblages at 45-50 m. Maldanids and tanaidomorphs were abundant in some 45-50 m samples, but again the distribution of these animals was patchy. These animals probably dominated assemblages in some areas but not in others at both 35-40 m and 45-50 m but not at 25-30 m.

The mean abundance of individual taxa present at each depth showed different patterns among depths (Appendix A3a). For example, the mean abundance of corophiids increased with depth whereas the mean abundance of phoxocephalids decreased with depth. Such patterns are investigated in greater detail in Section 8.1.3.3.

Survey 2 - June 1990

Assemblages of macrofauna again varied consistently among depths during survey 2, which also included samples from 65-70 m (Fig. 8.4a,b). Classification and ordination analyses showed that assemblages varied among depths and those at 25-30 m and 35-40 m were less similar than those at 45-50 m and 65-70 m. Assemblages did not vary consistently among locations, however (Fig. 8.4a,b,c).

Cirolanid isopods, spionid polychaetes and phoxocephalid, corophiid and urohaustorid amphipods were typical members of assemblages at 25-30 m during survey 2 (Appendix A3b). Mysids were also common, at 25-30 m, but were more patchy. Marginellid gastropods were also present at 25-30 m in small numbers. As in survey 1, assemblages at 25-30 m were characterised by fewer taxa than assemblages at the other depths. This pattern was consistent across all four surveys (Appendix A3).

Maldanids were also abundant at 35-40 m, but were not always typical of assemblages at this depth. Spionid polychaetes, urohaustorids and phoxocephalids were, again, typical members of the fauna at 35-40 m. Anthurid isopods and orbinid and capitellid polychaetes were also typical members of assemblage at this depth, but, were not common here during survey 1. Diplodontid and tellinid bivalves were the most common molluscs at 35-40 m during survey 2.

Tanaidomorph tanaidaceans were very abundant in patches at 45-50 m during survey 2, but were not typical of the assemblages. Apseudomorph tanaidaceans were less abundant than taniadomorphs, but were more typical of assemblages at 40-50 m. Spionid, cirratulid, lumbrinerid and syllid polychaetes and phoxocephalid amphipods were typical members of assemblages at 45-50 m. Nuculanid bivalves were also relatively abundant, but were not common at this depth during survey 1.

The similarity of assemblages at 65-70 m was variable (as shown by the spread of points in Fig. 8.4b), probably because the assemblages at BP, site 3 were somewhat different to those at the other two BP sites. Maldanids, syllids, cirratulids, phoxocephalids, apseudomorphs and anthurid isopods were typical of the fauna at 65-70 m during survey 2. Taxa typical of assemblages at both 45-50 m and 65-70 m included phoxocephalids, syllids and apseudomorphs.

Survey 3 - November 1990

Again, assemblages varied consistently among depths but not locations (Fig. 8.5a,b,c). Assemblages at 25-30 m were quite different to those at other depths (Fig. 8.5a,b). There was some similarity among assemblages at 35-40 m, 45-50 m and 65-70 m, but there was still a trend for assemblages to vary among depths (Figs 8.5a,b).

Phoxocephalid, corophiid, platyischnopid and oedicerotid amphipods were characteristic members of assemblages at 25-30 m during survey 3 (Appendix A3c). Cirolanid isopods, which were typical members of assemblages at this depth during survey 2, were not typical during survey 3. Diplodontid bivalves, and diastylid and bodotriid cumaceans were collected from 25-30 m but were uncommon.

Amphipods were common at 35-40 m during survey 3. Phoxocephalids, corophiids, aorids and urohaustorids were typical members of the fauna at this depth (Appendix A3c). Spionid polychaetes were also typical members of assemblages at 35-40 m during survey 3 but they were not very abundant. Maldanid and syllid polychaetes were abundant in patches at 35-40 m during survey 3.

Amphipods and polychaetes dominated assemblages at 45-50 m during survey 3 (Appendix A3c). Aorid, phoxocephalid, ampeliscid and lysianassid amphipods were typical taxa. Syllids and corophiids were abundant. Cirratulids, onuphids and paranthurid isopods were typical members of these assemblages but were less abundant than the other taxa. Nuculanid bivalves were again the most common mollusc.

Spionid and maldanid polychaetes were abundant at 65-70 m during survey 3 (Appendix A3a). Spionids were typical of the assemblages at these depths, but the distribution of maldanids was patchy. Syllid and cirratulid polychaetes, corophiid and aorid amphipods and bodotriid cumaceans were also representative of assemblages at 65-70 m. Nassarid gastropods were the most common mollusc in 65-70 m assemblages during survey 3.

Survey 4 - January 1991

Assemblages again varied consistently among depths but not locations (Fig. 8.6). Both classification and ordination analyses showed that assemblages at 25-30 m were different to those at 35-40 m, 45-50 m and 65-70 m (Fig. 8.6a,b). Differences among assemblages at 35-40 m, 45-50 m and 65-70 m were less distinct, but assemblages still varied with depth.

Spionid and onuphid polychaetes, phoxocephalid, corophiid, urohaustorid and oedicerotid amphipods and arcturid isopods were all abundant and typical members of assemblages at 25-30 m during survey 4 (Appendix A3d). Except for arcturids, these taxa were also typical of assemblages at 25-30 m assemblages during the other surveys.

Spionids, onuphids, syllids, corophiids, phoxocephalids and arcturids were typical components of assemblages at 35-40 m during survey 4. Maldanid polychaetes were also abundant at some sites. Diastylid cumaceans were abundant at 35-40 m during survey 3, but not during surveys 1 and 2. Tellinid bivalves were the most common mollusc.

The two most typical members of assemblages at 45-50 m during survey 4 were spionids and phoxocephalids. Corophiids, ampeliscids and diastylids were also typical of these assemblages while tanaidaceans were abundant but less typical of these assemblages.

Maldanids were abundant in patches at 65-70 m. Spionids, syllids, corophiids, apseudomorph tanaidaceans and bodotriid cumaceans were most typical of assemblages at 65-70 m during survey 4.

8.1.3.2.2 Differences Among the Composition of Assemblages at Different Depths

Many taxa contributed to differences among assemblages at the different depths. Few contributed consistently to these differences, but many were important at particular times or sites. For example, pectinid bivalves were only common during survey 1 and this was the only time that they contributed to differences between assemblages at different depths.

Most taxa that contributed to differences between depths were more abundant at a single depth during all surveys. This was not always true, however, and patterns of distribution among depths varied among surveys for some taxa, such as tanaidomorph tanaidaceans and maldanid polychaetes.

Overall, differences in assemblages among depths were mainly due to variations in the abundance of many taxa, not just a few dominant ones.

25-30 m and 35-40 m

A variety of taxa contributed to differences between assemblages at 25-30 m and 35-40 m (Appendix A4). Generally, taxa were most abundant at 35-40 m. Taxa that best distinguish assemblages are those that are consistently more abundant in assemblages at either depth. Note that taxa which contribute to differences among groups of assemblages at the different depths are not necessarily typical of assemblages at either depth.

During survey 1, tanaidomorph tanaidaceans and maldanid polychaetes were more abundant in assemblages at 35-40 m than at 25-30 m (Appendix A4a). The distribution of these animals at 35-40 m was patchy and they were not consistent contributors to differences between assemblages. Nevertheless, when tanaidomorphs and maldanids were present, they tended to be more abundant in assemblages at 35-40 m than at 25-30 m. Apseudomorph tanaidaceans, pectinid bivalves, aorid amphipods and chaetopterid polychaetes consistently contributed to differences between assemblages at 25-30 m and 35-40 m.

During surveys 2, 3 and 4, maldanids again contributed greatly to differences between assemblages at 25-30 m and 35-40 m (Appendix A4b,c,d). Although tanaidomorphs were more abundant at 35-40 m than at 25-30 m, they did not contribute consistently to differences between assemblages at these depths. Pectinids were relatively abundant at 35-40 m but not 25-30 m during survey 1, but they were not abundant during surveys 2, 3 and 4 and, therefore, did not contribute to differences between assemblages at these depths during the latter surveys.

During survey 2, maldanids, aorid and ampeliscid amphipods and apseudomorphs consistently contributed to differences between assemblages at 25-30 m and 35-40 m (Appendix A4b). During survey 3, maldanids, aorids, ampeliscids and oedicerotid amphipods and anthurid isopods consistently contributed to differences between assemblages at 35-40 m and 25-30 m (Appendix A4c). Oedicerotids were one of the few taxa that were more abundant at 25-30 m than at 35-40 m. During survey 4, maldanids, apseudomorphs, aorids and ampeliscids consistently contributed to differences between assemblages at 35-40 m and 25-30 m (Appendix A4d).

25-30 m and 45-50 m

Tanaidomorph and apseudomorph tanaidaceans, ischyrocerid and aorid amphipods, aeginellid caprellids, chaetopterid polychaetes and pectinid bivalves contributed consistently to differences between assemblages at 25-30 m and 45-50 m during survey 1 (Appendix A5a). Although the average abundance of maldanid polychaetes was greater at 45-50 m than at 25-30 m, their distribution was patchy and their contribution to differences between assemblages at 25-30 m and 45-50 m was variable. Pectinids were uncommon during surveys 2, 3 and 4 at 45-50 m and did not contribute greatly to variation between assemblages at 25-30 m and 45-50 m during these later surveys.

Polychaetes from the Cirratulidae and Lumbrineridae and nuculanid bivalves were relatively common members of assemblages at 45-50 m during survey 2, but were uncommon at 25-30 m (Appendix A5b). Other taxa that contributed consistently to differences between assemblages at 45-50 m and 25-30 m included tanaidaceans, maldanids, aorids and ampeliscids.

Nuculanid bivalves, chaetopterids, cirratulids, lumbrinerids, apseudomorphs and ampeliscids consistently contributed to differences between assemblages at 45-50 m and 25-30 m during survey 3 (Appendix A5c). Only chaetopterids were also important during survey 4 (Appendix A5d). Tanaidomorphs, apseudomorphs and ampeliscids also contributed to differences between assemblages at 25-30 m and 45-50 m during survey 4. Mysids were one of the few taxa that were more common at 25-30 m than at 45-50 m, but they were only abundant during surveys 2 and 4.

35-40 m and 45-50 m

Maldanid polychaetes and tanaidomorph tanaidaceans were more abundant in assemblages at 35-40 m than at 45-50 m during survey 1 (Appendix A6a). The distribution of maldanids, however, was patchy and they did not contribute consistently to differences between assemblages at these depths. In contrast, ischyrocerid and podocerid amphipods, aeginellid caprellids and pectinid bivalves were more abundant at 45-50 m than 35-40 m and contributed to differences between depths during survey 1. Tanaidomorphs and maldanids also contributed to differences between assemblages at 35-40 m and 45-50 m during survey 2 (Appendix A6b). Taxa that contributed consistently to differences between assemblages at these depths were tanaidomorphs, chaetopterid and lumbrinerid polychaetes and nuculanid bivalves.

During survey 3, maldanids and tanaidomorphs were more abundant at 35-40 m than at 45-50 m, as in survey 1 (Appendix A6c). Tanaidomorphs were again more consistent contributors to differences between assemblages at these depths than maldanids. Chaetopterids, lumbrinerids, podocerids and paranthurid isopods, philomedid ostracods and apseudomorphs also contributed to differences between assemblages at 35-40m and 45-50 m. On average, philomedids and apseudomorphs were more common at 45-50 m than at 35-40 m during survey 3.

Tanaidomorphs again contributed to differences between assemblages at 35-40 m and 45-50 m during survey 4 (Appendix A6d). Maldanids, tellinids and mysids were consistently more abundant at 35-40 m than at 45-50 m. Conversely, ampharetid polychaetes and podocerids were much more abundant at 45-50 m than at 35-40 m.

25-30 m and 65-70 m

Many taxa were considerably more abundant at 65-70 m than at 25-30 m (Appendix A7). During survey 2, maldanid, cirratulid and lumbrinerid polychaetes, apseudomorph and tanaidomorph tanaidaceans and ampeliscid and aorid amphipods consistently contributed to differences between assemblages at the two depths (Appendix A7a). Chaetopterid polychaetes were more abundant at 65-70 m than at 25-30 m, but because their distribution was patchy at 65-70 m, they did not contribute consistently to differences between depths. Urohaustorid amphipods and mysids were among the few taxa that were more abundant at 25-30 m than at 65-70 m. No urohaustorids were collected from 65-70 m in survey 2.

Taxa contributing a large proportion of dissimilarity between assemblages at 25-30 m and 65-70 m in survey 3 included maldanids, apseudomorphs, ampeliscids, spionids, cirratulids, sabellids, tanaidomorphs and lumbrinerids (Appendix A7a,b). Maldanids, sabellids and tanaidaceans were more common in assemblages at 65-70 m than 25-30 m and tanaidaceans were the most consistent contributors to differences among these assemblages (Appendix A7c). Despite their abundance, the distribution of chaetopterids was again patchy, and they did not consistently contribute to differences between assemblages during surveys 3 and 4.

35-40 m and 65-70 m

Tanaidomorph tanaidaceans, urohaustorid amphipods and tellinid bivalves were more common in assemblages at 35-40 m than those at 65-70 m during survey 2 and they accounted for a large proportion of the differences between assemblages at 35-40 m and 65-70 m (Appendix A8a). Lumbrinerid and cirratulid polychaetes and ampeliscid and corophiid amphipods also consistently contributed to differences between assemblages at 35-40m and 65-70m, and were most abundant in assemblages at 65-70 m. Nassarid gastropods were also more abundant at 65-70 m than 35-40 m but the distribution of these gastropods was patchy. This was also the case during survey 3. Nassarids were not abundant during survey 4.

Spionid, sabellid, owenid and cirratulid polychaetes consistently contributed to differences between assemblages at 35-40m and 65-70 m during survey 3 (Appendix A8b). Again urohaustorids were more abundant at 35-40 m than at 65-70 m. During surveys 2, 3 and 4, tanaidomorphs were major contributers to differences between assemblages at 35-40 m and 65-70 m (Appendix A8a,b,c). Unlike survey 2, tanaidomorphs were more common at 65-70 m than at 35-40 m during survey 4. Urohaustorids and tellinids were again consistent contributors to differences between assemblages at 35-40 m and 65-70 m. During survey 4 they were more common at 35-40 m than at 65-70 m. Owenids, spionids and apseudomorph tanaidaceans also consistently contributed to differences between the assemblages were more abundant at 65-70 m than 35-40 m. Chaetopterids were very abundant at 65-70 m during survey 4, but the distribution of these worms was patchy and they did not consistently contribute to differences between assemblages at these depths.

45-50 m and 65-70 m

Chaetopterid polychaetes accounted for a large proportion of the difference between assemblages at 45-50 m and 65-70 m and, in surveys 2, 3 and 4 they were most abundant at 65-70 m (Appendix A9a,c). Sabellid, cirratulid and owenid polychaetes consistently contributed to differences between assemblages at 65-70 m and 45-50 m during survey 2 and also occurred in larger numbers at 65-70 m. In contrast, nuculanid bivalves, tanaidomorphs and hermit crabs (Diogenidae) were most abundant at 45-50 m.

During survey 3, differences between assemblages at 45-50 m and 65-70 m were attributable to patterns in the distribution of maldanid, paraonid, spionid, owenid and sabellid polychaetes and nassarid gastropods (Appendix A9b). Nuculanid bivalves and urohaustorid amphipods again were more abundant at 45-50 m than at 65-70 m. Chaetopterids were abundant, but were very patchy at 65-70 m during survey 3 and, although they contributed to differences between assemblages at these depths, this contribution was less consistent than that of other taxa.

During survey 4, maldanids, chaetopterids, ampharetids and sabellids made large contributions to differences between assemblages at 45-50 m and 65-70 m (Appendix A9c). Families such as the sabellids, spionids, syllids and urohaustorids contributed to differences between the fauna at 45-50 m and 65-70 m.

8.1.3.2.3 Temporal Variation in Assemblages of Macrofauna at each Depth

This section considers the structure of assemblages at each depth over all surveys. The analyses describe variation in the composition of assemblages among surveys and locations at each depth. In general, consistent temporal variation occurred in assemblages at 25-30 m and 35-40 m. Assemblages at some 45-50 m sites showed marked temporal variation whereas those at other sites did not. Assemblages at 65-70 m varied among sites. At BP, the fauna at one site was very different to fauna at the other sites at this location. Assemblages at CB during survey 3 were also quite different from other assemblages this depth.

At each location, variation in the fauna at each site did not necessarily follow the same temporal pattern. The patterns of temporal variation in assemblages at the three sites within each location were more similar at 25-30 m and 35-40 m than the other depths sampled, leading to more consistent temporal variation over all locations and sites. The rest of this section describes these temporal patterns in more detail.

25-30 m assemblages

Assemblages at 25-30 m varied consistently among surveys but not among locations (Fig. 8.7a,b,c). Three main groups of assemblages distinguished at 25-30 m corresponded to different surveys. The greatest difference in the classification and ordination analyses was between assemblages sampled during surveys 1 and 4 compared to those sampled during surveys 2 and 3 (Fig. 8.7a,b). Differences between surveys 2 and 3 were not as large as differences among the other combinations of surveys (Fig. 8.7b). Taxa that were typical of surveys 1, and 4, and surveys 2 and 3 combined are listed in Appendix A10.

Stress values for the ordinations of data from 25-30 m were relatively large at 0.25, indicating that the data were not well represented in two dimensions. Nevertheless, the three main groups of assemblages described above were distinguishable in the ordination and classification plots (Fig. 8.7a,b).

Taxa typical of assemblages at 25-30 m in survey 1 were corophiid, phoxocephalid and urohaustoriid amphipods and spionid and syllid polychaetes (Appendix A10a). With the exception of the syllids, these taxa were also typical of assemblages at this depth during survey 4 (Appendix A10c). Most taxa were less abundant during surveys 2 plus 3 than during surveys 1 or 4 (Appendix A10 a,b,c). Phoxocephalid, corophiid and oedicerotid amphipods and cirolanid isopods were characteristic members of assemblages at 25-30 m in surveys 2 and 3 (Appendix A10b).

Many taxa contributed to the differences between assemblages during survey 1 and surveys 2 & 3 (Appendix A11a). Most were more abundant during survey 1. For example, ampeliscid, corophiid and aorid amphipods were consistent contributors to differences between assemblages collected during survey 1 than surveys 2 and 3 and were more abundant during survey 1. Apart from amphipods and polychaetes, taxa such as kelliellid, diplodontid and venerid bivalves; trochid and rissoid gastropods; arcturid and anthurid isopods and diastylid cumaceans contributed to differences between the assemblages.

Taxa that contributed consistently to differences between assemblages collected during surveys 1 and 4 included maldanid and capitellid polychaetes and ampeliscid amphipods (Appendix A11b). Consistent contributors to differences between surveys 2 and 3 and survey 4 were arcturids, spionids and diastylids (Appendix A11c).

Patterns of temporal variation of assemblages at each sites within each location are illustrated in Figure 8.8. The length of the arrows indicate the relative change in the structure of assemblages at each site over the four surveys. For instance, the structure of assemblages at site 3 at PH changed more between surveys 1 and 2 than between surveys 3 and 4. Evidence of a seasonal pattern of change would be indicated by assemblages sampled at the same time of year (e.g. surveys 1 and 4) being more similar to each other than to assemblages sampled in different seasons (surveys 2 and 3). Since we sampled only for one year, we cannot be definite about seasonal patterns.

There were five months between surveys 1 and 2 and surveys 2 and 3 whereas only 2 months separated surveys 3 and 4. The relative amount of change between these surveys in the structure of assemblages gives us an idea of changes at different temporal scales.

In many instances, assemblages at each site (within location) showed different patterns of temporal variation (Figure 8.8). At PH, assemblages at sites 1 and 2 changed similarly through time, but those at site 3 varied quite differently during surveys 1 to 3. Assemblages were similar at all three sites during survey 4. Only one site at CB could be sampled at 25-30 m. Assemblages at this site were distinct during survey 3, but became similar to most others sampled during survey 4. Assemblages at the three sites at BB were relatively similar during survey 1, varied differently through time, but 'converged' during survey 4. Assemblages at the three BP sites were similar during survey 1, but underwent large changes between surveys. Assemblages at sites 4 and 5 (BP) were again similar during survey 4 but differed from those present during survey 1. Patterns of temporal variation in assemblages at site 6 were different to those at the other two sites.

35-40 m assemblages

Assemblages at 35-40 m also varied consistently among surveys but not locations (Fig. 8.9a,b,c). Differences among surveys were not as marked as at 25-30 m (Fig. 8.8a,b). Assemblages sampled during surveys 1 and 4 were similar, suggesting possible seasonal variability. The stress value for the ordination plot was again relatively large (0.20, Fig. 8.9) suggesting that the data were not well represented in two dimensions. Differences in the structure of assemblages sampled during different surveys were, however, apparent in the ordination plot (Fig. 8.9a,b) and are discussed below.

During survey 1, corophiid and aorid amphipods and maldanid and spionid polychaetes dominated many assemblages at 35-40 m (Appendix A12a). Taxa that were consistent members of assemblages at 35-40 m during survey 1, but which occurred in smaller numbers, included phoxocephalid and ampeliscid amphipods. Tanaidomorph tanaidaceans were abundant but very patchy during survey 1 and therefore were not typical of assemblages at this depth and time. During survey 2, urohaustorid and phoxocephalid amphipods, spionid and orbinid polychaetes, diplodontid bivalves and anthurid isopods were typical members of the assemblages at 35-40 m, but they were not collected in large numbers (Appendix A12b). Maldanids and tanaidaceans were not typical of the assemblages at 35-40 m during survey 2.

During survey 3, assemblages were characterised by relatively few taxa (Appendix A12c). Phoxocephalids, corophiids and urohaustorids were again characteristic of the assemblages. Maldanids were relatively abundant, but the distribution of these worms was patchy. Phoxocephalids, corophiids, spionids and onuphids were typical members of assemblages during survey 4 (Appendix A12d). The mean abundance of these taxa was greater than during surveys 2 and 3. Diastylid cumaceans and apseudomorph tanaidaceans were also relatively abundant in assemblages at 35-40 m during survey 4.

Maldanids and tanaidomorphs were major contributors to differences among surveys in assemblages at 35-40 m (Appendix A13). Other taxa, however, were more consistent contributors to differences between the assemblages. For example, diastylids consistently contributed to differences in assemblages between surveys 1 and 2, surveys 3 and 2, and surveys 1 and 4, but not between surveys 1 and 3.

Taxa that were consistent contributors to differences between assemblages in surveys 1 and 2 included ischyrocerid, podocerid and corophiid amphipods, diastylid cumaceans and diplodontid bivalves (Appendix A13a). Except for diplodontid bivalves, these taxa were more abundant during survey 2 than survey 1. Taxa that made important contributions to differences between surveys 1 and 3 included sabellids, spionids, ischyrocerids and corophiids. These taxa were more abundant during survey 1 than survey 3 (Appendix A13b).

Differences between surveys 2 and 3 in the mean abundance of many taxa were small (Appendix A13c). Diastylids, which were more abundant during survey 3 than survey 2, and spionids, which displayed the opposite pattern, were the most consistent contributors to differences between these assemblages.

Differences in assemblages between surveys 1 and 4 were not as great as the differences among other surveys (Fig. 8.9). Taxa that were consistent contributors to the difference between these assemblages included ischyrocerid, corophiid, aorid and podocerid amphipods, apseudomorph tanaidaceans and diastylid cumaceans (Appendix A13d). Diastylids and aeginellid amphipods (Caprellidae) consistently contributed to differences in assemblages between surveys 2 and 4 (Appendix A13e). These taxa were not collected from 35-40 m during survey 2. The most consistent contributors to differences in assemblages between surveys 3 and 4 were spionids and sabellids (Appendix A13f).

Patterns of temporal variation in benthic assemblages were more similar among sites at 35-40 m than at 25-30 m (Figs. 8.8, 8.10). At PH, assemblages at the three sites were relatively similar during survey 1. Assemblages at sites 2 and 3 showed similar changes over time (Fig. 8.10). There was considerably more variation through time in the structure of the assemblage at PH site 1 than at sites 2 and 3.

Only site 11 at CB was sampled at 35-40 m. The assemblage at this site was quite distinct from those at other sites during survey 3, but underwent relatively large changes between surveys 3 and 4 and was similar to most other assemblages at 35-40 m during survey 4 (Figs. 8.8, 8.10).

Assemblages at the three sites in BB were similar during surveys 1 and 4, indicating that changes were possibly seasonal (Fig. 8.10). The patterns of temporal variation of assemblages at the three sites in BB were, however, quite different over the four surveys.

Assemblages at sites 5 and 6 at BP varied in a similar fashion through time. Those sampled during surveys 1 and 4 were similar indicating that changes may have been seasonal (Fig. 8.10). The pattern of change at site 4 was different from that at the other two sites at BP, but assemblages at all three sites were similar during survey 4.

45-50 m assemblages

Unlike assemblages at 25-30 m and 35-40 m, assemblages at 45-50 m showed little consistent variation among surveys (Fig. 8.11a,b). Again there was no consistent variation among assemblages at the different locations (Fig. 8.11c).

The stress value for the ordination plot was again relatively large (0.20, Fig. 8.11) suggesting the data were not well represented in two dimensions. Assemblages at six sites sampled during survey 3, however, constituted a group which was distinct from those at most other sites in both the classification and ordination plots (Fig. 8.11a,b). These appear on the left hand side of the ordination plot and from top to bottom are: CB site 10, BP site 4, CB site 11, BB site 8, CB site 12 and BB site 7. This group of assemblages is termed 'group A' and compared with all the other assemblages ('group B') except the PH site 2 assemblage during survey 1, which is represented by the point at the top right in the ordination plot (Fig. 8.11c).

Taxa that dominated assemblages groups A and B included many that were common at other depths, such as spionid polychaetes, and phoxocephalid, aorid and corophiid amphipods (Appendix A14a,b). But group B assemblages also had large numbers of tanaidaceans which were not typical of group A assemblages. Many other taxa contributed to differences between group A and B assemblages and most tended to be more abundant in group B assemblages (Appendix A15). Thus, some assemblages sampled during survey 3 tended to contain fewer animals than most other assemblages at 45-50 m.

Patterns of temporal variation were quite different at the three sites at PH (Fig. 8.12). Assemblages at the PH sites changed relatively little in comparison with changes at sites within the other locations. Assemblages at sites 10 and 11 at CB changed markedly between surveys 3 and 4 (Fig. 8.12). Changes in assemblages at site 12 were smaller, but assemblages at all three sites converged to be more similar during survey 4 than they were during survey 3. Assemblages at the three sites at BB showed different patterns of temporal variation after being relatively similar during survey 1 (Fig. 8.12).

Assemblages at sites 5 and 6 at BP changed little over time compared to changes at site 4 (Fig. 8.12). At site 4, assemblages were relatively similar during surveys 1, 2 and 4 but large changes occurred between surveys 2 and 3 and between surveys 3 and 4. During survey 3, assemblages this site grouped with other group B assemblages.

65-70 m assemblages

Assemblages at 65-70 m showed little consistent variation among surveys (Fig. 8.13a,b). During survey 3, assemblages at CB differed from other assemblages (Fig. 8.13a). Assemblages at BP also differed from those at other locations (Fig. 8.13c). Assemblages from CB during survey 3, BP during all surveys, and all other sites during all surveys at 65-70 m are described below as groups A, B and C respectively.

The stress value of the ordination plot was 0.16 (Fig. 8.13) indicating the data were adequately represented in two dimensions. The three groups noted above were obvious in both the ordination and classification plots (Fig. 8.13a,b).

Assemblages in group A were comprised of amphipods, polychaetes and tanaidaceans, with spionid polychaetes being particularly abundant (Appendix A16a). Corophiid and ampeliscid amphipods and cirratulid polychaetes were typical members of these assemblages. Maldanid polychaetes were typical members of assemblages in group B (Appendix A16b). Chaetopterid polychaetes were also very abundant in patches, but were less typical of assemblages than spionid, syllid and onuphid polychaetes. Nassarid gastropods were also relatively abundant in this group. Spionids and maldanids were very abundant members of assemblages belonging to group C (Appendix A16c). Corophiids, ampeliscids, spionids, syllids and apseudomorph tanaidaceans were typical members of this group.

Chaetopterids, maldanids, syllids, sabellids, nassarids and tanaidomorphs were consistent contributors to differences between group A and B assemblages (Appendix A17a). With the exception of tanaidomorphs and sabellid fanworms, these taxa were more abundant in group B than in group A assemblages. Taxa that consistently contributed to differences between group A and group C included ampeliscid, aorid and corophiid amphipods and lumbrinerid polychaetes (Appendix A17b). Many taxa were more abundant in group C than in group A.

Chaetopterids were very abundant at 65-70 m at BP, and they made an important contribution to the differences between group B and group C assemblages (Appendix A17c). The distribution of chaetopterids was, however, patchy and other taxa such as tanaidomorphs and aorids were more consistent contributors to differences between these assemblages. In contrast to chaetopterids, tanaidomporphs, aorids and many other taxa were more abundant in group C than in group A assemblages.

Patterns of temporal variation in assemblages at sites 1 and 2 at PH were similar, whereas assemblages at site 3 showed different patterns of variation (Fig. 8.14). These differences were, however, small and assemblages at all sites at PH and BB changed relatively little over time.

At CB, the relative size of temporal changes in the structure of assemblages at 65-70 m was similar to those observed for the same sites at 45-50 m (Figs. 8.12, 8.14). There were relatively large changes in the assemblages at sites 10 and 11 at CB between surveys 3 and 4. Changes at site 12 were smaller. Assemblages at the three sites again converged to be similar during survey 4.

The assemblage at BP site 6 was quite distinct from assemblages at the other sites (Fig. 8.14). Compared to the other sites, this assemblage underwent relatively large changes between surveys 2, 3 and 4.

8.1.3.3 Analyses of Populations of Macrofauna

Macrobenthic taxa that were representative of assemblages and others that were good discriminators of groups of assemblages were chosen for analysis (Table 8.5). The numbers of polychaete, mollusc and crustacean taxa (taxon richness) and the total number of taxa were also analysed. These variates of taxon richness were positively correlated, and therefore, the analyses may give similar results. This should be considered when interpreting the ANOVAs. 36 ANOVAs were done under each design. With $\alpha = 0.05$ we expect at least 5 of these ANOVAs to show significant factors by chance alone.

The data were split into three subsets for univariate analyses (Section 8.1.2.4). The aim of these analyses was to examine the patterns of variation of the selected populations among survey times, depths, locations and sites within locations. Overall, there was significant natural spatial and temporal variability in the distribution and abundance of the these populations, but this was generally not consistent among locations, sites or depths through time (Table 8.6). The variability observed in these analyses is common in populations of marine macrofauna (e.g. FRI 1992). The following sections describe the spatial and temporal variation of the populations sampled.

8.1.3.3.1 Design 1: Comparison of all 4 Surveys at 3 Depths at PH, BB and BP

Variation among times

Only one test for consistent significant differences in the mean abundance of any variate among surveys was done as there were significant time-space interactions in all other design 1 ANOVAs (Appendix A18). This test, of the mean abundance of nuculanid bivalves, did not detect any significant differences among surveys.

Variation among depths

Only the mean abundance of decapods was consistently different among depths over all surveys, sites and locations (Appendix A18). There was a significant increase in the mean abundance of decapods with depth. At 25-30 m there was an average of 0.27 (Standard Error (SE) = 0.049) decapods per grab which was significantly fewer than at 35-40 m where there were, on average, 1.47 (SE = 0.18) decapods. Significantly more decapods occurred at 45-50 m than at the other depths (mean = 3.76, SE = 0.45).

Variation among locations

Tests for consistent differences in the mean abundance among locations were done for 22 of the variates examined (Table 8.5). No significant differences were detected among locations.

Variation among sites within locations

Consistent differences occurred among sites for ostracods, pycnogonids and the number of mollusc taxa, irrespective of depth and the time of sampling (Appendix A18).

Similar numbers of pycnogonids were collected from the six PH and BP sites (Fig. 8.15). At BB, however, pycnogonids tended to be most abundant at site 7, less abundant at site 9 and rare at site 8. Thus, the variation among sites within locations occurred largely at BB. The mean abundance of ostracods varied among sites within PH (Fig. 8.15). More ostracods tended to be collected at sites 1 and 3 than at site 2. The abundance of ostracods at sites at BP and BB did not vary as greatly as sites at PH. The mean number of mollusc taxa also varied among sites within locations, but differences were small; between 4 and 6 taxa were collected per sample (Fig. 8.15).

Interactions between time and depth

Significant time by depth interactions occurred for cirratulids, lumbrinerids, phoxocephalids, ostracods, ophiuroids and the number of polychaete taxa. Patterns of temporal variation differed among at least two of the three shallowest depths sampled (Fig. 8.16).

Table 8.5. Taxa chosen for univariate analyses. (A) = amphipod, (C) = cumacean, (T) = tanaidacean.

Polychaeta	Mollusca	Crustacea	Other Taxa
Chaetopteridae	Bivalvia:	Ampeliscidae (A)	Ophiuroidea
Cirratulidae	Nuculanidae	Aoridae (A)	Bryozoa
Lumbrineridae	Pectinidae	Corophiidae (A)	Pycnogonida
Maldanidae	Tellinidae	Lysianassidae (A)	
Onuphidae	Gastropoda:	Phoxocephalidae (A)	
Sabellidae	Nassariidae	Platyischnopidae (A)	
Spionidae		Podoceridae (A)	
Syllidae		Urohaustoriidae (A)	
		Isopoda	
		Bodotriidae (C)	
		Diastylidae (C)	
		Tanaidomorpha (T)	
		Apseudomorpha (T)	
		Ostracoda	
		Decapoda	

Table 8.6. Summary of the frequency of significant and non-significant outcomea of F-tests done under the three analytical designs. Sig. = significant difference was detected, ns = no significant difference was detected, nt = no test was done due to a significant higher order interaction involving this term.

Factor	Design 1			Design 2			Design 3		
	Sig.	ns	nt	Sig.	ns	nt	Sig.	ns	nt
Time	0	1	35	1	0	35	4	4	28
Depth	1	0	35	0	0	36	5	0	31
Location	0	22	14	1	20	15	5	14	17
Site(Loc)	3	1	32	1	0	35	1	6	29
TxD	6	2	28	1	4	31	2	18	16
TxL	6	25	5	6	25	5	12	24	0
TxS(L)	6	7	23	4	2	30	2	17	17
DxL	4	27	5	6	25	5	6	30	0
DxS(L)	4	9	23	7	1	28	12	7	17
TxDxL	5	31	-	5	31	-	0	36	-
TxDxS(L)	23	13	-	28	8	-	17	19	-

There was no significant difference among surveys in the abundance of cirratulids at 25-30 m, but there were few cirratulids at this depth (Fig. 8.16). At 35-40 m, there were fewer during survey 3 than surveys 1 and 4. At 45-50 m, more cirratulids were collected during survey 2 than during the other three surveys. During all surveys, cirratulids were more abundant at 45-50 m than at 25-30 m. During surveys 1 and 4 the mean abundance of cirratulids at 35-40 m and 45-50 m was similar, but during survey 2 the mean abundance of cirratulids was greater at 45-50 m. During survey 3, the mean abundance of cirratulids at 25-30 m and 35-40 m was similar and less than at 45-50 m.

The mean abundance of lumbrinerids from 45-50 m was greater than at 35-40 m or 25-30 m during surveys 1, 2 and 3 (Fig. 8.16). No differences in the mean abundance of lumbrinerids at 35-40 m and 25-30 m were detected during any survey. No significant differences were detected in the mean abundance among depths during survey 4. At 25-30 m and 35-40 m there was an average of less than one lumbrinerid per sample (Fig. 8.16) and there were no differences among surveys. Lumbrinerids tended to be more abundant at 45-50 m but mean numbers decreased between surveys 1 and 3. There were significantly more lumbrinerids collected during survey 1 than surveys 3 and 4 at 45-50 m. There was no significant difference between survey 2 and surveys 3 and 4 nor between surveys 1 and 2.

Phoxocephalids varied among depths between surveys 1 and 3 but there was a similar increase between surveys 3 and 4 at all depths (Fig. 8.16). At 25-30 m, more phoxocephalids were collected during surveys 1 and 4 than surveys 2 and 3. During survey 1, there were more phoxocephalids at 25-30 m than in deeper areas. At 35-40 m, no differences occurred among surveys. At 45-50 m, significantly more phoxocephalids occurred during surveys 2 and 4 than surveys 1 and 3.

Patterns of temporal variation of ostracods at 45-50 m differed from those at 25-30 m and 35-40 m (Fig. 8.16). The mean abundance of ostracods at 45-50 m increased during the study, whereas the mean abundance of ostracods at 25-30 m and 35-40 m decreased slightly (Fig. 8.16). During survey 1, there were no differences among depths. During surveys 2, 3 and 4 there were fewer ostracods at 25-30 m and 35-40 m than at 45-50 m.

Patterns of temporal variation of ophiuroid populations also varied among depths (Fig. 8.16). During survey 1, similar abundances of ophiuroids occurred at 35-40 m and 45-50 m, but fewer occurred at 25-30 m. During surveys 2 and 3, there were significantly more ophiuroids at 45-50 m than in shallower areas. The mean number of ophiuroids increased at all depths between survey 3 and survey 4. This increase was much greater at 35-40 m and 45-50 m than at 25-30 m (Fig. 8.16). The mean abundance of ophiuroids at all depths was significantly greater during survey 4 than during the first three surveys. At 25-30 m, there was no difference in mean abundances of ophiuroids among surveys 1,2 and 3. At 35-40 m, the mean number of ophiuroids was greater during survey 1 than during surveys 2 and 3, whereas at 45-50 m, the mean abundance was greater during survey 2 than during surveys 1 and 3.

The mean number of polychaete taxa at 35-40 m and 45-50 m was significantly greater than at 25-30 m during all surveys (Fig. 8.16). During surveys 1 and 4, there was no difference between the mean number of polychaete taxa at 35-40 m and 45-50 m whereas during surveys 2 and 3 there were more polychaete taxa at 45-50 m than at 35-40 m. At 25-30 m and 35-40 m, there were significantly more polychaete taxa during survey 1 than during the other surveys, whereas at 45-50 m, more taxa were collected during surveys 1 and 2 than during surveys 3 and 4.

Interactions between time and location

Patterns of temporal variation of pectinid bivalves, ampeliscid amphipods, isopods, bodotriid and diastylid cumaceans and ophiuroids varied among locations (Appendix A18, Fig. 8.17).

Pectinids were more abundant at BP and BB than PH during survey 1 (Fig. 8.17). At PH no significant changes occurred among surveys but there were few pectinids. At BB and BP, significantly more pectinids were collected during survey 1 than during the remaining surveys.

Patterns of temporal variation of ampeliscids were similar at BB and BP (Fig. 8.17). Numbers of ampeliscids declined between surveys 1 and 3, but increased between surveys 3 and 4. At PH, no significant differences occurred among surveys. At BP, more ampeliscids were collected during survey 1 than during survey 4. Larger numbers occurred during surveys 1 and 4 than during surveys 2 and 3. At BB, more ampeliscids were collected during surveys 1, 2 and 4 than during survey 3. The mean abundance of ampeliscids varied inconsistently among locations (Fig. 8.17). During survey 1, there were more ampeliscids at BB and BP than at PH (Fig. 8.17). During surveys 2 and 4 there were more at BB than at PH and BP. During survey 3, there were no significant differences among locations.

Similar numbers of isopods were collected from all locations during surveys 1, 2 and 4 but during survey 3 there were fewer isopods at BB than PH and BP (Fig. 8.17).

The mean number of bodotriids increased at all locations between surveys 3 and 4 (Fig. 8.17). This increase was much greater at PH and BB than BP. There were more bodotriids at PH during survey 4 than during the previous surveys. Further, the mean abundance of bodotriids was greater at PH than BP and BB during survey 4.

Patterns of temporal variation of diastylids among locations were similar during surveys 1 and 2, but there were more diastylids at PH than BB and BP during survey 3 (Fig. 8.17). More diastylids were collected from BB during survey 4 than the first three surveys. Increases in the mean abundance of diastylids at BB between surveys 3 and 4 were larger than increases at PH and BP during the same period, but there were significantly more diastylids at PH and BP during survey 4 than during the other surveys.

Patterns of temporal variation of ophiuroids also varied among locations (Fig. 8.17). The mean abundance of ophiuroids increased at all locations between surveys 3 and 4 but this increase was much greater at BP and BB than PH. There were significantly more ophiuroids at BP and BB during survey 4 than during the first three surveys. The abundance of ophiuroids at PH was small and there were no significant changes through time (Fig. 8.17). There were no significant differences in the mean abundance of ophiuroids at any location during surveys 1 and 3, but during survey 2 there were more ophiuroids at BP than PH or BB. There were also more ophiuroids at BP and BB than at PH during survey 4. (Fig. 8.17).

Interactions between time and sites within locations

Significant interactions between time and sites within locations occurred for cirratulids, decapods, ophiuroids, the number of polychaete and crustacean taxa and the total number of taxa (Appendix A18).

There were few cirratulids at the shallower depths at PH during any survey (Fig. 8.18). At BP, similar patterns of temporal variation occurred at sites 4 and 6, where there were large numbers of cirratulids during survey 2. The mean abundance of cirratulids at site 5 at BP tended to be smaller than at sites 4 and 6 during survey 2, but similar at other times. There was an increase in the abundance of cirratulids between surveys 3 and 4 at all sites at BP. There was a large but variable number of cirratulids at site 8 at BB during survey 2. There were few cirratulids at the other sites at BB.

Patterns of temporal variation of decapods were similar at the three sites at PH but there tended to be more at site 2 than at site 1 and site 3 (Fig. 8.19). At BP site 6, there was a relatively large number of decapods collected during survey 2. Numbers of decapods at this site were relatively small during other surveys and during all surveys at the other two sites at BP. There were relatively few decapods at BB and populations showed similar trends through time at all sites. The mean abundance of decapods increased at all sites between surveys 3 and 4.

Patterns of temporal variation of ophiuroids varied at two of the spatial scales investigated: among locations (see previous section) and sites. The time by site interaction was caused by inconsistent variation at site 4 at BP as all other sites showed similar trends through time (Fig. 8.20). The mean abundance of ophiuroids at all sites at PH was small and showed little temporal variation (Fig. 8.20). At BB, there was a gradual decrease in the abundance of ophiuroids between survey 1 and survey 3. Numbers of ophiuroids increased markedly between survey 3 and survey 4. Patterns of temporal variation at sites 5 and 6 at BP were similar; the mean abundance was relatively constant between survey 1 and survey 3 but increased between survey 3 and survey 4 (Fig. 8.20). At site 4, however, relatively large numbers of ophiuroids were collected during survey 2. The mean abundance of ophiuroids increased at all sites at BP between survey 3 and survey 4.

The mean number of polychaete taxa was greatest at site 3 at PH during survey 1, but, numbers at all sites were similar thereafter (Fig. 8.21). The number of polychaete taxa at BB and BP showed similar temporal trends; there was a gradual decrease in the number of taxa between survey 1 and survey 3, and an increase between survey 3 and survey 4. A similar temporal trend was apparent for crustacean taxa at all sites at BB and at site 4 at BP (Fig. 8.22). Crustacean taxa at the other two sites at BP showed a similar trend through time. Crustacean taxon richness varied between about 13 and 18 taxa per grab at PH.

An average of between 16 and 43 taxa were collected per grab (Fig. 8.23). Site 1 at PH had a greater taxonomic richness than the other two sites at this location during survey 1, but all sites had similar numbers of taxa thereafter. At BP, the mean number of taxa showed similar patterns of temporal variation at all sites during surveys 1, 2 and 4. Between survey 2 and survey 3, the number of taxa decreased at sites 4 and 6 but increased at site 5. The number of taxa showed similar patterns of temporal variation at all sites at BB. The number of polychaete, crustacean and total number of taxa tended to be smallest during survey 3 at BB (Figs. 8.21, 8.22, 8.23).

Interactions between depth and location

There were significant differences among locations in the abundance of chaetopterid and syllid polychaetes, ophiuroids and the number of polychaete taxa, but these differences also varied among depths (Appendix A18).

Fewer than 2.5 syllids per grab occurred at all locations at 25-30 m (Fig. 8.24). At 35-40 m there was no difference among locations. At 45-50 m, however, many more syllids occurred at BP than at PH and BB. There was no difference in the mean abundance of syllids at different depths at PH. There only small differences among depth at BB. The mean abundance of syllids increased markedly with depth at BP.

A similar pattern of variation among depths and locations occurred for chaetopterids (Fig. 8.24). Very few were collected at 25-30 m. There was no significant difference among locations at 35-40 m. There were more chaetopterids at BP than at PH and BB at 45-50 m. At PH and BP there were more chaetopterids at 45-50 m than at the shallower depths, but this difference among depths was much smaller at PH than BP. There was no difference among depths at BB.

The mean number of polychaete taxa at 25-30 m was similar at all locations. Significantly more taxa were collected at 35-40 m and 45-50 m at BP than at the equivalent depths at other locations. As with the syllids and chaetopterids, the greatest difference among locations occurred at 45-50 m. The mean number of polychaete taxa increased with depth at all locations but differences were greatest at BP.

Interactions between depths and sites within locations

Significant interactions between depths and sites within locations were detected for four variates (Appendix A18): nuculanid bivalves, gastropods, phoxocephalid amphipods and ophiuroids. Nuculanids were not collected from 25-30 m at any site (Fig. 8.25). The mean abundance of nuculanids at 45-50 m tended to be greater than at 35-40 m at all sites at PH and BB, but at site 6 (BP), there were similar numbers of nuculanids at 35-40 m and 45-50 m.

Phoxocephalids were also abundant at most sites (Fig. 8.25). At site 3 (PH) most phoxocephalids occurred at 25-30 m, while at site 7 (BB) most were collected from 35-40 m. Patterns of variation among depths differed among sites for the number of gastropods (Fig. 8.25). At site 3 (PH) and site 6 (BP) there were relatively large numbers of gastropods at 25-30 m.

Interactions among times, depths and locations

Significant interactions among times, depths and locations occurred for gastropods, pycnogonids and the numbers of mollusc, crustacean and total taxa. Two examples are described here: the abundance of gastropods and the total number of taxa.

There were relatively large temporal changes in the mean abundance of gastropods at PH and BP at 25-30 m (Fig. 8.26). Changes at BB were less pronounced. Significant differences among locations were only detected at 25-30 m during survey 3, when more gastropods occurred at PH than at BP. Temporal changes in the mean number of gastropods at 35-40 m were smaller than at 25-30 m (Fig. 8.26). No differences were detected in abundance of gastropods among locations or surveys at this depth. Patterns of temporal variation of gastropods at 45-50 m tended to differ at each location (Fig. 8.26). At all locations, the mean number of gastropods declined between survey 2 and survey 3 but there were different trends at each location between the other surveys. There were no significant differences among locations, but there were more gastropods at PH during survey 4 than during survey 1 and survey 3. There were no other differences among surveys.

Temporal changes in taxonomic richness at 25-30 m were similar at each location and no there were no differences among locations at this depth (Fig. 8.27). At PH and BB there were no significant differences among surveys, but at BP more taxa were collected during survey 1 than during the other surveys. At 35-40 m, patterns of temporal variation in taxonomic richness differed among locations (Fig. 8.27). At BB, more taxa were collected during survey 1 and survey 4 than during survey 2 and survey 3. A pattern occurred at BP but the magnitude of the differences among surveys was smaller. At PH, temporal changes in the mean number of taxa were smaller than at the other locations and no differences occurred among surveys.

Patterns of temporal change in taxonomic richness at 45-50 m were similar at BB and BP, but assemblages at BB during survey 3 were less rich than those at BP and PH (Fig. 8.27). Mean taxonomic richness at 45-50 m at BB was also smaller during survey 3 than at other times. Mean taxonomic richness at 45-50 m at PH during survey 1 was significantly less than at other locations during this survey. The mean number of taxa at PH increased over time and was similar to that at the other locations during survey 2 and survey 4.

Interactions among times, depths and sites within locations

Significant interactions among times, depths and sites were detected for 23 variates (Appendix A18). Examples of these include corophiids, apseudomorph tanaidaceans, spionids, onuphids and tellinid bivalves. Multivariate analyses showed that corophiids and spionids were representative of most macrobenthic assemblages. Onuphids and apseudomorphs were also common members of assemblages and tellinids were the most typical molluscs at the depths examined in design 1 analyses.

Patterns of temporal variation of corophiids varied among sites and depths (Fig. 8.28). At BB, corohphiids were very abundant at sites 8 and 9 at 45-50 m and 35-40 m, respectively, during survey 1, but were rare thereafter. Temporal variation was greatest at 35-40 m and 45-50 m at most sites, except at site 6 (BP). Corophiids at all sites at PH were least abundant during survey 2 and elsewhere during surveys 2 and/or 3.

Apseudomorph tanaidomorphs were more abundant at 45-50 m and 35-40 m than at 25-30 m, where few were collected (Fig. 8.29). Relatively few apseudomorphs occurred at 35-40 m at PH. The number of apseudomorphs at 35-40 m and 45-50 m was smallest during survey 3, and increased between survey 3 and survey 4 at many sites.

Patterns of temporal variation of spionids also varied among sites and depths (Fig. 8.30). Generally, the number of spionids decreased between survey 1 and survey 3 and increased between survey 3 and survey 4. Large numbers of spionids occurred at site 4 and site 5 at BP during survey 2. Numbers of spionids were smallest were smallest during survey 3 at all sites at BP and BB. Large numbers occurred at 25-30 m at site 3 (PH) during survey 1, but fewer occurred in survey 2. This difference may be an artefact of the relocation of this site between surveys 1 and 2 (Section 8.1.2.1), although similar decreases were noted where there was no relocation of sites.

Patterns of temporal variation of onuphids at each site varied among depths (Fig. 8.31). As with the spionids and corophiids, the mean abundance of onuphids at all sites at BB was small during survey 3. Onuphids were abundant but patchy at 25-30 m and 35-40 m during surveys 1 and/or 4 at some sites. Increases in abundance were noted between survey 3 and survey 4 at some sites and depths but this trend was not as apparent as in the previous examples. Tellinids were often relatively abundant at 35-40 m but at site 8 at BB they tended to be most abundant at 25-30 m (Fig. 8.32). Mean abundance at BB sites 8 and 9 was small as in the other variates discussed above. There were large increases in the mean abundance of tellinids between survey 3 and survey 4 at 35-40 m at site 2 (PH), sites 4 and 6 (BP) and site 9 (BB). Numbers were small at 45-50 m (mean ≤ 2) throughout the study.

8.1.3.3.2 Design 2: Comparison of all 4 Depths during Surveys 2, 3 and 4 at PH, BB and BP

Variation among times

Only the number of mollusc taxa varied consistently among surveys. The mean number of mollusc taxa collected was significantly greater during survey 2 (mean = 5.8, SE = 0.2) and survey 4 (mean = 6.1, SE = 0.2) than survey 3 (mean = 4.7, SE = 0.2).

Variation among depths

There were no consistent differences detected among depths.

Variation among locations

Only the abundance of bodotriid cumaceans varied significantly among locations (Appendix A19). There were significantly more bodotriids at PH (mean = 3.1, SE = 0.3) than at BP (mean = 1.7, SE = 0.2) and BB (mean = 1.8, SE = 0.2).

Variation among sites within locations

Only pycnogonids varied consistently among sites (Appendix A19). They tended to be most common at the sites at PH, site 5 at BP and site 7 at BB (Fig. 8.33).

Interactions between time and depth

A significant interaction between times and depths only occurred for the number of polychaete taxa (Appendix A19). The number of polychaete taxa tended to increase with depth (Fig. 8.34). The interaction occurred because of temporal changes at 35-40 m and 45-50 m. During survey 2, more polychaete taxa occurred at 45-50 m and 65-70 m than at 35-40 m. During survey 3, the number of polychaete taxa increased with depth. During survey 4, the number of polychaete taxa was similar at 35-40 m and at 45-50 m but less than at 65-70 m.

At 25-30 m and 65-70 m, the number of polychaete taxa did not vary among surveys. At 35-40 m, there were significantly more taxa during survey 4 than during survey 3 but no difference was detected between survey 2 and survey 3 nor survey 2 and survey 4. At 45-50 m, more polychaete taxa occurred during survey 2 than surveys 3 and 4.

Interactions between time and location

Significant interactions between times and locations occurred for spionids, pectinids, aorids, phoxocephalids, diastylid cumaceans and ophiuroids (Appendix A19). Most pectinids were collected during survey 1 and the patterns of temporal variation are shown in figure 8.17.

Patterns of temporal variation differed among locations for spionids, phoxocephlaids, aorids, diastylids and ophiuroids due to large increases in abundance at some locations between survey 3 and survey 4 (Fig. 8.35). This led to differences among locations during survey 4. Significantly more diastylids, and phoxocephalids occurred at BB than at BP or PH during survey 4. The number of spionids did not differ among locations during survey 4. There were significantly more aorids at BB and PH than at BP during survey 4. Finally, ophiuroids were more abundant at BP and BB than PH during survey 4.

Interactions between time and sites within locations

Significant interactions between times and sites within locations occurred for lysianassids, the number of crustacean taxa and the total number of taxa. Patterns of temporal variation of lysianassids were different at the sites within each location (Fig. 8.36). Large increases in the abundance of lysianassids between survey 3 and survey 4 only occurred at site 7 at BB.

There was less temporal variation in the number of taxa collected at each site (Fig. 8.37). The mean number of taxa at PH and BP was relatively constant over time, whereas the mean number of taxa at BB was smallest during survey 3.

Interactions between depth and location

Significant interactions between depths and locations were detected for cirratulids, syllids, phoxocephalids, lysianassids, ophiuroids and the number of polychaete taxa (Appendix A19).

The mean abundance of cirratulids at PH and BB was significantly greater at 65-70 m than at shallower depths (Fig. 8.38). Similar numbers of cirratulids occurred at 35-40 m, 45-50 m and 65-70 m at BP. There were few cirratulids at 25-30 m. At 35-40 m and 45-50 m cirratulids were similarly abundant at all locations. At 65-70 m, there were significantly more cirratulids at PH than at BP. No significant difference was detected between the mean abundance of cirratulids at BP and BB nor BB and PH.

Syllids were distributed differently among depths at each location (Fig. 8.38). There were few syllids at 25-30 m. At PH and BB, syllids were most abundant at 65-70 m. At BP, syllids were most abundant at 45-50 m and 65-70 m, and significantly more occurred at 35-40 m than at 25-30 m and at 65-70 m than at 35-40 m. At 35-40 m, syllids were more abundant at PH and BP than at BB (Fig. 8.38). At 45-50 m, syllids were most abundant at BP. At 65-70 m, there were similar numbers of syllids at all locations.

The number of polychaete taxa tended to increase with depth (Fig. 8.38). At PH, there were significant differences among all depths. At BP a similar number of taxa occurred at 45-50 m and 65-70 m. At BB, significantly more polychaete taxa occurred at 65-70 m than the shallower depths and there were also significantly more polychaete taxa at 35-40 m and 45-50 m than at 25-30 m. Similar numbers of polychaete taxa occurred at each location at each depth.

Phoxocephalids occurred in similar numbers at all depths at PH (Fig. 8.38). At BP, mean abundance tended to decrease with depth and more phoxocephalids occurred at 25-30 m and 35-40 m than at 65-70 m. At BB, there were large populations of phoxocephalids at 35-40 m and 65-70 m, but no significant difference was detected among depths. The mean abundance of phoxocephalids at 25-30 m, 35-40 m and 45-50 m was not significantly different among locations (Fig. 8.38). At 65-70 m, phoxocephalids were most abundant at BB and more abundant at PH than at BP.

Lysianassids were distributed differently among depths at each location (Fig. 8.38). They were most abundant at 45-50 m at BP. At BB, they were most abundant at 45-50 m and 65-70 m. At PH, more lysianassids occurred at 45-50 m than at 25-30 m and 35-40 m but no significant difference was detected between mean abundance at 45-50 m and 65-70 m nor 35-40 m and 65-70 m. Lysianassids were similarly abundant at all locations at 25-30 m, 35-40 m and 45-50 m. At 65-70 m lysianassids were most abundant at BB.

Ophiuroids were more abundant at 45-50 m than the other depths at BP (Fig. 8.38). Very few ophiuroids were collected from PH and there were no significant differences among depths. At BB, ophiuroids were more abundant at 35-40 m, 45-50 m and 65-70 m than at 25-30 m. At 25-30 m, 35-40 m and 65-70 m ophiuroids occurred in similar numbers at each location. At 45-50 m, ophiuroids were most abundant at BP.

Interactions between depths and sites within locations

Interactions between depths and sites within locations occurred for pectinids, aorids, lysianassids, the number of polychaete taxa, mollusc taxa, crustacean taxa and the total number of taxa (Appendix A19). Three examples are illustrated in Figure 8.39.

There were several patterns of variation among depths for aorids and lysianassids. Aorids were abundant at 45-50 m at two sites at both PH and BB. They were uncommon at BP and 25-30 m (Fig. 8.39). Lysianassids tended to be most abundant at 45-50 m at all sites at BP but not at the other locations. Taxonomic richness tended to increase with depth at all sites except site 6 at BP (Fig. 8.39)

Interactions among times, depths and locations

Significant interactions among times, depths and locations were detected for sabellids, lumbrinerids, pycnogonids, the number of crustacean taxa and the total number of taxa (Appendix A19).

Sabellids tended to be most abundant at 65-70 m (Fig. 8.40). Sabellids were more abundant at PH and BB than at BP during all surveys at 65-70 m. During survey 2, there were significantly more sabellids at BB than at PH. There were different patterns of temporal variation of sabellids at 65-70 m at all locations. At PH, the mean number of sabellids was similar during survey 2 and survey 3 but increased between survey 3 and survey 4. Sabellids were most abundant at PH during survey 4. At BB, the abundance of sabellids at 65-70 m decreased between survey 2 and survey 3 but increased between survey 3 and survey 4. Significantly more sabellids were collected during survey 2 and survey 4 than during survey 3 at BB. At BP, the mean abundance of sabellids at 65-70 m increased between survey 2 and survey 3, and sabellids were most abundant during survey 3 and survey 4.

Lumbrinerids were also abundant at 65-70 m at PH and BB, whereas few were collected from BP (Fig. 8.41). At 65-70 m, lumbrinerids were most abundant at PH and BB. During survey 2, more lumbrinerids occurred at BB than at PH, whereas the opposite was true during survey 3. Similar numbers of lumbrinerids occurred at PH and at BB during survey 4 at 65-70 m. At 45-50 m, more lumbrinerids occurred at BP and at PH than BB during survey 3, and more were at BP than at PH and BB during survey 4. During survey 2, lumbrinerids were similarly abundant at each location.

Different patterns of temporal variation occurred at each location for lumbrinerids at 65-70 m (Fig. 8.41). At PH, lumbrinerids increased between survey 2 and survey 3 and significantly more lumbrinerids occurred during survey 3 and survey 4 than during survey 2. At BB, lumbrinerids were more abundant in survey 2 and survey 4 than survey 3 at BB. This pattern is similar to that described for many other taxa at BB, where few animals occurred during survey 3.

Taxonomic richness tended to increase with depth but this pattern varied among locations (Fig. 8.42). At PH, there was a consistent increase in the mean number of taxa with depth. During survey 2 and survey 4 there were more taxa at 45-50 m and 65-70 m than at 25-30 m and 35-40 m. During survey 3, there were more taxa at 65-70 m than at 45-50 m, and more taxa at 45-50 m than at 35-40 m or 25-30 m. At BP, temporal variation in the number of taxa at 65-70 m was different to that at the other depths. During survey 2, most taxa occurred at 45-50 m. More taxa were collected from 45-50 m and 65-70 m than from 35-40 m where there were more taxa than at 25-30 m during survey 3. During survey 4, least taxa were collected from 25-30 m.

Temporal patterns of taxonomic richness were similar at 25-30 m, 35-40 m and 65-70 m at BB (Fig. 8.42). At 45-50 m, however, the number of taxa decreased between survey 2 and survey 3. Between survey 3 and survey 4 there were similar increases in taxonomic richness at all depths. During survey 2, most taxa were collected from 45-50 m and 65-70 m at BB. During survey 3, most taxa occurred at 65-70 m at BB. During survey 4, more taxa were collected from 35-40 m, 45-50 m, and 65-70 m than 25-30 m at BB.

During surveys 2, 3 and 4, there were similar numbers of taxa at 25-30 m at PH, BP and BB. During surveys 2 and 3, taxonomic richness at 35-40 m at PH and BP was greater than at BB. During survey 4, however, richness was greater at BB than PH, but no difference was detected between BB and BP nor PH and BP at this depth. At 45-50m, similar numbers of taxa occurred at PH, BP and BB in surveys 2 and 4, but during survey 3, more taxa were collected from PH and BP than BB. At 65-70 m, there tended to be more taxa at PH and BB than BP during surveys 2 and 4. During survey 3, more taxa were collected from PH than BB but no difference was detected between the mean number of taxa at BB and BP nor BP and PH.

Interactions among times, depths and sites within locations

Twenty-three significant interactions were detected among times, depths and sites within locations (Appendix A19, Table 8.5). Chaetopterid, maldanid, spionid and syllid polychaetes, nuculanid bivalves, nassariid gastropods, corophiid amphipods, isopods, and apseudomorph and tanaidomorph tanaidaceans are used as examples.

Chaetopterids were abundant only at BP (Fig. 8.43). Large numbers of chaetopterids occurred at site 4 at 65-70 m, and they were less abundant at 45-50 m at this site. Chaetopterids were also common at 35-40 m at site 4 during survey 2, but declined thereafter. No chaetopterids were collected from 25-30 m at any BP sites. At site 5 there were few chaetopterids collected from 65-70 m during survey 2 and survey 3 but they were very abundant during survey 4 (Fig. 8.43). At site 6, chaetopterids were relatively abundant at 45-50 m during all surveys (Fig. 8.43). They were also abundant at 65-70 m during survey 2 at this site, but few were collected at this depth at other times.

Maldanids were relatively abundant at the 35-40 m, 45-50 m and 65-70 m at all sites (Fig. 8.44). They were rare at 25-30 m.

There were large numbers of maldanids at 65-70 m at site 3 (PH) during survey 3 and survey 4. At site 2 (PH) maldanids were most abundant at 65-70 m and at site 1 (PH) they were also abundant at 35-40 m. There were various patterns of temporal variation at the other sites but maldanids were most common at 45-50 m and 65-70 m and, at some sites, 35-40 m.

Spionids were most abundant at 65-70 m (Fig. 8.45). There were many patterns of temporal varion but the number of spionids at 25-30 m, 35-40 m and 45-50 m tended to increase between survey 3 and survey 4 at all sites. There was a large but variable number of spionids at 65-70 m at site 6 (BP).

Syllids were most abundant at 65-70 m at PH and BB, although there large but variable numbers at 35-40 m at site 1 (PH) during survey 3 (Fig. 8.46). Temporal variation in the number of syllids at all sites at PH and BB was small except at 35-40 m at site 1 (PH). At BP, syllids were very abundant at 45-50 m (Fig. 8.46). Syllids were also abundant at 65-70 m at BP and, at site 4, they were abundant at 35-40 m. The number of syllids tended to show more temporal variation at BP than at PH and BB.

Nuculanid bivalves were often most abundant at 45-50 m (Fig. 8.47). Unlike some other taxa, the number of nuculanids only increased at a few sites between survey 3 and survey 4.

Nassarids were most abundant at 65-70 m but the distribution and abundance of these gastropods was patchy (Fig. 8.48). Few nassarids were sampled from most sites and when the mean abundance was large differences among replicate samples were also large indicating small-scale aggregations. This is not suprising as nassarids may be scavengers, aggregating near food.

Corophiids were relatively abundant at all sites, depths and times (Fig. 8.49). Although they tended to be most abundant at 65-70 m, especially at PH and BB, this was not always true. Temporal variation in the number of corophiids was relatively small except for populations at 45-50 m at site 2 (PH) and 25-30 m at site 6 (BP).

Temporal change in the abundance of isopods was quite variable (Fig. 8.50). They were relatively abundant at all depths, but they tended to be least abundant at 25-30 m. Temporal variation in the number of isopods at some sites and depths was large. The number of isopods increased between survey 3 and survey 4 at some sites and depths.

Apseudomorph tanaidaceans were most abundant at 45-50 m and 65-70 m at PH (Fig. 8.51). Few were collected from 25-30 m and 35-40 m at this location. Similarly, few apseudomorphs occurred at 25-30 m at BP and BB, but at sites 5, 6 (BP) and 7 (BB), relatively large numbers occurred at 35-40 m. The number of apseudomorphs increased between survey 3 and survey 4 at some sites and depths.

The mean abundance of tanaidomorph tanaidaceans at 35-40 m and 45-50 m at site 9 (BB) during survey 2 was large but patchy (Fig. 8.52). During surveys 3 and 4 few tanaidomorphs occurred at 35-40 m and 45-50 m at this site. Elsewhere at BB, were most common at 65-70 m, but there were relatively large numbers at 35-40 m and 45-50 m during some surveys. Tanaidomorphs were also abundant at 35-40 m and 45-50 m during some surveys at site 1 (PH). At sites 2 and 3 (PH), they were most abundant at 65-70 m. At BP, tanaidomorphs were most abundant at 35-40 m at site 4, but at sites 5 and 6 they tended to be most abundant at 45-50 m. Tanaidomorphs were rare at 25-30 m at all sites.

8.1.3.3.3 Design 3: Comparison of all 4 Locations during Surveys 2, 3 and 4 at 45-50 m and 65-70 m

This series of analyses compared populations at Cape Banks (CB) with those at the other locations during survey 3 and survey 4 and at 45-50 m and 65-70 m. More significant main effects occurred in these analyses than in design 1 and 2 analyses. This may have been due to fewer levels of time and depth being compared in these analyses than in analyses using designs 1 and 2 (Table 8.5).

Variation among times

Consistent differences between survey 3 and survey 4 occurred for ampeliscis, lysianassids, the number of polychaete taxa and the number of mollusc taxa irrespective of the depth and sites sampled (Appendix A20).

Ampeliscids were more abundant during survey 4 (mean = 13.3, SE = 1.44) than during survey 3 (mean = 9.8, SE = 1.53). Similarly, lysianassids were more abundant during survey 4 (mean = 3.95, SE = 0.37) than during survey 3 (mean = 2.09, SE = 0.24).

The number of polychaete taxa and the number of mollusc taxa also increased between survey 3 and survey 4. An average of 10.9 (SE = 0.45) polychaete families were collected during survey 3 compared to 13.0 (SE = 0.40) during survey 4. Similar increases occurred for the number of mollusc taxa. An average of 4.65 (SE = 0.25) families were collected during survey 3 and an average of 6.72 (SE = 0.29) during survey 4.

Variation among depths

Significant differences between depths occurred for ampeliscids, urohaustorids, the number of polychaete taxa, the number of mollusc taxa and the total number of taxa (Appendix A20).

Ampeliscids were more abundant at 65-70 m (mean = 16.5, SE = 1.83, n = 96) than at 45-50 m (mean = 6.55, SE = 0.78). Conversely, urohaustorids were more abundant at 45-50 m (mean = 1.11, SE = 0.22) than at 65-70 m (mean = 0.052, SE = 0.027).

The number of polychaete taxa, mollusc taxa and the total number of taxa was greater at 65-70 m (means: 14.0, 6.56, 43.2; SE: 0.39, 0.27, 1.19, respectively) than at 45-50 m (means: 9.91, 4.80, 34.2; SE: 0.39, 0.28, 1.12, respectively).

Variation among locations

Significant differences among locations occurred for bivalves, ampeliscids, corophiids, platyischnopids and bodotriids (Appendix A20). Bivalves and bodotriids were most abundant at PH (Fig. 8.53).

Corophiids were more abundant at PH than at CB but no significant difference was detected among PH, BB and BP nor BB, BP and CB (Fig. 8.53). The mean abundance of ampeliscids tended to be greatest at PH followed by BB with similar mean abundances recorded at BP and CB (Fig. 8.53). However no significant difference were detected among locations, possibly because the mean abundance also varied among sites within locations (see below). Platyischnopids were rare at all locations, they tended to be most abundant at BB and CB (Fig. 8.53). Significant differences were only detected between BB and BP; no difference was detected between BB, CB and PH nor BP, PH and CB.

Variation among sites within locations

Consistent differences among sites only occurred for ampeliscids (Appendix A20, Fig. 8.53). The mean abundance of ampeliscids varied mainly among sites within PH and BP. The number of ampeliscids also varied among locations (see above).

Interactions between time and depth

Significant time by depth interactions only occurred for sabellid and spionid polychaetes out of the 20 tests done (Appendix A20). Sabellids and spionids were more abundant at 65-70 m than 45-50 m during both surveys. Also, more of these polychaetes occurred during survey 4 than during survey 3 at both depths. The interactions occurred because the number of sabellids and spionids increased at a greater rate at 65-70 m than at 45-50 m between survey 3 and survey 4 (Fig. 8.54).

Interactions between time and location

Significant time by location interactions were detected for 12 variates (Table 8.5; Appendix A20). These were cirratulids, onuphids, spionids, pectinids, aorids, phoxocephalids, diastylids, ostracods, decapods, ophiuroids, the number of crustacean taxa and the total number of taxa. Most of these variates increased or remained relatively constant between surveys 3 and 4. The interactions were generally caused by large increases in the numbers of the taxa at some locations between survey 3 and survey 4 (Fig. 8.55).

The number of cirratulids at PH decreased between survey 3 and survey 4, whereas the number at the other locations increased or remained relatively constant (Fig. 8.55). During survey 3, more cirratulids occurred at PH than elsewhere. During survey 4, there was no difference between CB, BB and PH. At BP, the number of cirratulids was constant over time and mean abundance was less than PH and CB during survey 4. No difference was detected between BP and BB.

Onuphids tended to be most abundant at CB and they increased in number between survey 3 and survey 4 (Fig. 8.55). There was no significant difference among locations during survey 3, but onuphids were signficantly more abundant at CB than at the other locations during survey 4.

The number of spionids increased significantly between survey 3 and survey 4 at BB and CB (Fig. 8.55). During survey 3, spionids were significantly more abundant at PH than CB, and during survey 4, spionids were significantly more abundant at CB than at BP. There were no other significant differences in the number of spionids between locations.

Pectinids were relatively uncommon at 45-50 m and 65-70 m (Fig. 8.55). Nevertheless, the number of pectinids increased significantly at PH between survey 3 and survey 4, and there were significantly more pectinids at PH than at the other locations during survey 4.

Aorids were most abundant at PH during survey 3 (Fig. 8.55). A significant increase in the number of aorids occurred at PH, BB and CB between survey 3 and survey 4, but little change occurred at BP. During survey 4, more aorids occurred at PH and BB than at CB, and aorids were least abundant at BP.

There were only small differences in the number of phoxocephalids at each location during survey 3 (Fig. 8.55). Significant increases in the number of phoxocephalids occurred between survey 3 and survey 4 at BB and CB, but little change occurred at PH and BP. During survey 4, phoxocephalids were most abundant at BB and CB.

The abundance of diastylid cumaceans did not differ significantly among locations during survey 3 (Fig. 8.56). Significant increases between survey 3 and survey 4 occurred at CB and BB, but these increases were larger at BB than CB. During survey 4, diastylids tended to be most abundant at BB, but no significant difference was detected between BP, PH and CB nor CB and BB.

Ostracods were most abundant at PH, and more abundant at BP than at BB and CB during survey 3 (Fig. 8.56). The number of ostracods significantly increased at BB and CB between survey 3 and 4 but no significant change occurred at PH and BP. During survey 4, there tended to be more ostracods at BB and PH than CB and BP but no significant difference among locations was detected.

Decapods were most abundant at PH, and more abundant at BP than at CB during survey 3 (Fig. 8.56). The number of decapods increased significantly at all locations between survey 3 and survey 4. During survey 4, more decapods occurred at PH than BP; no other differences occurred among locations.

There were only small differences between the number of ophiuroids at each location during survey 3 (Fig. 8.56). The number of ophiuroids increased significantly at all locations between survey 3 and survey 4. These increases were greater at CB, BB and BP that at PH and ophiuroids were least abundant at PH during survey 4.

The number of crustacean taxa and the total number of taxa underwent similar patterns of temporal variation (Fig. 8.56). There tended to be more taxa at PH than BP and more taxa at BP than CB and BB during survey 3. Significant increases in both variates occurred at BB and CB between survey 3 and survey 4. During survey 4, there were no diffences among locations for either variate.

Interactions between time and sites within locations

Significant interactions between times and sites within locations occurred for sabellid polychaetes and nassarid gastropods (Appendix A20).

Increases in the number of sabellids between survey 3 and survey 4 occurred at some sites at PH, BB and CB (Fig. 8.57). The number of sabellids remained relatively constant at the other sites.

The number of nassarid gastropods was relatively constant at all sites at PH and CB, and at two sites at BB and BP between survey 3 and survey 4 (Fig. 8.58). At site 7 (BB), the mean number of nassarids increased between surveys but variability was large. At this site, 76 nassarids were collected in one sample, but < 10 were collected in the other seven samples. Thus, this change at may be due to sampling an aggregation of nassarids. At site 6 (BP), the abundance of nassarids decreased between survey 3 and survey 4. This change may also highlight the patchy distribution of nassarids.

Interactions between depth and location

Significant depth by location interactions were detected for cirratulids, lumbrinerids, syllids, tanaidomorph tanaidaceans, bryozoans and pycnogonids (Appendix A20).

Cirratulids were more abundant at 65-70 m than 45-50 m at PH and BB but not at CB or BP (Fig. 8.59). There were no significant differences among locations in the number of cirratulids at 45-50 m. At 65-70 m, cirratulids were most abundant at PH.

Lumbrinerids were distributed among depths and locations in a similar fashion to cirratulids (Fig. 8.59). They were more abundant at 65-70 m than at 45-50 m at PH, BB and CB. There were no significant differences among locations in the number of lumbrinerids at 45-50 m. At 65-70 m, lumbrinerids were most abundant at PH and more occurred at BB than BP.

Syllids were more abundant at 65-70 m than at 45-50 m at PH and BB (Fig. 8.59). At BP and CB syllids tended to be more abundant at 45-50 m than at 65-70 m, but these differences were not statistically significant. Syllids were more abundant at BP than at BB or PH at 45-50 m. There were no differences among locations at 65-70 m.

Tanaidomorph tanaidaceans were more abundant at 65-70 m than at 45-50 m at BB (Fig. 8.59). Conversely, they were more abundant at 45-50 m than at 65-70 m at BP (Fig. 8.59). There was no difference between depths in the number of these crustaceans at PH and CB. At 45-50 m, there were no differences in the number of tanaidomorphs among locations, whereas, at 65-70 m, they were least abundant at BP.

Bryozoans were only more abundant at 65-70 m at BB (Fig. 8.59). At 45-50 m, they were abundant at PH and BP but no significant differences were detected between CB and PH. No significant differences in the abundance of bryozoans were detected among locations at 65-70 m, but they were uncommon at CB.

More pycnogonids were collected at 65-70 m than at 45-50 m at PH and BB (Fig. 8.59). No significant differences among locations occurred at either depth.

Interactions between depths and sites within locations

Significant interactions between depths and sites within locations occurred for cirratulids, syllids, sabellids, nuculanids, pectinids, nassarids, lysianassids, phoxocephalids, ostracods, decapods, ophiuroids, and the number of crustacean taxa (Appendix A20).

Cirratulids tended to predominate at 65-70 m at all PH sites and at BB, site 7 (Fig. 8.60). Similar numbers occurred at both depths within all other sites. Sabellids tended to be more abundant at 65-70 m at the PH and CB sites and at BB site 7 (Fig. 8.60). Sabellids were less common elsewhere. Syllids tended to predominate at 65-70 m at all sites at PH and BB. These worms were abundant at 45-50 m and 65-70 m at BP and locally abundant at 45-50 m at site 10 at CB.

Nuculanid bivalves were most abundant at 45-50 m at many sites at PH, BP and BB (Fig. 8.60). At CB, nuculanids were also abundant at 65-70 m. Pectinid bivalves were uncommon during surveys 3 and 4 at 45-50 m and 65-70 m (Fig. 8.61). Nassarid gastropods tended to be most abundant at 65-70 m, except at sites 4, 9 and 11 (BP, BB and CB respectively) (Fig. 8.61).

Lysianassids were abundant at 45-50 m and 65-70 m but differences among depths varied among sites within all locations (Fig. 8.61). Phoxocephalids tended to occur in similar numbers at both 45-50 and 65-70 m except at sites 7 and 8 (BB) where many occurred at 65-70 m (Fig. 8.61). Ostracods were similarly abundant at both depths at most sites (Fig. 8.62). But, at site 2 (PH), there tended to be more ostracods at 65-70 m than at 45-50 m. The opposite occurred at site 3 (PH). The mean abundance of decapods was similar at both depths for about half of the sites (Fig. 8.62). More decapods occurred at 65-70 m than at 45-50 m for at least one site within each location. At site 2 (PH), decapods tended to be more abundant at 45-50 m than at 65-70 m.

The abundance of ophiuroids was similar between depths at most sites (Fig. 8.62). Exceptions were at PH site 3, where more tended to occur at 65-70 m, and at BP sites 5 and 6 where more tended to be more at 45-50 m. Crustacean taxa occurred in similar numbers at both depths at most sites (Fig. 8.62). Exceptions were BP site 6 where there tended to be more at 45-50 m and BB site 8 where the opposite occurred.

Interactions among times, depths and locations

No significant interactions between times, depths and locations were detected using design 3.

Interactions among times, depths and sites within locations

Significant interactions among times, depths and sites were detected for 17 of the 36 variates (Table 8.5). Variability at this level does not highlight the Cape Banks sites, and most of the interactions are discussed more fully in sections 8.1.3.3.1 and 8.1.3.3.2 above. Examples are presented for chaetopterids, maldanids, onuphids, bivalves, aorids and tanaidomorph tanaidaceans, most of which were common in assemblages at 45-50 m and 65-70 m.

Chaetopterids were rare at all sites except for two sites at BP (see Section 8.1.3.3.2, Figs. 8.43, 8.63). In this respect CB is similar to PH and BB (Fig. 8.63).

Maldanids occurred at all sites, but variability was inconsistent among sites and depths (Fig 8.64). They were usually most common at 65-70 m. Large numbers of maldanids were collected at site 3 (PH) during survey 3 and survey 4 as discussed previously .

Onuphids were rare at 45-50 m and 65-70 m at all locations except CB (Fig. 8.65). At CB, they were abundant at 45-50 m and 65-70 m at different sites and the number of onuphids increased between survey 3 and survey 4 at most sites and depths.

Bivalves were relatively abundant at all sites at 45-50 m and 65-70 m (Fig. 8.66). The number of bivalves tended to increase between survey 3 and survey 4 at BB and CB. Temporal variation was less consistent at sites within BP and PH.

Aorids tended to be more abundant at PH, BB and CB than BP (Fig. 8.67). The number of aorids increased between survey 3 and survey 4 at some sites and depths. Temporal trends at CB were similar to those at the other locations.

Tanaidomorph tanaidaceans were also relatively abundant at 45-50 m and 65-70 at most sites, but few were collected at 65-70 m at BP (Fig 8.68). Again, temporal trends at Cape Banks were similar to those at the other locations.

8.1.4 Conclusions

Taxonomically-rich assemblages of polychaetes, crustaceans and molluscs exist in the sand bodies studied. The number of animals is comparable to the few other studies done in nearshore marine habitats off NSW (e.g. FRI 1992). Crustaceans were the most abundant constituent, followed by polychaetes and molluscs. Important families of infauna in this study included corophiid and phoxocephalid amphipods, tanaidaceans, and spionid, syllid and maldanid polychaetes. These animals were distributed widely among the sand bodies whereas others, such as chaetopterids, had a more local distribution.

This study has shown that there is significant spatial and temporal variation in assemblages and populations of macrofauna off the coast of Sydney. Populations of benthic macrofauna often showed significant variation through time which was inconsistent among sites (and vice versa). This is a common feature of populations of marine invertebrates and was also observed for infaunal populations off Sydney by the FRI (1992). The many significant space-time interactions detected in this study suggest that populations of macrofauna are patchy in time and space.

There was consistent variation among depths in the distribution of assemblages and populations and macrofauna. Depth gradients were apparent for assemblages during all surveys. They were also clear for many taxa where the distribution among depths often varied among sites and over time. Similarity analyses suggested that differences in assemblages of macrofauna among depths were due to changes in the abundance of many taxa, not just a few dominant taxa. In other words, the assemblages appear to be structured by a large number of taxa rather than a few very abundant ones. Polychaetes such as spionids, syllids and amphipods such as corophiids were present in relatively large numbers at all depths. Other taxa such as chaetopterids and maldanids were very abundant at some places and during some surveys but not others.

Patterns of variation among depths may have important consequences for the impact of marine aggregate extraction on assemblages of macrofauna. Extraction of marine aggregate from shallower areas would remove fewer animals than extraction from deeper areas because populations were generally smaller and less taxonomically-rich in shallower areas. FRI (1992) found that spionids may also be abundant in 100 m of water. But other taxa such as maldanids, syllids, amphipods, cumaceans and tanaidaceans may be less abundant in these deeper waters (FRI 1992).

Within the broad-scale patterns of distribution among depths, there was a variety of patterns of temporal and spatial change in macrofaunal assemblages. Assemblages changed over time and these changes were not necessarily similar at the smallest spatial scale examined for assemblages. i.e. among sites within locations. Similarly, different patterns of temporal variation in the abundance of many taxa were apparent at small spatial scales.

Identification to family was sufficient to identify natural patterns of variation in assemblages and populations of macrofauna in this study. This level of identification has been used successfully to detect changes in assemblages of macrofauna due to pollution (Warwick 1988a,b; Ferraro and Cole 1990). Thus, identification to family often is now considered taxonomically sufficient to detect changes in assemblages of macrofauna (Warwick 1988a,b; Ferraro and Cole 1990; Clarke 1993).

Broad-scale patterns of distribution are considered to be caused by large-scale (both spatial and temporal) abiotic physical and chemical factors (Barry and Dayton 1991). Within these broad patterns of distribution, other processes may alter abundances at smaller spatial and temporal scales (Barry and Dayton 1991). Processes operating at these smaller-scales may be abiotic, biotic or a combination of the two (Thrush et al. 1991).

The broad-scale distribution of assemblages among depths may be related to the extent of disturbance by wave-action. In shallow water, the sediment is physically disturbed more than in deeper water. This disturbance may make shallow habitats less hospitable to some taxa. Waves may scour food from the sediment and prevent detritus and larvae from settling. Spatial and temporal mosaics of patches may be caused by disturbance (Johnson 1973; Grassle and Sanders 1973; Thistle 1981). Biological interactions may be more important in structuring assemblages in deeper water where disturbance by waves is less frequent and severe.

The physical structure of the benthic habitat may also contribute to differences among depths. The number of taxa and the abundance of tube-dwelling forms such as tanaidaceans, chaetopterids and some corophiids tended to increase with depth. Morrisey et al. (1992) noted that more individuals and taxa occurred at a site in Botany Bay with large numbers of chaetopterid tubes than at nearby sites without tubes. They suggested that the presence of tubes may facilitate the presence of other animals in some way (Morrisey et al. 1992). Gallagher et al. (1983) showed that tubes of polychaetes and tanaidaceans facilitated the recruitment of other taxa. Similar mechanisms may contribute to the pattern for larger numbers of taxa and infauna to be collected in deeper water in this study. If so, this has important implications for aggregate extraction. If the taxonomic richness of assemblages in deeper (65-70 m) areas depends on the presence of tubes and tube-worms, aggregate extraction at these depths may cause longer-term changes than aggregate extraction in shallower areas where tube-dwelling macrofauna are less abundant.

It is difficult to determine which processes cause the smaller-scale patterns of temporal and spatial differences within depths in an observational study. Nevertheless, some patterns of variation provide clues to the mechanisms that cause them. In this study, the abundance of many infaunal populations increased between survey 3 and survey 4. Recruitment of macrofauna may have caused this pattern.

Increases in the abundance of macrofauna between survey 3 and survey 4 varied at several spatial scales. In this study, variable spatial patterns of recruitment would show up as interactions between time and other the factors (locations, sites within locations and depths). For example, between survey 3 and survey 4 there were large increases in the abundance of: aorid amphipods at PH and BB but not BP; phoxocephalid amphipods at BB but not PH or BP; and ophiuroids at BP and BB but not PH (see Fig. 8.35). Other temporal changes varied at the smaller spatial scale of sites within locations and among depths. Consistent temporal changes over time, independent of depth, location or site, were rare. This indicates that the recruitment of macrofauna in the areas studied is likely to be variable at several spatial scales and may be a major factor contributing to the space-time interactions observed in this study.

Variation of recruitment in space is well known for marine invertebrates (Gaines et al. 1985; Underwood and Fairweather 1989). The most important consequence of variable patterns of recruitment is that the structure of assemblages becomes variable, and probably unpredictable, through time and space (Underwood and Fairweather 1989). Certain taxa may not be present in some areas simply because they fail to reach these areas, whereas other taxa will recruit to some areas in large numbers (Underwood and Fairweather 1989).

It is possible that the trend for the abundances of some taxa and the number of taxa to be smallest during survey 3 may be a seasonal phenomenon. Recruitment may be a seasonal phenomenon and, coupled with physical factors such as disturbance by waves that may also be seasonal, may explain the patterns observed. Again, it is likely that any seasonal changes also vary in space for the macrofauna studied. For example, the pattern of smaller abundances during survey 3 occurred mainly at Bate Bay, but not necessarily at Providential Head which is only 5-10 km away.

Also, some assemblages of macrofauna at 45-50 m were relatively depauperate during survey 3 whereas others were not.

The lack of differences among locations in populations and assemblages may have been due to relatively large variability at smaller spatial scales (i.e. among sites or grab samples) or because no differences exist. We conclude that the proposed extraction areas are not outstanding, in terms of assemblages and populations of macrofauna, when compared to other similar habitats. Thus, it is unlikely that the proposal threatens any unique assemblages of macrofauna.

This study has shown that significant variation occurred mostly at small spatial-scales and at a temporal scale of 2 to 6 months or less. Any monitoring of the effects of marine aggregate extraction should also assess variation at these scales. A consequence of short-term temporal variation is that large-scale monitoring programmes with infrequent sampling may not detect important temporal changes. Measurements at different time-scales are required to detect changes in temporal variance (Underwood 1991). Changes in temporal variance may have serious consequences for populations of organisms (see Underwood 1991; Part IV).

Short-term temporal variation may imply short life cycles and turnover times of macrofauna. If so, physical disturbance may not have long-term effects as recolonisation of disturbed patches would be in the order of months or less.

Clearly, there is a large potential for temporal and spatial variability in the assemblages and populations of macrofauna of the proposed extraction areas. An assessment of how the proposed aggregate extraction may affect these assemblages is presented in Part IV of this report.

8.2 DISTRIBUTION OF SEDIMENTS AND MACROFAUNA

8.2.1 Introduction

The sand-bodies at Providential Head (PH) and Cape Banks (CB) are made up of a moderately well sorted, fine to medium grained sand unit (Unit A) at the surface which overlies a less well sorted, finer grained sand unit (Unit C) (Mining Tenement Management (MTM 1993). The median grain size of Unit A ranges between 0.125 and 0.5 mm, and Unit C between 0.125 and 0.25 mm (MTM 1993). Thus, differences between the texture of the sediments are visually subtle. At PH, Unit A commonly thickens seawards from approximately 0.5 m in 30 m of water to greater than 6 m in 40-50 m of water (MTM 1993). Seaward of 40-50 m, Unit A covers the seaward face of the sand-body and merges with the fine-grained, mid-shelf muddy sands (Unit B) in water depths of 60-70 m. Extraction of Unit A has the potential to expose the finer-grained Unit C. Where Unit A is absent at the surface, however, the finer-grained Unit C sands occur naturally at the surface.

The distribution of benthic macrofauna is often correlated with distributions of particular grain sizes of sediment at spatial scales of tens of metres to tens of kilometres (Butman 1987). Local heterogeneity in sediment topography (due to geological or biological processes) can cause significant small-scale (cm to m) variations in the grain size of sediments because of local changes in the near-bottom flow regime (Butman 1987). Patchiness in the distribution of soft-sediment macrofauna at these small scales may be attributable to this sediment heterogeneity (Rhoads and Young 1970; Eckman 1983).

The aim of this part of the study was to determine if the distribution of assemblages or populations of macrofauna were correlated with characteristics of the sediment.

8.2.2 Methods

Two samples of sediment were collected from each site and depth once during the study. Samples of sediment from 25-30 m, 35-40 m and 45-50 m were collected at PH, BP and BB during survey 1. Samples of sediment from 65-70 m were collected during survey 2 at these locations. Samples of sediment from all depths at CB were collected during survey 3. The samples of sediment were collected with the Smith-MacIntyre grab used during the main study. The samples of sediment were sent, unsieved, to a Metromix laboratory for analysis. Data were obtained for median grain size, sorting, percent gravel, percent sand and, percent silt for each sample.

For each site and time that samples of sediment were collected, we calculated the average of each sediment parameter per site and the total abundance of each taxon collected. Ordination analyses were performed on this set of data in a similar manner to the main study (section 8.1.2.3), that is, using fourth-root transformation, the Bray-Curtis similarity measure and non-metric multidimensional scaling.

Data on median grain size and percent silt were superimposed on the ordination. This would show if variation in the median grain size or percent silt of sediments was linked with variation in assemblages.

Correlation analyses were done to see if the abundance of selected taxa and the average number of taxa collected per site covaried with the median grain size. Pearson correlation coefficients were calculated for this set of data (no distinction was made among the times the samples of sediment were collected). Data on total abundance per site were transformed to $\log_{10}(X+1)$ prior to analysis; the average number of taxa per site was calculated from untransformed data. The taxa used were those analysed in the main study of distribution and abundance (see Table 8.4, section 8.1.3.3).

8.2.3 Results

The surface sediments were mainly fine to medium-fine sands, that is, median grain size between 100 µm and 300 µm (Fig. 8.69 in Appendix A22, Volume II). There was a trend for sediments to become slightly finer with depth as the amount of silt increased (Fig. 8.70). Samples from 65-70 m at BP tended to have the most fine-grained sediments, probably because they contained a relatively large amount of silt (Fig. 8.70).

Ordination analysis revealed a trend for assemblages to vary among depths (Fig. 8.71) as was the case for the main study (Section 8.1.3.2). The plots of this ordination with median grain size and % silt content superimposed (Fig. 8.71) show that the changes in these sedimentary parameters were not linked clearly to changes in assemblages. However, sediments at 65-70 m tended to be finer than those at the other depths and may have contributed to differences between assemblages at these depths and the shallower depths.

Correlations between the average median grain size and the total abundance (and average number of taxa) per site were significant for 12 variates (Table 8.7). For all these variates, except the Podoceridae, the correlation between median grain size and abundance (or number of taxa) was negative (i.e. the abundance of these taxa (and number of taxa) tended to be greatest in the finer sediments). The opposite occurred for the abundance of podocerid amphipods.

Most of the significant correlations between median grain size and abundance (or average number of taxa) were weak and explained only ≤10% of the total variation in the abundance of the variate. Notable exceptions were for the abundance of spionids, gastropods and nassarid gastropods, where the correlation explained about 35% of the total variation in abundance.

8.2.4 Conclusions

This study has shown that variation in the abundance of some taxa may be associated with variations in median grain size. Although the median grain size tended to decrease slightly with increasing depth, the clear trend for assemblages to vary among depths that was observed in the main study does not appear to be linked strongly to the distribution of sediments among depths. However, the relatively large silt content of sediments at 65-70 m, may be part of the reason these assemblages are somewhat different to those from the other depths.

The main study of the distribution and abundance of benthic macrofauna showed that the abundance of many taxa and the number taxa tended to be greatest at 65-70 m. There are many possible explanations for this pattern but, given that sediments tended to be finer at this depth than the shallower areas, an increased availability of food, a decreased regime of natural disturbance and/or a differential distribution of larvae due to hydrodynamic processes are plausible explanations (see Butman 1987).

Fine sediments and detritus tend to accumulate in regions of slow water movement and large abundances of organisms have been observed in these areas, possibly due to an increased supply of food associated with fine sediments (see Butman 1987). A decreased regime of disturbance may lessen mortality of macrofauna in deeper waters and/or decrease the degree of resuspension of food. Water movements that deposit finer sediments in deeper waters may also deposit larvae, thus enhancing populations in these areas (Butman 1987).

No information on temporal variation of sediments was collected for this study. It is likely that surface sediments are reworked continually, especially in shallow areas (see Section 8.3). Large temporal changes in the distribution of sediments, however, would probably only occur on a geological time-scale.

Butman (1987) suggested that the large-scale correlations between benthos and different types of sediment may be explained by hydrodynamic processes and that differences in the type of sediment do not cause differences in assemblages. If so, the subtle changes in sediment grain size that may be caused by the current proposal should have little effect on assemblages of macrofauna as long as hydrodynamic processes are not altered. Geomarine (1993) predicted that changes in the hydrodynamic regime would be minimal.

Extraction of marine aggregate may lead to patches of fine-grained, Unit C, sand being exposed as Unit A is removed (MTM 1993). The taxonomically-rich assemblages at 65-70 m are probably not caused by the characteristics of the sediment at this depth, but they do show that taxonomically-rich assemblages may occur in relatively fine-grained sediments. Further, nearly all the significant correlations suggested that the abundance of macrofauna and number of taxa tended to be larger in finer sediments. This pattern is probably a reflection of the relatively large number of taxa and macrofauna that occurred in the slightly finer sediments at 65-70 m.

Table 8.7. Pearson correlation coefficients (r) for the average median grain size and total abundance ($\log_{10}(X+1)$ transformed) and average number of taxa (untransformed) per site ($n = 44$). r^2% measures the percent of variation in the abundance or taxonomic richness data that is explained by the correlation with median grain size. P indicates whether the correlation is significant at the 5% level (<0.05), the 1% level (<0.01) or not significant (ns, >0.05). (A) = amphipoda, (C) = cumacea, (T) = tanaidacea.

Variate	r	r^2%	P
Polychaeta:			
Chaetopteridae	0.185	3.4	ns
Cirratulidae	-0.345	11.9	<0.05
Lumbrineridae	-0.120	1.4	ns
Maldanidae	-0.318	10.1	<0.05
Onuphidae	0.117	1.4	ns
Sabellidae	-0.221	4.9	ns
Spionidae	-0.604	36.5	<0.01
Syllidae	0.082	0.7	ns
Mollusca:			
Bivalvia	0.030	0.1	ns
Nuculanidae	0.243	5.9	ns
Pectinidae	0.174	3.0	ns
Tellinidae	0.216	4.7	ns
Gastropoda	-0.579	33.5	<0.01
Nassariidae	-0.606	36.7	<0.01

Variate	r	r^2%	P
Crustacea:			
Ampeliscidae (A)	-0.369	13.6	<0.01
Aoridae (A)	-0.128	1.6	ns
Corophiidae (A)	-0.128	1.6	ns
Lysianassidae (A)	-0.142	2.0	ns
Phoxocephalidae (A)	-0.118	1.4	ns
Platyischnopidae (A)	0.042	0.2	ns
Podoceridae (A)	0.326	10.6	<0.05
Urohaustoriidae (A)	0.138	1.9	ns
Isopoda	-0.371	13.8	<0.05
Bodotriidae (C)	-0.006	0.0	ns
Diastylidae (C)	-0.269	7.2	ns
Tanaidomorpha (T)	-0.010	0.0	ns
Apseudomorpha (T)	-0.167	2.8	ns
Ostracoda	-0.344	11.8	<0.05
Decapoda	-0.342	11.7	<0.05
Crustacean Taxa	-0.260	6.8	ns
Polychaete Taxa	-0.297	8.8	ns
Mollusc Taxa	-0.386	14.9	<0.05
Total Taxa	-0.323	10.4	<0.05

8.3 THE EFFECTS OF A STORM ON BENTHIC INFAUNA

8.3.1 Introduction

The main study of soft-sediment macrofauna (Section 8.1) demonstrated that assemblages and populations in the proposed extraction areas were highly variable in space and time. Many factors may contribute to this variability, including biological interactions and physical disturbances (see section 8.1.1.2.6). How the effects of aggregate extraction on benthic assemblages would compare with the effects natural physical disturbance is an important consideration for the assessment of the impact of the current proposal. The aim of this part of the study was to determine the effects of a naturally-occurring physical disturbance on the spatial and temporal variation of assemblages and populations of macrofauna.

Storms are a naturally-occurring physical disturbance and may have important effects on the structure of assemblages. Boesch et al. (1976) found that many common species of macrofauna had been eliminated and there were large increases in the abundance of opportunistic species following a hurricane that caused drastic reductions in salinity and dissolved oxygen concentrations in an estuary. Dobbs and Vozarik (1983) found large post-storm increases in the number of individuals and species of macrofauna in the water column but no differences in the density of macrofauna in two areas before and after a storm. They suggested that disturbance by storms may be a mechanism of post-larval dispersal.

Dayton et al. (1989) described massive damage to limestone reefs and associated assemblages of algae and animals caused by a large storm off the Californian coast. Damage occurred at depths of greater than 20 m but the storm appeared to be a 1-in-200 year event. Seymour et al. (1989) described extensive kelp (Macrocystis pyrifera) mortality caused by the same storm. They indicated that smaller storms have also caused considerable mortality in these populations of kelp.

Peterson (1985) described mortality of two species of suspension- feeding bivalves (Protothaca staminea and Chione undatella) in a lagoon due to sedimentation following a storm. The effect of sedimentation depended on the physical environment. In a high-current sandy channel, sedimentation was slight and there were no detectable effects on the survival of the bivalves (Peterson 1985). In a lower-energy environment of muddy sands, the storm deposited about 100 mm of silt and clays which increased substantially the mortality of both species.

Storms often affect large areas of the coastline and most studies of the effects of storms are ad hoc comparisons of pre- and post-storm abundances at a site that is being sampled for another reason. If one area is sampled before and after a storm, then any difference in the abundance of animals may be due to the storm, natural temporal variation or a range of other perturbations that may affect the size of populations over time. This is because patterns of temporal variation of the populations are not known.

There is no easy way around this sort of confounding. In this study we have highlighted the patterns that are possibly caused by the storm and discussed the alternatives.

8.3.2 Methods

8.3.2.1 Study Sites and the Storm Event

Samples were taken from sites 1 and 3 at PH immediately after a storm in August 1990 (Fig. 8.1). These were compared with samples taken from these sites during surveys 2 (before the storm) and surveys 3 and 4 (after the storm) (Table 8.8). Samples were taken from 25-30 m, 35-40 m, 45-50 m and 65-70 m during all surveys. We expected that assemblages and populations in shallower water would be most affected by the storm.

Table 8.8. Sampling dates for sites used at PH in the storm study. The time between each survey is given in days.

Survey	Site	Sampling date	Time Interval (days)
2	1	25/7/90	
	3	26/7/90	
			18-19
Post-Storm	1	14/8/90	
	3	14/8/90	
			90-91
3	1	14/11/90	
	3	13/11/90	
			50-51
4	1	4/1/91	
	3	4/1/91	

Geomarine (pers. comm.) provided the following information. Waverider-buoy data obtained from the Public Works Department (Manly Hydraulics Laboratory) for Sydney indicated that a severe storm occurred from 1-3 August 1990. The peak signficant wave height (average height of the highest 33% of waves) during the storm was 7.2 m. The maximum wave height was 11.8 m. Another storm occurred on 7 August 1990 with a significant wave height peaking at 3.7 m.

Analyses by Geomarine indicated that wave conditions at the peak of the first and major storm would have caused sheet flow of sediment to a water depth of 50 m. Sediment would have been moving back and forth over 7 m in 25 m of water, and over 4 m in 50 m of water. Even at 65-70 m water depth, any wave-generated bedforms that existed prior to the storm would have degenerated and sheet flow conditions were approached. Over the buildup of the storm, sediment at depths of 25-70 m would have been reworked to a depth of over 100 mm under wave-generated ripples.

8.3.2.2 Sampling and Laboratory Procedures

Sampling and laboratory procedures were similar to those used in the main study (see section 8.1.2). Four replicate grab samples were collected from each site and depth on 14 August 1990, sieved through a 1 mm mesh and hand-sorted. Macrofauna from the post-storm survey were identified by staff at The Ecology Lab. Polychaetes were identified to family, molluscs to class (Bivalvia, Gastropoda and Scaphopoda) and crustaceans to order/class (ostracods, amphipods, isopods, tanaidaceans etc.). Other taxa were identified to phylum but were uncommon and not analysed further.

8.3.2.3 Statistical Analyses

Multivariate and univariate analyses were used. Both classification (group-average clustering) and ordination (non-metric multidimensional scaling) techniques were used for the multivariate analyses (see Clarke 1993). Data from each depth were analysed separately to identify temporal changes and differences among sites. Prior to ordination and classification, replicates were summed and fourth-root transformations applied. The Bray-Curtis similarity measure was used throughout.

In practice, classification and ordination analyses showed similar results for each set of analyses and only ordinations are discussed here. These ordinations show the variation in assemblages at each depth and site over the four surveys. Assemblages that are similar are close together on these plots while those that are different are further apart. Thus, any large effect of the storm on the structure of an assemblage will be shown by large differences in assemblages between survey 2 and the post-storm survey. Changes between these two surveys may be followed by further large changes that indicate 'recovery' of assemblages from the storm.

A three-factor, fully orthogonal ANOVA was used to examine differences among survey times, depths and sites for abundant taxa. Interactions among times and depths may indicate differential effects of the storm among depths. Prior to analysis, abundance data were transformed to $\log_{10}(X+1)$ and Cochran's Test was used to determine if error variances were homogeneous (see Section 8.1.2.4). All factors in the ANOVA were fixed, thus the residual was used as the denominator for calculating all F-ratios. Ryan's Test was used to determine differences among surveys for significant factors in the ANOVAs.

8.3.3 Results

8.3.3.1 Analyses of Assemblages

At 25-30 m, assemblages at the two PH sites were different during all surveys (Fig. 8.72 in Appendix A22, Volume II). There were relatively large temporal changes in the assemblage at site 1. But changes between survey 2 and the post-storm survey were smaller than changes between the following surveys, thus, there was probably no large change in the structure of the assemblage due to the storm. At site 3, changes between survey 2 and the post-storm survey at 25-30 m were small, indicating that the storm did not induce major changes in the assemblage at this site and depth. There were large changes in the assemblage between the post-storm survey and survey 3, while changes between surveys 3 and 4 were relatively small.

At 35-40 m, assemblages at the two sites were again different during all surveys (Fig. 8.72). Temporal changes between survey 2 and the post-storm survey were again no greater than changes that occurred between the other surveys.

At 45-50 m, assemblages at both sites were quite similar during survey 3 but distinct during all other surveys (Fig. 8.72). Differences between the assemblages sampled during survey 2 and the post-storm survey were not large compared to the changes that occurred between the other surveys, at either site.

At 65-70 m, there were again differences between the assemblages during all surveys (Fig. 8.72). At both sites there were relatively large changes in assemblages between survey 2 and the post-storm survey. Following the post-storm survey, assemblages at both sites tended to become more similar to those sampled during survey 2 than those sampled immediately after the storm. This pattern suggests that storm-induced changes occurred to assemblages in deep water.

8.3.3.2 Analyses of Populations

Populations of 17 taxa were examined using ANOVA (Table 8.9). These taxa were abundant at PH sites 1 and 3 and all of these, except paraonid polychaetes, were common members of macrofaunal assemblages in the main study.

Table 8.9. Taxa chosen for univariate analyses.

Polychaeta	Mollusca	Crustacea
Chaetopteridae	Bivalvia	Amphipoda
Cirratulidae	Gastropoda	Isopoda
Lumbrineridae		Cumacea
Maldanidae		Tanaidacea
Onuphidae		Ostracoda
Paraonidae		Decapoda
Sabellidae		
Spionidae		
Syllidae		

Variation among times

Signficant variation among surveys was detected in populations of sabellid and spionid polychaetes, bivalves, amphipods and isopods (Table 8.10). These changes were consistent over all depths and sites, but showed different patterns among variates (Fig. 8.73).

The mean abundance of sabellids tended to be greater during the post-storm survey than the other surveys (Fig. 8.73). This may be due to recruitment of these worms or storm-induced redispersal or other processes.

The mean abundance of spionids was greatest during survey 4 and there were no significant differences detected among the other surveys (Fig. 8.73). There are no obvious changes in spionid populations that coincided with the storm.

There were significantly fewer bivalves, on average, collected during the post-storm survey than the other surveys (Fig. 8.73). This pattern may have been caused by the storm.

The mean abundance of amphipods underwent similar changes (Fig. 8.73). On average, there were significantly fewer amphipods collected during the post-storm survey than just prior to the storm (survey 2). There was a large increase in the mean abundance of amphipods between the post-storm survey and survey 3, possibly indicating recolonisation (Fig. 8.73). Large numbers of amphipods were also collected during survey 4. Although this pattern could be associated with the storm, the difference between the mean number of amphipods collected during survey 2 and the post-storm survey was small. It is more likely that this pattern is due to natural temporal variation.

The mean abundance of isopods also underwent changes that could have been caused by the storm (Fig. 8.73). The mean abundance of isopods was significantly smaller during the post-storm survey than during the other surveys.

Table 8.10. Summary of ANOVAs done for the storm study. The numbers below each factor indicate the degrees of freedom for each F-test. MS = mean square, P = probability of a significant result occurring by chance, result = the outcome of the F-tests performed. α indicates the level of probability at which the analysis was interpreted. If P < α then there are significant differences in the abundance of the organism among the levels of the factor or interaction. The probability for each term is included here to enable the reader to interpret the analyses at different levels of α. A ** indicates a significant factor or interaction, — indicates that no test was done due to a significant higher-order interaction involving this term, and ns indicates that there was no significant difference detected in the test of that term.

Variate		Time	Depth	Site	TxD	TxS	DxS	TxDxS	Residual
	df:	3,96	3,96	1,96	9,96	3,96	3,96	9,96	
Chaetopteridae	MS	0.251	1.237	0.078	0.117	0.298	0.057	0.206	0.045
α = 0.005	P	0.001	0.000	0.190	0.010	0.000	0.288	0.000	
	result	—	—	—	—	—	—	**	
Cirratulidae	MS	0.027	7.118	0.104	0.069	0.075	0.068	0.043	0.054
α = 0.005	P	0.689	0.000	0.168	0.263	0.253	0.292	0.621	
	result	ns	**	ns	ns	ns	ns	ns	
Lumbrineridae	MS	0.147	4.823	0.253	0.209	0.010	0.340	0.096	0.049
α = 0.005	P	0.034	0.000	0.025	0.000	0.892	0.000	0.052	
	result	—	—	—	**	ns	**	ns	
Maldanidae	MS	0.080	13.584	0.688	0.256	0.355	4.255	0.285	0.087
α = 0.05	P	0.435	0.000	0.006	0.004	0.009	0.000	0.002	
	result	—	—	—	—	—	—	**	
Onuphidae	MS	0.149	0.898	.000	0.066	0.011	0.251	0.093	0.085
α = 0.005	P	0.162	0.000	0.944	0.644	0.939	0.037	0.377	
	result	ns	**	ns	ns	ns	ns	ns	
Paraonidae	MS	0.064	3.606	0.235	0.134	0.128	0.065	0.042	0.028
α = 0.05	P	0.084	0.000	0.005	0.000	0.005	0.079	0.161	
	result	—	—	—	**	**	ns	ns	
Sabellidae	MS	0.217	6.142	0.292	0.119	0.089	0.489	0.117	0.062
α = 0.05	P	0.018	0.000	0.032	0.056	0.232	0.000	0.061	
	result	**	—	—	ns	ns	**	ns	
Spionidae	MS	1.299	5.215	0.184	0.122	0.016	0.376	0.112	0.082
α = 0.05	P	0.000	0.000	0.138	0.166	0.902	0.005	0.216	
	result	**	—	—	ns	ns	**	ns	
Syllidae	MS	0.115	3.552	0.019	0.027	0.125	0.719	0.238	0.078
α = 0.005	P	0.225	0.000	0.624	0.957	0.192	0.000	0.003	
	result	—	—	—	—	—	—	**	
Bivalvia	MS	0.326	0.056	0.087	0.095	0.063	0.092	0.098	0.073
α = 0.05	P	0.006	0.513	0.279	0.244	0.462	0.294	0.228	
	result	**	ns	ns	ns	ns	ns	ns	

Table 8.10, continued.

Variate		Time	Depth	Site	TxD	TxS	DxS	TxDxS	Residual
	df:	3,96	3,96	1,96	9,96	3,96	3,96	9,96	
Gastropoda	MS	0.512	0.767	0.256	0.262	0.177	0.835	0.162	0.068
α = 0.05	P	0.000	0.000	0.055	0.000	0.056	0.000	0.018	
	result	—	—	—	—	—	—	**	
Amphipoda	MS	1.748	1.983	0.010	0.066	0.124	0.265	0.047	0.064
α = 0.05	P	0.000	0.000	0.692	0.416	0.129	0.008	0.676	
	result	**	—	—	ns	ns	**	ns	
Isopoda	MS	0.344	0.656	0.235	0.102	0.038	0.071	0.103	0.066
α = 0.05	P	0.002	0.000	0.062	0.140	0.630	0.361	0.137	
	result	**	**	ns	ns	ns	ns	ns	
Cumacea	MS	2.715	1.048	0.208	0.146	0.024	0.119	0.040	0.056
α = 0.05	P	0.000	0.000	0.057	0.010	0.735	0.102	0.695	
	result	—	—	ns	**	ns	ns	ns	
Tanaidacea	MS	0.680	11.744	1.288	0.658	0.500	0.272	0.328	0.084
α = 0.05	P	0.000	0.000	0.000	0.000	0.001	0.025	0.000	
	result	—	—	—	—	—	—	**	
Ostracoda	MS	0.952	3.729	0.184	0.343	0.172	0.379	0.143	0.063
α = 0.05	P	0.000	0.000	0.092	0.000	0.049	0.001	0.025	
	result	—	—	—	—	—	—	**	
Decapoda	MS	0.194	2.541	0.124	0.077	0.163	0.057	0.062	0.054
α = 0.05	P	0.017	0.000	0.134	0.189	0.034	0.377	0.340	
	result	—	**	—	ns	**	ns	ns	

Variation among depths

Significant variation among depths was detected in populations of cirratulids, onuphids, isopods and decapods (Table 8.10). Cirratulids tended to be most abundant at 65-70 m and onuphids tended to be most abundant at 35-40 m and 45-50 m. There were no significant temporal changes in populations of these worms. The abundance of isopods and decapods tended to increase with depth. There was also significant temporal variation in populations of these crustaceans (see below).

Variation among sites

There were no significant differences detected among sites that were consistent over times and depths (Table 8.10).

Interactions between times and depths

Significant interactions between times and depths were detected for populations of lumbrinerids, paraonids and cumaceans (Table 8.10). Few lumbrinerids were collected from 25-30 m and 35-40 m (Fig. 8.74). At 45-50 m, lumbrinerids tended to be most abundant, on average, during the post-storm survey, but this difference was not statistically significant. At 65-70 m, the mean abundance of lumbrinerids tended to increase between survey 2, the post-storm survey and survey 3. This implies that populations of lumberinerids were not affected negatively by the storm.

Paraonid polychaetes were only abundant at 65-70 m (Fig. 8.74). At this depth, the mean abundance of paraonids tended to increase over surveys 2 to 4. There was no decrease in the mean abundance that coincided with the storm.

Cumaceans were relatively abundant at all depths but again they tended to be most abundant in deeper water (Fig. 8.74). Patterns of temporal change in the mean abundance of cumaceans were only consistent with storm-induced changes at 45-50 m. At this depth, significantly fewer cumaceans were collected during the post-storm survey than survey 2, and there were significant increases in the mean abundance of these crustaceans between the post-storm survey and survey 3.

At 25-30 m, there were no significant temporal changes over survey 2, the post-storm survey and survey 3 but there were significantly more cumaceans collected, on average, during survey 4. At 35-40 m, there were significantly less cumaceans collected during survey 2 and the post-storm survey than during surveys 3 and 4. At 65-70 m, similar numbers of cumaceans were collected during survey 2 and the post-storm survey and there was a significant increase in the mean abundance of cumaceans following the post-storm survey. These temporal changes imply that there was no negative effect of the storm on populations of cumaceans.

Interactions between times and sites

Significant interactions between times and sites were detected for populations of paraonids and decapods (Fig. 8.75). There were no significant temporal changes in the mean abundance of paraonids at either site that coincided with the storm. The interaction was caused by a significant increase in the mean abundance of paraonids at site 1 between surveys 3 and 4 that did not occur at site 3.

The mean abundance of decapods at both sites 1 and 3 tended to decline slightly between survey 2 and the post-storm survey (Fig. 8.75). However these changes were small and not significant and there was no obvious changes that coincided with the storm.

Interactions between depths and sites

Significant interactions between depths and sites were only detected for populations of lumbrinerids, sabellids, spionids and amphipods (Table 8.10). These changes are not discussed further here but are covered in section 8.1.

Interactions among times, depths and sites

Significant interactions among times, depths and sites were detected for populations of chaetopterids, maldanids, syllids, gastropods, tanaidaceans and ostracods (Table 8.10).

There were few chaetopterids at PH site 1 (Fig. 8.76). At site 3 these worms were abundant mainly at 45-50 m and 65-70 m. At 45-50 m, the mean abundance of chaetopterids collected during survey 2 and the post-storm survey were similar (and greater than during surveys 3 and 4). At 65-70 m, the mean abundance of chaetopterids dropped significantly between survey 2 and the post-storm survey and no chaetopterids were collected during surveys 3 and 4. This local absence may also be a storm-induced change, but also may be due to the patchy distribution of chaetopterids.

Maldanids were abundant at 35-40 m and 65-70 m at PH site 1 (Fig. 8.77). The mean abundance of maldanids at 35-40 m changed little between survey 2 and the post-storm survey but there was a significant increase between the post-storm survey and survey 3. At 65-70 m, there was little temporal variation in the mean abundance of maldanids. At PH site 3, maldanids were abundant mainly at 65-70 m where there was a large increase in the mean abundance of maldanids between survey 2 and the post-storm survey.

There were no significant changes in the mean abundance of syllids at any site or depth except 35-40 m at site 1 (Fig. 8.78). There were relatively large but variable increases in the mean abundance of syllids at this site and depth.

Gastropods tended to be most abundant at 65-70 m at PH site 1 and there were few temporal changes at the shallower depths except for a tendency for populations to increase in size slightly between surveys 3 and 4 (Fig. 8.79). At 65-70 m, there was a large decrease in the abundance of gastropods that coincided with the storm followed by a large increase in abundance between the post-storm survey and survey 3. There was also a smaller decrease in the mean abundance of gastropods at this site and depth between surveys 3 and 4 but this change was not significant.

At site 3, gastropods were often abundant at 25-30 m (Fig. 8.79). At this depth there was no significant decrease in the mean abundance of gastopods that coincided with the storm. The mean abundance of gastropods tended to increase between the post-storm survey and survey 3 followed by a decrease between surveys 3 and 4. At 35-40 m and 45-50 m there was little temporal variation. At 65-70 m, there were fewer gastropods collected during survey 2 than the post-storm survey (as was the case at site 1) and the mean abundance of gastropods tended to increase over the remaining surveys. This pattern of temporal variation may have been caused by the storm.

Few ostracods were collected from 25-30 m or 35-40 m at either site (Fig. 8.80). At site 1, temporal changes in the mean abundance of ostracods at 45-50 m and 65-70 m were similar. There were significant decreases in mean abundance between survey 2 and the post-storm survey at both depths followed by increases in abundance between the post-storm survey and survey 3. These changes may have been caused by the storm. At site 3, there were different patterns of temporal variation at 45-50 m and 65-70 m. At 45-50 m, there were no significant changes between survey 2 and the post-storm survey but significantly more ostracods were collected during surveys 3 and 4 than the earlier surveys. At 65-70 m, there was a significant decrease in the mean abundance of ostracods between survey 2 and the post-storm survey and the mean abundance of ostracods did not increase over the later surveys. This pattern of temporal variation may be due to the storm.

Significant temporal changes in the mean abundance of tanaidaceans at PH site 1 occurred at 35-40 m and 45-50 m (Fig. 8.81). At 35-40 m, significantly more tanaidaceans were collected during survey 3 than 4 and during both these surveys than survey 2 and the post-storm survey. At 45-50 m, there was a significant decrease in the mean abundance between survey 2 and the post-storm survey. The mean abundance of taniadaceans at this depth stayed small during survey 3 but there was a significant increase between surveys 3 and 4. These changes may be induced by the storm.

At PH site 3, tanaidaceans were only abundant at 45-50 m and 65-70 m (Fig. 8.81). At 45-50 m, significantly more tanaidaceans were collected during surveys 2, 4 and the post-storm survey than survey 3. At 65-70 m, there was a significant decrease in the mean abundance of taniadaceans between survey 2 and the post-storm survey. The mean abundance of tanaidaceans stayed low during survey 3 but increased slightly between surveys 3 and 4. This pattern of temporal variation is consistent with storm-induced changes.

8.3.4 Conclusions

This study has shown temporal variation in some populations and assemblages that may be due to disturbance by a storm. Although we expected assemblages and populations at the shallower depths would be affected most by the storm, temporal changes consistent with a direct effect of the storm were most often found at 65-70 m. However, there was no obvious widespread destruction of assemblages by the storm. This lack of outstanding change has been recorded previously by Dobbs and Vozarik (1983).

The abundance of some taxa (e.g. the sabellids, maldanids and lumberinerids) increased between the pre- and post-storm surveys. This may be due normal temporal variation or redispersal by the storm. Dobbs and Vozarik (1983) collected more polychaetes and polychaete species in the water-column immediately after a storm than before a storm. They suggested that storms may be a mechanism of post-larval dispersal of sedentary macrofauna. Sabellids and maldanids are ostensibly sedentary animals and stormdriven redispersal of adults may be important for such taxa.

In this study, we concentrated on decreases in the mean abundance of infauna between pre- and post-storm surveys. There are other, indirect effects that may be caused by the storm. For instance, the mean abundance of many of the animals included in this study increased between the post-storm survey and survey 3. This may be a response to open space or food that may have resulted from the storm. Macrofauna such as amphipods, which are quite mobile, increased in abundance during this period.

On a longer temporal scale, Barry (1989) showed that recruitment of a sedentary, gregarious tube-dwelling polychaete <u>Phragmatopoma lapidosa californica</u> (Sabellariidae) to shallow marine habitats along the open coast of California was significantly correlated with the intensity of disturbance by waves during the previous 2-5 months. Individuals appeared to respond to disturbance by releasing gametes. Thus, individuals maximised reproductive effort when faced with an increase in both the probability of death and the availability of settlement space (Barry 1989). Such changes may only be revealed by studies done at a larger spatial and temporal scales beyond the scope of the current study.

Sub-lethal effects of the storm such as changes in behaviour and growth were not addressed by this study. Turner and Miller (1991) simulated storm events in laboratory studies of juvenile clams, <u>Mercenaria mercenaria</u> and found that shell growth was reduced during storms. Significantly more pseudofaeces (particles rejected by the palps and gills before entering the digestive system) were produced when these bivalves were subjected to large concentrations of suspended sediment (Turner and Miller 1991). Thus both feeding behaviour and shell growth were affected by sediment suspended by wave action. The effect of storms on shell growth, however, did not last; clams with reduced growth during the simulated storms recovered to the normal growth-rate rapidly after the storms (Turner and Miller 1991).

The lack of outstanding change in benthic assemblages and populations may be due to the behaviour and adaptations of animals living in environments that are often disturbed. For example, benthic animals may burrow deeper into the sediment or move downwards in their tubes in response to disturbance (Dobbs and Vozarik 1983). Also, the strong depth-gradients revealed in the main study of the distribution and abundance (section 8.1) may be related to wave-action. If so, animals living in the shallower areas may be adapted better to disturbance than those living in the deeper areas and there will be little differential effect of storms among depths. For example, tube-dwellers such as tanaidaceans, maldanids and chaetopterids were rarely collected from 25-30 m or 35-40 m during the main study but were often abundant at 45-50 m and 65-70 m. This distribution may reflect the regime of wave-disturbance on the coast of NSW or some other factor correlated with wave-disturbance.

This study has described the possible effects of a relatively severe storm on benthic macrofauna. It would appear that many macrofaunal organisms are likely to be resilient to the natural physical disturbances associated with storms. The next section describes an experiment in which physical disturbance of the seabed, designed to simulate extraction of aggregate, is done to examine the rate of recolonisation of disturbed patches by macrofauna.

8.4 EXPERIMENTAL PHYSICAL DISTURBANCE

8.4.1 Introduction

The most direct effect of marine aggregate extraction on benthic macrofauna would be their removal from strips of sediment, and the creation of defaunated furrows. The rate of recolonisation of these furrows is an important consideration and would depend on many factors, including the size of the disturbed areas. We experimentally mimicking the small-scale effects of marine aggregate extraction. The aim of the experiment was to measure the rate of recolonisation of defaunated areas of similar widths and depths to those that would be formed should the current proposal be approved. It is important to note that this experiment only considers disturbance at the scale of the furrows created by aggregate extraction, not at larger scales of the proposed extraction.

The rate and mode of recolonisation of macrofauna depends on the size of the disturbed patch (e.g. Smith and Brumsickle 1989). Recolonisation of disturbed patches may occur by mobile adult macrofauna and/or recruitment of larvae. Bell and Devlin (1983) reported that the density of dominant macrofauna in small defaunated patches of sediment (100 cm^2) had returned to control levels after 8 hours. Evidence from demersal trapping suggested that benthic crustaceans and polychaetes occurred in the water column during this investigation and that adult macrofauna recolonised the patches (Bell and Devlin 1983). Smith and Brumsickle (1989) reported that recolonisation of large patches of defaunated sediment (1750 cm^2) took between 16 and 41 days. They showed that post-larval immigration was an important mode of recolonisation of both the large (1750 cm^2) and small (50 cm^2) patches. Post-larval immigration, however, was more important for recolonisation of the small patches than the large patches. In a study of a large (>3 km^2), defaunated area, Santos and Simon (1980) concluded that initial colonisation of polychaetes and molluscs was mostly by settling larvae rather than adults, yet amphipods and cumaceans initially recolonised these large patches as adults.

Most studies of recolonisation of defaunated sediments, including those mentioned above, have been done in relatively sheltered, estuarine environments. In marine environments exposed to wave-action, disturbed patches may be filled by sediment in a relatively short time. Thus, there would probably be passive recolonisation by adult macrofauna that are washed into pits by wave-action, movement of sediments and/or currents (e.g. Savidge and Taghon 1988).

Rapid increases in abundance of opportunistic species in disturbed patches are thought to be responses to free space and/or increased availability of food (Thistle 1981; Oliver and Slattery 1985). Oliver and Slattery (1985) noted large increases in the abundance of lysianassid amphipods in areas disturbed by gray whales during feeding. The influx of lysianassids began within minutes of the disturbance and lasted only a few hours. Oliver and Slattery (1985) thought that these amphipods were scavenging the remains of the damaged invertebrates left in the disturbed areas. Van Blaricom (1982) found larger numbers of some benthic taxa in pits created by sting-rays than in surrounding, undisturbed areas. He concluded that these taxa responded to food in the form of detritus washed into and trapped in the pits.

In the current study, recolonisation of dredged patches (1 x 2 m) occurred within 1-2 months. Recolonisation was mainly by adult macrofauna. This mode of recolonisation may depend on the size of the dredged patch (thus the distance to intact fauna), the mobility of sediments and mobility of nearby taxa.

8.4.2 Methods

8.4.2.1 Study Site

The experiment was done on a sandy seafloor in 24 m of water off The Gap, Sydney (Fig. 8.1c). This site was chosen for several reasons. First, samples of sediment analysed before the start of the experiment indicated that the sediments at the study site were very similar to those in the proposed extraction areas. Second, the study site was adjacent to a rocky reef and therefore was unlikely to be trawled by fishing vessels which would remove the pegs used to mark experimental plots. Moreover, the reef/sand boundary was similar to that at Providential Head. Third, the site fulfilled the safety requirements set for SCUBA diving regarding depth. We recognise that these constraints may limit the main study of the distribution and abundance (section 8.1) may be related to wave-action. If so, animals living in the shallower areas may be adapted better to disturbance than those living in the deeper areas and there will be little differential effect of storms among depths. For example, tube-dwellers such as tanaidaceans, maldanids and chaetopterids were rarely collected from 25-30 m or 35-40 m during the main study but were often abundant at 45-50 m and 65-70 m. This distribution may reflect the regime of wave-disturbance on the coast of NSW or some other factor correlated with wave-disturbance.

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8.4.2.2 Experimental Design

Forty, 1 x 2 m plots were spaced at approximate intervals of 5 m along the 24 m depth contour at the study site. The size of the plots was chosen to approximate the scale of the proposed aggregate extraction.

Ten plots were randomly assigned to each of the following four treatments:

(1) control plots, - unpegged and sampled as representative of natural, undisturbed areas;

(2) peg-control plots - marked with pegs and sampled to provide an estimate of any effects due to pegging of the dredged plots;

(3) 0.2 m plots - marked with pegs, in which sand was removed to 0.2 m below the seafloor;

(4) 0.3 m plots - marked with pegs, in which sand was removed to 0.3 m below the seafloor.

8.4.2.3 Physical Disturbance and Sampling

Star posts (1.5 m long, hammered about 0.75 m into the sediment) were used to mark the corners of the 1 x 2 m plots. Plots were tagged individually to enable relocation. The control plots were relocated from a map of their positions relative to the pegged plots and during sampling they were defined by a portable quadrat (1 x 2 m). The pegging of plots took place from 17-19 September 1991 and the star posts were in position for about 3 weeks before removal of sand commenced on 8 October 1991. Dredging of sand from the 0.2 m and 0.3 m plots was completed on 21 October 1991 when the first samples were taken from plots of each treatment.

Dredging was done by divers using an airlift made from a 12 m length of 90 mm PVC pipe. Compressed air was fed through a hose and injected into the pipe about 0.3 m above the suction end. Divers controlled the airflow using a valve. Weights were attached to the suction end of the pipe and a float was tied to the upper end. Weights attached to about 15 m of rope, tied to the upper end of the pipe, were used to maintain a suitable angle on the airlift so that dredged material was deposited away from the plots.

Samples were collected from all treatments at four times: immediately after the extraction of sand from 0.2 m and 0.3 m plots, 1 week after extraction, 1 month after extraction and 2 months after extraction (see Appendix A21 for exact dates of sampling). Only the samples from immediately after dredging, 1 month after dredging and 2 months after dredging were sorted and used in the analyses.

Each plot was only sampled once. This was to ensure that the samples: (1) represented the status of benthic populations and assemblages at various stages after the sand extraction; (2) were independent of previous sampling; and (3) were independent estimates of temporal variation.

Three core samples (area 0.027 m^2, depth 0.1 m) were taken from each of two plots from each treatment on each sampling occasion. The samples were sieved through a 1 mm mesh and the material retained was stained with Biebrich scarlet and preserved in 10% formalin and seawater. Samples were collected from the middle of the plot and not from the batters created by slumping at the sides of dredged plots or adjacent to the pegs. We considered this a conservative measure because benthic organisms may have been retained in the batters.

The samples were rinsed over a 1 mm mesh in the laboratory to remove excess formalin and stain. Animals were hand-sorted from the samples using the aid of a magnifying lamp (approx. 2X). Polychaetes were identified to family, crustaceans to order (amphipoda, isopoda etc.), molluscs to class (bivalves and gastropods) and other taxa to phyla. Spionid and syllid polychaetes were identified to species as they were the most abundant polychaetes. The biomass of crustaceans, polychaetes, molluscs and other taxa was recorded for each sample. One large bivalve (about 15 mm across) was recorded in a peg-control sample but the weight of this animal was not used in the ANOVA.

8.4.2.4 Statistical Analyses

Statistical analyses of benthic assemblages and populations were done using ordination and ANOVA techniques, respectively. The total abundance of animals from both plots sampled within each time and treatment was used in multivariate ordination. All taxa were used in this procedure at the various levels of taxonomic resolution achieved. The ordination procedure used was non-metric multidimensional scaling (Field et al. 1982; Clarke 1993; Kenkel and Orloci 1986). Data were fourth- root transformed and the Bray-Curtis similarity measure used.

Analysis of variance (ANOVA) techniques were used to detect significant differences in the abundances of selected populations and the total biomass between sampling times, treatments, time by treatment interactions and plots within each time and treatment (Table 8.11). A time by treatment interaction was interpreted to indicate that the pattern of temporal change varied inconsistently among treatments. This is the expected outcome of the ANOVA if the abundance of an animal in the control and peg-control treatments remained relatively constant while the abundance in the 0.2 m and 0.3 m dredged plots increased due to recolonisation. The interpretation of significant factors in

ANOVA is given in Table 8.12.

Since benthic populations are often aggregated (Stephenson and Cook 1977; Downing 1979), population data were routinely transformed to $\log_{10}(X+1)$ prior to analysis by ANOVA. Data on the number of taxa were not transformed unless required to homogenise variances. Cochran's Test was used to check for homogeneity of variances and alpha (α) was set at 0.05 if variances were homogeneous. Non-significant factors ($\underline{P} \geq 0.25$) were pooled according to the procedure in Winer (1971) to increase the power of the remaining tests.

Table 8.11. ANOVA model used to detect significant sources of variation in selected populations. f, r denote fixed and random factors respectively, df = degrees of freedom, 'F vs' shows the denominator of the F-test and df-test shows the degrees of freedom of the F-test.

Source	df	F vs	df-test
Time^f	2	Plot	2,12
Treatment^f	3	Plot	3,12
Time x Treat.	6	Plot	6,12
Plot (Time,Treat.)^r	12	Res.	12,48
Residual	48		
Total	71		

Table 8.12. Interpretation of significant factors in ANOVA.

Factor	Interpretation
Times	Mean abundance differed among sampling times and this difference was consistent over the four treatments and two plots sampled from each treatment and time.
Treatments	Mean abundance differed among treatments and this difference was consistent over the sampling times and the two plots sampled from each treatment and time.
Time by Treatment interaction	Abundance varied among sampling times in a different fashion for at least two treatments.
Plots (Time,Treat)	Abundance varied between two plots sampled from at least one treatment and time.

8.4.3 Results

We observed that the dredged plots had been filled with sand after approximately 1 week. Amphipods, isopods, bivalves, gastropods and spionid polychaetes were the most abundant taxa collected (Table 8.13). Note that all figures referred to in this section are in Appendix A22, Volume II.

8.4.3.1 Analyses of Assemblages

Assemblages of macrofauna in plots dredged previously were very similar to those in undredged (control and peg-control) plots after 1 month (Fig. 8.82). After two months, the assemblages in the dredged plots were still very similar to those in the control plots indicating that reestablishment of assemblages in dredged plots had occurred.

The assemblages in dredged plots were very different to those in the control plots immediately after dredging. Moreover, the structure of assemblages in the dredged plots changed greatly between the first two sampling periods, whereas in control and peg-control plots, the structure of assemblages changed little.

Assemblages of macrofauna in control plots and peg-control plots were very similar at all times of sampling (Fig. 8.82). Thus, at the level of assemblages, the results of the experiment are not an artefact of pegging the experimental plots.

8.4.3.2 Analyses of Populations

Populations of all polychaetes, the spionid polychaetes Dipsio glabrilamellata and Prionospio nirripa, bivalves, gastropods, amphipods, isopods and phoronids were analysed using ANOVA. The total number of taxa and total number of individuals were also analysed.

Total Abundance

The total abundance of animals varied over time in a different fashion for the control and dredged plots (time by treatment interaction, Table 8.14, Fig. 8.83). During the first sampling period (immediately after dredging), few animals were collected from the dredged plots (0.2 m and 0.3 m) and the mean abundance of animals in the control plots was similar (Fig. 8.83). After one month, there were more animals in plots dredged previously compared to control plots. This may be due to an influx of opportunistic taxa. After two months, the total abundance of individuals in control and dredged plots was similar (Fig. 8.83).

Table 8.13. Total abundance of taxa collected in the disturbance experiment.

Polychaeta			Mollusca		Crustacea		Other Taxa	
Aphroditidae	2		Bivalvia	485	Amphipoda	644	Ascidiacea	16
Capitellidae	9		Gastropoda	195	Isopoda	139	Bryozoa	5
Chaetopteridae	2				Cumacea	34	Cnidaria	9
Cirratulidae	3				Ostracoda	9	Echinoidea	30
Dorvilleidae	7				Decapoda	7	Holothuroidea	7
Eulepethidae	2				Mysidacea	7	Hirudinea	1
Magelonidae	2				Leptostraca	2	Nematoda	5
Maldanidae	1				Cirripedia	13	Nemertea	21
Nephtyidae	6						Ophiuroidea	3
Nereididae	1						Phoronida	65
Onuphidae	19						Platyhelminthes	10
Opheliiae	7						Pycnogonida	5
Orbiniidae	15						Sipuncula	5
Oweniidae	1							
Phyllodocidae	2							
Polyodontidae	1							
Sigalionidae	2							
Spionidae	211							
Dispio glabrilamellata		81						
Spio pacifica		13						
Pseudopolydora kempi		4						
Prionospio nirripa		112						
Prionospio wambiri		1						
Spirorbidae	1							
Syllidae	38							
Pionosyllis sp.1		8						
Pionosyllis sp.2		20						
Exogone heterosetosa		1						
Exogone sp.2		1						
Typosyllis sp.		5						
Odontosyllis polycera		1						
Sphaerosyllis capensis		1						
Syllides sp.1		1						
Terebellidae	3							

Table 8.14. Summary of ANOVA results for selected populations and biomass variables. Pooling of non-significant factors ($P \geq 0.25$) followed the procedure in Winer (1971). All variates were transformed to $\log_{10}(X+1)$ prior to analysis.

Variate		Time	Treat.	Time x Treat.	Plot (Time,Treat)	Residual
	df:	2,12	3,12	6,12	12,48	
Total Individuals	MS	2.706	0.258	0.648	0.056	0.012
$\alpha = 0.05$	P	0.000	0.023	0.000	0.000	
	test	—	—	**	**	
Total No. Taxa	MS	264.04	10.39	26.82	11.22	2.85
$\alpha = 0.05$	P	0.000	0.458	0.094	0.000	
	test	**	ns	ns	**	
Polychaeta	MS	1.971	0.146	0.165	0.141	0.036
$\alpha = 0.05$	P	0.001	0.412	0.380	0.000	
	test	**	ns	ns	**	
Dispio glabrimellata	MS	0.399	0.037	0.048	0.088	0.044
$\alpha = 0.05$	P	0.034	0.741	0.765	0.047	
	test	**	ns	ns	**	
Prionospio nirripa	MS	0.742	0.016	0.151	0.134	0.043
$\alpha = 0.05$	P	0.020	0.946	0.400	0.002	
	test	**	ns	ns	**	
Bivalvia	MS	0.680	0.437	0.806	0.091	0.030
$\alpha = 0.05$	P	0.008	0.020	0.001	0.003	
	test	—	—	**	**	
Gastropoda	MS	1.087	0.059	0.239	0.067	0.049
$\alpha = 0.05$	P	0.000	0.475	0.029	0.213	
	test	—	—	**	ns	
Amphipoda	MS	2.152	0.217	0.419	0.079	0.043
$\alpha = 0.05$	P	0.000	0.090	0.007	0.068	
	test	—	—	**	ns	
Isopoda	MS	1.030	0.257	0.030	0.086	0.036
$\alpha = 0.05$	P	0.001	0.074	0.896	0.017	
	test	**	ns	ns	**	
Phoronida	MS	0.779	0.096	0.076	0.041	0.036
$\alpha = 0.05$	P	0.000	0.127	0.172	0.349	
	plots pooled with residual:					
	MS	0.779	0.096	0.076		0.037
	P	0.000	0.062	0.072		
	df	2,60	3,60	6,60		
	test	**	ns	ns		

Table 8.14, continued.

Variate		Time	Treat.	Time x Treat.	Plot (Time,Treat)	Residual
	df:	2,12	3,12	6,12	12,48	
Polychaete Biomass	MS	5.782	1.278	0.453	0.334	0.295
$\alpha = 0.05$	P	0.000	0.039	0.306	0.359	
	plots pooled with residual:					
	MS	5.782	1.278	0.453		0.303
	P	0.000	0.009	0.195		
	df	2,60	3,60	6,60		
	test	**	**	ns		
Mollusc Biomass	MS	9.532	1.982	9.878	2.374	0.175
$\alpha = 0.05$	P	0.000	0.056	0.001	0.183	
	test	—	—	**	ns	
Crustacean Biomass	MS	3.778	0.687	0.830	0.144	0.119
$\alpha = 0.01$	P	0.000	0.021	0.005	0.300	
	plots pooled with residual:					
	MS	3.778	0.687	0.830		0.124
	P	0.000	0.002	0.000		
	df	2,60	3,60	6,60		
	test	—	—	**		

The total number of animals collected also differed between the two plots sampled from at least one treatment during each sampling period (Table 8.14, Fig. 8.84). This indicates that there was small-scale spatial variation in the rate of recolonisation (Fig. 8.84). Nevertheless, the total number of animals in plots for both dredged treatments tended to be greater than that in the control plots after 1 month (Fig. 8.84). After two months, the total number of animals in one plot that had been dredged to 0.3 m was less than the total number in the other 0.3 m plot. On average, however, the total abundance of animals was similar among treatments.

Overall, the rate of recolonisation of the plots dredged previously was generally less than one month, but there may have been an influx of opportunistic species in the first month. Also, the rate of recolonisation showed some variation on a small spatial scale (i.e. among plots).

Total Number of Taxa

The total number of taxa varied between the plots sampled from each treatment during each sampling period (Table 8.14, Fig. 8.85). Thus, the number of taxa showed small-scale spatial variation and recolonisation rates varied among plots. There were some taxa in the dredged plots immediately after dredging (Fig. 8.85). These animals included amphipods, bivalves, gastropods, polychaetes and/or other taxa which either probably escaped the dredging treatment, or immigrated to the plots immediately after dredging. Very few individuals, however, were collected in the dredged plots during this time (see above).

After 1 month, the mean number of taxa in the control, peg-control and one each of the 0.2 m and 0.3 m dredged plots was similar (Fig. 8.85). The mean number of taxa in the other 0.2 m and 0.3 m dredged plots was greater than the mean number in the control and peg-control plots. This may indicate an influx of opportunistic taxa to some dredged plots. After 2 months, there were only small differences in the mean number of taxa in plots from the same treatment. There was little difference in the mean number of taxa collected from the different treatments but the peg-control plots tended to have slightly fewer taxa than plots from the other treatments (Fig. 8.85).

The total number of taxa also varied significantly among sampling periods (Table 8.14, Fig. 8.86) indicating that there were similar changes in the mean number of taxa over time in plots from all treatments. The mean number of taxa increased between the post-dredging survey and the 1 month survey, and decreased slightly between the 1 and 2 month surveys.

Polychaeta

The total abundance of polychaetes and the abundance of the spionids _Dispio glabrimellata_ and _Prionospio nirripa_ were analysed using ANOVA. The abundance of these taxa differed between the two plots sampled from each treatment during each sampling period (Table 8.14). There were also significant differences among sampling times that were consistent among treatments for these populations (Table 8.14).

The mean abundance of these three variates was small in all plots immediately after dredging (Figs. 8.87 to 8.89). After 1 month, the mean abundance of these polychaetes had increased but recolonisation of the dredged treatments varied between plots. There were only small changes in the mean abundance of these polychaetes between the 1 and 2 month surveys (Fig. 8.86) and the mean abundance in all treatments was similar after 2 months. There were some differences in the mean abundance between plots within some treatments, however, indicating small-scale differences in natural changes in control and peg-control treatments and the rate of recolonisation in the dredged treatments.

Bivalves

A significant interaction between times and treatments was detected for the abundance of bivalves (Table 8.14). In addition, the abundance of bivalves differed between the two plots sampled from each treatment during each sampling period (Table 8.14).

The mean abundance of bivalves in the peg-control, 0.2 m and 0.3 m dredged treatments was similar after 1 month indicating that bivalves had recolonised the dredged plots (Fig. 8.83). There were, however, few bivalves in the control plots after 1 month. After 2 months, the mean abundance of bivalves in peg-control plots was greater than in plots from other treatments.

The dramatic decrease in the size of bivalve populations in control plots between the post-dredging survey and 1 month survey makes the results of the experiment difficult to interpret. One explanation is that a species of bivalve colonised the dredged plots and the peg-control plots during the experiment whereas another species of bivalve common in one of the control plots, died out. If so, then we may conclude that pegging of plots may have had a positive effect on the rate of colonisation of pegged plots by bivalves.

There were some differences in the rates of recolonisation between plots and there was a large difference between the mean abundance of bivalves in the control plots in the post-dredging survey (Fig. 8.90). There was a large number of bivalves in one control plot during this time indicating that the abundance of bivalves may vary on a small spatial scale. There were no other major differences between the two plots sampled from each treatment during each survey.

Gastropods

There was a significant interaction between times and treatments in the abundance of gastropods (Table 8.14, Fig. 8.83). Gastropods had recolonised the 0.2 m and 0.3 m dredged plots after 1 month when the mean abundance in these plots tended to be greater than in the control and peg-control plots (Fig. 8.83). After 2 months, the mean abundance of gastropods was similar in all treatments.

Amphipods

There was a significant interaction between times and treatments in the mean abundance of amphipods (Table 8.14, Fig. 8.83). Amphipods had recolonised the 0.2 m and 0.3 m dredged plots after 1 month. The mean abundance of amphipods in the control plots tended to be greater than in the peg-control plots during the 1 month and 2 month surveys indicating that any effect of pegging the plots would have had a negative effect on the recolonisation rate of amphipods (Fig. 8.83).

Isopods

The mean abundance of isopods varied among sampling times and between plots within times and treatments (Table 8.14). The mean abundance of isopods tended to increase in all treatments between the post-dredging and 1 month sampling periods (Fig. 8.86). There was little difference in the mean abundance of isopods during the 1 and 2 month surveys (Fig. 8.86). Isopods may have recruited to plots from all treatments between the post-dredging survey and the 1 month survey.

There were some differences in the rate of recolonisation of isopods to the 0.2 m and 0.3 m dredged plots (Fig. 8.91). The mean abundance of isopods in the 0.3 m dredged plots was still relatively small after 2 months whereas there was increase in the abundance of isopods in control, peg-control and 0.2 m dredged plots between the post-dredging survey and the 1 month survey. After 2 months, there were few isopods in the plots that had been dredged to 0.3 m, but, there were also few isopods in one of each of the control and peg-control plots at that time. Thus, the small abundance of isopods in the 0.3 m dredged plots is not attributable directly to dredging and may be a natural phenomenon.

Phoronids

The mean abundance of phoronids varied consistently over time in all treatments implying that they recruited or immigrated to all plots (dredged or undredged) during the experiment (Table 8.14, Fig. 8.86). Few phoronids were present in samples taken immediately after dredging. The mean abundance of phoronids increased in all plots and treatments after 1 month but decreased slightly between the 1 month and 2 month surveys (Fig. 8.86).

Analyses of Biomass

The biomass of polychaetes varied among times and treatments and there was no significant interaction between these factors (Table 8.14). Biomass tended to increase from the time of dredging to the 1 month sampling in all treatments (Fig. 8.92) as was the case for the mean abundance of polychaetes (see above). The biomass of polychaetes also tended to be greater in the control, peg-control and 0.2 m dredged plots than in the 0.3 m dredged plots (Fig. 8.92).

There was a significant time by treatment interaction for the biomass of molluscs (Table 8.14). One month after dredging, the biomass of molluscs in 0.3 m dredged treatments tended to be greater than the other treatments and least in the control plots (Fig. 8.92). After 2 months, the biomass of molluscs was similar in all treatments. This pattern implies that the pegging of plots had positive short-term effects on the abundance and/or size of molluscs that was greatest in the plots that were also dredged.

A significant time by treatment interaction also occurred for biomass of crustaceans (Table 8.14). One month after dredging, biomass was similar in all treatments (Fig. 8.92). After 2 months, there tended to be a greater biomass in the control plots than the pegged plots, indicating that pegging may have had a negative effect on rates of recolonisation of crustaceans and/or the size of crustaceans recolonising the plots.

8.4.4 Conclusions

Macrofauna recolonised the experimentally dredged patches within 1-2 months. Recolonisation was mainly by immigration of adult animals from surrounding patches. Since the plots had been filled with sand after about a one week, some animals were probably washed passively into the dredged plots (e.g. Savidge and Taghon 1988). There was probably also active recolonisation by adults from nearby areas and the water column. This may explain the rapid influx of relatively sedentary taxa such as bivalves to the dredged plots, and the quick recovery of biomass.

Rates of recolonisation of relatively sedentary taxa may depend on sediment transport or recruitment of larvae. If the defaunated furrows left by extraction are not filled with sand, passive recolonisation of relatively sedentary taxa such as bivalves may not occur and the rate of recolonisation of these taxa may be slower than reported in this study. Mobile taxa such as amphipods should, however, rapidly recolonise small defaunated areas from surrounding patches, regardless of the rate of sediment movement to these areas.

Rates of recolonisation of some taxa may be even faster than the rates recorded in this experiment. For example, Bell and Devlin (1983) reported that recolonisation of small, defaunated patches (100 cm^2) by adult infauna took less than 8 hours.

Recolonisation of adults from nearby patches is obviously scale-dependent. Larger denuded patches may take longer to recolonise and may rely on larval recolonisation (Santos and Simon 1980). The results of the current study are, however, applicable to the current proposal as patches of undisturbed sediment would be left between the strips removed by extraction. These strips may also be filled rapidly with sediment and macrofauna in the vicinity, especially from shallow water. Due to the unknown suction power of the extraction head, other experiments may need to be done, as part of a monitoring programme, to determine the exact width of the area removed by each run of the vessel.

The mode of recolonisation (adult or larval) may vary among taxa. Santos and Simon (1980) concluded that initial colonisation of a large patch of defaunated sediment by polychaetes and molluscs was by settling larvae, rather than adults. Amphipods and cumaceans initially recolonised the area as adults (Santos and Simon 1980). In the current study, samples were taken one month after dredging and the major groups of taxa present in control plots had recolonised the dredged plots by this time. Thus, we cannot determine which groups recolonised the dredged plots first.

A limitation of the current study is that it was done, for logistical reasons, at the shallow end of the depth range proposed for extraction. There may be different rates of recolonisation in deeper water because different assemblages occur there (Section 8.1). The assemblages and populations of these deeper waters, however, were still highly variable in space and time and we predict that they should also recolonise disturbed patches rapidly (i.e. in a few months).

The rates of recolonisation of some taxa in deeper water may depend on the rate of recolonisation of tubicolous taxa. Tubicolous animals such as maldanid and chaetopterid polychaetes and tanaidaceans were abundant at the deeper depths sampled in the main study (45-50 m, 65-70 m) and not abundant in shallower water or recorded in the disturbance experiment. These tubicolous animals may facilitate the recruitment of other taxa, thus increasing the taxonomic richness of assemblages (Gallagher et al. 1983). The rates of recolonisation of some taxa to disturbed patches in the 45-70 m depth range may be slower than the rates of recolonisation reported at shallower depths if the rates of recolonisation of tubicolous taxa are slower and the presence of tubicolous animals (or their tubes) is required for recolonisation of other taxa.

In this study, the total abundance of animals tended to be more abundant in the dredged treatments than the control and peg-control treatments after 1 month. This may be due to colonisation of the dredged patches by mobile, opportunistic taxa that are responding to space, food, or other resources (e.g. Oliver and Slattery 1985). If so, this response was relatively short-lived and a similar total number of animals were present in dredged plots and undredged plots after 2 months.

Overall, recolonisation of dredged patches (1 x 2 m) occurred within 1-2 months. Recolonisation was probably mainly by adult macrofauna and some animals may have been passively washed into the dredged holes. Rates of recolonisation in deeper waters and over larger areas may depend on the size of dredged patchs (the distance to intact fauna), the mobility of sediments, the mobility of nearby taxa, recruitment of macrofauna, and the presence of tubicolous taxa that may facilitate the settlement and/or survival of other taxa.

8.5 BENTHIC SCAVENGERS

8.5.1 Introduction

One important component of the benthic macrofauna that may not have been sampled adequately using the benthic grab was the scavengers. These aninals inhabit most marine environments and, in demersal environments, they consist mostly of crustaceans. They feed mainly on dead organisms located using chemosensory organs (Dahl 1979; Busdosh et al. 1982; Hargrave 1985; Lowry 1986). Research in the Atlantic (Thurston 1979; Vader and

Romppainen 1985), the Pacific (Sekiguchi and Yamaguchi 1983; Ingram and Hessler 1983; Hessler et al. 1978) and polar seas (Busdosh et al. 1982; Slattery and Oliver 1986) has focused on lysianssoid amphipods which are the dominant scavengers in cold water environments.

Little is known about the biology or ecology of scavengers in Australian waters. Workers at the Australian Museum have shown, by the use of trapping, that cirolanid isopods, cypridinid ostracods and lysianassoid amphipods are abundant demersal scavengers in eastern Australian waters (J. Lowry, Australian Museum, pers. comm.). The use of baited traps to collect benthic invertebrates is a relatively common methodology (e.g. Kennelly and Craig 1989; Keable 1992).

Because they are relatively mobile, benthic scavengers may not be sampled adequately with benthic grabs (J. Lowry, pers. comm.). Traps were therefore used to sample small invertebrate scavengers at the two proposed extraction areas, Providential Head (PH) and Cape Banks (CB), and at one reference location, Bate Bay (BB) (Fig. 8.1). Ostracods, isopods and amphipods were the most abundant animals collected. Due to their mobility and behaviour, these taxa may be able to colonise disturbed areas rapidly and they may be attracted to areas where benthic organisms have been killed or injured (Oliver and Slattery 1985).

8.5.2 Methods

We aimed originally to sample at Providential Head, Cape Banks, Bate Bay and Bass Point on two occasions. This proved impossible due to loss of gear and strong oceanic currents at the time (January to March, 1991) and samples were collected once from PH, BB and CB. Two sites were sampled within each location at the same time. These were sites 1 and 2 (PH), 11 and 12 (CB) and 7 and 8 (BB) (Fig. 8.1).

Each trap had a float and anchor and was separated from other traps by at least 100 m. Traps were deployed from a trawler late in the day and left overnight, the time when scavengers are reported as being most active (Keable 1992 and references therein). Three traps each were set at 25-30 m, 35-40 m, 45-50 m and 65-70 m at each site. They were set at PH on 14 January 1991; at CB on 11 April 1991 and at BB on 12 April 1991. At CB site 12, traps at 25-30 m and 35-40 m were set on rocky reef. Some traps were dragged considerable distances from where they were deployed and these samples were not used.

Traps were made from 100 mm diameter PVC pipe, with two chambers 200 mm long (after Keable 1992, Fig. 8.93, in Appendix A22, Volume II). The first chamber had a funnel entrance which narrowed to an opening of 20 mm. The funnel was held in place by a push-on end-cap with the centre cut out. This chamber led to the second via another funnel with an opening of 7.5-10 mm. The end of the second chamber was covered by 0.5 mm nylon mesh held in place by another end-cap. The mesh allowed water to circulate inside the trap. Chambers were opened by taking off the end-caps. The traps were baited with a pilchard in the second chamber. Anchors and marker buoys were attached to the eye-bolt. These traps only sampled scavengers small enough to pass through the 20 mm opening, hence they excluded large crabs and fish.

The animals from two samples from each site were sorted and counted. Animals from the third sample were retained for further examination, if required. The abundance of ostracods in large samples was estimated from subsamples. Staff from the Australian Museum and the Ecology Lab identified the specimens.

Due to problems with sampling, data were not analysed using inferential statistics. Patterns of occurrence and abundance of scavengers were described from the data.

8.5.3 Results

Large numbers of scavengers were trapped during the study (Table 8.15). The most abundant were ostracods, amphipods and isopods (Table 8.15). Ostracods were often an order of magnitude more abundant than other taxa.

At PH, amphipods, mainly Lysianassidae, tended to be more abundant at 25-30 m and 35-40 m than in deeper waters. Isopods, mainly Cirolanidae, tended to be most abundant in deeper waters at site 1, but not at site 2. Ostracods (Cypridinidae) were abundant at all depths. The other taxa collected included gastropods (Nassarius), decapods and leptostracans.

At CB, amphipod and isopod scavengers tended to be most abundant at 65-70 m. Ostracods were again abundant at all depths, but were often most abundant in the deeper areas. Gastropods were abundant in one trap at 65-70 m, but otherwise they were relatively uncommon.

At BB, amphipod and isopod scavengers tended to be most abundant at 25-30 m and 35-40 m at site 8. Ostracods were very abundant at 45-50 m at site 7. The distribution of other taxa such as gastropods and ophiuroids was patchy.

8.5.4 Conclusions

Ostracods, amphipods and isopods were the most abundant benthic scavengers collected. These taxa were collected in large but variable numbers at all depths and sites. Ostracods were often an order of magnitude more abundant than either amphipods and isopods. The distribution of other scavengers such as gastropods was very patchy.

Table 8.15. Abundance of scavengers collected from each location. Traps believed to have been set on rocky reefs are marked with an asterisk.

(a) Providential Head

Site	Site 1								Site 2					
Depth	25-30m		35-40m		45-50m		65-70m		35-40m		45-50m		65-70m	
Replicate No.	R1	R3	R1	R2	R1	R3	R1	R3	R1	R3	R1	R2	R1	R3
Polychaeta										3	2			
Mollusca:														
Gastropoda							8	1		1	39	22		3
Octopus								1						
Crustacea:														
Amphipoda	269	962	860	601	223	180	10	9	531	759	109	184	75	140
Isopoda	255	479	392	513	149	162	3	3	499	383	332	287	200	175
Cumacea														
Ostracoda	795	3904	2534	3598	6038	6187	2095	2782	1815	2296	2506	2790	7384	6056
Copepoda														
Decapoda		1					4	9	2	1				3
Leptostraca		1				3	1		5		2	2		2
Echinodermata:														
Echinoidea														
Ophiuroidea														

(b) Cape Banks

Site	Site 11								Site 12							
Depth	25-30m		35-40m		45-50m		65-70m		25-30m		35-40m		45-50m		65-70m	
Replicate No.	R1	R2	R1	R2	R1	R2	R1	R2	R1*	R2*	R1*	R2*	R1	R2	R1	R2
Polychaeta																
Mollusca:																
Gastropoda	4	3			16	11	88	3		1	2		2	5		
Octopus																
Crustacea:																
Amphipoda	127	89	24	192	40	31	2136	928	23	1	1		2	1	1604	265
Isopoda	249	347	294	240	96	62	672	512	68	49	7	5	12	14	476	994
Cumacea																
Ostracoda	8310	3720	7016	26128	23752	11608	15744	14686	6914	2835	2772	1948	105	3353	12712	7367
Copepoda												1				
Decapoda	2	3								1			1	1	3	
Leptostraca					16		40	35							4	33
Echinodermata:																
Echinoidea																
Ophiuroidea													1			

Table 8.15, continued.

(c) Bate Bay

Site	Site 7					Site 8					
Depth	35-40m	45-50m		65-70m		25-30m		35-40m	45-50m		65-70m
Replicate No.	R3	R1	R2	R1	R2	R1	R2	R3	R1	R2	R1
Polychaeta					3						
Mollusca:											
Gastropoda	95			3	1	1	1	280	7		75
Octopus											
Crustacea:											
Amphipoda	195	222	157	231	7	983	1018	1576	196	123	143
Isopoda	628	500	527	191	192	363	598	1441	577	120	76
Cumacea			1								
Ostracoda	10608	27720	30240	7816	905	18896	10738	5696	12144	977	11168
Copepoda	1									1	
Decapoda	1		3	1	1			4	3	2	1
Leptostraca		6	4	10	6			1			13
Echinodermata:											
Echinoidea											2
Ophiuroidea							1	60			

Cypridinid ostracods have been collected in other studies of scavenging using baited traps (e.g. Stepien and Brusca 1985; Keable 1992). Stepien and Brusca (1985) found that large numbers of cypridinid ostracods (Vargula tsujii) were attracted to traps containing live kelpfish off the coast of California. Ostracods were consistently the first scavengers attracted to the fish in the traps and may have been responding to chemicals released by sexually mature fish (Stepien and Brusca 1985). Fish that were attacked only by ostracods suffered little physical damage (Stepien and Brusca 1985).

Cirolanid isopods (often refered to as sea-lice) are well known scavengers and predators (e.g. Hale 1929; Stepien and Brusca 1985). Stepien and Brusca (1985) noted that cirolanid isopods invaded traps containing live kelpfish later than ostracods, but were responsible for the deaths of kelpfish in cages. These isopods were not attracted to healthy adult fish, but were attracted to injured fish (Stepien and Brusca 1985). Stepien and Brusca (1985) suggested that the slight damage inflicted on fish by ostracods may have been sufficient to attract cirolanid isopods. Lysianassid amphipods were also caught in traps but were generally less abundant than ostracods and isopods (Stepien and Brusca 1985).

Lysianassid amphipods are well known scavengers, especially in higher latitude areas (Slattery and Oliver 1986). They respond rapidly to the availability of large items of food (Slattery and Oliver 1986) and may attack damaged invertebrates (Oliver and Slattery 1985).

The behaviour and mobility of benthic scavengers has implications for the proposal to extract marine aggregate. Large numbers of ostracod, isopod and amphipod scavengers may rapidly colonise the furrows left by aggregate extraction. They may consume injured and dislodged invertebrates left in or near the furrows (cf. Oliver and Slattery 1985). The persistence of scavengers in disturbed areas may vary among taxa. Oliver and Slattery (1985) reported that two species of lysianassid amphipod showed different responses to feeding-pits left by gray whales. One species, (Anonyx sp.) formed dense swarms in pits immediately after the disturbance but dispersed within hours. Another species of lysianassid amphipod (Orchomene minuta) invaded the pits more slowly but remained for at least 60 days. Taxa occurring in surrounding, undisturbed areas gradually increased in numbers inside the pits and biomass of animals in the pits often recovered within two months (Oliver and Slattery 1985).

The period over which scavengers responded to bait in this study was up to 18 to 24 hours (traps were left overnight). The feeding behaviour and mobility of scavengers may be related to the availability of food (Slattery and Oliver 1986). For example, Slattery and Oliver (1986) found that a lysianassid amphipod that inhabited deep water (>100 m) where food was sparse (Orchomene plebs) came to baited traps more rapidly and in greater numbers than a species (Orchomene pinguides) that lived in shallow water (<10 m) where food was more common and scavenging events were more predictable. In this study, ostracods may have responded to baits more rapidly than amphipods and isopods (e.g. Stepien and Brusca 1985), they may have attracted from a greater area, or they may simply have been more abundant than the amphipods and isopods collected.

Scavengers were collected at night during this study. Keable (1992) found that benthic scavengers were attracted to traps almost exclusively at night. Ostracod, isopod and amphipod scavengers may be members of the demersal zooplankton which migrate into the water column at night. The attacks on caged fish observed by Stepien and Brusca (1985) occurred at night. Oliver and Slattery (1985), however, observed lysianassid amphipods swarming into freshly dug pits during the day in high latitude areas.

The large numbers of scavengers collected by trapping is not surprising, given that the bait is likely to attract scavengers from a large area. In fact, we cannot estimate the density of scavengers from trap studies as we do not know the area over which the animals were attracted to the traps. This area may be highly variable. For example, the direction and strength of currents may influence the area over which the bait is detected by scavengers.

Larger mobile scavengers such as crabs and fish were not sampled during this study but may also be important scavengers in the study region. Caddy (1973) showed that fish and crabs were attracted to scallop-dredge tracks within 1 hour of fishing and were observed in the tracks at 3-30 times the densities observed outside the tracks. Fish and crabs may have been attracted to the tracks for many reasons such as the provision of shelter and/or food (Caddy 1973). In addition to the scavengers sampled in the current study, demersal fish and crabs may also be attracted to the disturbed tracks left by the extraction vessel under the current proposal.

The results of this study and other trapping studies suggest that cypridinid ostracods, cirolanid isopods and lysianassid amphipods are very mobile and active scavengers. It is not clear whether these animals would be able to avoid being sucked up during extraction of sand by dispersing into the water column, but it is likely that scavengers would be attracted to the area after the extraction head had passed by to feed on any damaged animals that remained.

There are some methodological problems with the survey of benthic scavengers. First, the sampling has to be done in two stages (i.e. deployment and collection) and if the weather changes, or the ocean currents strengthen, the traps may not be recoverable for many days, if at all. Second, the marker buoys can be stolen. Third, interpretation of the results is problematic, as described above. Benthic scavengers, however, may play a significant rôle in the response of the benthic assemblages to the disturbance associated with aggregate extraction, thus studies of these scavengers may be a useful part of a monitoring programme for any aggregate extraction (see Part IV).

CHAPTER 9. DEMERSAL FISHES AND MOBILE INVERTBRATES

9.1 INTRODUCTION

The fishes occurring on soft-sediments may form diverse assemblages (e.g. Gray, et al. 1990; Federizon 1992; Fisheries Research Institute, FRI 1992) and are of considerable commercial importance in southeastern Australia (e.g. Tilzey et al. 1990). The proposal to extract marine aggregate could affect fish directly (e.g. there may be behavioural responses to the extraction vessel), or indirectly (e.g. by removal of benthic food sources). This chapter reviews existing information and presents the methods, results and conclusions of two studies on the distribution and abundance of bottom-dwelling ("demersal" or "ground") fishes and mobile invertebrates (e.g. prawns and squid). The first was done by The Ecology Lab for the present proposal. The second was done by FRI as part of the monitoring programme for Sydney's Deepwater Ocean Outfalls, which happened to include surveys of fishes in or near the proposed extraction areas.

9.1.1 Aims of the Study

The study on demersal fishes and mobile invertebrates aimed to:

1. provide a review of the literature on demersal fishes and mobile invertebrates relevant to the proposal;

2. describe the spatial and temporal variation of demersal fishes and mobile invertebrates within the areas proposed for extraction of marine aggregate;

3. predict the effects of the proposed extraction operation on demersal fishes and mobile invertebrates (Part IV); and

4. formulate a proposal for monitoring the effects of the proposed extraction operation on demersal fishes and mobile invertebrates (Part IV).

9.1.2 Existing Information

Ecological studies of demersal fishes and mobile invertebrates off the NSW coast have been done in relation to Sydney's deepwater ocean outfalls (Jones 1977; Gibbs 1987; FRI 1992), the Broken Bay marine aggregate proposal (Carey and Talbot 1980) and a survey of contaminants in fish (The Ecology Lab 1992). There have been several ecological studies of fish occurring in deeper estuarine waters in NSW (e.g. SPCC 1981; Henry 1984; The Ecology Lab 1988; Gray et al. 1992; Paxton et al. in prep). There has also been research done on commercial fisheries. The research trawler 'Kapala' has done numerous surveys of trawl grounds off the NSW coast (e.g. Gorman and Graham 1982a, 1986). These authors provided data on catch rates (kg h^{-1}) for many fishes common below 100 m depth, but did not compare fishes statistically among geographical regions, depths or survey times. Tilzey et al. (1990) summarised biological data on the 7 most important fish species (by weight) landed in south east Australia and summarised logbook records of fish catches. There have also been studies done on east Australian king prawns, Penaeus plebejus, one of the most important invertebrate species in NSW waters (e.g. Ruello 1975; Glaister et al. 1987, 1990).

9.1.2.1 Early Studies for Sydney's Deepwater Ocean Outfalls

Surveys of demersal fishes were done as part of the Shelf Benthic Study (Jones 1977), described previously in Chapter 8. A commercial prawn net (20 mm mesh net) deployed from a chartered trawler was used to sample fishes off Malabar. Two transects were sampled, one "short" transect of 20-30 min duration along the 70 m contour from Little Bay to Cape Banks, and one "long" transect of 45-60 min from 70-130 m in a northwest/south east direction from the Little Bay (cf. Fig. 3.4). The short transect was located just offshore of the proposed extraction area at Cape Banks (Fig. 3.5). About 1 or 2 trawls were made along the short transect, and 1 along the long transect, every month from September 1972 to January 1974 (Jones 1977).

Apart from limited trawling along the 70 m contour off Marley Beach in June 1973, no control sites were sampled. The study, therefore, provides poor replication to assess within site variability and inadequate controls to examine among site variability. Thus, we cannot determine the extent to which the results reflect the true structure of fish assemblages at the site, or the extent to which the results can be generalised within the region.

From 42 trawls done during the survey, 57 species of fish (in 40 families) were recorded. The most abundant were crested flounder (Lophonectes gallus), bellowsfish (Macrorhamphosus scololepis), nannygai or redfish (Centroberyx affinis), three-spined cardinal fish (Apogonops anomalis), yellowtail (Trachurus novaezelandiae), cocky gurnard (Lepidotrigla argus) and tiger flathead (Neoplatycephalus richardsoni). Jones (1977) concluded that no significant monthly differences were apparent from the data, although the survey design did not allow this conclusion to be tested statistically. Fish were collected in all months except October 1973, when nothing was collected after 2 days of trawling. This trawling followed a severe storm, and the water at the time was very dark and murky. Jones (1977) speculated that there may have been toxic algae in the water which affected fish.

Jones (1977) identifed two major feeding groups of fishes, omnivores and carnivores, and noted the absence of herbivores, which were common on nearby rocky reefs. Within the two major groups, omnivores included old wife (Enoplosus armatus), crested flounder, leatherjackets (Fam. Monacanthidae) and eastern boxfish (Anoplocapros inermis), although Jones (1977) considered that some of these species may be primarily carnivorous. There were several feeding guilds among the carnivores, including fish which ate very small invertebrates (primarily crustaceans), such as boarfish (Fam. Pentacerotidae), bellowsfish, three-spined cardinal fish and yellowtail. Fish which fed on larger species of invertebrates included bottom-dwelling sharks and rays (e.g. Port Jackson shark, Heterodontus portusjacksoni and shovelnose ray, Aptychotrema rostrata), gurnards (Fam. Triglidae) and pufferfish (Fam. Tetraodontidae). Fish which fed on fish and invertebrates included tiger flathead and stargazers (Fam. Uranoscopidae) while dories (Fam. Zeidae) fed exclusively on fish.

Length freqency data for the two most abundant species, crested flounder and bellowsfish, suggested no large recruitments to the area during the study. Crested flounder were believed to breed year round, showing no major recruitment. Gravid females were present in most months. Jones (1977) suggested that breeding may occur further inshore, as few juveniles were collected, although the lack of smaller fish may have reflected gear selectivity.

9.1.2.2 Broken Bay Marine Aggregate Proposal

Carey and Talbot (1980) sampled demersal fishes for their investigations into the proposal to extract marine aggregate off Broken Bay. Trawls were done along the 20 m depth contour by day and night in July 1979 and February 1980. They used a 'squid net' with 2 cm mesh, operated from a small commercial trawler. No reference sites were sampled and trawls were not replicated, hence the findings of this study were very limited.

Samples of fish were retained for examination of gut contents. An attempt was made to relate these results to those of the macrobenthic study (see Section 8.1.2.2). This is limited because of the low number of samples of fish and macrobenthos and, as no benthic samples were taken at the time of the second fish survey, it is not possible to relate the dietary items in the fish at that time to the abundance of macrofauna.

About 34 species of fish were collected during the study. The catch was dominated by stingarees (Urolophus viridis - which were probably misidentified U.kapalae - and U.testaceus), flatfish (e.g. narrow-banded sole, Aseraggodes macleayanus) and long-spined flathead (Platycephalus longisinus). The catch generally appeared to be quite different from that of Jones (1977), but the studies were confounded in space, time, depth and gear type.

Carey and Talbot (1980) found crustaceans to be the most common food item, followed by polychaetes and molluscs. They concluded that the fish sampled depended largely on soft-bottom macrofauna and that fish in the area fed on items known to be abundant there. They predicted that, if the composition and abundance of the invertebrate community changed as a result of aggregate extraction, the composition and abundance of the fish fauna would probably be affected also. Given the flaws in the data, this prediction must be considered as an unsupported.

9.1.2.3 Recent Studies for Sydney's Deepwater Ocean Outfalls

Two surveys of fish have recently been done for Sydney's deepwater ocean outfalls (Gibbs 1987; FRI 1992). Both collected replicate samples at several sites and depths, thus they are the first in which measures of variablity within and among sites were obtained for Sydney's nearshore demersal fishes.

Gibbs (1987) undertook pilot surveys for the ocean outfalls programme in March and April, 1987, to determine the optimum sampling strategy for monitoring the effects of the deepwater ocean outfalls. Soft-bottom substrata were sampled by day and, to a limited extent, by night, at 9 locations using 3 types of otter trawl. Samples taken from three depths, 30, 60 and 100 m, with 16, 31 and 8 trawls done at each depth, respectively. Sample sites were selected off Malabar (just to the north of the proposed Cape Banks extraction area) and in Bate Bay.

In all, 13,381 fish from 101 species was collected by Gibbs (1987). Eight species of fish accounted for 80% of the catch, the most common being redfish, cocky gurnard, stingarees and tarwhine (Rhabdosargus sarba). Several invertebrates were also collected, including cuttlefish (Sepia sp.), squid (Sepioteuthis australis and Nototodarus gouldi) and Balmain bugs (Ibacus peroni). Unfortunately, Gibbs did not provide information on the depth distribution of the fishes and invertebrates collected by trawl. Other than the limited analyses done, there is no information on the distribution of fish among sites and depths.

FRI have been sampling demersal fishes on a quarterly basis since 1989, as part of the monitoring programme for the deepwater ocean outfalls. Surveys done prior to the commissioning of the outfalls (which occurred from about June 1990) were described in FRI (1992). Trawls were done at 4 times using a large demersal net at 30 m off Long Reef, Bondi and Port Hacking; at 60 m off Long Reef, Bondi, Malabar and Port Hacking; and at 100 m off North Head and Port Hacking. The 30 and 60 m sites off Port Hacking extend into the proposed extraction area for Providential Head, while the site at 60 m off Malabar extends just to the north of the proposed extraction area for Cape Banks (Figs. 3.2 and 3.5).

In all, 15,131 fishes from 101 species and 54 families was collected by FRI (1992). The study demonstrated that demersal fish in inshore waters off Sydney are highly variable in space and time. In other words, richness and abundance of fish were not consistent among sites over time. Also, while no statistical comparison of fishes was done across depths, graphical trends suggest that there were large differences in the abundance of fish in the depth range of 30-100 m.

9.1.2.4 Study of Bioaccumulation in Coastal Fishes

As part of a study of bioaccumulation, shelf-dwelling fishes were trawled from up to 3 depth ranges in 9 transects along 155 km of the Sydney coastline (The Ecology Lab 1992). The study was done during spring, 1989. A large prawn net was deployed from a commercial trawler. The depth ranges were 25-55 m, 80-125 m and 235-270 m. The average trawl time was about 16 min, but data were standardised to 20 min for all trawls (The Ecology Lab 1992). Most species of fish were identified as "taxa" rather than species, due to difficulties with identifying some groups.

57,600 fish from 101 fish taxa were collected (The Ecology Lab 1992). The distributions and abundances of fish varied on two spatial scales: among regions (over 155 km) and within regions, (over about 50 km). Several mechanisms were suggested to explain the large variability reported (The Ecology Lab 1992):

1. the location and size of food patches may affect patchiness of fishes;

2. spawning-related migrations may aggregate fish;

3. ontogenetic changes in habitat preferences may also occur (e.g. juvenile tiger flathead may prefer shallower habitats than adults (Fairbridge 1951));

4. depth preferences may occur at a smaller scale than those examined, consequently, the high CVs may be due to depth partitioning within the sampled ranges;

5. adult populations of bony fishes (which usually have a planktonic disperal stage) may reflect the location and size of settlement events; and

6. the slightly different times at which each region was sampled may have introduced temporal confounding.

None of these explanations was preferred by The Ecology Lab (1992). Clearly, any or all of these may apply in any given situation.

Despite the large variability observed, many species showed depth gradients. For example, bellowsfish and three-spined cardinal fish tended to be more abundant with increasing depth; smooth boxfish, leatherjackets (Fam. Monacanthidae), and long-spined flathead were dominant in shallower depths; and crested flounder generally preferred the middle depth range. Some species showed regional variation, for example, tiger flathead showed no depth preferences in the northern and Sydney regions, but significantly more occurred in deep and medium waters than shallow water in the southern region (The Ecology Lab 1992).

9.1.2.5 Local Estuarine Studies

Studies have been done of demersal fishes in the deeper waters of NSW estuaries and embayments, including the Hawkesbury River estuary (Gray et al. 1990), Sydney estuary (Henry 1984; Paxton et al. in press), Botany Bay (SPCC 1981a,b) and Jervis Bay (The Ecology Lab 1988). SPCC (1981a) speculate on the possible location of nursery areas and breeding grounds for fish which occur in the deeper parts of estuaries and in the nearshore region. For example, snapper (Pagrus auratus), red gurnard (Chelidonichthys kumu), robust whiting (Sillago robusta) and tarwhine (Rhabdosargus sarba) appeared to use deep, soft substrata in Botany Bay as nursery areas, while small-toothed flounder (Pseudorhombus jenynsii) were common as small juveniles in shallow muddy areas and seagrass beds (SPCC 1981a). All these species are, according to SPCC (1981a), known to be residents of the open coast and offshore habitats as adults.

9.1.2.6 Studies Related to Commercial Fisheries

Data exist for many of the fish targeted by commercial trawlers in southeastern Australia as a result of exploratory trawling by research vessels, attendance by scientists on commercial vessels and at fish markets, compilation of statistics on port landings and, recently, logbook data from trawler operators (Tilzey et al. 1990). As a result, there are data on the biology of important fish species and on fishing practices (see Chapter 14 for a description of commercial fishing activities). Tilzey and his co-workers summarised some of this information, although they cautioned that there is a lack of knowledge on the distribution of many exploited species.

One finding from the literature is that many demersal fish on the NSW continental shelf have been overfished in the 75 years of commercial trawling on the NSW coast. In particular, tiger flathead were overfished between the 1920's and 1950's (Colefax 1934; Fairbridge 1951, 1952). These authors described a trawl ground off Sydney extending from Botany Bay to Wattamolla. This ground extended from about 60 m to 160 m and, because the substratum there was described as "mud and coral" (Fig.1 in Colefax 1934), it probably occurred seaward of the proposed extraction areas. From 1918 to 1925 huge catches, mostly of tiger flathead, were made yearly on this ground between September and December. The flathead caught were described as very large and "bursting with roe" (Colefax 1934). This annual event, which became known as the "Botany Glut", failed in 1926 and does not appear to have occurred since (e.g. Fairbridge 1952). It is impossible to say whether the failure of the glut was due to fishing or to some other factor, but it is plausible that overfishing played a rôle, given the general declines related to fishing in later years.

Fairbridge (1952) concluded that the ground trawled off Botany Bay was a "prolific" breeding ground. According to Tilzey et al. (1990), however, if they exist, specific spawning grounds have not been defined, nor are there details of larval development. Fairbridge (1952) recommended that the trawl ground off Botany Bay be closed to trawling as an experimental measure, to monitor possible recovery of stocks there. No such closure was implemented but, according to Rowling (1979), stocks of tiger flathead have improved with the imposition of regulations on the minimum mesh size of nets used in the fishery.

The 7 most important fish species (by weight) landed in south- eastern Australia in the period 1986-1987 (Tilzey et al. 1990) included 3 species likely to occur in the areas and within the depth range which has been proposed for aggregate extraction - tiger flathead, red spot or eastern school whiting (Sillago bassensis flindersi) and nannygai. The other 4 species are more common in much deeper water and are discussed no further here.

Tiger flathead occur on sand and mud from depths of 10-170 m (Tilzey et al. 1990). In the eastern Bass Strait, older fish occur typically on offshore grounds (> 65 m deep) and younger fish occur further inshore. They live 8-12 years and recruit to the fishery at 3-4 years. There are several reports of a spring - summer spawning migration, in which tiger flathead migrate to waters < 100 m, followed by dispersal back to deeper waters. Colefax (1938) reported that tiger flathead lie on the seabed by day, move up into the water column at night, and feed on copepods, euphasids and other crustaceans. Log book data examined by Tilzey et al. (1990) suggested that tiger flathead occurred continuously from Barrenjoey Head to south eastern Tasmania. No "spawning" migrations to shallower waters were detected. In southern waters, however, log book data suggested that tiger flathead congregated between southeastern Bass Strait and the eastern Tasmanian shelf during summer. Tiger flathead were trawled to 400 m depth, but most of the catch was from 100-149 m.

School whiting reportedly occur on clean sandy substrata from the surf zone to 55 m and spawn in summer on the south coast of NSW and in winter off the north coast (Tilzey et al. 1990). Spawning areas, habitats and mechanisms of larval dispersal are not known, but Dixon et al. (1987) (cited in Tilzey et al. 1990) suggested that larvae move from the Australian mainland to Tasmania. These authors defined 4 main stocks on the basis of genetic markers: north of Newcastle, NSW; south of Newcastle to Portland, Victoria; Tasmania; and Bass Strait across to Kangaroo Island. School whiting live up to 8 years and recruit to the fishery at 3 years. School whiting have been found to eat crustaceans and polychaetes (Burchmore et al. 1988).

Logbook data suggest that eastern school whiting occur throughout coastal NSW and Vic and are caught as deep as 90 m, thus they extend in commercial quantities below the 55 m previously stated (Tilzey et al. 1990). There was no evidence of any aggregations associated with spawning, but in the south there was evidence of congregation in eastern Bass Strait during autumn/winter (Tilzey et al. 1990).

Nannygai occur in 10-450 m depth from NSW south to southwestern WA, but are reportedly most common along the east coast (Tilzey et al. 1990). Most of the trawl catch comes from depths much greater than the depths of the proposed extraction area (100-149 m in spring and summer; 200-249 m in winter). Little is known of the early life history of nannygai. No spawning sites have been found, but spawning off NSW has been observed in late summer and autumn. Juveniles occur in shallow waters, including large bays and estuaries, while adults occur in deep coastal waters on reefs, mud or sand. Nannygai on the east coast constitute a single stock (Tilzey et al. 1990). Recent tagging studies (Rowling 1989, cited in Tilzey et al. 1990) support the existence of a single stock between Crowdy Head and Eden, NSW, within which there is a significant internal movement. No seasonal migrations have been recorded, but there are pronounced diel movements: nannygai school near the seafloor at dawn and dusk and disperse through the water column at night.

There are biological data on several species of commercially important invertebrates. For example, penaeid prawns constitute a very valuable group of marine animals, and the eastern Australian king prawn, Penaeus plebejus, is the second most valuable species of penaeid landed on the east coast (Scott 1985; Rothlisberg et al. 1988; both cited in Glaister et al. 1990). There are three species of interest in relation to the marine aggregate proposal, eastern king prawns, school prawns (Metapenaeus macleayi) and greentail or inshore greasyback prawn (M. bennettae). These species all recruit to estuarine habitats and spend a major part of their life cycle in estuaries.

In Botany Bay, small juvenile eastern king prawns recuited to Zostera seagrasses during the summer, while adults were trawled from deep, soft substrata, also during the summer (SPCC 1981c). They undertake a spawning migration into offshore waters to depths of 220 m (Grey et al. 1983). During their offshore migration, they also move north - prawns tagged off Botany Bay were recovered to the north of Moreton Bay, Qld (Ruello 1975; Glaister et al. 1987). After leaving the estuaries, eastern king prawns may stay adjacent to the estuary, or commence their migration immediately. They migrate along the coast at depths of about 45-90 m (S. Montgomery, FRI, pers. comm.). Glaister et al. (1987) estimated that migrating eastern king prawns move 0.5-9.4 nautical miles per day. In the lab, eastern king prawns have been observed to bury in sandy substrata to depths of 100 mm (S. Montgomery, pers. comm.).

School prawns migrate to depths of 60 m and prefer muddy, turbid habitats (Grey et al. 1983). They were trawled in deep soft substrata in Botany Bay, predominantly during summer, and it was concluded that school prawns probably leave the estuary to spawn (SPCC 1981c). Unlike eastern king prawns, they migrate only short distances (up to about 70 km) from their original estuary (S. Montgomery, pers. comm.). Greentail prawns are predominant in estuaries and coastal lakes, although they occur in shallow coastal waters to depths of about 14 m (Grey et al. 1983).

9.1.2.7 Summary of Existing Information

The review of existing information utilises several sources of information related to ecological, pollution and fisheries research. The literature on commercial fisheries suggests that demersal fish communities off NSW may have been altered due to overfishing. Thus, the assemblages likely to be affected by the proposed extraction of marine aggregate may already have been affected by fishing.

The earlier ecological studies tended to lack sample replication, but later studies (e.g. FRI 1992; The Ecology Lab 1992) demonstrated that many assemblages of fish from soft-sediments may be highly variable in time and space, like the macrofauna of that habitat (Chapter 8). Some studies, however, have found that fish assemblages vary with depth (e.g. The Ecology Lab 1992). The sampling design for this study, described in the next section, was designed to address the questions of whether assemblages within the proposed extraction areas show large variability in time and space, and whether significant variability occurs in the depth range of 20-70 m. This depth range includes the range over which extraction is proposed (i.e. 25-65 m).

Three other important issues arising from the review of the literature are: 1) the possible extent of linkages between other habitats; 2) migration of demersal fishes and mobile invertebrates; 3) and the locations of spawning and nursery grounds. The information on each of these issues is limited, but the literature highlights the likely significance of adjacent estuaries to offshore areas and vice versa - SPCC (1981a) concluded that many of the fish sampled in Botany Bay spend a major part of their life cycle in offshore waters but used habitats within the bay as nursery areas. As no comparable sampling was done outside the bay at the time of the study, however, there is no relative assessment of the value of offshore or nearshore areas as nursery habitat.

As do pelagic fish (Chapter 7), several species of demersal fish and invertebrates migrate in NSW waters. Migrations of gemfish (Rexea solandri) are the best known of the demersal fish, but these occur in waters far deeper than the proposed extraction areas. The eastern Australian king prawn and school prawn migrate offshore in about the same depth range as the proposed extraction areas. Also, crayfish (Jasus verreauxi) are believed to migrate to and from shallow rocky reefs over sand to deepwater habitats off the continental slope (S. Montogomery, pers. comm.). Apart from this, we found no migrations documented for demersal fishes and mobile invertebrates in the habitat and depth range of interest to the Applicant. There is some speculation that tiger flathead may spawn in waters shallower than 100 m, but this has not been demonstrated. Estuarine species such as sand whiting (Sillago ciliata), yellowfin bream (Acanthopagrus australis) and luderick (Girella tricuspidata) are believed to spawn in relatively shallow waters at the entrances to estuaries, well inshore of the proposed extraction areas (SPCC 1981a). However, tarwhine (Rhabdosargus sarba) have been trawled in large numbers, apparently in the depth range of interest to this study (e.g. Gibbs 1987). The field study described below provided a description of the assemblages of fish and mobile invertebrates which would add to existing knowledge of the nearshore waters and assist in predicting the effects of the proposed extraction on fish utilising the proposed extraction areas.

9.2 METHODS

Demersal fish and mobile invertebrates in the proposed extraction areas were described from 2 studies, one done by The Ecology Lab for the project, the other done by FRI as part of the monitoring programme for deepwater ocean outfalls. The methods and results of these are described separately within this chapter, because differences in methodology prevented the data sets from being compared directly. The first study is referred to as the "Metromix aggregate study" and the FRI data set is referred to as the "FRI study".

9.2.1 Study Sites, Survey Times, Sampling and Laboratory Procedures

9.2.1.1 Metromix Aggregate Study

Up to five locations were trawled on 4 occasions: Providential Head (PH), Cape Banks (CB), Bate Bay (BB); Bass Point (BP) and seawrd of Lake Illawarra (IL) (Figs. 9.1a,b; 9.2a). During survey 1 (23/3/90-30/4/90), BB, PH, IL and BP were trawled within two depth ranges. At that time, the Applicant considered BP for extraction of marine aggregate, hence the sampling design compared 2 locations, PH and BP, which would be putatively impacted should extraction proceed, with two references, BB and IL. After commencement of the study, the Applicant decided not to proceed with the proposal to extract marine aggregate at Bass Point because only a relatively small resource was identified there, the resource was more distant from Sydney and several complex environmental issues were emerging.

During survey 2 (21/8/90-19/9/90), the study was expanded to include an additional depth range because advice to the Applicant suggested that a) the resource extended into deeper areas than previously thought and b) technological advances permitted extraction to about 65 m depth (J. Hann, Metromix, pers. comm.). Following survey 2 the Applicant decided not to seek approvals to extract marine aggregate at Bass Point and to seek approval to extract at Cape Banks. In surveys 3 and 4 (21/11/90-17/12/90 & 14/2/91-2/4/91, respectively) sampling was done at CB but continued at BP to provide a spatial reference against which variability at PH and CB could be compared. Also, sampling was terminated at IL for logistical reasons. Therefore, in the last 2 surveys, the design compared two locations, PH and CB, which would be putatively impacted if extraction proceeded, with reference locations at BB and BP.

At Cape Banks, no trawlable grounds could be found in the depth range of 20-30 m. Therefore, sampling was done only at 40-50 m and 60-70 m.

Trawls were done at two sites within each location to provide an estimate of spatial variability at two scales (Fig. 9.1a,b). At PH, one site extended from Little Marley Beach to Providential Head and the other from Curracurrong to North Garie Head (Fig. 9.1a). These sites are just to the south of the proposed extraction area. We were not granted a permit to trawl between Marley Beach and Port Hacking Head by NSW Fisheries because of concerns by the Department that sampling would interfer with trawling being done by FRI as part of the monitoring programme for the deepwater ocean outfalls.

All trawls were done from commercial fishing trawlers which were chartered for the study. The trawlers were equipped with radar and depth sounders. Sites were identified as described in Section 8.1.2.2. In practice, each site covered a north-south distance of about 3-5 km. Three replicate trawls were done at each depth and site during each survey. Each trawl was about 12 min long from the time the net reached the seabed to when it was winched off the bed. This time was selected as the maximum practical time for trawling within a site, taking into account obstructions such as reefs and wrecks. All trawling was done during the day.

A purpose-built Stephenhauser net, designed and constructed by Kent Bollinger, Newcastle, was used in the study (Fig. 9.3). It consisted of 2.5 cm mesh throughout and was designed and rigged to trawl firmly against the seafloor, thus maximising samples of demersal animals.

Following every trawl, fish and invertebrates were sorted on board the trawler. Wherever possible, animals were identified, counted and returned to the water. Species of economic value were also measured (to fork length, LCF). Where large catches occurred, subsamples of 30-40 fish were measured per trawl. Species which could not be identified or processed in the field were either iced or placed in dilute formaldehyde and returned to the lab to complete processing. Assistance with identification was provided by the Australian Museum and all samples of taxonomic interest were lodged with the Museum.

9.2.1.2 FRI Study

The FRI and the EPA jointly provided the data for the FRI study. The data analysed here form only a part of that collected for the ocean outfalls study (e.g. FRI trawl data from 100 m depths were not examined). Details of sampling procedures are provided in FRI (1992). There are several aspects of the methodology relevant to the present proposal which are described here.

Catch data were analysed from 4 locations, Long Reef (LR), Bondi (BO), Malabar (MA) and Port Hacking (HA - Fig. 9.4), on 7 occasions: autumn 1989, winter 1989, spring 1989, autumn 1990, winter 1990, spring 1990 and summer 1990. At Long Reef, Bondi and Port Hacking, trawls were done at 30 m and 60 m but at Malabar no trawlable ground occurred at 30 m. All trawling was done during the day.

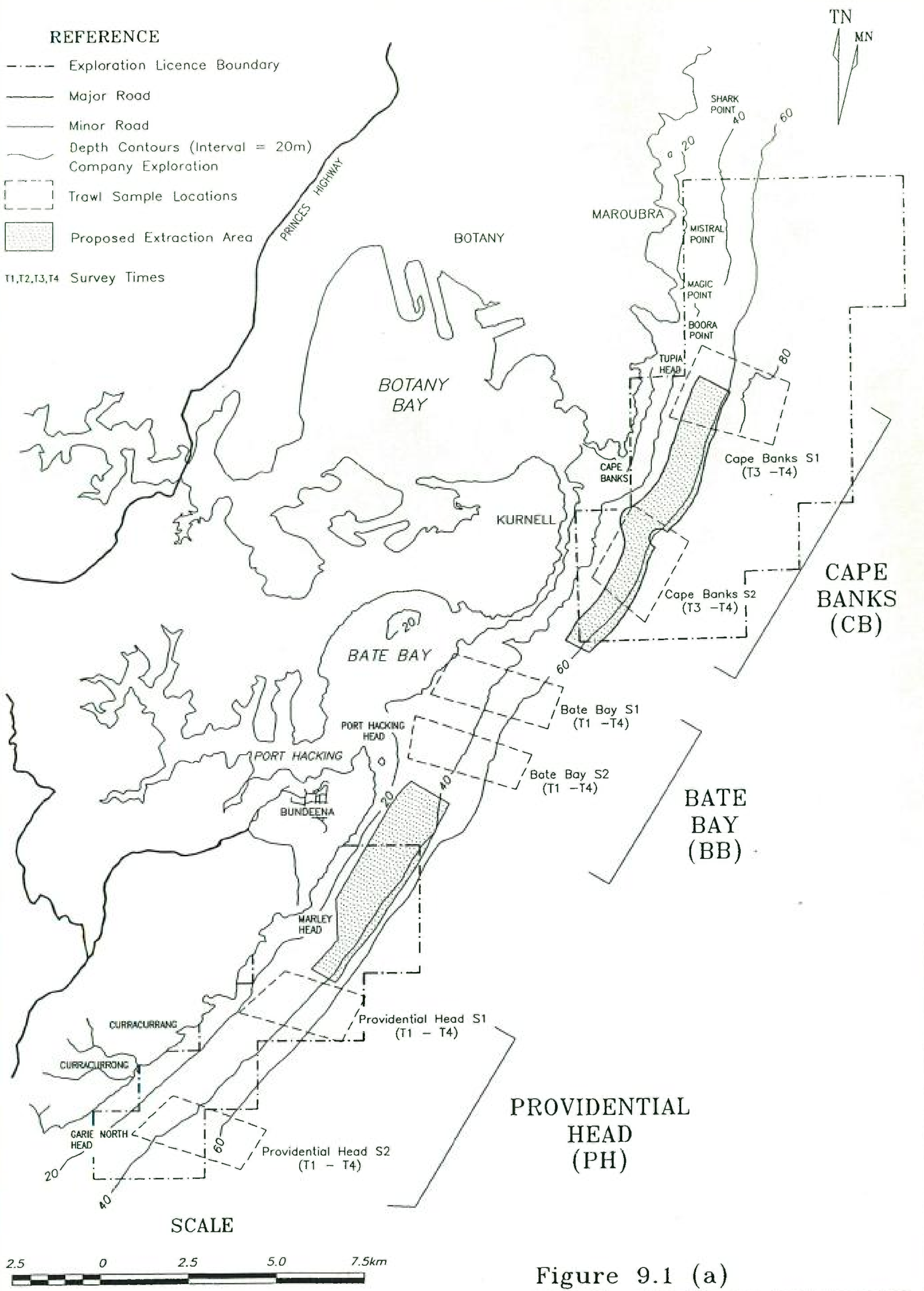
Long Reef and Bondi are north of the locations sampled by The Ecology Lab. Moreover, the 30 m station off Bondi was adjacent to a large, cliff-face sewage outfall, which was decommissioned in July, 1991. FRI (1992) found that fish catches at this depth off Bondi were often larger than elsewhere and speculated that this may have been due to the presence of the outfall. The location in 60 m off Malabar was slightly north of the 60-70 m depth for the Metromix aggregate study (N. Otway, pers. comm.). Finally, the 30 m and 60 m stations off Port Hacking extended from Port Hacking Head to about Marley Beach and therefore included the area where sampling was not permitted for the Metromix aggregate study (Section 9.2.1.1).

The otter trawl used by FRI was designed to sample demersal fish (FRI 1992). It was larger than that used in the Metromix aggregate study and was trawled for 20 min intervals. Therefore, potentially important differences in the methodology include the larger size of FRI's net and longer trawl times. Note that the FRI study did not trawl at sites within locations. FRI obtained 3 replicate trawls at each depth and location in each survey.

9.2.2 Statistical Analyses

9.2.2.1 Metromix Aggregate Study

Data were analysed using similar procedures to those described in Section 8.1.2.3. For the analysis of assemblages using multivariate analyses, we included all locations (including Illawarra), sites, depths and survey times. An important difference between the macrofauna and demersal fishes and mobile invertebrates is that for the latter we were readily able to



SOURCE : R.W.CORKERY & CO. PTY. LIMITED
3rd September, 1993

Figure 9.1 (a)
TRAWL SAMPLING LOCATIONS
CAPE BANKS, BATE BAY AND
PROVIDENTIAL HEAD

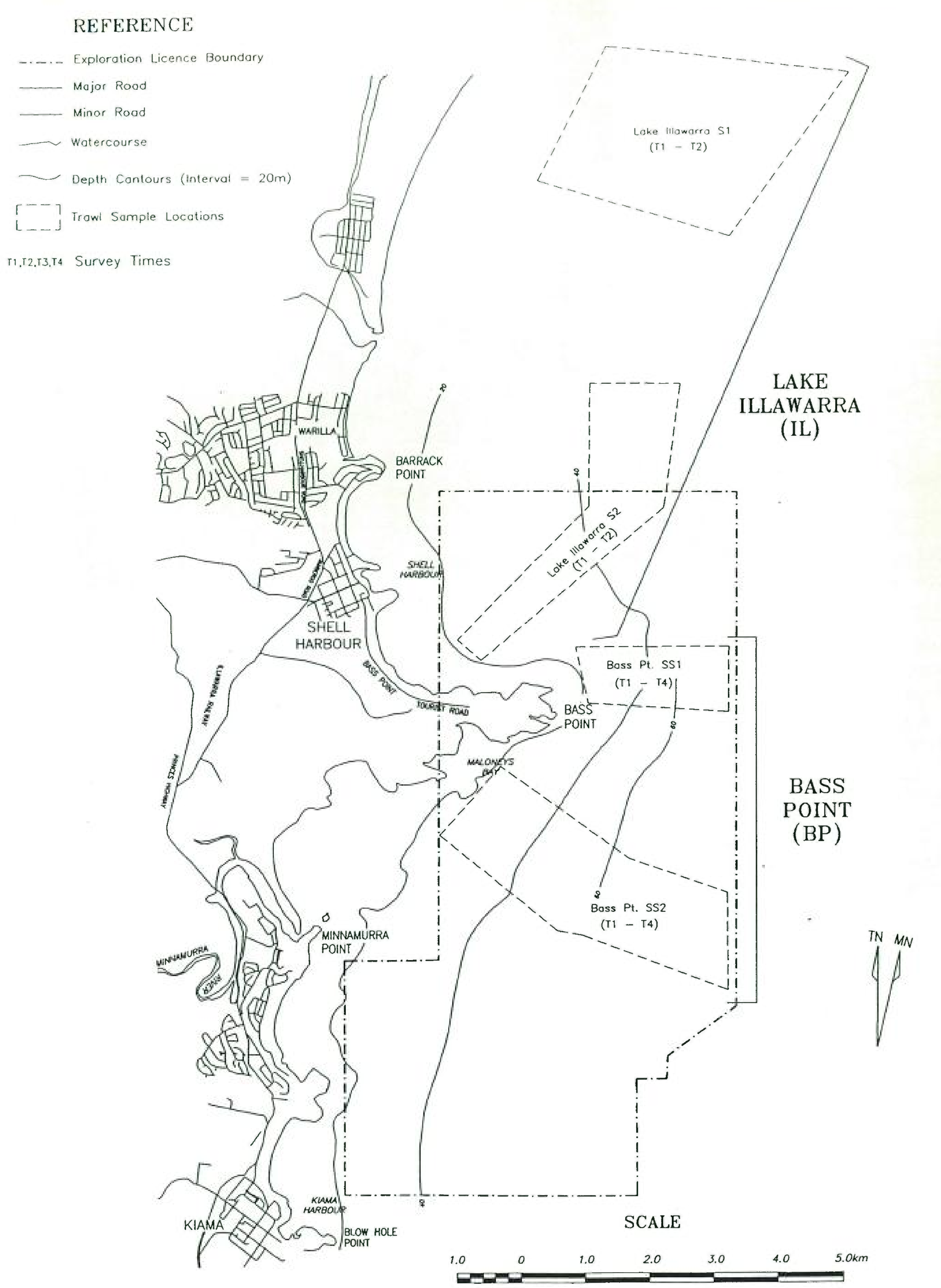
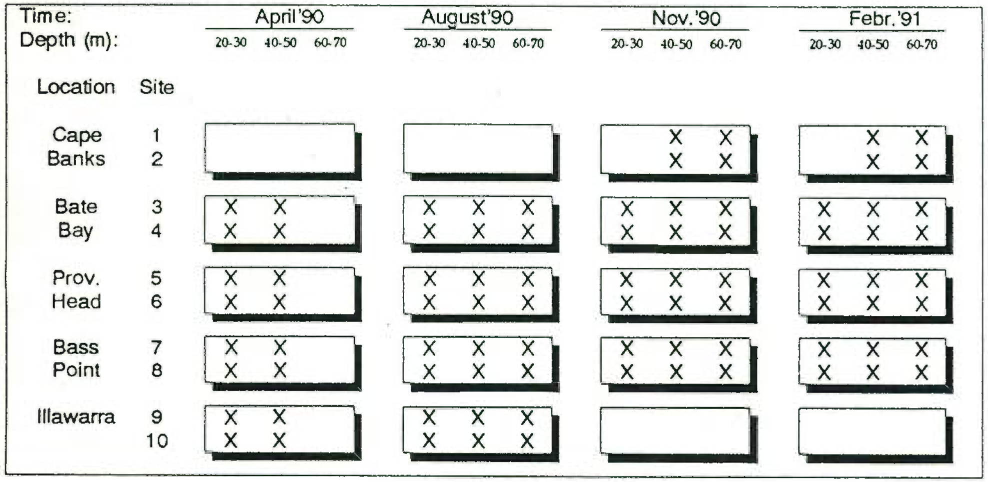


Figure 9.1 (b)
TRAWL SAMPLING LOCATIONS
BASS POINT & LAKE ILLAWARRA

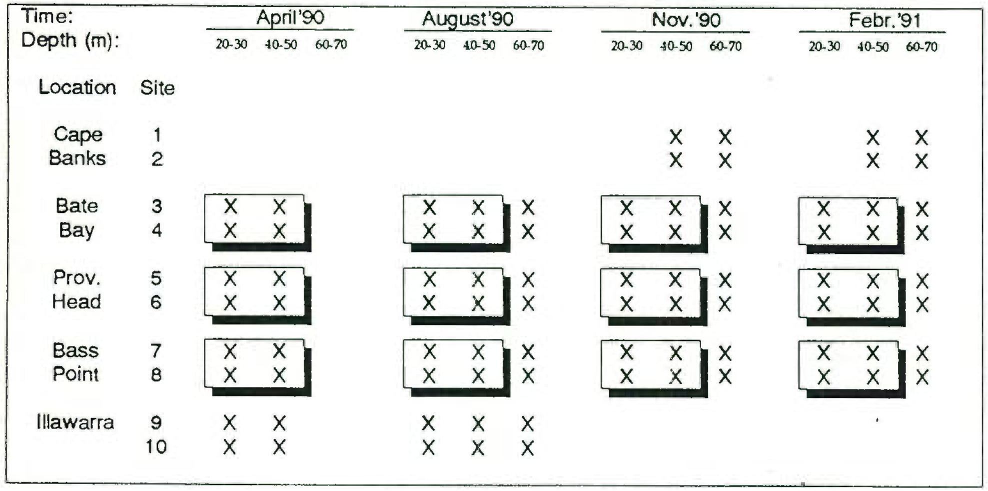
SOURCE : R.W.CORKERY & CO. PTY. LIMITED
3rd September, 1993

(a) Distribution of all samples (X=3 replicates)



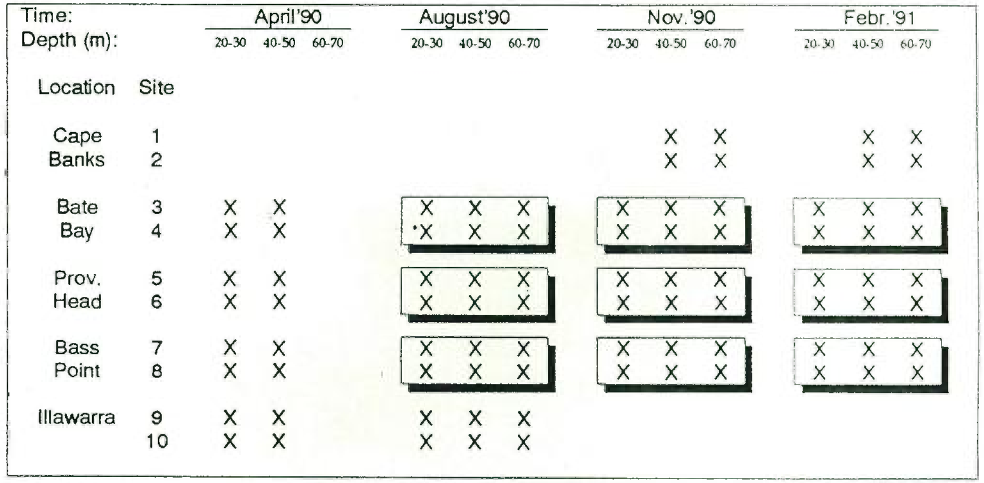
Time:		April'90			August'90			Nov.'90			Febr.'91		
Depth (m):		20-30	40-50	60-70	20-30	40-50	60-70	20-30	40-50	60-70	20-30	40-50	60-70
Location	Site												
Cape Banks	1								X	X		X	X
	2								X	X		X	X
Bate Bay	3	X	X		X	X	X	X	X	X	X	X	X
	4	X	X		X	X	X	X	X	X	X	X	X
Prov. Head	5	X	X		X	X	X	X	X	X	X	X	X
	6	X	X		X	X	X	X	X	X	X	X	X
Bass Point	7	X	X		X	X	X	X	X	X	X	X	X
	8	X	X		X	X	X	X	X	X	X	X	X
Illawarra	9	X	X		X	X	X						
	10	X	X		X	X	X						

(b) Design 1 - Providential Head (X=3 replicates)



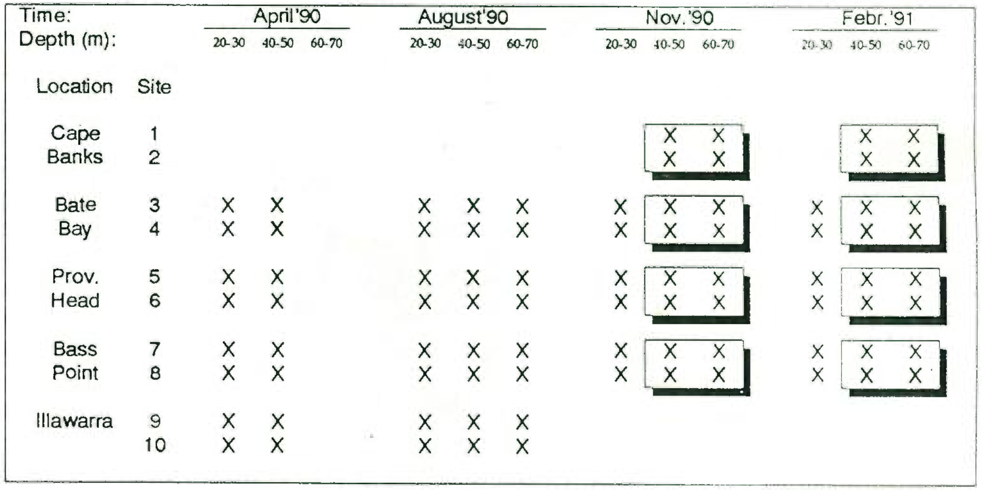
Time:		April'90			August'90			Nov.'90			Febr.'91		
Depth (m):		20-30	40-50	60-70	20-30	40-50	60-70	20-30	40-50	60-70	20-30	40-50	60-70
Location	Site												
Cape Banks	1								X	X		X	X
	2								X	X		X	X
Bate Bay	3	X	X		X	X	X	X	X	X	X	X	X
	4	X	X		X	X	X	X	X	X	X	X	X
Prov. Head	5	X	X		X	X	X	X	X	X	X	X	X
	6	X	X		X	X	X	X	X	X	X	X	X
Bass Point	7	X	X		X	X	X	X	X	X	X	X	X
	8	X	X		X	X	X	X	X	X	X	X	X
Illawarra	9	X	X		X	X	X						
	10	X	X		X	X	X						

(c) Design 2 - Providential Head (X=3 replicates)



Time:		April'90			August'90			Nov.'90			Febr.'91		
Depth (m):		20-30	40-50	60-70	20-30	40-50	60-70	20-30	40-50	60-70	20-30	40-50	60-70
Location	Site												
Cape Banks	1								X	X		X	X
	2								X	X		X	X
Bate Bay	3	X	X		X	X	X	X	X	X	X	X	X
	4	X	X		X	X	X	X	X	X	X	X	X
Prov. Head	5	X	X		X	X	X	X	X	X	X	X	X
	6	X	X		X	X	X	X	X	X	X	X	X
Bass Point	7	X	X		X	X	X	X	X	X	X	X	X
	8	X	X		X	X	X	X	X	X	X	X	X
Illawarra	9	X	X		X	X	X						
	10	X	X		X	X	X						

(d) Design 3 - Cape Banks (X=3 replicates)



Time:		April'90			August'90			Nov.'90			Febr.'91		
Depth (m):		20-30	40-50	60-70	20-30	40-50	60-70	20-30	40-50	60-70	20-30	40-50	60-70
Location	Site												
Cape Banks	1								X	X		X	X
	2								X	X		X	X
Bate Bay	3	X	X		X	X	X	X	X	X	X	X	X
	4	X	X		X	X	X	X	X	X	X	X	X
Prov. Head	5	X	X		X	X	X	X	X	X	X	X	X
	6	X	X		X	X	X	X	X	X	X	X	X
Bass Point	7	X	X		X	X	X	X	X	X	X	X	X
	8	X	X		X	X	X	X	X	X	X	X	X
Illawarra	9	X	X		X	X	X						
	10	X	X		X	X	X						

Figure 9.2. The distribution of trawl samples and analytical designs comparing balanced subsets of these samples by ANOVA.

250 Square X 20 Fathom Stephenhausen Net

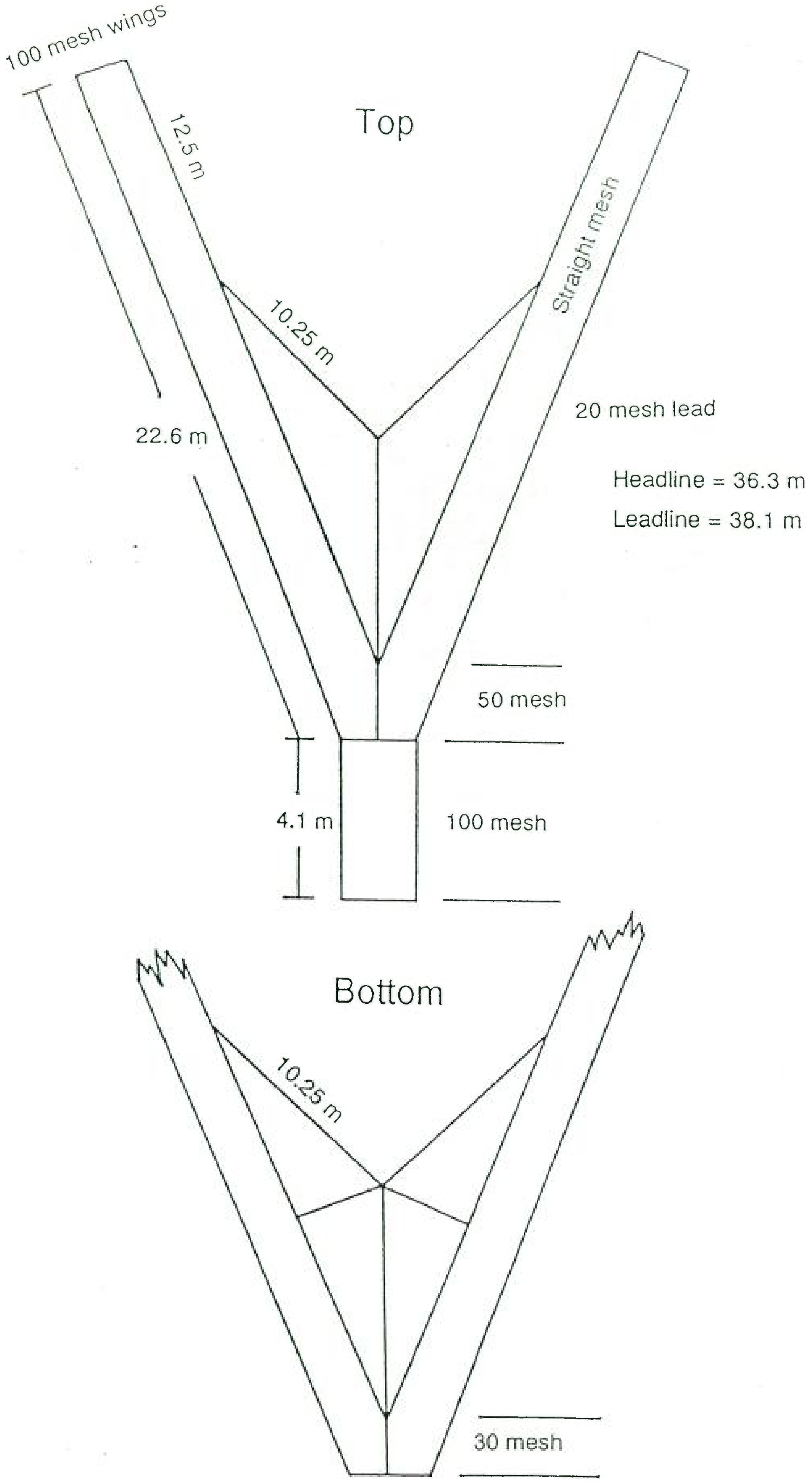


Figure 9.3 Design of net used for main aggregate study.

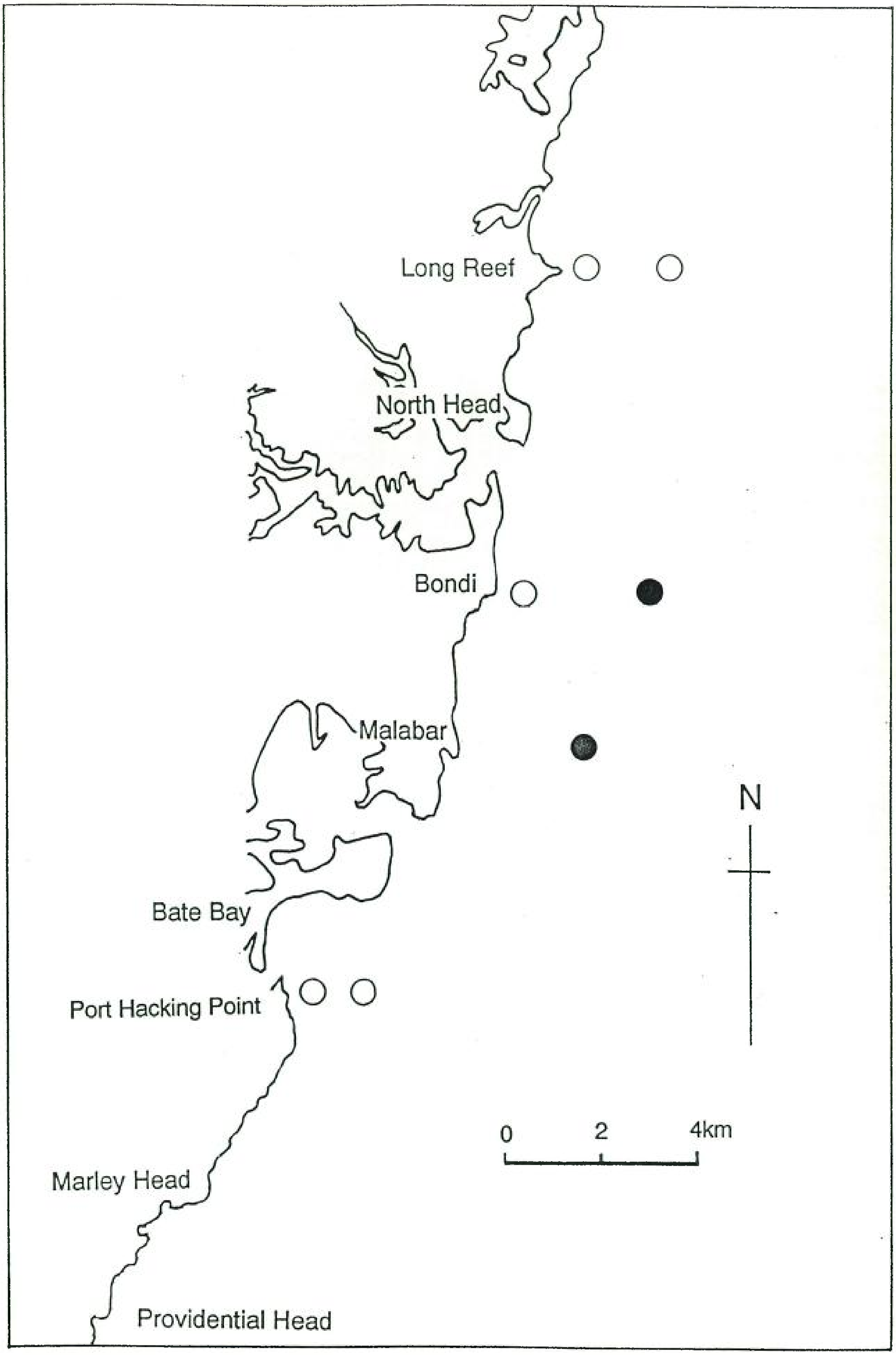


Figure 9.4 Sampling locations for FRI study (from FRI 1992). Solid circles = sites at deep ocean outfalls.

identify most animals to species, hence the analyses were done at this taxonomic level. One or two groups were difficult to differentiate, for example, there were several species of gurnards of the genus Lepidotrigla. In this case the group is treated simply as Lepidotrigla spp.

Three statistical designs were used to analyse populations of species, as described in Section 8.1.2.3 (see Table 8.2). As with the macrofauna, each design focused on a particular issue: design 1 compares populations over all four survey periods; design 2 compares them over all 3 depths; and design 3 focuses on Cape Banks (Fig. 9.2b-c, Table 9.1). 4-way ANOVAs were used in the same way as described previuosly, although the number of levels in each factor and the replication differed (Table 9.2).

As described in Section 8.1.2.3, Cochran's Test was used to test the assumption of homogeneous variances. Data with heterogeneous variances were transformed to $\log_{10}$ or $\sqrt{(x+1)}$ and resubmitted to Cochran's Test. Where variances remained heterogeneous after transformation, the α-level for the test was reduced, as described in Section 8.1.2.3. Also, Student Newman Keuls tests or Ryans tests were done (at the same α-level as the ANOVA) to identify where significant means occurred among treatments for significant factors in the ANOVAs (Section 8.1.2.3).

Length frequency data were obtained for fish of economic value. These data were examined to determine any trends in size distribution among locations, times or depths. Data for sites were pooled within locations. The results were interpreted graphically.

9.2.2.2 FRI Study

The data obtained from the FRI and EPA were analysed in a similar way to the Metromix aggregate study, although there was insufficient time to do multivariate analysis of assemblages. For the analysis of populations, two analytical designs were used to accomodate all the data. FRI design 1 was a 3-way ANOVA comparing locations (LR, BO and HA), depths (30 m and 60 m) and time (7 surveys). Design 2 was a 2-way ANOVA comparing locations (LR, BO, HA and MA) and time (7 surveys) at 60 m only. All factors were considered fixed.

As described previously, Cochran's Test was used to test the assumption of homogeneous variances. Also, Student Newman Keuls tests or Ryans tests were used to identify where significant means occurred among treatments.

Table 9.1 Configuration of data into 3 designs for univariate statistical analyses. In all series there were two sites sampled within each location, depth and time, and the number of replicate trawls, n = 3. EA= proposed extraction area, Ref=reference area

Data Series	Times	Depths (m)	Locations (treatments)
Design 1	April 1990 August 1990 November 1990 February 1991	20-30 40-50	Bate Bay (Ref) Providential Head (EA) Bass Point (Ref)
Design 2	August 1990 November 1990 February 1991	20-30 40-50 60-70	Bate Bay (Ref) Providential Head (EA) Bass Point (Ref)
Design 3	November 1990 February 1991	40-50 60-70	Cape Banks (EA) Bate Bay (Ref) Providential Head (EA) Bass Point (Ref)

Table 9.2 General ANOVA model used for the Metromix aggregate study. "F vs" indicates the denominator in each F-ratio, and the degrees of freedom are presented for the three ANOVA designs.

Source	Expected Mean Square	F vs	df: Design 1	Design 2	Design 3
Time [T]	$\sigma^2_e + an\sigma^2_{TS(L)} + acdn\sigma^2_T$	TxS(L)	3, 9	2, 6	1, 4
Depth [D]	$\sigma^2_e + bn\sigma^2_{DS(L)} + bcdn\sigma^2_D$	DxS(L)	1, 3	2, 6	1, 4
Location [L]	$\sigma^2_e + abn\sigma^2_{S(L)} + abdn\sigma^2_L$	S(L)	2, 3	2, 3	3, 4
Site(Loc) [S(L)]	$\sigma^2_e + abn\sigma^2_{S(L)}$	Residual	3,96	3,108	4,64
T x D	$\sigma^2_e + n\sigma^2_{TDS(L)} + cdn\sigma^2_{TD}$	TxDxS(L)	3, 9	4, 12	1, 4
T x L	$\sigma^2_e + an\sigma^2_{TS(L)} + adn\sigma^2_{TL}$	TxS(L)	6, 9	4, 6	3, 4
T x S(L)	$\sigma^2_e + an\sigma^2_{TS(L)}$	Residual	9,96	6,108	4,64
D x L	$\sigma^2_e + bn\sigma^2_{DS(L)} + bdn\sigma^2_{DL}$	DxS(L)	2, 3	4, 6	3, 4
D x S(L)	$\sigma^2_e + bn\sigma^2_{DS(L)}$	Residual	3,96	6,108	4,64
T x D x L	$\sigma^2_e + n\sigma^2_{TDS(L)} + dn\sigma^2_{TDL}$	TxDxS(L)	6,9	8,12	3,4
T x D x S(L)	$\sigma^2_e + n\sigma^2_{TDS(L)}$	Residual	9,96	12,108	4,64
Residual	σ^2_e				

9.3 RESULTS

9.3.1 Metromix Aggregate Study

9.3.1.1 General Observations

During the study, 252 trawls were done, 66 each at Bate Bay, Providential Head and Bass Point, 30 at Illawarra and 24 at Cape Banks. The net became snagged on the seafloor several times at Bass Point and Cape Banks. Some of the damage caused at Cape Banks was believed to be due to jetsom from vessels entering Botany Bay. Apart from this, the net provided large catches of fish and invertebrates. In addition to these, the net sometimes trawled kelp fronds and masses of the green alga *Caulerpa filiformis*. It is highly unlikely that this alga was growing in the locations where it was trawled, it had probably been carried there in the currents from shallow reef habitats, possibly having being dislodged by storms.

In all, we collected 132,215 fish from about 150 species from 64 families (Appendix B1). Also, 2,692 invertebrates from 35 species were collected. Most of the species are relatively common and widespread on the NSW coast; none is considered rare or endangered. Although many of the species are subject to fishing bag limits for recreational fishers, or to catch quotas for commercial fishers, none is protected under current legislation.

The total numbers of species collected at each location, depth and time are shown in Tables 9.3 and 9.5. In 20-30 m, between 30 and 46 species species of fish were collected at each location; at 40-50 m numbers of species ranged from 26 to 47; and at 60-70 m there were from 27 to 44 species collected at each location and survey. The numbers of invertebrate species collected were much smaller (Table 9.5). Numbers of species of invertebrates collected ranged from 2 to 7, 4 to 13 and 6 to 13 with increasing depth. Richness and abundance of invertebrates were relatively low at 20-30 m.

Species which were numerically dominant in the samples varied among depths and times, and to a lesser extent among locations (Tables 9.3 and 9.4). In 20-30 m, catches tended to be dominated by a genus of gurnards (*Lepidotrigla*) of no commercial value. These may include at least three species, *L. agrus*, *L. mulhalli* and *L. vanessa*, but we resolved the group only to genus. Another member of the genus, *L.papilio*, was easily identified and counted separately.

The 20-30 m range was also dominated by long-spined flathead, *Platycephalus longispinus*, a small species of no commercial value and limited value to recreational fishing; stingarees (several species of *Urolophus*) and box fish, *Anoplocapros inermis* (Table 9.4a). Of the invertebrates, Balmain bugs, *Ibacus peroni*, an unidentified species of octopus and calamari squid, *Sepioteuthis* australis, predominated (Table 9.4a).

The 40-50 m range was also dominated by Lepidotrigla spp. and P. longispinus, in addition to crested flounder, Lophonectes gallus and eastern school whiting, Sillago bassensis flindersi (Table 9.3b). Among the invertebrates, the cuttlefish, Sepia plangon and several species of crabs, paricularly the hermit crab, Dardanus arrosor, predominated (Table 9.4b). In 60-70 m, dominant species included S. b. flindersi, tiger flathead (Neoplatycephalus richardsoni), L. gallus, Lepidotrigla spp. and to a lesser extent, John Dory (Zeus faber - Table 9.3c). S. plangon tended to dominate the invertebrate catches (Table 9.4c).

The numbers of fish species of economic value tended to increase with depth (Table 9.3). At 20-30 m, S.b.flindersi and T. novaezelandiae were dominant species on only 3 occasions (Table 9.3a). At 40-50 m, S.b.flindersi occurred at most locations and times, while T.novaezelandiae, N.richardsoni, C.affinis and T.declivus also dominated the catch (Table 9.3b). A similar pattern occurred at 60-70 m (Table 9.3c).

Tables 9.3 and 9.4 also show the coefficients of variation (CV) for each dominant species at each depth, time and location. CVs ranged from moderate (e.g. 19% for Lophonectes gallus at Cape Banks at 60 to 70 m depth in summer, 1991) to very high (e.g. 243% for Trachurus novaezelandiae at Providential Head at 40 to 50 m depth in winter, 1990). Moreover, the CVs for particular species often varied substantially among times and locations. For example, during survey 1, CVs for Lepidotrigla spp. were around 60% at all locations at 20-30 m. In survey 2, CVs ranged from 69 to 116% (Table 9.3a). Thus the extent of variability can vary among species, locations and from one survey to the next.

9.3.1.2 Analysis of Assemblages

Analyses were done on assemblages of fish but not invertebrates because of the low numbers collected. Those species which were common were examined individually (Section 9.3.1.2).

The analysis of assemblages of fish confirmed the trends suggested in the previous section. Clear patterns of variation in assemblages among depths occurred during all surveys (Figs. 9.5-8, in Appendix B9, Volume II). The stress values for the ordinations including depths were relatively low, indicating that the 2-dimensional plot represented the patterns of variation well.

Assemblages of fish at the five locations were similar. In survey 1, the assemblage at BB 20-30 m grouped near to the 40-50 m assemblages, while one of the BB 40-50 m sites grouped with the 20-30 m assemblages (Fig. 9.5). In survey 2, there was a clear differentiation of assemblages between the 60-70 m samples and

Table 9.3 Summary of catches of the five most numerically-dominant species of fish at different locations and depths over four survey periods. spp = total number of species; Tot Abun = total number of individuals collected; % = percentage of abundance for that location, depth and time; CV = coefficient of variation (mean/standard deviation) based on the number of trawls per location, depth and time, with sites combined (n=6). See Appendix B1 for list of species collected.

a. 20-30 m depth

Bate Bay				Providential Head				Illawarra				Bass Point			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Survey 1:															
spp = 32				spp = 42				spp = 48				spp = 46			
Lepidotrigla	49	1340	60	Lepidotrigla	37	1097	60	Lepidotrigla	41	2789	67	Lepidotrigla	44	1530	62
P.longispinus	22	593	53	P.longispinus	14	428	51	P.longispinus	19	1283	66	P.longispinus	16	551	46
U.Kapalae	10	286	79	U.paucimaculat.	11	333	115	U.kapalae	15	1028	81	S.bassensis	13	432	133
P.unicolor	7	185	74	A.inermis	10	297	58	S.bassensis	6	401	145	U.kapalae	12	424	84
U.testaceus	4	104	76	U.kapalae	9	261	66	A.inermis	4	296	60	A.inermis	6	196	139
Survey 2:															
spp = 35				spp = 30				spp = 41				spp = 37			
T.novaezeland.	39	751	143	U.kapalae	41	560	30	T.novaezeland.	34	619	203	U.kapalae	25	116	50
P.longispinus	21	439	41	A.inermis	18	248	46	U.kapalae	23	426	85	P.longispinus	22	104	68
Lepidotrigla	12	249	69	P.longispinus	11	157	68	A.inermis	13	242	71	A.inermis	21	99	70
U.kapalae	7	155	62	U.testaceus	11	152	18	U.testaceous	8	141	56	Lepidotrigla	7	31	116
U.testaceus	6	134	76	Lepidotrigla	6	76	85	P.longspinus	6	103	42	U.paucimaculatus	7	31	80
								Cape Banks							
								Species of fish	%	Tot Abun	CV (%)				
Survey 3:															
spp = 29				spp = 35								spp = 41			
Lepidotrigla	18	249	85	P.longispinus	18	341	55					A.inermis	25	527	65
U.kapalae	18	248	115	A.inermis	18	335	62					Lepidotrigla	18	382	43
P.longispinus	30	411	37	U.paucimaculat.	15	284	125	NO				U.kapalae	16	351	34
U.paucimaculatus	9	119	103	Lepidotrigla	13	249	40					P.longispinus	14	311	35
A.inermis	8	115	38	U.kapalae	9	236	144	SURVEY				H.portusjacksoni	8	162	152
Survey 4:															
spp = 45				spp = 44								spp = 46			
P.longispinus	33	459	45	U.testaceous	21	476	71					A.inermis	33	622	113
Lepidotrigla	14	200	132	A.inermis	21	470	32	NO				U.kapalae	19	367	82
U.Kapalae	9	125	139	U.kapalae	14	316	84					T.novaezeland.	19	353	185
S.bassensis	5	73	241	Lepidotrigla	11	240	63	SURVEY				R.sarba	8	162	171
P.jenynsii	5	65	51	P.longispinus	9	214	56					U.testaceus	3	66	57

Table 9.3, continued

b. 40-50 m depth

Bate Bay				Providential Head				Illawarra				Bass Point			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Survey 1:															
spp = 39				spp = 36				spp = 46				spp = 43			
Lepidotrigla	55	993	108	Lepidotrigla	35	306	108	Lepidotrigla	38	2110	56	S.bassensis	60	3765	87
S.bassensis	21	378	58	A.inermis	20	181	102	S.bassensis	32	1737	48	Lepidotrigla	25	1586	33
P.longispinus	7	130	114	P.longispinus	15	130	130	P.longispinus	11	605	87	P.longispinus	5	294	55
L.gallus	4	67	39	N.ayraudi	8	68	79	L.gallus	5	292	68	L.gallus	4	247	127
S.novaeholland.	2	40	121	U.kapalae	4	36	182	T.novaezeland.	2	132	94	A.inermis	1	87	191
Survey 2:															
spp = 36				spp = 26				spp = 44				spp = 31			
Lepidotrigla	28	633	79	T.novaezeland.	48	444	243	U.kapalae	20	222	130	S.bassensis	68	1870	61
S.bassensis	18	418	208	P.longispinus	15	139	41	Lepidotrigla	16	177	147	T.novaezeland.	10	280	151
P.longispinus	15	350	70	Lepidotrigla	10	95	103	T.novaezeland.	15	164	211	P.longispinus	6	154	36
U.kapalae	11	247	95	A.inermis	8	75	34	S.bassensis	7	81	118	T.declivus	6	153	198
T.novaezeland.	7	154	117	U.kapalae	3	30	52	U.testaceus	7	78	124	Lepidotrigla	2	58	64
								Cape Banks							
								Species of fish	%	Tot Abun	CV (%)				
Survey 3:															
spp = 30				spp = 29				spp = 30				spp = 41			
Lepidotrigla	41	555	93	Lepidotrigla	16	181	111	A.inermis	42	384	46	S.bassensis	47	2648	70
P.longispinus	18	244	31	A.inermis	16	177	64	C.affinis	13	122	245	A.inermis	24	1387	105
C.affinus	10	139	156	T.novaezeland.	15	175	203	P.longispinus	6	54	58	N.richardsoni	8	468	48
L.gallus	10	131	46	M.australis	12	134	110	U.kapalae	6	51	117	Lepidotrigla	5	261	71
N.richardsoni	7	93	38	P.longispinus	11	122	68	Lepidotrigla	5	46	120	S.australasicus	3	182	245
Survey 4:															
spp = 37				spp = 44				spp = 35				spp = 47			
Lepidotrigla	33	1272	45	T.novaezeland.	50	1690	124	N.ayraudi	22	64	68	S.bassensis	53	4278	55
S.bassensis	29	1130	73	S.bassensis	29	965	116	P.auratus	10	28	159	A.inermis	25	1971	170
L.gallus	13	505	63	A.inermis	9	317	82	U.kapalae	9	26	161	Lepidotrigla	7	542	88
T.novaezeland.	8	326	172	Lepidotrigla	2	81	84	L.papilio	7	20	125	L.gallus	2	190	78
P.longispinus	6	238	65	L.gallus	2	72	98	P.marmoratus	5	16	146	T.novaezeland.	2	187	119

Table 9.3, continued

c. 60-70 m depth

Bate Bay				Providential Head				Illawarra				Bass Point			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Survey 1:															
NO SURVEY				NO SURVEY				NO SURVEY				NO SURVEY			
Survey 2:															
spp = 36				spp = 27				spp = 43				spp = 42			
S.bassensis	27	1020	137	T.novaezeland.	51	1644	133	S.bassensis	59	1408	111	T.novaezeland.	32	1088	120
L.gallus	19	689	106	L.gallus	18	562	41	T.novaezeland.	19	443	157	T.declivus	17	578	140
T.novaezeland.	18	653	88	Lepidotrigla	16	526	65	T.declivus	5	117	182	C.affinis	7	295	185
Lepidotrigla	17	639	55	N.richardsoni	8	244	42	L.gallus	4	89	25	Lepidotrigla	8	270	67
N.richardsoni	13	473	34	S.bassensis	4	117	36	N.richardsoni	3	82	82	L.gallus	6	204	60
								Cape Banks							
								Species of fish	%	Tot Abun	CV (%)				
Survey 3:															
spp = 24				spp = 29				spp = 39				spp = 33			
L.gallus	33	345	21	S.bassensis	68	5785	114	L.gallus	23	301	80	S.bassensis	36	932	147
S.bassensis	25	261	60	T.novaezeland.	11	960	98	T.novaezeland.	22	288	134	L.gallus	27	709	56
Lepidotrigla	22	230	64	L.gallus	9	811	90	Lepidotrigla	14	185	47	Lepidotrigla	10	255	122
N.richardsoni	11	118	70	Lepidotrigla	6	507	119	N.richardsoni	7	97	76	N.richardsoni	9	224	87
R.australis	2	22	106	N.richardsoni	3	236	63	A.inermis	3	41	80	T.novaezeland.	4	95	111
Survey 4:															
spp = 32				spp = 36				spp = 44				spp = 35			
L.gallus	34	1799	51	T.novaezeland.	40	3014	34	L.gallus	30	1350	19	S.bassensis	57	5690	92
S.bassensis	20	1082	108	S.bassensis	22	1688	73	S.bassensis	30	1336	65	M.scolopax	14	1403	128
T.novaezeland.	19	1015	74	M.scolopax	17	1285	130	Lepidotrigla	22	971	22	T.novaezeland.	8	779	114
N.richardsoni	9	456	94	L.gallus	9	650	62	C.affinis	4	166	152	N.richardsoni	7	710	153
Z.faber	8	397	109	Z.faber	5	403	116	Z.faber	3	123	71	L.gallus	6	619	38

Table 9.4 Summary of catches of the five most numerically-dominant species of invertebrates at different locations and depths over 4 surveys. Headings as per Table 9.3.

a. 20-30 m depth

Bate Bay				Providential Head				Illawarra				Bass Point			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Survey 1:															
spp = 2				spp = 7				spp = 4				spp = 7			
I.peroni	93	12	127	*I.peroni*	50	21	66	*S.australis*	44	7	112	*S.australis*	32	8	136
Octopus sp.	8	1	273	*S.australis*	36	15	146	*I.peroni*	31	5	214	*I.peroni*	24	6	122
				D.arrosor	5	2	273	*Octopus sp.*	19	3	122	*D.arrosor*	24	6	187
				S.apama	2	1	273	*S.plangon*	6	1	237	*S.plangon*	8	2	173
				Unid. crab	2	1	273					*Octopus sp.*	4	1	273
Survey 2:															
spp = 5				spp = 3				spp = 6				spp = 2			
I.peroni	38	16	68	*I.peroni*	50	3	122	*S.australis*	53	9	131	*S.plangon*	50	3	273
C.bimaculata	29	12	196	*Octopus sp.*	33	2	173	*I.peroni*	18	3	187	*S.australis*	50	3	187
S.australis	21	9	62	*S.plangon*	17	1	273	*P.pelagicus*	12	2	173				
Octopus sp.	10	4	136					*S.apama*	6	1	273				
D.arrosor	2	1	273					*S.plangon*	6	1	273				
								Cape Banks							
								Species of fish	%	Tot Abun	CV (%)				
Survey 3:															
spp = 6				spp = 3								spp = 5			
I.peroni	71	27	30	*I.peroni*	75	6	141					*S.plangon*	42	8	164
Octopus sp.	18	7	141	*Octopus sp.*	13	1	273					*S.apama*	26	5	131
S.australis	3	1	273	*S.plangon*	13	1	273		NO			*S.australis*	16	3	122
N.gouldi	3	1	273									*D.arrosor*	11	2	173
S.plangon	3	1	273						SURVEY			*I.peroni*	5	1	273
Survey 4:															
spp = 6				spp = 3								spp = 6			
I.peroni	42	5	214	*I.peroni*	50	2	173					*S.australis*	40	4	203
S.plangon	17	2	273	*S.plangon*	25	1	273		NO			*S.apama*	20	2	173
N.gouldi	17	2	173	*D.arrosor*	25	1	273					*Octopus sp.*	10	1	273
T.strigimanus	8	1	273						SURVEY			*P.pubescens*	10	1	273
Octopus sp.	8	1	273									*D.arrosor*	10	1	273

Table 9.4, continued

b. 40-50 m depth

Bate Bay				Providential Head				Illawarra				Bass Point			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Survey 1:															
spp = 8				spp = 10				spp = 8				spp = 13			
S.plangon	70	86	191	S.plangon	127	56	127	S.plangon	48	32	204	S.plangon	36	28	174
D.arrosor	12	15	159	S.australis	129	23	129	S.australis	33	22	92	S.australis	31	24	79
S.australis	7	9	147	D.arrosor	150	10	150	Octopus sp.	8	5	214	D.arrosor	10	8	136
Octopus sp.	7	8	146	Octopus sp.	187	3	187	S.apama	5	3	187	S.apama	4	3	187
H.australiensis	2	2	173	A.kulmaris	273	2	273	H.maculosa	2	1	273	I.peroni	4	3	187
Survey 2:															
spp = 8				spp = 5				spp = 5				spp = 6			
S.australis	44	12	87	D.arrosor	83	19	72	S.plangon	48	12	136	D.arrosor	38	15	84
Venericardia sp.	15	4	273	T.strigimanus	4	1	273	D.arrosor	16	4	203	S.plangon	36	14	78
Octopus sp.	15	4	136	I.peroni	4	1	273	S.apama	12	3	122	S.australis	10	4	136
P.pelagicus	11	3	187	P.pelagicus	4	1	273	H.australiensis	12	3	187	H.australiensis	10	4	136
C.bimaculata	4	1	173	C.bimaculata	4	1	273	S.australis	12	3	187	C.bimaculata	3	1	273
								Cape Banks							
								Species of fish	%	Tot Abun	CV (%)				
Survey 3:															
spp = 6				spp = 7				spp = 8				spp = 4			
S.plangon	56	35	55	D.arrosor	74	52	84	S.plangon	60	27	116	S.plangon	69	33	152
D.arrosor	27	17	164	S.plangon	16	11	98	P.diogenes	9	4	173	D.arrosor	27	13	179
I.peroni	11	7	112	Chlamys sp.	3	2	173	S.apama	9	4	136	P.fumata	2	1	273
Octopus sp.	3	2	173	N.gouldi	3	2	273	Octopus sp.	7	3	122	S.apama	2	1	273
N.gouldi	2	1	273	Octopus sp.	1	1	0	D.arrosor	7	3	187				
Survey 4:															
spp = 9				spp = 8				spp = 10				spp = 9			
S.plangon	86	249	225	D.arrosor	57	45	148	S.plangon	47	27	98	S.plangon	44	26	100
D.arrosor	4	12	106	S.plangon	27	21	87	S.apama	10	6	141	D.arrosor	24	14	49
C.bimaculata	4	11	216	Octopus sp.	6	5	156	D.arrosor	10	6	122	S.australis	12	7	153
N.gouldi	3	9	102	L.tuberculatus	5	4	173	Octopus sp.	10	6	223	T.strigimanus	8	5	131
S.australis	1	3	122	P.diogenes	1	1	273	P.diogenes	9	5	178	Octopus sp.	3	2	173

Table 9.4, continued

c. 60-70 m depth

Bate Bay				Providential Head				Illawarra				Bass Point			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Survey 1:															
NO SURVEY				NO SURVEY				NO SURVEY				NO SURVEY			
Survey 2:															
spp = 9				spp = 9				spp = 11				spp = 13			
S.plangon	50	65	52	*S.plangon*	37	17	72	*S.plangon*	41	25	92	*S.plangon*	39	58	50
C.bimaculata	34	44	159	*D.arrosor*	30	14	72	*D.arrosor*	15	9	102	*D.arrosor*	22	33	56
P.plebejus	5	6	187	*L.tuberculatus*	17	8	196	*S.australis*	11	7	185	*P.plebejus*	9	14	188
D.arrosor	5	6	141	*T.strigimanus*	4	2	173	*C.bimaculata*	8	5	178	Penaid prawn	9	14	273
A.laevis	4	5	156	*P.plebejus*	2	1	273	*P.plebejus*	5	3	273	*S.australis*	7	11	135
								Cape Banks							
								Species of fish	%	Tot Abun	CV (%)				
Survey 3:															
spp = 4				spp = 10				spp = 9				spp = 10			
S.plangon	74	23	101	*N.gouldi*	48	42	204	*S.plangon*	78	112	156	*S.plangon*	68	70	66
N.gouldi	13	4	136	*S.plangon*	22	19	129	*D.arrosor*	10	15	164	*D.arrosor*	12	12	79
D.arrosor	10	3	122	*D.arrosor*	16	14	65	*N.gouldi*	3	5	214	*P.fumata*	10	10	150
A.laevis	3	1	273	*C.bimaculata*	6	5	100	*L.tuberculatus*	3	4	136	*S.australis*	3	3	273
				C.miles	2	2	173	*A.laevis*	3	4	87	*L.tridentatus*	2	2	173
Survey 4:															
spp = 6				spp = 12				spp = 11				spp = 10			
S.plangon	40	46	88	*S.plangon*	31	18	88	*S.plangon*	75	161	35	*S.plangon*	72	73	104
L.tuberculatus	21	24	79	*L.tuberculatus*	16	9	139	*D.arrosor*	16	35	150	*C.bimaculata*	9	9	139
C.bimaculata	18	20	126	*C.bimaculata*	16	9	41	*C.bimaculata*	5	10	100	*P.fumata*	5	5	273
D.arrosor	17	19	69	*D.arrosor*	14	8	68	*S.apama*	1	3	122	*D.arrosor*	5	5	156
N.gouldi	3	3	187	*T.strigimanus*	5	3	122	*A.laevis*	*	1	273	*Majidae*	3	3	187

the 20-30 m samples, with those at 40-50 m being intermediate (Fig. 9.6). A similar pattern occurred in surveys 3 and 4, when CB was sampled (Figs. 9.7 and 8). In most cases, the assemblages at the proposed extraction areas (i.e. PH and CB) were similar to those at the control locations.

In contrast to the variation among depths, there was little consistent variation in assemblages among surveys within each depth range, particularly at 20-30 m and 40-50 m (Figs. 9.9-11). Stress values for these ordinations were relatively large, thus temporal patterns may be weak. At 60-70 m, the assemblages sampled during survey 4 differed from those sampled during surveys 2 and 3. This was probably due to larger numbers of several species in 60-70 m in during survey 4, notably, Zeus faber, Macrorhamphosus scolopax, Sillago bassensis flindersi, Trachurus novaezelandiae and Lophonectes gallus (Appendix B1).

Within each of the depths, some sites and locations grouped together over time, but the analyses suggest that, overall, the 5 locations were relatively similar. In 20-30 m the 2 sites in BB tended to group together during survey 1 as did the two sites at BP in survey 2 (Fig. 9.7). In 40-50 m there was also little distinction among most of the times for sites and locations, with the exception of one site at BB in survey 3, both sites at CB in survey 4 and one site at PH in survey 1 (Fig. 9.8). In 60-70 m assemblages of fish showed less similarity among locations and surveys, but there are several sites within locations which are very similar during some surveys. Examples include PH in survey 3 and BB, CB and PH in survey 4 (Fig. 9.9).

9.3.1.3 Analysis of Populations

Species were chosen for analysis of the basis of their frequency and abundance in the samples and their economic importance. As with the macrofauna (Section 8.1.3.3), the data were split into three subsets. Overall, significant spatial and temporal variability was found among fishes and mobile invertebrates and, like the macrobenthos, the variability was often inconsistent among locations, depths or sites through time (Table 9.5). The following sections describe the spatial and temporal variation of the populations sampled. Summaries of analyses are given in Appendix B2-B4; figures referred to are in Appendix B9 (Volume II).

9.3.1.3.1 Design 1: Comparison of all 4 Surveys and 2 Depths at BB, PH and BP

Variation among times

Of the 22 variates analysed using design 1, only the shovelnose ray, Aptychotrema rostrata, showed significant variation through time which was consistent among locations, sites within locations and depths (Appendix B2). Abundance of A.rostrata was typically low in the trawls, although they were found in most catches. Numbers peaked in survey 3, when a average of about 2 fish (SE = 0.5) were taken per trawl. This was significantly larger than in surveys 1 and 4, when 0.7 (SE = 0.2) and 0.3 (SE = 0.1) fish were caught, respectively, but was not significantly different to survey 2 (mean = 0.9, SE = 0.3).

Variation among depths

Aptychotrema rostrata and small-tooth flounder, Pseudorhombus jenynsii, both showed a significant preference for 20-30 m compared with 40-50 m which was independent of times, locations and sites (Fig. 9.12).

Table 9.5 Summary of analyses for 3 series of data comparing Times (T), Depths (D), Locations (L) and Sites at each location (S(L)). Designs as per Table 9.1. Sig = the number of statistically significant results for that factor; ns = non-significant results for that factor; nt = the number of tests not considered due to higher-order effects. Dashes indicate that these interactions were considered in every test. The number of variates tested for each design is shown in brackets. See Appendix B2-B4 for individual analyses.

Factor	Series 1			Series 2			Series 3		
	sig	ns (22)	nt	sig	ns (23)	nt	sig	ns (26)	nt
Time	1	0	21	2	2	19	5	5	16
Depth	2	0	20	2	3	18	3	8	16
Location	2	8	12	1	13	9	2	13	11
Site(Location)	1	4	17	2	4	17	4	11	11
T x D	4	2	16	2	7	14	1	16	9
T x L	7	11	4	3	15	5	4	17	5
T x S(L)	4	7	11	6	8	9	3	19	4
D x L	0	18	4	1	17	5	2	19	5
D x S(L)	6	6	10	4	10	9	5	17	4
T x D x L	4	18	-	5	18	-	5	21	-
T x D x S(L)	10	12	-	9	14	-	4	21	-

Variation among locations

Two species showed significant differences among locations (Fig. 9.13) which were consistent among times and depths. The eagle ray, Myliobatus australis, was more abundant at PH than BB, but abundance was statistically similar between PH and BP, and between BP and BB. The boxfish, Anoplocapros inermis, occurred in statistically similar numbers at PH and BP, and both had more than at BB.

Variation among sites within locations

Only the red gurnard, Chelidonichthys kumu, showed significant differences among sites which were independent of times and depths (Fig. 9.14). Here numbers of C.kumu were significantly less at Site 5 (PH) than at any other site during the study. No other differences among sites were evident.

Interactions between times and depths

Four variates showed significant variation among depths which were dependent upon the time of sampling. Three examples are illustrated in Figure 9.15. The total abundance of fishes was significantly greater at 20-30 m during survey 1 (based on transformed data), although the figure, plotted from the raw data, suggests no difference. In survey 4 more fish were sampled at 40-50 m and no differences occurred between depths during surveys 2 and 3.

Species richness of invertebrates was significantly greater at 40-50 m during surveys 1, 2 and 4. The interaction appears to have occurred because of a decline in richness during survey 4 in 20-30 m but an increase in 40-50 m. However, there was no significant decline through time at 20-30 m, although there were significantly more species at 40-50 m in survey 4 compared with surveys 2 and 3. Abundance of invertebrates showed a similar trend in 40-50 m (Fig. 9.15), although there were significantly more invertebrates collected from deeper water in all surveys. No differences in abundance occurred in 20-30 m throughout the study, where invertebrates occurred in small numbers. At 40-50 m, there were significantly more invertebrates in survey 4 compared to survey 2, but no other comparisons were significant.

Interactions between times and locations

Seven variates showed significant interactions between times and locations (Appendix B2); 5 examples are illustrated here (Fig. 9.16). More fish were recorded at BP than PH or BB during surveys 1 and 3. During survey 2 more fish were recorded in BB than PH, while no differences were detected among locations during survey 4. Lepidotrigla spp. were significantly more abundant in BB than elsewhere during surveys 2 and 4, but showed no differences in survey 3. During survey 2 there were more at BP than PH. For most of the variates, there was little consistency among locations through time. Lepidotrigla, however, showed a large decline at all locations from survey 1 to 2.

Long-spined flathead, Platycephalus longispinus, were more abundant in BB than elsewhere during surveys 2 and 4, but showed no significant differences at other times. Pseudorhombus jenynsii showed no differences among locations in surveys 1 and 3. In survey 2, there were more at BB than PH and in survey 4 there were more at BB than elsewhere and more at PH than BP. The squid, Sepioteuthis australis, showed no differences among locations during surveys 3 and 4. During survey 1 there were fewer at BB than PH or BP but during survey 2 there were more at BB than the other locations.

Interactions between times and sites within locations

Four variates showed significant time by site interactions, Myliobatis australis, Urolophus testaceus, species richness and abundance of fishes (Appendix B2). The latter 2 are illustrated (Fig. 9.17). For species richness of fishes, the northern site at PH generally ranked low amongst the 6 sites compared. During the first survey, there were fewer species recorded there, on average, than all other sites except the nearby southern site at BB. In survey 2 there were more species recorded at site 3 (BB) than at site 5 (PH), but no other differences among sites were detected. In survey 3 there were significantly fewer species at site 3 (BB) than any other site and more species at BP, site 8, than anywhere else except site 6, PH. In survey 4 more species occurred at site 8, BP than sites 5 (PH) or 3 (BB), and more occurred at site 3 (BB) than site 6.

For abundance of fishes, site 5, PH ranked lowest among sites during all surveys, but was generally not significantly different from most of the other sites (Fig. 9.17). Moreover, one or both of the BP sites usually ranked very highly among sites. During survey 1, more fish were collected from site 8, BP, than sites 4 and 5, and more were collected at site 7, BP, than from site 5. During survey 2, more fish were collected from site 3, BB than site 5, site 8 or site 4. In survey 3, site 8 had significantly more fish than sites 4 and 5, while in survey 4, sites 7 and 6 had more fish than site 5.

Interactions between depths and locations

None of the analyses using design 1 showed significant effects for this term.

Interactions between depths and sites within locations

Six variates showed significant interactions between depths and sites, these are illustrated here by richness and abundance of fishes, and by richness and abundance of invertebrates (Fig. 9.18). Significantly more species of fish were collected at site 8 (BP) than any other site at 20-30 m, but there were fewer species at site 5 (PH) than elsewhere at 40-50 m. At this depth there were also more species at site 7 (BP) than site 3 (BB).

Abundance of fishes did not differ among sites in 20-30 m (Fig. 9.18). In 40-50 m there were fewer fish at site 5, PH than any other site, more at site 8 than anywhere else except site 7, BP and more fish at sites 9 (BP) and 3 (BB) than site 4 (BB).

The number of species of invertebrates did not differ among sites at either depth, but trended towards larger abundances at site 4 (BB) in 40-50 m. Overall, more species were collected in deeper water (Fig. 9.18). Abundance of invertebrates showed no significant differences among sites at 20-30 m and at all sites there were more invertebrates in 40-50 m than 20-30 m (Fig. 9.18). More invertebrates were collected from site 4, BB, than sites 6 (PH), 3 (BB) or 8 (BP) and more occurred at site 5 (PH) than sites 6 or 3.

Interactions among times, depths and locations

Four variates showed significant interactions among times, depths and locations (Appendix B2), there are illustrated here by the red gurnard, Chelidonichthys kumu, the hermit crab, Dardanus arrosor and the balmain bug, Ibacus peroni (Figs. 9.19-21). C.kumu showed no significant differences among locations at either depth for the first 3 surveys (Fig. 9.19). In survey 4, however, there were more at BB in 20-30 m than PH or BP and in 40-50 m there were more at BP and BB than PH.

Dardanus arrosor showed little variation among locations in 20-30 m (Fig. 9.20). At 40-50 m there was no difference among locations in survey 1. In survey 2 there were more D.arrosor at BP and PH than BB and in survey 3 there were more at PH than elsewhere. In survey 4 there were more D.arrosor at PH than BB. Ibacus peroni showed significant variation among locations at both depths (Fig. 9.21). During surveys 1, 2 and 3, all locations in 20-30 m differed significantly. In survey 4, more I.peroni occurred at BB than BP. In 40-50 m depth, no differences occurred among locations in surveys 1,2 and 4, but more were collected from BB than PH or BP in survey 3.

Interactions among times, depths and sites within locations

Nearly half the variates analysed using design 1 showed significant interactions between times, depths and sites (Appendix B2). Six examples are described here to show a range of trends observed (Figs. 9.22-27). The stingaree, Urolophus kapalae, was one of the most abundant species in 20-30 m and was generally more abundant there than in 40-50 m (Fig. 9.22). There were few trends in abundance and little consistency among depths and sites through time. For example, a gradual decline in abundance of U. kapalae occurred at site 4, BB, but not elsewhere. Also, a large increase in abundance in 40-50 m during survey 2 at BB did not occur elsewhere at that time.

John dory, Zeus faber, occurred in low numbers at PH and, for most of the study, at the other locations. During survey 4 increases were noted at each site in BB and BP, with the largest increase occurring at site 4, BB (Fig. 9.23). During surveys 2 and 4 there were significantly more Z.faber at site 4 than any other site and fewer at site 5, PH than elsewhere, but no other significant differences among sites were detected.

Platycephalus longispinus was one of the most abundant species sampled and was often most common in 20-30 m (Fig. 9.24). During survey 1, there were significantly fewer P. longispinus in

40-50 m at site 5, PH and site 3, BB, than any other site. In 20-30 m, numbers declined between surveys 1 and 2 at all sites except site 3, BB. They then increased at site 5, 6 and 7 in survey 3. In 40-50 m, numbers declined during the study at sites 6 and 7. By survey 4 there were significantly fewer P. longispinus at these sites than anywhere else at that depth.

Lepidotrigla spp. showed marked declines in 20-30 m from surveys 1 to 2 (Fig. 9.25). In survey 1, more occurred in shallow water at sites 8 (BP) and 4 (BB) than sites 5 (PH), 7 (BP) and 3 (BB). Numbers remained generally low for the rest of the study. In deeper water, there were more Lepidotrigla spp. at site 3, 7 and 8 than elsewhere in 40-50 m. In survey 2, there were more at site 3 in 40-50 m than any other site at that depth and in survey 4 there were more at sites 3, 4 and 8 than any other site at that depth.

Trachurus novaezelandiae showed large variability in numbers throughout the study. It was uncommon at sites 4 (BB) and 5 (PH), but was very abundant at some times elsewhere (Fig. 9.26). Despite this, there were few significant differences detected among sites due mainly to large within-site variability. Large occurrences of T. novaezelandiae occurred in 20-30 m at site 3 (BB) during survey 2, and in 40-50 m at site 6 (PH) in surveys 2 and 4.

Sepioteuthis australis occurred in low numbers in many of the trawls. As with the previous examples, variability often showed little consistency among sites, depths and times (Fig. 9.27). In 20-30 m, three patterns of variability were noted. At sites 3, 4 and 5 there were few or no S. australis in survey 3, but there was an increase in survey 2, followed by a gradual decline thereafter. At sites 6 and 7 mean numbers declined from survey 1 to 2 and remained low thereafter. At site 8, abundance was low in all surveys. In 40-50 m, numbers were low at sites 4 and 5 during survey 1, increased during survey 2 and declined thereafter. At the other sites, numbers were relatively large in survey 1, but declined thereafter.

9.3.1.3.2 Design 2: Comparison of 3 Surveys and 3 Depths at BB, PH and BP

Variation among times

Two variates showed significant differences among the last three surveys, which were independent of depths, locations and sites (Appendix B3, Fig. 9.28 in Appendix B9). The abundance of fishes was greater during survey 4 than surveys 2 and 3, while Chelidonichthys kumu was more abundant in surveys 3 and 4 than survey 2.

Variation among depths

Two variates showed significant differences among depths which were consistent across times, locations and sites (Fig. 9.29). In design 1, Aptychotrema rostrata was more abundant 20-30 m than 40-50 m. Here, more occurred in 20-30 m than the other two depths and their abundance in 40-50 m and 60-70 m did not differ. Neoplatycephalus richardsoni preferred 60-70 m. There were significantly more there than at the other depths and there were also significantly more in 40-50 m than 20-30 m.

Variation among locations

Only Sepioteuthis australis showed significant differences among locations independent of time and depth (Fig. 9.30). This squid was less abundant at PH than the other two locations.

Variation among sites within locations

Chelidonichthys kumu and Zebrias fasciatus varied among sites (Fig. 9.31). More C. kumu occurred at site 8, BP, than either site at PH, or site 4, BB. There were also more at sites 3, BB, and 7, BP, than at site 5, PH.Z. fasciatus were more abundant at site 4, BB than any other site except site 6, PH. No other comparisons among sites were significantly different.

Interactions between times and depths

Two variates showed significant variation among depths which were dependent upon the time of sampling, Myliobatus australis and Lophonectes gallus (Appendix B3). L.gallus was significantly more abundant at 60-70 m during each survey (Fig. 9.32). In surveys 3 and 4 there were also more in 40-50 m than 20-30 m. During the study numbers tended to increase in 60-70 m and 40-50 m, but remained low in 20-30 m throughout (Fig. 9.32).

Interactions between times and locations

Three variates showed significant interactions between times and locations, Trigonorhina fasciata, Myliobatus australis and, illustrated in Figure 9.33, Platycephalus longispinus (Appendix B3). Similar trends in abundance through time were observed at PH and BP for P. longispinus. BB ranked highest in all the surveys, but a significant difference among locations was only detected in survey 2, when more occurred at BB than elsewhere.

Interactions between times and sites within locations

Six variates showed significant interactions between times and sites (Appendix B3). The 3 examples illustrated show few consistent patterns (Fig. 9.34). The mean number of fish species collected per site ranged from about 12 to 21 (depth averaged). Most sites varied little through time, except sites 3 and 4, BB, which declined during survey 2 and increased in survey 4. Neoplatycephalus richardsoni showed a very patchy distribution among sites over time, probably because there were large depth effects for this species. Trends in abundance were noted at site 3, BB, where numbers declined from survey 2 to 3 and increased in survey 4, and at site 8, BP, where numbers increased over the 3 surveys (Fig. 9.34).

Lophonectes gallus also varied greatly within sites, due to the strong preference for the 60-70 m depth statum (Fig. 9.34). Despite this, there were significant differences in abundance at the BB sites over time. In survey 2, there were significantly more L. gallus at site 3, BB than all other sites, which in turn showed no significant differences. During survey 3 none of the sites differed. In survey 4 numbers increased at sites 3 and 4, BB, and there were more L. gallus at site 3 than any other site and more at site 4 than either PH site or site 7, BP.

Interactions between depths and locations

Only Platycephalus longispinus showed a significant interaction between depths and locations (Fig. 9.35). This species was least abundant at 60-70 m at all locations. In 20-30 m, more P. longispinus occurred at BB than BP, but statistically similar numbers occurred at PH. In 40-50 m there were more at BB than any other location, while in 60-70 m no differences among locations occurred.

Interactions between depths and sites within locations

Four variates showed significant interactions between depths and sites (Appendix B3), 3 of which are illustrated here (Fig. 9.36). More species were recorded, on average, from site 8, BP, than elsewhere in 20-30 m. In 40-50 m, more occurred at site 7, BP, than sites 5, PH and 3, BB. There were also more at site 4, BB than site 5. In 60-70 m, more species occurred at site 7 than site 4.

The abundance of fishes showed no significant differences among sites in 20-30 m (Fig. 9.36). In 40-50 m, however, there were fewer fish at site 5, PH than any other site. There were also more at site 7, BP than site 4, BB and site 6, PH, and more at site 8, BP than site 6, PH. In 60-70 m, there were more fish at site 6, PH than at site 3, BB; no other differences were significant.

Lophonectes gallus has showed strong depth preferences for 60-70 m (Fig. 9.34). In comparing depths at each site, there were again clearly more fish in 60-70 m than shallower water (Fig. 9.36). There were also significant differences among sites at each depth. In 20-30 m, more L. gallus occurred at site 3, BB, than any other site except site 8, BP. There were also more at site 8 than site 5, PH. In 40-50 m more occurred at the sites at BB and at site 8 than at the other sites. In 60-70 m, more L. gallus were found at site 3 than sites 8 (BP), 4 (BB) and 5 (PH). No other comparisons were significant.

Interactions among times, depths and locations

Five variates showed significant interactions among times, depths and locations (Appendix B3), 2 of which are illustrated here (Fig. 9.37). Numbers of invertebrates in 20-30 m differed among locations during survey 2, when more invertebrates were found at BB than elsewhere. In survey 3 more occurred at BB than PH and in survey 4 no differences among locations were detected. In 40-50 m, no significant differences were detected among locations at any time. In 60-70 m, no differences occurred during surveys 2 and 4, but more invertebrates occurred at PH and BP than BB during survey 3.

Dardanus arrosor were rare in 20-30 m and there were no significant differences among locations at any depth (Fig. 9.37). In 40-50 m there were more hermit crabs at PH and BP than BB during survey 2; more at PH than either of the other locations in survey 3; and no differences among locations in survey 4. In 60-70 m more D.arrosor occurred at BP than PH, and more at PH than BB in survey 2. During survey 3 there were more at PH and BP than BB, and during survey 4 there were more at BB than BP.

Interactions among times, depths and sites within locations

Nine variates were significant at this level of the analysis (Appendix B3). Six examples are discussed here (Figs. 9.38-43), 4 of which showed significant interactions at this level in the design 1 analyses. In describing the interactions here, variability among depths is emphasised, particularly in 60-70 m. Lepidotrigla spp. showed very different trends through time and over depth at most sites (Fig. 9.38). At site 3, BB, numbers tended to be greater in 40-50 m, a trend not found elsewhere. At the other site at BB, abundance was relatively constant at 20-30 m, but at 40-50 m numbers increased in survey 4, whereas at 60-70 m numbers decreased after survey 1. At PH, Lepidotrigla spp. tended to prdominate in 60-70 m at site 5, while they were similar, and increased slightly through time at the other depths. At site 6 numbers were relatively constant over the 3 surveys. At BP the abundance of Lepidotrigla spp. was relatively small at all depths at site 7, but at site 8 numbers ended to increase from survey 1 to 2. After survey 2, abundance tended to increase in 40-50 m, decrease in 20-30 m and remain constant in 60-70 m.

As was seen in the comparisons of depth and location, Platycephalus longispinus was uncommon in 60-70 m. An exception with sites was at site 8, BP, where more long-spined flathead occurred in 60-70 m than at that depth in all other sites during surveys 2 and 3 (Fig. 9.39). Variability at 20-30 m and 40-50 m was often large and inconsistent among sites through time (cf. Section 9.3.1.3.1). Trachurus novaezelandiae was frequently collected from 60-70 m depth (Fig. 9.40). This species was often very patchy in the catches and few consistent patterns were observed in the data. Pseudorhombus jenynsii was usually uncommon in 60-70 m (Fig. 9.41). Exceptions occurred during survey 2 at sites 4, BB and 7, BP.

Species richness of invertebrates was relatively large 60-70 m at most sites (Fig. 9.42). At sites 4, BB and 6, PH, numbers of species tended to increase with depth. At site 7, BP, there tended to be more at 60-70 m than the shallower depths. All other sites, however, little consistency was noted among depths through time. Sepioteuthis australis also showed little consistency among sites (Fig. 9.43). It was uncommon at the PH sites and often tended to decrease at one or more depths from survey 2 to 3.

9.3.1.3.3 Design 3: Comparison of 2 Surveys and 2 Depths at CB, BB, PH and BP

Design 3 investigated the assemblages of fish and mobile invertebrates at Cape Banks and Providential Head and 2 reference areas over 2 sampling periods. There were twice as many variates with significant main effects compared with designs 1 and 2. This is probably because there were fewer levels for time and depth, although more locations and sites were compared.

Variation among times

Five variates showed significant time effects which were independent of depths, locations and sites (Appendix B4 and Fig. 9.44 in Appendix B9). Four were signifiantly more abundant in survey 4 but Anoplocapros inermis was more abundant in survey 3.

Variation among depths

Three variates showed significant depth effects independent of times, locations and sites (Fig. 9.45). These included Zeus faber, Pseudorhombus jenynsii and the portunid crab, Charybdis bimaculata. In all cases more occurred in 60-70 m than 40-50 m.

Variation among locations

Two variates showed significant location effects which were consistent across times and depths (Appendix B4; Fig. 9.46). Heterodontus portusjacksoni was more abundant at BP than the 3 other locations, which had similar numbers. Anplopcapros inermis was more abundant at BP than the other locations and more abundant at BB and PH than CB.

Variation among sites within locations

Significant differences among sites occurred for abundance of fish and Zebrias fasciata and for species richness and abundance of invertebrates (ApFpendix B4; Fig. 9.47). On average, more fish were recorded at both sites at BP and at site 4, BB than at either site at PH or CB, or site 3, BB. No other differences were statistically significant. Both Z. fasciata and the abundance of invertebrates tended to be more abundant at site 2, CB, but no specific differences among sites could be detected (Fig. 9.47). Species richness of invertebrates was significantly larger at site 3, BB and site 5, PH than at site 8, BP or site 1, CB. No other differences were detected among sites.

Interactions between times and depths

Heterodontus portusjacksoni showed a significant interaction between time and depths (Fig. 9.48). In survey 3 there was no difference between depths for Port Jackson sharks but in survey 4 numbers increased significantly in 60-70 m and there were more there than in 40-50 m.

Interactions between times and locations

Three of the 4 variates showing significant interactions between times and locations are illustrated here (Appendix B4; Fig. 9.49). For species richness of fish, fewer occurred at CB in survey 3 than elsewhere, while in survey 4 numbers of species generally increased and no significant differences among locations occurred. The abundance of invertebrates was greater at BB than CB in survey 3, but in survey 4 it was greater at CB and PH than BB or BP. Dardanus arrosor was more abundant at BB than any of the other locations in survey 3, but showed no differences among locations in survey 4 (Fig. 9.49).

Interactions between times and sites within locations

Neoplatycephalus richardsoni and Lophonectes gallus showed significant differences among sites which were dependent upon the survey time (Fig. 9.50). In survey 3, N.richardsoni was more abundant at site 8, BP, than both sites at PH, site 3, BB and site 1, CB. There were also more at site 4, BB, site 7, BP and site 2, CB than site 6, PH and site 3, BB. Finally, there were more at site 1 than site 6. In survey 4, there were more N. richardsoni at site 1 than any other site except those at BP.

The abundance of L. gallus was significantly less at site 6, PH than elsewhere in survey 3 and none of the other sites differed. In survey 4 there were more at site 1, CB than either site in BB or PH (Fig. 9.50). There were also more at site 2, CB, than site 3, BB. No other comparisons were significant.

Interactions between depths and locations

Sepia plangon was one of 2 variates showing significant interactions between depths and locations (Appendix B4, Fig. 9.51). In 40-50 m, more cuttlefish occurred at CB than BB; no other comparisons were significant. In 60-70 m there were more at PH than CB or BB and more at BP than BB; no other comparisons were significant.

Interactions between depths and sites within locations

Five variates showed significant interactions between depths and sites (Appendix B4), here illustrated by Lepidotrigla spp. (Fig. 9.52). In 40-50 m, Lepidotrigla spp. were more abundant at site 1, CB, than any other site. They were also more numerous at site 8, BP than any of the remaining sites except site 2, CB, which in turns had more than both sites at PH and site 3, BB. In

60-70 m there were more at site 6, PH than site 4, BB.

Interactions among times, depths and locations

Five variates showed significant interactions among times, depth and locations, 4 of which are illustrated here (Appendix B4; Figs. 9.53,54). The abundance of fishes increased in 40-50 m from survey 3 to 4 at 3 locations; at PH it declined slightly. During survey 3 more fish were collected at BP than elswhere. In survey 4 there were more at BP, CB and BB than PH. At 60-70 m there was also an increase between surveys at all locations except BB. In survey 3 there were more fish at BB than any other location, in survey 4 no differences were detected among locations.

Neoplatycephalus richardsoni also showed significant differences among depths and surveys (Fig. 9.53). In 40-50 m there were more N. richardsoni at BP than the other locations and more at CB than BB or PH. In survey 4 there were more at BP than BB or PH; no other differences were detected. At 60-70 m no differences were detected during survey 3. In survey 4 there were more at BP and CB than BB and PH. Chelidonichthys kumu showed no differences among locations in 40-50 m during survey 2 (Fig. 9.54). Numbers increased in survey 4 at BP and CB, and there were more at BP than all other locations and more at CB than BB or PH. In 60-70 m there were more C.kumu at BP than the other locations in survey 3. In survey 4 numbers tended to decline at BP and increase elsewhere. At that time no differences occurred among locations.

Lophonectes gallus showed little difference among locations in 40-50 m in survey 3 (Fig. 9.54). In survey 4 there were more at CB and BP than the other locations and more at BB than PH. In 60-70 m small declines in abundance occurred at BB and BP between surveys. In survey 3 there were more at those locations than at PH. In survey 4 there were more at CB than BP, but no other differences were detected.

Interactions among times, depths and sites within locations

Four variates showed significant interactions between times, depths and sites, 3 of which are presented here (Appendix B4; Figs. 9.55-57). The abundance of Platycephalus longispinus was low at 60-70 m and trends towards smaller numbers in survey 4 were noted in 40-50 m at all sites except site 2, CB (Fig. 9.55). Numbers at sites 1 and 2 CB were similar to other sites, although there were significantly more P. longispinus in 40-50 m in survey 3 at site 1 than at sites 6 (PH) and 7 (BP) in survey 3; and more at site 2 in survey 4 than all other sites except except site 2 and site 8, BP.

Numbers of Sillago bassensis flindersi were relatively low at the CB sites and showed similar trends to those in BB and PH (Fig. 9.56). That is, numbers were either constant or increased slightly from survey 3 to 4. Much larger increases tended to occur at site 7, BP and in 60-70 m at site 8, BP. In 40-50 m at site 8 there was a decline of about 250 fish per trawl, on average, from survey 3 to 4. Trachurus novaezelandiae occurred in similar numbers at both sites in CB compared with many of the other sites (Fig. 9.57). There was also a general increase in numbers at CB, which was similar to both sites in BB. No other consistent patterns were apparent.

9.3.1.4 Size Distribution of Species of Economic Value

Length frequency data for fishes of economic value are summarised in Appendix B5. This section describes trends in the data by reference to Appendix B5, graphical presentations (Figs. 9.58 - 9.80 in Appendix B9) and published accounts of size distributions in the literature (e.g. SPCC 1981b). Fish lengths are combined for depths, location and sites for each time in Appendix B5a. This provides an overview of size distributions for the nearshore sandy habitat. Appendix B5b compares locations during each survey (depths pooled) where sample size, N ≥ 50; Appendix B5c compares depths during each survey (locations pooled) where N ≥ 50.

1. Squatina australis (Fig. 9.58). 213 angel sharks were measured during the study (Appendix B3a). Length ranged from 231-1210 mm and the average length per survey ranged from 508 mm (SE = 29) in survey 3 to 572 mm (SE = 24) in survey 2. Angel sharks grow to about 1500 mm (Last et al. 1983) and a congenor from southern Africa, S. africana is reportedly born at 280-340 cm (Bass et al. 1975). It is therefore likely that all size classes of this shark occur on sand bodies off Sydney. Sharks in the smallest size class, 250 mm, were most abundant during survey 3, suggesting that angel sharks may give birth during spring.

2. Zeus faber (Fig. 9.59-60). 878 John Dory were measured, 71% of them in survey 4 (Appendix B3a). This species grows to 660 mm (May and Maxwell 1986) and matures at about 300 mm (SPCC 1981b). During the study, fish ranging from 41-510 mm were recorded, representing sizes from small juveniles to large adults. During survey 1, fish spanned 121-500 mm, and were generally classified as large juveniles and adults. In survey 2, a few small juveniles were recorded, but most fish were adults of large juveniles. In survey 3, there was a large peak of small juveniles in the 90 mm size class and in survey 4 there was a large peak in the 150 mm size class. Most of these fish occurred in the 60-70 m depth stratum and all were present at each location (Fig. 9.60), suggesting that the arrival of this size class occurred over a relatively large geographic scale.

3. Centroberyx affinis (Fig. 9.61). 373 nannygai were measured, although only 5 were measured from survey 1 (Appendix B3a). According to Last et al. (1983), this species reaches a maximum length of 460 mm. In this study, lengths ranged from 25-290 mm and most of the fish collected were either small adults or juveniles (cf. Tilzey et al. 1990).

4. Chelidonichthys kumu (Fig. 9.62). From the 846 red gurnard measured, several patterns in length frequency distributions were apparent. This species is reported to reach 530 mm total length, while fish measuring less than 264 mm in Botany Bay were regarded as juveniles (SPCC 1981b). During survey 1, the largest class of fish occurred in the range of 190-270 mm (Fig. 9.62). This persisted during survey 2, but during survey 3 the peak size class was at 350 mm. During this survey, however, there were several fish as small as 65 mm, possibly representing recruitment. In the final survey small fish were again present in the catch, but the peak size class was around 210 mm.

5. Platycephalus caeruleopunctatus. Relatively low numbers of blue-spotted flathead were collected in each survey and sample sizes were not large enough to compare depths or locations. All of the blue-spotted flathead collected were relatively large (up to 583 mm). Smaller size classes were evident during surveys 2 and 4, but there was no evidence of recruitment of juveniles to the locations studied (Fig. 9.63).

6. Platycephalus fuscus. This species is regarded predominantly as a resident of estuaries (SPCC 1981b,c). Only 12 individuals were collected during the study, all from 20-30 m. Most were very large fish, reaching up to 664 mm. Large dusky flathead have also been observed close to shallow coastal reefs (M. Lincoln Smith, pers. obs.).

7. Platycephalus longispinus. Over 4000 long-spined flathead were measured during the study and, although they are of marginal value, they were so abundant that a study of their length frequency distribution may be of value in assessing the effects of aggregate extraction on populations of this species, should approval be given. Long-spined flathead are reported to reach 380 mm in length (SPCC 1981b), although fish up to 395 mm were recorded in the Metromix aggregate study (Appendix B5a).

Figure 9.64a-d shows the length distribution of fish at each location during each survey. During survey 1, most long-spined flathead were around the size range of 190-230 mm. A few smaller fish at BB and PH may represent recent recruits. By survey 2, some 3½ months later, most of the fish are between 170-210 mm at BB and PH. At Illawarra (IL) and BP, there appear to be two modes in the size distribution, around 190 mm and 240 mm at IL, and around 190 mm and 220 mm at BP. Small fish, possibly recent recruits, also occur at BB and BP. During survey 3 there are no data for IL and CB was not sampled at 20-30 m. A large peak occurs at 210 mm at CB, although the sample size is small. At BB possible modes occur around 190 and 230 mm, at PH most fish occur in the size range of 200-240 mm and at BP most are in the range of 210-260 mm. In the last survey the sample size at Cape Banks was small and not plotted (N < 50). At BB, most fish occur in the size range of 160-230 mm, at PH most occur between 170 and 260 mm and at BP, 4 possible modes occur.

Figure 9.65 shows size distributions for long-spined flathead among depths. Comparisons are shown for surveys 2 and 3, where sufficient data are available to compare 3 depths. During survey 2, fish at 20-30 m depth range from 50-367 mm in length and average 196 mm (Appendix B5c). They are therefore likely to include juvenile and adult fish. At 40-50 m, fish range from 97-336 mm (mean = 201 mm) and include fewer smaller fish. There may also be two modes in the population (Fig. 9.65). At 60-70 m, fish range from 140-350 mm (mean = 262 mm) and the population is generally made up of larger fish. There may also be up to 4 size classes represented in the population, centred around 140 mm, 180 mm, 250 mm and 300 mm. Survey 3 shows a similar trend: at 20-30 m fish range from 92-395 mm (mean = 211 mm); at 40-50 they range from 126-311 mm (mean = 220 mm); and from 60-70 m they range from 170-311 mm (mean = 258 mm - see Appendix B5c). Note that sample sizes at 60-70 m for both surveys are relatively small and the standard errors for the means relatively large (Appendix B5c).

8. Neoplatycephalus richardsoni. 2063 tiger flathead were measured in the study, although only 75 of these came from the first survey (Appendix B5a). Males grow to about 500 mm while females attain 630 mm (Rowling 1979). Length at first maturity occurs in fish from about 2 years old (Fairbridge 1951). Fish may mature at as little as 170 mm, but most fish mature from about 250 mm (Fairbridge 1951).

During the Metromix aggregate study, tiger flathead from 79-542 mm long were collected, representing most stages of the post-settlement life history. Most of the fish sampled, however, could be considered as small adults (Fig. 9.66). There was no evidence of any large-scale migration of large adults, or recruitment of juveniles, to the sand bodies in general. Nor was there any evidence of variation in size distribution among locations (Appendix B5b). Length frequency data were plotted for 40-50 m and 60-70 m for surveys 2-4 (Fig. 9.67). There was no evidence of depth preferences by small juveniles or large adults, although slightly larger fish may have occurred, on average, in 40-50 m (Appendix B5c).

9. Sillago bassensis flindersi. 3417 school whiting were measured and large numbers collected in each survey (Appendix B5a). This species attains a length of 330 mm (May and Maxwell 1986). In this study, lengths ranged from 34-305 mm and included fish ranging from small juveniles to large adults. In survey 1, 2 size classes predominated (Fig. 9.68). In the other surveys, most fish ranged between 135 mm and 200 mm. A comparison of locations is provided for surveys 2-4 (Fig. 9.69-71). In survey 2 fish collected from PH and BB tended to be smaller than those from BP and IL. In survey 3, fish of similar size were collected from CB, PH and BP, but fish were slightly smaller at BB. In survey 4, fish of similar lengths were collected from CB and BP, but they were slightly smaller at BB and PH. There was little evidence of variation in length frequency over different depths (Appendix B5c).

10. Pseudocaranx dentex. Silver trevally are fast, active fishes which would probably be underestimated due to the type of net used in the Metromix aggregate study and the short duration of the trawls. Moreover, larger fish may be able to avoid the net more easily than smaller ones. These two factors bias estimates of the size distribution of trevally in the study region. Silver trevally occurred in at least 2 size classes in the catch (e.g. see Fig. 9.72 for survey 1 catch). Most of the silver trevally collected were small fish, although a few adults were also collected (cf. SPCC 1981b).

11. Trachurus novaezelandiae. As with silver trevally, larger yellowtail scad probably avoided the net. Most of the catch was made up of fish smaller than 200 mm in length, which was the length at first maturity recorded for this species in Botany Bay (SPCC 1981b). Two size classes predominated during the study: 85 mm and 105 mm (Fig. 9.73). This is reflected in the relatively constant mean and low standard error for each survey (Appendix B5a).

12. Trachurus declivus. As with the last two species, the size distribution for jack mackerel may have been underestimated in the catch. Most of the fish collected were well below the published maximum length for the species (460 mm - Last et al. 1983) and are presumed to be juveniles (e.g. Fig. 9.74).

13. Acanthopagrus australis. Only 18 yellowfin bream were collected. All of these were adults (cf. SPCC 1981b).

14. Pagrus auratus. 341 snapper were collected. Larger snapper probably avoided the net, thus there may be a bias towards smaller fish in the catch. Snapper recruited as small juveniles to Botany Bay from December to April and apparently left the bay as large juveniles (approximately 127-224 mm) about 1 year later (SPCC 1981b). Most of the fish collected in the Metromix aggregate study correspond to this age class and, under the SPCC (1981b) model, would probably be fish that had migrated recently from the estuarine nursery habitat (Fig. 9.75). Although the data are very limited, we found no evidence for any variation in size over depth (Appendix B5c).

15. Rhabdosargus sarba. 103 tarwhine were collected, most in survey 4 (Appendix B5a) and all from 20-30 m depth. Lengths ranged from 170 mm to 370 mm. The maximum length reported for the species is 450 mm (SPCC 1981b). Tarwhine recruit to estuarine habitats where they remain for about a year. They were reported to migrate from Botany Bay to nearshore habitats at a length range of 155-184 mm (SPCC 1981b). In survey 4, 3 size classes were identified (Fig. 9.76). The first included fish 170-240 mm long and probably consisted of fish which, under the SPCC (1981b) model, had recently left their estuarine nursery habitats. The other two sizes probably represent larger juveniles and adults.

16. Pseudorhombus arsius. Only 41 large-toothed flounder were collected (Appendix B5a). Lengths ranged from 213 mm to 362 mm

(mean = 301, SE = 5.1). In Botany Bay, this species matured at 190 mm (males) or 240 mm (females), thus the samples collected in the Metromix aggregate study were either all adults, or mostly adults with a few large juvenile females. Adults were abundant in Botany Bay, where they were most common in the deeper areas near the sea (SPCC 1981b).

17. Pseudorhombus jenynsii. 647 small-toothed flounder were collected (Appendix B5a). They ranged from 86-392 mm and, thus, included juveniles and adults. In Botany Bay, small-tooth flounder matured at 180 mm (males) or 240 mm (females - SPCC 1981b). They were not common in the bay as adults and were believed to migrate to coastal waters (SPCC 1981b). In the Metromix aggregate study, fish collected in survey 1 were mostly 200-280 mm long (Fig 9.77). In survey 2 there appeared to be two size classes, one around 150-170 mm, the other from 240-290 mm in length. During survey 3, there were again 2 size classes, 190-250 mm and 280-360 mm. In survey 4, large juveniles or small adults were prevalent. Overall, there may be a population of larger juveniles and adults present throughout the year, with evidence of recruitment of large juveniles, especially in August 1990.

Small-toothed flounder were found to have a strong preference for shallow water (e.g. Section 9.3.1.3.1). In survey 1 fish lengths for samples from 20-30 m showed a much greater range than those from 40-50 m (Fig. 9.78).

18. Meuschenia freycineti. 167 variable leatherjackets were measured (Appendix B5a). According to SPCC (1981b), this species grows to 450 mm in length, recruits to nursery habitats in Botany Bay and migrates to coastal habitats (primarily rocky reefs) at lengths of 155-184 mm. None of the variable leatherjackets trawled was considered to have settled recently, thus they are presumed to have migrated to the study areas from nurseries elsewhere. The size range of specimens collected was 116-426 mm (Appendix B5a). Length frequencies for survey 2 suggest two size classes (Fig 9.79). The smaller class consisted of fish 174-220 mm, while the larger and more common class ranged in size from about 240 mm to 426 mm.

19. Meuschenia trachylepis. Yellowfinned leatherjackets are another species which recruit to estuarine habitats (SPCC 1981b). We collected only 33 fish, ranging in length from 156-372 mm. They appear to be more common on rocky reefs than sandy substrata and the few collected here may represent stragglers from reefs.

20. Nelusetta ayraudi. 530 chinaman leatherjackets were collected, most during surveys 1 and 4 (Appendix B5a). This species attains a length of 1 m (May and Maxwell 1986), which suggests that most of the samples collected (range: 90-320 mm) were juveniles. Samples collected in survey 1 tended to be larger than those from survey 4, although there was a greater size range during the last survey (Fig. 9.80).

9.3.2 FRI Study

9.3.2.1 General Findings

Data were examined for a total of 147 trawls, 42 each from Long Reef, Bondi and Port Hacking and 21 from Malabar. In all, 30,472 fish were collected, from 108 species (Appendix B6). No data were supplied on invertebrate catches.

The numbers of species recorded per location were generally lower than for the Metromix aggregate study, although in the latter there were 6 trawls done (3 trawls at 2 sites) within each location compared with only 3 trawls in the FRI study. Along the 30 m contour, numbers of species collected ranged from 16-34, while along the 60 m contour, numbers ranged from 14-40 (Table 9.6). At HA (within the proposed extraction area at Providential Head), numbers of species ranged from 16 to 24 and 14 to 29 at 30 m and 60 m, respectively. At MA, (just to the north of the proposed extraction area at Cape Banks) numbers ranged from 11 to 19 species per survey at 60 m. These numbers are similar or slightly less than the reference locations.

The fish assemblages at 30 m were similar to those described in the Metromix aggregate study. In the FRI study, dominant species included stingarees (Urolophus paucimaculatus, U. kapalae and U. testaceus), gurnards (Lepidotrigla argus and L. mulhalli), boxfish (Anoplocapros inermis) and long-spined flathead (Platycephalus longispinus). Unlike the Metromix aggregate study, the FRI study discriminated between species of Lepidotrigla.

The assemblages at 60 m were also similar to those described in the Metromix aggregate study, with Lepidotrigla spp. and species such as Zeus faber, Trachurus novaezelandiae, Neoplatycephalus richardsoni and Sillago bassensis flindersi becoming predominant (Table 9.6b). Two results may be suspect. These were a catch of 2553 Squatina australis at Port Hacking in spring, 1990 and 183 Eubalichthys mosaicus at Long Reef in winter 1990. Both species tend to occur in low numbers and neither is known to aggregate in such large numbers.

Coefficients of variation recorded for the dominant species were similar to those for the Metromix aggregate study. Variability both among species and within species at different times and locations was often large. Examples of large variability include Apogonops anomalus in 30 m at LR in autumn, 1989, U.paucimaculatus at Bondi and Port Hacking autumn 1989, Rhabdosargus sarba at Bondi during spring 1989 and Sillago bassensis flindersi at in 60 m at LR in autumn 1989.

Compared with the Metromix aggregate study, catches from the FRI study were small, especially considering the larger net and longer trawl time adopted by FRI. Smaller fish may have been

Table 9.6 FRI study: summary of catches of the five most numerically-dominant species of fish at different locations and depths over 7 surveys. Headings as per Table 9.3. n = 3. Refer to Appendix B6 for complete scientific names.

a. 30 m.

Long Reef				Bondi				Port Hacking			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Autumn, 1989:											
spp = 30				spp = 21				spp = 18			
U.paucimacul.	40	208	47	U.paucimacul.	29	212	10	L.argus	36	151	52
L.argus	12	63	86	L.argus	27	195	38	P.longispinus	21	89	79
A.anomalus	10	51	173	H.portusjack.	13	95	148	Urolophus spp.	13	55	86
L.mulhalli	7	39	173	A.inermis	10	76	28	A.inermis	12	51	26
P.auratus	7	35	99	P.longispinus	7	52	24	U.paucimacul.	4	16	173
Spring, 1989:											
spp = 19				spp = 27				spp = 17			
U.kapalae	61	179	86	L.argus	35	242	86	A.inermis	30	111	74
L.argus	16	46	30	A.inermis	31	214	40	L.argus	29	107	95
A.inermis	5	16	84	R.sarba	13	90	173	U.paucimacul.	20	72	64
P.auratus	3	9	57	P.longispinus	5	33	86	U.kapalae	6	21	93
U.paucimacul.	3	8	43	U.kapalae	4	24	62	U.testaceus	4	13	93
Winter, 1989:											
spp = 23				spp = 25				spp = 16			
U.paucimacul.	56	145	41	U.paucimacul.	32	168	32	A.inermis	34	102	20
L.argus	9	24	94	L.argus	24	127	34	U.paucimacul.	22	67	79
P.dentex	8	21	173	A.inermis	19	101	46	L.argus	22	66	22
P.longispinus	4	10	34	P.longispinus	4	23	94	A.rostrata	6	18	44
U.testaceus	4	10	75	C.kumu	4	19	81	U.testaceus	4	13	74
Autumn, 1990:											
spp = 28				spp = 32				spp = 20			
U.kapalae	61	467	42	A.inermis	29	171	29	P.longispinus	28	96	3
U.testaceus	6	46	55	U.paucimacul.	15	91	7	A.inermis	18	62	39
P.longispinus	5	41	41	L.argus	15	87	105	L.argus	12	43	22
U.paucimacul.	4	31	22	U.kapalae	9	52	23	U.kapalae	10	36	22
A.inermis	4	30	36	M.freycineti	7	41	25	A.rostrata	9	32	35
Spring, 1990:											
spp = 29				spp = 24				spp = 19			
U.kapalae	54	231	45	A.inermis	45	94	35	T.novaezeland.	64	468	32
A.inermis	12	52	65	L.argus	21	44	81	U.paucimacul.	12	87	91
A.anomalus	12	51	173	P.longispinus	8	16	75	U.kapalae	8	59	85
L.argus	7	28	44	N.richardsoni	3	7	89	L.argus	7	48	48
M.freycineti	3	12	90	U.kapalae	3	6	132	A.inermis	4	32	14

Table 9.6, continued

Long Reef				Bondi				Port Hacking			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Summer, 1990:											
spp = 34				spp = 30				spp = 24			
Pempheris spp.	29	88	49	*P.longispinus*	26	248	6	*T.novaezeland.*	33	299	88
U.kapalae	23	71	21	*A.inermis*	22	210	18	*U.paucimacul.*	17	156	47
Optivus spp.	8	24	106	*T.novaezeland.*	18	173	152	*L.argus*	11	100	106
U.sufflavus	5	16	43	*L.argus*	11	105	17	*A.inermis*	7	68	29
P.lineatus	4	12	25	*L.mulhalli*	5	46	72	*U.kapalae*	7	66	109
Winter, 1990:											
spp = 25				spp = 22				spp = 17			
U.kapalae	72	261	44	*U.kapalae*	33	86	17	*L.argus*	32	264	21
R.sarba	5	19	105	*A.inermis*	18	47	22	*A.inermis*	21	172	79
U.sufflavus	4	13	70	*H.portusjack.*	12	32	71	*U.paucimacul.*	20	163	55
A.australis	4	13	70	*P.longispinus*	6	15	72	*U.kapalae*	13	103	32
M.freycineti	2	9	57	*F.petimba*	5	13	26	*U.testaceus*	5	41	52

b. 60 m

Long Reef				Bondi				Port Hacking				Malabar			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Autumn, 1989:															
spp = 30				spp = 20				spp = 14				spp = 16			
L.argus	30	107	26	*U.paucimacul.*	41	129	52	*L.argus*	81	140	132	*L.argus*	47	74	69
S.b.flindersi	19	67	142	*L.argus*	24	75	79	*S.b.flindersi*	4	7	173	*P.scaber*	8	13	74
P.longispinus	18	63	9	*U.testaceus*	13	41	173	*P.jenynsii*	3	5	124	*P.longispinus*	6	10	17
U.paucimacul.	11	38	19	*A.inermis*	5	17	113	*A.inermis*	2	4	43	*A.inermis*	6	10	45
L.mulhalli	4	13	173	*P.auratus*	4	14	173	*N.ayraudi*	2	4	173	*T.fasciata*	6	9	57
Spring, 1989:															
spp = 31				spp = 32				spp = 15				spp = 18			
L.argus	32	85	66	*L.argus*	19	117	84	*L.argus*	75	355	60	*C.affinis*	42	193	173
P.longispinus	11	28	62	*L.mulhalli*	14	87	70	*N.ricardsoni*	16	74	85	*L.argus*	36	164	50
N.richardsoni	8	20	52	*P.auratus*	13	78	56	*Z.faber*	3	15	72	*A.inermis*	4	19	32
S.diversidens	8	20	108	*A.inermis*	11	66	59	*A.inermis*	2	10	17	*P.auratus*	3	17	158
A.inermis	7	18	116	*Z.faber*	9	55	13	*R.australis*	1	5	91	*L.mulhalli*	3	12	43

Table 9.6, continued.

Long Reef				Bondi				Port Hacking				Malabar			
Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)	Species of fish	%	Tot Abun	CV (%)
Winter, 1989:															
spp = 30				spp = 19				spp = 14				spp = 18			
L.argus	21	86	8	A.inermis	31	84	31	L.argus	90	298	32	M.australis	22	45	30
C.affinis	17	70	151	L.mulhalli	23	62	48	P.longispinus	2	7	89	U.paucimacul.	19	38	31
S.diversidens	11	45	41	U.paucimacul.	9	24	78	Z.faber	2	5	69	L.argus	15	31	73
U.paucimacul.	10	41	8	Z.faber	7	20	34	A.inermis	1	4	173	A.inermis	12	25	61
S.b.flindersi	6	26	93	M.australis	7	19	9	P.jenynsii	1	4	114	P.auratus	11	22	150
Autumn, 1990:															
spp = 27				spp = 28				spp = 22				spp = 19			
T.novaezeland.	44	138	158	T.novaezeland.	48	338	58	L.argus	53	362	110	C.affinis	66	468	173
L.argus	14	43	28	L.mulhalli	11	78	60	S.b.flindersi	16	109	166	Z.faber	8	56	30
P.longispinus	7	22	103	H.portusjackson.	8	54	168	L.mulhalli	9	60	143	L.argus	4	31	84
L.mulhalli	5	17	87	A.inermis	6	45	30	N.richardsoni	8	55	86	A.inermis	4	29	46
T.fasciata	4	14	12	U.paucimacul.	6	42	42	A.inermis	3	21	28	L.mulhalli	4	25	72
Spring, 1990:															
spp = 30				spp = 23				spp = 22				spp = 16			
T.novaezeland.	76	783	124	A.inermis	15	59	15	S.australis ?	51	2553	77	L.mulhalli	36	80	119
S.novaeholland.	10	101	170	L.mulhalli	13	50	173	T.novaezeland.	42	2076	26	S.b.flindersi	22	49	120
L.argus	2	25	61	N.richardsoni	12	48	76	S.b.flindersi	3	168	69	A.inermis	14	31	16
U.paucimacul.	2	17	71	S.b.flindersi	12	47	88	L.argus	2	107	73	N.richardsoni	9	20	45
S.australis	2	16	173	U.paucimacul.	12	46	87	N.richardsoni	1	42	77	Z.faber	5	11	110
Summer, 1990:															
spp = 40				spp = 37				spp = 29				spp = 17			
L.argus	28	187	26	L.mulhalli	38	565	13	L.argus	41	493	66	L.argus	40	160	65
C.affinis	21	137	173	L.argus	11	160	22	T.novaezeland.	23	271	89	L.mulhalli	23	94	61
S.b.flindersi	13	89	35	U.paucimacul.	10	153	17	S.b.flindersi	21	246	106	M.australis	11	45	105
L.mulhalli	10	65	41	P.auratus	7	106	96	L.Mulhalli	5	63	54	A.inermis	6	26	63
P.longispinus	6	40	37	T.novaezeland.	7	101	130	N.richardsoni	3	35	42	H.portusjackson.	3	13	58
Winter, 1990:															
spp = 24				spp = 31				spp = 15				spp = 11			
E.mosaicus ?	30	183	168	P.auratus	15	95	84	L.argus	95	616	49	L.argus	66	189	42
P.scaber	24	147	47	A.inermis	12	73	53	U.testaceus	1	7	107	U.kapalae	13	38	71
L.argus	24	147	42	L.argus	11	68	86	F.petimba	1	6	50	Z.faber	10	29	83
R.australis	5	31	14	L.mulhalli	10	64	49	S.b.flindersi	1	4	114	R.australis	2	7	65
M.scoloplax	5	28	44	U.paucimacul.	9	58	55	S.novaeholland.	1	4	173	N.ayraudi	2	7	65

underestimated by the FRI study, including Lophonectes gallus, Platycephalus longispinus, Trachurus novaezelandiae and Sillago bassensis flindersi, although the larger Neoplatycephalus richardsoni also appeared to be relatively more abundant in the samples from the Metromix aggregate study. In contrast, the Metromix aggregate study may have underestimated species such as Pagrus auratus and Centroberyx affinis. These conclusions should be interpreted cautiously as the two studies differ in sample times and locations. As a general conclusion, however, it would appear that the samples from the Metromix aggregate study compare favourably against those from the FRI study. In particular, both studies found similar assemblages of fish in or near the proposed extraction areas.

9.3.2.2 Analysis of Populations

The analysis of populations for the FRI study highlighted many of the same trends identified from the Metromix aggregate study (Appendix B7-B8). In both studies, most of the variability occurred at the highest order interaction (i.e. times by depths by locations for FRI design 1, or times by locations for FRI design 2 - Table 9.7). Many of the variates also had heterogeneous variances (Appendix B7-B8), indicating large variability within the treatment levels. Figures referred to in the following sections are shown in Appendix B9, Volume II.

9.3.2.2.1 FRI Design 1: Comparison of 7 Surveys and 2 Depths at LR, BO and HA

Main effects: time, depth and location

Trygonorhina fasciata, Urolophus testaceus and Heterodontus portusjacksoni had significant time, depth and location effects, respectively (Appendix B7). T. fasciata was more abundant during survey 6 than surveys 2,3 or 5. U.testaceus preferred 30 m to 60 m. H. portusjacksoni showed a trend towards greater numbers at Bondi (BO), but this could not be demonstrated statistically.

Interactions among factors

Most of the variates analysed showed significant interactions between factors. Examples of the 4 types of interaction are described in the following paragraphs.

Sillago bassensis flindersi was one of two species which showed a significant interaction between times and depths (Fig. 9.81). Abundance was generally greatest in 60 m, although significant differences were only detected among depths during surveys 4, 5 and 6. Five variates showed significant time by location interactions, exemplified here by Aptychotrema rostrata, Lepidotrigla argus and Pagrus auratus (Fig. 9.82). A. rostrata tended to predominate at HA during the study. In survey 3 more

Table 9.7. Summary of analyses for 2 series of data comparing a)

Times (T), Depths (D) and Locations (L) and b) Times and Locations alone. Data collected by FRI, designs as described in Section 9.2.2.2. Heading descriptors as per Table 9.5.

Factor	Sig	ns	nt
<u>a) Times, depths and locations (28 variates)</u>			
Time	1	3	25
Depth	1	3	25
Location	1	3	25
T x D	2	7	19
T x L	5	5	19
D x L	5	4	18
T x D x L	19	9	-
<u>b) Times and locations (30 variates)</u>			
Time	0	4	26
Location	1	3	26
T x L	25	5	-

were found at HA than BO, during survey 4 more were found at HA and LR than BO and during survey 6 more were found at HA than the other locations. <u>L. argus</u> also tended to be more common at HA. During survey 2 and 6 there were more at HA than LR and in surveys 4 and 7 there were more at HA than BO or LR. <u>P. auratus</u> was not sampled at HA. In survey 1 there were significantly more at LR than BO or HA and during surveys 2, 6 and 7 there were more at BO than LR and HA.

Interactions between depth and location occurred for 5 variates, 3 of which are illustrated here (Fig. 9.83). <u>Aptychotrema rostrata</u> was more abundant at HA in 30 m depth than the other locations, but no differences occurred among locations in 60 m. There were also more in 30 m than 60 m at HA, but no differences among depths at the other locations. <u>Lepidotrigla argus</u> was more abundant at BO and HA than LR in 30 m, and was more abundant at HA than BO or LR in 60 m. Lastly, <u>Pagrus auratus</u> was more abundant at LR than BO or HA in 30 m but was more abundant at LR than the other locations in 60 m.

Of the 19 variates which had significant interactions among times, depths and locations, 6 are briefly described here. <u>Neoplatycephalus richardsoni</u> was uncommon in 30 m throughout the FRI study (Fig. 9.84). A small increase was recorded at HA during survey 6. At 60 m abundance tended to increase at HA during surveys 2, 4, 5 and 6, with smaller increases elsewhere. <u>Platycephalus longispinus</u> showed large variability among locations through time at 30 m, with no clear patterns (Fig. 9.85). Abundance was low at 60 m, but there tended to be more at LR at all times except in survey 6.

Species richness of fish in both depths tended to be low at HA compared to BO and LR (Fig. 9.86). The total abundance of fish showed no consistent pattern at either depth (Fig. 9.87). The number of species of economic value tended to be small at HA during the study, except during survey 6, when similar numbers occurred at all locations (Fig. 9.88). As with total abundance, the numbers of fish of economic value showed no consistent pattern among sites (Fig. 9.89). There were relatively large increases in 30 m at BO in surveys 2 and 6, and at HA in survey 6. In 60 m there was a large increase in the number of fish of economic value during survey 5.

9.3.2.2.2 FRI Design 2: Comparison of 7 Surveys at LR, BO, MA and HA (60 m depth)

Of the 30 variates analysed using FRI design 2, none showed time as a significant main effect and only Heterodontus portusjacksoni showed location as a significant main effect (Appendix B8). H. portusjacksoni tended to be more abundant at BO than the other locations. Most of the other variates showed significant interactions between times and locations. Generally, Malabar (MA) was similar to the other locations. Five examples are presented of significant time by location effects (see Figs. 9.90-94, in Appendix B9).

9.4 CONCLUSIONS

The study of fish and mobile invertebrates showed that a diverse assemblage of these animals occurs within the area proposed for extraction of marine aggregate and at nearby control locations. The numbers of species and their abundance compares favourably with other studies done on soft substrata in NSW (e.g. FRI 1992), although direct comparisons are limited by the different survey times, locations and methodologies. It should also be noted that the literature indicates that these assemblages have been subject to heavy fishing pressure (e.g. Fairbridge 1952) and that the assemblages in the proposed extraction areas were very similar to those of two reference locations studied.

The analysis of fish assemblages distinguished three assemblages corresponding to the three depth ranges sampled across the sand bodies. In broad terms, the assemblage at 20-30 m was dominated by stingarees, (Urolophus kapalae, U. testaceus and U. paucimaculatus), long-spined and blue-spotted flathead (Platycephalus longispinus and P. caeruleopunctatus), cocky gurnards (Lepidotrigla spp.), small-tooth flounder (Pseudorhombus jenynsii) and boxfish (Anoplocapros inermis). The assemblage at

40-50 m appears to be transitional between the shallow and deep areas. Thus, species such as cocky gurnards and long-spined flathead were present, along with species such as school whiting (Sillago bassensis flindersi), crested flounder (Lophonectes gallus) and, less frequently, tiger flathead (Neoplatycephalus richardsoni). At 60-70 m school whiting, tiger flathead and crested flounder were abundant, as well as bellowsfish (Macrorhamphosus scololepis), three-spined cardinal fish (Apogonops anomalus) and, in smaller numbers, nannygai (Centroberyx affinis) and john dory (Zeus faber). The analysis also suggested that these assemblages showed few major differences among locations and times.

The Metromix aggregate study and the FRI study both provided comparisons of populations of demersal fish in or near the proposed extraction areas. Neither Cape Banks nor Providential Head were particularly outstanding in comparison with Bate Bay or Bass Point. The study suggests that some species, such as school whiting, preferred Bass Point. Similarly, in the FRI study, which ran over a two year period, neither Port Hacking or Malabar showed very large numbers of species or individuals compared with Long Reef or Bondi. FRI found that the assemblage of fish at the 30 m contour at Bondi tended to be more diverse and have larger numbers of fishes than other areas sampled - possibly as a result of the close proximity to a sewage outfall (FRI 1992).

The strong depth gradient apparent for the assemblages was also seen for populations of species in the Metromix aggregate study and to a lesser extent in the FRI study. Some of the species of stingarees as well as long-spined flathead and small-toothed flounder often showed significant differences among depths (particularly when 20-30 m was compared with 60-70 m), while in the deeper areas school whiting and tiger flathead predominated. In comparing populations among times, locations and sites, however, this study demonstrated that many of species within the assemblage can be highly variable in numbers.

There were no data to suggest that any species are 'confined' within or show a significant preference for either of the extraction areas. Rather, the study suggests that the sand bodies of the nearshore area represent a relatively continuous habitat over which the demersal fish and mobile invertebrates have very patchy distributions in space and time. Overlying this, however, are species which move to the nearshore zone from other habitats or which migrate through this zone. One important group of species includes those which migrate out of estuaries onto the open coast. The best known examples of this are eastern king prawns and school prawns. There is also evidence that fishes such as small-toothed flounder may migrate from nursery areas within estuaries into shallow coastal waters (SPCC 1981b).

In addition, there were no data, either from our study or the literature, to suggest that any of the locations studied (i.e. proposed extraction areas or reference areas) were important nursery or spawning grounds. Fairbridge (1952) asserts that the trawl ground off Botany Bay was once an important spawning ground for tiger flathead, but this area appears to have been beyond the seaward boundaries of the proposed extraction areas. School prawns are known to migrate into shallow nearshore waters to spawn and the nearshore areas of the study region may of significance to local stocks.

The main issues which need to be addressed in assessing the effects of the marine aggregate proposal include the scale over which effects would extend; the effects on linkages with other habitats, such as estuaries; and the potential for the proposal to affect local fisheries. These matters are addressed further in Part IV of the report.

CHAPTER 10. ASSEMBLAGES OF ROCKY SHORES, REEFS AND SHIPWRECKS

10.1 INTRODUCTION

Rocky shores, reefs and shipwrecks support very different assemblages of marine organisms to those of the sandy substrata described in the last two chapters. This is due mainly to two factors. First, these stuctures have solid substrata, which provide points of attachment for many sessile organisms, including macroalgae, large sponges and corals - which are rare on soft substrata. Second, these stuctures are often topographically complex. Thus, sessile organisms may become adapted to a variety of microhabitats, such as vertical or horizontal surfaces, caves and crevices, shaded or exposed areas, etc. The complexity of reefs also provides shelter for mobile invertebrates (e.g. sea urchins, abalone and crayfish) and fish.

The complexity of the rocky substratum is often compounded by topographic complexity provided by the sessile organisms that grow there. Thus, there are features such as kelp 'forests' and beds of short algal 'turf' which contain their own associations of organisms. Unlike terrestrial forest and turf, the reef floor provides only a point of attachment and not a source of nutrients, which are derived from the water. In common with the sandy habitats described above, the water medium also provides a means of dispersal over large distances for many species, although some sessile, colonial invertebrates may disperse over very short distances. The dispersal phase (usually as eggs or larvae) of many reef-dwelling organisms can lead to very patchy settlement of progeny (e.g. Caffey 1985; Lincoln Smith et al. 1991) and factors affecting the survival in the plankton may have a very large effect on the resulting adult population (Fairweather 1991a; Underwood and Fairweather 1989).

Rocky shores, reefs and shipwrecks are heavily utilised by humans. Rocky shores are very popular areas for fossicking, fishing and bait and food collecting (e.g. Kingsford et al. 1991). They have also played a very important rôle in studies of marine ecology (e.g. Underwood and Denley 1984; but see also Appendix C). Shallow reefs are very popular for SCUBA diving, fishing and spearfishing (e.g. Lincoln Smith et al. 1989). Deeper reefs are popular fishing grounds - both for recreational and commercial fishing - and shipwrecks are popular fishing and diving areas (e.g. Pollard 1989).

Sandstone rocky shores dominate the coastline adjacent to the proposed Providential Head extraction area. These shores have not been intensively studied, probably due to their inaccessibility. In describing the oceanic flora and fauna adjacent to Royal National Park, the Sutherland Branch of the National Parks Association (NPA 1991) described, in a draft submission on a proposed marine and estuarine protected area (MEPA) an "idealised" transect from the mean high tide to 50 m depth along a rock coastline typical of the NSW coast as follows (NPA 1991).

For example, NPA (1991) state that between 0-5 m, where surf action dominates, barnacles, sea anemones, green and brown seaweeds, crabs, sea urchins and many sponges occur. From 5-10 m depth, brown algae (especially kelp forests off Marley) and predominate. From 10-50 m depth, sponges and soft corals take over. Fish which dominated the shallow "white-water" included marblefish and blackfish, while the intermediate depths were dominated by mado, wrasse, stripey and marblefish. Fish common on reefs from 10-50 m included old wife, banded sea perch, morwong, blue wrasse, ling, sergeant baker, white ear and one spot demoiselles (NPA 1991). Fiddler rays, stingrays, Port Jackson and wobbegong sharks and pelagic species such as kingfish, trevally, tuna and other shark species were also common. According to the NPA (1991), the wrecks off Royal National park are frequented by kingfish, rays, trevally and wobbegongs.

The description provided by the NPA (1991) was simplistic, both in terms of reef zonation (Underwood et al. 1991) and structure of fish assemblages (Lincoln Smith et al. 1993). Moreover, reef does not extend to 50 m depth adjacent to the proposed extraction area at Providential Head - most of the rock reef there ends at depths of 20-30 m or less.

Unlike Providential Head, the rocky shores and shallow subtidal reefs at Cape Banks have been studied intensively by researchers from the Institute of Marine Ecology (IME) at the University of Sydney (see Appendix C for references). Studies done at Cape Banks have provided information on processes that structure rocky shore assemblages in temperate Australia and have lead to the development of ecological procedures that are applied worldwide. Cape Banks is also an important area for ongoing long-term ecological research in Australia. As part of the studies for the marine aggregate EIS, the IME reviewed ecological studies done at Cape Banks and described generally some of the potential effects that aggregate extraction may have on intertidal communities at Cape Banks (see Appendix C).

Under the current proposal to extract marine aggregate, no operations would occur within at least 250 m of any recognised reefs or shipwrecks and, as part of the extraction plan, all parts of the extraction areas would be surveyed for reefs and shipwrecks before extraction occurred (Chapter 3). It is, however, highly unlikely that any natural reefs occur at the surface of the shelf sand body, although there are extensive reefs fringing the coastline (Chapter 6). This contrasts with the Broken Bay extraction proposal, where reefs occurred within the proposed extraction area (Carey and Talbot 1980).

The Applicant recognises that rocky shores and reefs should be given a very high conservation value on the basis of their diverse assemblages of plants and animals, and their relatively high usage by humans.

Shipwrecks, however, represent an anthropogenic addition to the seabed and, in terms of marine ecology, their conservation value is more debatable. In supporting what may be essentially a rocky reef community, the artificial habitat created by shipwrecks such as the s.s.Tuggerah and s.s.Woniora have displaced, to an unknown extent, part of a natural community on the shelf sand body. Fortuitously for humans, wrecks such as these are good places to fish (Pollard 1989) and interesting, albeit dangerous, places to SCUBA dive (Kerr 1992; Lippmann 1989). As Polovina (1991, cited in Kerr 1992) pointed out, however, it is not clear to what extent artificial habitat redistributes exploitable biomass, aggregates previously unexploited biomass, or improves aspects of survival and growth and provides new production.

On the other hand, shipwrecks are frequented by fishers, who catch fish there and by SCUBA divers, who watch or photograph the biota and the structural features of the wreck (Chapter 14). Thus, to assign a high conservation value to shipwrecks on the basis of the marine ecology is questionable, but it is more realistic to assign a high value in terms of their current human usage.

We therefore conclude, on the basis of existing information, that the rocky shores, reefs and shipwrecks have a high conservation value, but not for identical reasons.

This chapter reviews the ecology of rocky shores, reefs and shipwrecks, derived from existing information, in three broad sections. The first section examines rocky shores, with information predominantly on the littoral zone, extending to just below the low tide mark. It is here that most of the research on rocky habitats has been done, probably because it is relatively very accessible. The second section examines shallow rocky reefs, which are studied mostly by snorkelling and SCUBA diving. These are considered to extend to about 25 m depth. The third section deals with shipwrecks and deeper reefs. Whilst they often accessible to SCUBA divers, severe limitations on bottom time limit the work than can be done by diving and other sampling methods are often used.

10.2 ROCKY SHORES

10.2.1 Algae and Invertebrates

This section describes the assemblages of algae and invertebrates that inhabit rocky shores in the study region and NSW and some of the processes that structure these assemblages. Recent reviews by Underwood (1990) and Underwood and Kennelly (1990) detail much of the current understanding of processes on rocky shores in Australia. Reference should be made to these papers for further information.

Historically, algae and invertebrates on rocky shores in NSW have been qualitatively described in terms of the vertical distribution of the dominant organisms. Dakin et al. (1948) defined three broad zones in terms of the dominant organisms at different levels on oceanic rocky shores in NSW. These are the supralittoral, littoral and sublittoral zones. These zones merely reflect the distribution of large, abundant species, but they are a useful reference point for qualitative descriptions.

The supralittoral zone is the highest level on rocky shores inhabited by marine animals. It is dominated by the littorinid snail Littorina unifaciata with Nodilittorina pyramidalis also occurring but generally in fewer numbers (Dakin et al. 1948). Algae rarely occur in this zone.

The littoral (intermediate) zone contains most of the animals on rocky shores. The width and species composition of this zone is somewhat dependent on the degree of wave-splash and hence the exposure of the shore to swell and the physical characteristics of the shore (Dakin et al. 1948). In areas of intermediate exposure, the littoral zone is often dominated by the honeycomb barnacle, Chamaesipho columna (Dakin et al. 1948) but often there are areas among these patches barnacles that are grazed by the limpet, Cellana tramoserica and gastropods (Underwood et al. 1983). The barnacle, Chthamalus antennatus is also often found on these shores, often towards the top of the littoral zone (Dakin et al. 1948).

On rocky shores in more sheltered areas of the coast, barnacles may be sparse or absent in the littoral zone and grazing gastropods such as Austrocochlea constricta, Bembicium nanum and Nerita atramentosa are often abundant (Underwood et al. 1983). On shores exposed to much greater wave-action, the barnacles Tesseropora rosea and Catomerus polymerus are often common (Dakin et al. 1948, Underwood et al. 1983). The small limpet, Patelloida latistrigata is often common amongst the barnacles on these shores (Underwood et al. 1983).

Towards the lowest levels of the littoral zone there is often a heavy encrustation of tubeworms, Galeolaria caespitosa (Dakin et al. 1948). Cunjevoi, Pyura stolonifera, may be common in the lowest part of the littoral zone. The distribution of cunjevoi may extend to the very lowest tidal levels and the shallow subtidal zone (i.e. the sublittoral) and they are often covered by foliose algae (Dakin et al. 1948). The sublittoral fringe of rocky shores is often dominated by the kelps Ecklonia radiata and Phyllospora comosa (Dakin et al. 1948).

Underwood (1981b) quantitatively described patterns of vertical and horizontal distribution and seasonal changes in these patterns for common intertidal organisms on a sandstone shore at Green Point, NSW. He identified a high-shore animal community, a mid-shore mixed one and a low-shore algal one (Underwood 1981b) which correspond roughly to the supralittoral,

littoral and sublittoral zones.

The high-shore animal community was dominated by the littorinid snails, Littorina unifasciata, Littorina acutispira and Nodilittorina pyramidalis (Underwood 1981b). Much of the mid-shore areas were covered by the encrusting macroalga, Hildenbrandia prototypus, and sessile animals such as barnacles and the tubeworm Galeolaria caespitosa. These sessile animals were distributed in patches and the bare space among patches was dominated by grazers such as Austrocochlea constricta, Bembicium nanum, Nerita atramentosa and Cellana tramoserica (Underwood 1981b). The predatory whelk, Morula marginalba was also distributed in patches and found feeding on barnacles or aggregated in cracks and crevices (Underwood 1981b).

Most of the space low on the shore was covered by foliose macroalgae, including Gelidium pusillum, Ulva lactuca, Sargassum spp., Pterocladia capillacea and Colpomenia sinuosa (Underwood 1981b). Some macroalgal grazers occurred among the algae e.g. the starfish Patiriella calcar, the turban snail Turbo undulata and the slit limpet Montfortula rugosa.

There was a general tendency for algae, grazers and Littorina unifasciata to be distributed further up the shore with increasing exposure to wave-action (Underwood 1981b). There was also a shift of dominance from Chamaesipho to Tesseropora at mid-shore levels and more Galeolaria at low-levels and Chthamalus at high-levels with greater exposure to wave-action (Underwood 1981b).

Some species of algae also became less abundant in spring and/or summer compared to autumn and/or winter, probably due to the harsher physical conditions, such as dessication, prevailing in warmer periods (Underwood 1981b). The vertical distribution of some species of algae showed no variation among seasons, however others (e.g. Ilea fascia and Ulva lactuca) occurred only towards the bottom of the shore in summer but returned to their upper limit by autumn or winter. Underwood (1981b) also found that algal diversity was smallest during spring and summer.

The vertical patterns of distribution of intertidal organisms as described by Dakin et al. (1948) give the impression that the distribution of organisms along a shore is relatively homogeneous and static. This is far from the case. Underwood (1981b) sampled intertidal organisms in transects only metres apart and found considerable variation in abundances at this small scale. On most shores there is considerable patchiness in the distribution of organisms along the shore and over time.

The processes affecting the distribution and abundance of organisms on rocky shores include both physical and biological components. It was once thought that physical factors such as desiccation were the main structuring forces on rocky shores (e.g. Lewis 1964). The vertical distribution of species on a shore was considered to be a function of their exposure during periods of emersion. More recently, biological interactions have been shown to be important as they can modify or cause patterns of vertical distribution of organisms on rocky shores. Perhaps the best example of this is that the upper limit that foliose macroalgae reach on rocky shores in NSW is not determined by physical factors but by the grazing of gastropods which removes the spores and microscopic stages of foliose algae from the shore before they can grow (Underwood and Denley 1984; Underwood 1990).

Interactions between sessile organisms and grazers common at mid-shore levels often structure assemblages there. While exposed shores may be dominated by Tesseropora and sheltered shores may be dominated by grazing gastropods at mid-shore levels, there is often a mixture of patches dominated by barnacles and others by limpets in mid-shore areas of shores with intermediate exposure (Underwood et al. 1983). Interactions between Tesseropora and Cellana are a major factor in producing the dynamic mixture of patches on the mid-shore in areas of intermediate wave exposure (see Underwood et al. 1983).

Predation by whelks, Morula marginalba on barnacles may also create space on the shore as the empty barnacle tests are removed by waves. This predation may be localized around the cracks and crevices on the shore where the whelks congregate (Underwood 1990). Fairweather (1990a) discussed interactions of predation on rocky shores with processes such as competition, mutualism, desiccation and variations in recruitment.

Disturbances, especially those that remove patches of dominant animals, are important processes on rocky shores (e.g. Dayton 1971). McGuinness (1987a,b) studied the importance of disturbance in structuring assemblages of invertebrates and algae on intertidal boulders in NSW. He found that disturbance of boulders had little effect on the assemblages of algae that develop on the tops of boulders (McGuinness 1987b). More species of invertebrates did, however, settle or survive on the undersides of boulders that could not be moved by waves (McGuinness 1987b). Overall, disturbance killed organisms and created free space on boulders, but the effects on the structure of assemblages varied among species and the actions of other factors (McGuinness 1987b).

Open space created by human removal of cunjevoi, crabs and grazing gastropods could have major effects on the structure of intertidal assemblages (e.g. Kingsford et al. 1991). For example, preliminary work on the harvesting of Pyura stolonifera in NSW has shown that cut tests of Pyura remain attached to rocks only up to two weeks (Fairweather 1991b). An experiment showed that no appreciable recolonisation occurred in harvested patches by Pyura in two years; maybe because juveniles generally recruit near to or onto adult Pyura (Fairweather 1991b). Thus, recovery of populations of Pyura would be slow, if at all. Studies in Chile have also shown that the size-structure and densities of some populations may be altered by harvesting by the public (Duràn et al. 1987).

Recruitment may also affect assemblages (Underwood and Fairweather 1989). Most intertidal organisms disperse via planktonic propagules. As these propagules are transported by oceanic processes such as currents, the supply of propagules and, therefore, recruitment may be patchy in time and space (e.g. Caffey 1985; Raimondi 1990). Patterns of recruitment may have a strong influence of the distribution of adults despite subsequent processes of mortality.

Processes of recruitment are also important in determining the vertical distribution of organisms on rocky shores. For example, Denley and Underwood (1979) showed that the vertical distribution of the barnacle Tesseropora rosea on Australian shores was determined primarily by recruitment. The barnacles never settled above the upper limit of the adults on the shore (Denley and Underwood 1979).

10.2.2 Tidepool Fishes

Few studies have been done on the biology and ecology of fishes inhabiting rock pools in NSW waters. Overseas studies have shown that these fishes form relatively diverse assemblages, consisting of species that use the rock pools throughout their post-settlement life, or as nursery areas before they move to other habitats (e.g. Gibson 1972, 1982). Marliave (1986) found that planktonic dispersal of rocky intertidal fish larvae was very limited, both offshore and probably alongshore, along a protected shoreline in western Canada. In New Zealand, Kingsford and Choat (1989) found that pre-settlement gobiesocids and trypterygids - groups commonly found in rock pools - were most abundant very close to the shoreline, typically in waters of 0-2 m depth.

In NSW, Bell et al. (1980) studied the diet of three size classes of rock blackfish, Girella elevata. Small juveniles and juveniles were collected, by poisoning, from rock pools in the Sydney region and adults were collected from spearfishing competitions held in the region. Bell et al. (1980) suggested that rock blackfish recruited to rock pools, which they used as nursery areas. They moved to pools progressively lower on the intertidal as they grew and finally moved into shallow subtidal reef areas as large juveniles or sub-adults (Bell et al. 1980). Many other species of fish have also been observed in rock pools as small juveniles (M. Lincoln Smith, pers. obs.), including white ear (Parma microlepis), sweep (Scorpis lineolatus), mullet (Mugilidae), sergeant major (Abudefduf spp.) and black cod (Epinephelus damelii). The relative importance of rock pools as nursery areas compared to other habitats is unknown.

10.3 SHALLOW ROCKY REEFS

10.3.1 Algae and Invertebrates

Shallow rocky reefs of temperate waters have been described as a mosaic of kelp stands, diverse foliose and turfing algae and thin encrusting coralline algae or 'barrens' (Jones and Andrew 1990 and references therein). In NSW, shallow subtidal habitats have only recently been described quantitatively (Underwood et al. 1991). One of their study sites was at Cape Banks and another at Bare Island, at the entrance to Botany Bay. The following paragraphs summarise Underwood and his co-workers' (1991) research.

Seven shallow subtidal habitats have been described in NSW, including Fringe, Pyura, Phyllospora forest, Barrens, Turf, Ecklonia forest, and Deep Reef habitats. The Fringe habitat generally was found only in the most shallow waters. Turfing algae occupied much of the space in the Fringe habitat and various other species including mussels Brachidontes hirsutus, sea urchins Centrostephanus rodgersii and Heliocidaris erythrogramma, and gastropods, Australium tentiforme and Turbo torquatus were often present. The species composition of assemblages in the Fringe habitat varied among the locations and sites within locations sampled on the coast of NSW.

The Pyura habitat occurred at two locations in northern NSW (Charlotte Head and Southwest Rocks). As the name implies, the ascidians Pyura stolonifera and Pyura gibbosa covered large areas of the reefs at these locations. Algae, and the gastropods Cabestana spengleri were common among the ascidians at some sites within these locations.

The Phyllospora forest habitat occurred at the two most southern locations, Merimbula and Batehaven. Dense patches of the alga Phyllospora comosa were, however, extremely patchy and the Phyllospora habitat often only covered a small band of reef adjacent to the intertidal zone.

The Barrens habitat was most represented at the more southern locations in NSW and this habitat typically contained many sea urchins (Centrostephanus). The limpets Patelloida alticostata and Cellana tramoserica were most comon in the Barrens habitat. Patches of crustose coralline algae occurred in the Barrens habitat.

The Ecklonia forest habitat was most common at Botany Bay compared to the northern and southern locations. Crustose coralline algae covered a relatively large but variable proportion of the substratum beneath the canopy of Ecklonia. The invertebrate herbivores Australium tentiforme and Turbo torquatus were also relatively common beneath Ecklonia but occurred in small numbers.

The Turf habitat was characterised by patches of algae such as turfing coralline species, filamentous species, Ecklonia and Sargassum. Few animals were present in these areas and sea urchins were conspicuously absent.

The Deep Reef habitat, as defined by Underwood et al. (1991), occurred in water depths of greater than 9 m and may be present only at distances of greater than 100 m offshore. In this habitat algae was sparse and large sponges were common. Other taxa common in the Deep Reef habitat included alcyonarians, gorgonians and bryozoans.

As part of studies on the effects of spoil disposal off Port Kembla (SPCC 1983; 1986; Roach 1992a) surveyed benthos at sites on the Five Islands and at Bass Point. A general zonation was noted across reefs, with kelp beds predominating in shallow water, followed by a barrens zone ("encrusting algae" - SPCC 1983) and sponge zone, which extended to the edge of the reefs, typically at about 22-30 m depth (SPCC 1983). The extent of each zone, however, varied among reefs (SPCC 1983). For example, at Martin Islet, the kelp zone extended to about 10 m at a site on each side of the islet, but at Bass Islet, kelp extended to 22 m at a site on the southern side of the islet and only to 10 m at one on the northern side.

Roach (1992) focused work on the sponge zone, which was roughly equivalent to the Deep habitat of Underwood et al. (1991). In addition to describing the benthic communities and their variability during a period of spoil disposal, analysis of photographs for the proportion of slides containing more than 10% fine silt cover was determined for the four surveys done for the study at each of six study sites (Roach 1992). One study site facing the dump site showed an accumulation of silt, but control sites well to the south of the dump site (and unlikely to have been affected by the spoil disposal) also showed an accumulation of silt throughout the study. It was concluded that the sediments in the region are mobile and move continuously onto and off the reefs (Roach 1992). The extent to which such movements occurs is unknown.

Underwood et al. (1991) suggested that the distribution of habitats within rocky reefs may be related to depth, wave exposure and biological processes, especially herbivory. Recent work has shown that there are relatively complex interactions among among inhabitants of rocky reefs. For example, Kennelly (1987) found that turfing algae can inhibit recruitment of kelp, Ecklonia radiata. Jones and Andrew (1990) described the rôles of fish and sea urchins in patch dynamics in Australasian waters. They found that fish and sea urchins showed distinct patterns of distribution among depth strata. Within depth strata, herbivores may be restricted to, or forage preferentially in, particular habitat patches, causing a mosaic of different feeding activities. These patches are either related to specific features of the habitat, such as kelp patches or topography, or behavioural interactions.

The shallow reef habitat opposite the Providential Head extraction area supports many of the habitats described by Underwood et al.(1991) (Lincoln Smith et al 1993; M. Lincoln Smith, pers. obs.). The reefs are relatively narrow, but show distinctive zonation of Fringe habitat, Kelp forests, barrens and, near the seaward edge of the reef, sponge gardens. In particular, there is a large rock shelf with extensive sponge growth at depths of 20-25 m off Marley Head (M. Lincoln Smith, pers. obs.). Similar patterns of zonation occur off Botany Bay, including Cape Banks (Lincoln Smith 1985; Lincoln Smith et al 1993).

10.3.2 Fishes

Fishes on shallow rocky reefs in NSW have not been studied extensively (Lincoln Smith 1985). Most of the studies have been done by SCUBA diving, using visual survey procedures (e.g. Burchmore et al. 1985; Kingsford 1988; Lincoln Smith 1985; Lincoln Smith et al. 1991; 1993). The following account is drawn from these studies.

Assemblages of rocky reef fish in the Sydney region are dominated in terms of numbers of species by wrasses (Labridae) and leatherjackets (Monacanthidae). Amongst the most abundant individuals are the Scorpidae, primarily mado (Atypichthus strigatus) and sweep (Scorpis lineolatus), hulas (Trachinops taeniatus, Family Plesiopidae) and Pempheridae (three species, Pempheris compressus, P. multiradiata and P. affinis). Other common species include one-spot pullers, white ear and girdled parma (Chromis hypselepis, Parma microlepis and P. unifasciata, Family Pomacentridae), red morwong (Cheilodactylus fuscus, Family Cheilodactylidae) and several species of the Serranidae (e.g. Hypoplectrodes spp., Acanthistius ocellatus). These species are all be considered to reside on rocky reefs - they are recorded there as adults and they have been observed on the reefs as recently-settled juveniles.

In contrast to these species, there are many others which occur only as transients on local rocky reefs. Some of these, such as luderick, Girella tricuspidata and yellow-fin bream, Acanthopagrus australis, are believed to recruit primarily to estuarine habitats (SPCC 1981b) and make their way to shallow coastal habitats as adults. Others, such as yellowtail, Trachurus novaezelandiae utilise several habitats, including estuaries (SPCC 1981b), rocky reefs (Lincoln Smith et al. 1993) and open coastal waters (Chapter 9).

Several researchers have studied the distribution of species of fish across reefs (e.g. Lincoln Smith 1985; Kingsford 1988; Jones and Andrew 1990; Smith and Lincoln Smith 1993). For example, Lincoln Smith (1985) found much greater numbers of fish in a barrens habitat than an nearby kelp bed at Henry Head, at the entrance to Botany Bay. Kingsford (1988) found that *Girella tricuspidata* and *G. elevata* were most common in very shallow water. Jones and Andrew (1990) found that *Odax cyanomelas* was associated closely with the kelp beds upon which it feeds. The Ecology Lab (Smith and Lincoln Smith 1993) found large differences between the assemblages of fish in shallow water at the tops of vertical dropoffs (≈ 6 m depth) compared with those in boulder fields at the base of the dropoffs (≈ 18 m depth). For example, *G. tricuspidata* and kelpfish (*Chironemus marmoratus*, Chironemidae) and rock cale (*Crinodus lophodon*, Aplodactylidae) were prevalent at the tops of dropoffs and rare at the bases; while half-banded seaperch (*Hypoplectrodes mccullochi*) tended to be most common in the boulder habitat. *G. elevata*, which Kingsford (1988) described as predominating in shallow water, were very common as large adults in the deeper boulder habitat. With many of these studies, the reef microhabitats often appear to be correlated with depth, thus it is not clear whether differences among assemblages are related to depth, habitat or a combination of both.

A survey of reef fish over several spatial scales over two years indicated that most of the species of rocky reef fish are highly variable in space and time (Lincoln Smith *et al*. 1993). Moreover, in most cases, species of fish varied inconsistently among reefs through time, in much the same way that many of the species examined in chapter 9 (above) varied on the sandy substrata of the proposed extraction areas.

Lincoln Smith *et al*. (1991) described settlement patterns of rocky reef fish which had recently settled onto reefs along the NSW coast. Surveys were done over spatial scales ranging from <1 km (i.e. adjacent reefs separated by sand) to over 200 km (comparisons between Sydney, Jervis Bay and Batemans Bay). Settlement patterns were highly variable over all scales. There were often apparent differences in the abundance of recently settled fish among reefs for many species, but these differences were often masked by great variability in abundance within reefs (defined as when the coefficient of variation, mean/standard deviation > 1.0). The high within reef variability may have been maintained by diversity of microhabitats on the reefs (Lincoln Smith *et at*. 1991). Two major conclusions of the study were that settlement events for rocky reef fish in NSW are highly patchy over several spatial scales and that this variability means that detecting changes in settlement patterns would be difficult (i.e the changes would need to be very large) without using large sample sizes (Lincoln Smith *et al*. 1991).

As part of a large-scale study of reef fishes, Lincoln Smith *et al*. (1993) censused fish on 12 rocky reefs along the NSW coast, including two each near Botany Bay and Port Hacking. The depth range surveyed was approximately 5-10 m. The assemblages of fish on reefs at Botany Bay ranked amongst the most diverse and abundant of the reefs studied. A site off Port Hacking Point tended to have relatively small numbers of species and individuals, while a site at Bass and Flinders Point ranked highly. The results suggest that the fish assemblages at the entrances to Botany Bay and Port Hacking are relatively typical of the central and south coast of NSW and, like the assemblages at all of the other reefs surveyed, are highly variable through space and time.

There are few studies on the linkages between the biota of rocky reefs and other habitats. In the study region, there is the potential for linkages between rocky reefs and estuaries and sandy substrata. SPCC (1981a) and Bell and Worthington (1992) discuss the linkages between rocky reefs and estuaries for fishes. Some species recruit to estuarine habitats such as seagrass beds, then migrate to reefs as large juveniles or adults. Examples of these include blue groper (Achoerodus viridis) and several species of leatherjackets (Fam. Monacanthidae). One problem with our knowledge of such linkages is that we have little information on the significance of other habitats in fulfilling these rôles. Other species of fish appear to move more regularly between estuaries, rocky reefs and possibly coastal surf beaches. Examples of these include yellowfin bream (Acanthopagrus australis) and luderick (Girella tricuspidata).

Much less is known of the linkages between reef-dwelling animals and nearby sandy substrata. In New Zealand, MacDiarmid (1992) found that spiny lobsters, Jasus edwardsii, forage at night over sand-flats adjacent to reefs. In NSW, the most common species of spiny lobster, Jasus verreauxi, is believed to migrate annually across the continental shelf (S. Montgomery, FRI, pers. comm.). Foraging over sand flats by J. verreauxi has not, to our knowledge, been reported. Russell (1975) found that several species of fish, notably the goatfish (Upeneichthys porosus) foraged over sand near a small artificial reef built in 20 m depth in waters off northeastern New Zealand. Russell (1975) stated that most rocky reef fish have only a limited range of movement and rarely venture beyond visual distance from their home reef. He asserted that one mechanism of movement between reefs was displacement and disorientation during storms.

10.4 ASSEMBLAGES ON SHIPWRECKS AND DEEP ROCKY REEFS

The ecology of deep reefs is poorly understood largely because of the difficulties associated with sampling this habitat (Section 10.1). In NSW, there has been little work done, apart from very limited photographic and settlement surveys (Jones 1977; EPA 1992B), qualitative assessments of artificial reefs (derelict vessels) done by NSW Fisheries (Pollard 1989; Kerr 1992), trapping, longlining and netting on reefs done by the FRI (Gibbs 1987; FRI 1992) and some popular accounts of biota on shipwrecks (e.g. Byron 1986).

Jones (1977) considered that depth, associated light changes and silt, with its potential for smothering fauna, would be major factors influencing rocky bottom benthos. As part of the Shelf Benthic Study (Jones 1977), surveys were done at three locations, Long Reef, North Head and Jervis Bay to depths exceeding 66 m. The aim was to measure changes in community structure along a gradient of decreasing siltation and increasing light intensity and to distinguish between the effects of silting from the cliff face outfall at North Head from silt transported from Sydney Harbour. Unfortunately, the study was poorly replicated and confounded by the potential effects of locations, degree of exposure to silt and by the presence of a different kind of silt (i.e. highly organic) associated with the outfall.

The general findings of the study include the following (Jones 1977):

1. Algal cover generally decreased with depth, while the cover of sponges, polyzoans and cnidarians increased.

2. Very heavy storms during the study appeared to severely affect reef benthos. For example, following one storm, algal beds at Long Reef were stripped and benthos at North Head was 'damaged'.

3. 'Drifting' sand was sometimes observed to move onto and cover portions of algal beds at Long Reef, killing short turfing species.

As part of the studies for the deepwater ocean outfalls off Sydney, there have been several studies of fish and mobile macroinvertebrates (Gibbs 1987; FRI 1992) and of sessile biota (EPA 1992b; Roberts and Henry 1992). The fish studies involved the use of nets, lines and traps to obtain quantitative samples. Netting and trapping yielded fish and invertebrates but the data were highly variable and the sampling equipment logistically difficult to work with. Longlining proved more suitable and this procedure has been used on both rocky and sandy substrata (FRI 1992).

Studies of sessile biota were done by using remotely-operated cameras and by deployment of settlement boxes, to examine recruitment to substrata (EPA 1992b). These studies have proved unsuccessful, yielding very little useful information on the benthic communities of deep reefs. Further studies proved more successful (Roberts and Henry, 1992). Surveys were done of reef in depths of 45-55 m at three sites each off North Head, Long Reef and Bungan Head. The reef in these areas was made up mainly of flat rock, with lesser amounts of convoluted rock, sediments and a sediments overlaying rock. According to Roberts (pers. comm.) there is evidence that parts of the reefs are frequently covered by sediment and he suggests that this may be one cause of mortality to benthos.

Macrobenthos generally covered 10-15% of the hard substrata examined photographically (Roberts and Henry 1992). Also, there were typically 7-10 organisms per slide. Sponges covered about 5% of the substratum and contributed 5-7 organisms per slide and were considered to constitute the major biological component of the macrobenthos. A number of common taxa were observed throughout the study area (Roberts and Henry 1992). The sponges Echinoclathria gigantea and Phyllospongia calyciformis were readily identifiable at the species level, while Mycale sp., Tethya sp. and Thorecta sp. could be classified to genus. Other species identified commonly were Iodictyum phoeniceum (Bryzoa) and the cnidarians Mopsea australis and Primnoella australasiae. According to Roberts (pers. comm.), encrusting algae occur in the samples, but foliose algae, such as kelp have not been observed below 35 m depth.

NSW Fisheries created large artificial reefs off Narrabeen made from derelict vessels (Pollard 1989). The first reef was created in 1977, and numerous vessels have been sunk at the site since. They occur in depths of around 46-50 m on sandy substrata. Apart from qualitative surveys and reports of good catches of fish around the wrecks (Pollard 1989), no detailed studies have been done of the effects of the artificial habitat on the seabed, or on community structure of the biota occurring on the habitats (J. Matthews, FRI, pers. comm.).

Little is known of the biota of shipwrecks in the Sydney region. From discussions with divers and our own personal experience, there is no doubt that large numbers of fish are associated with shipwrecks such as the s.s.Tuggerah, s.s.Undola and s.s.Woniora (see also Byron 1986). No foliose algae such as kelp occur on these deep shipwrecks, but the structures are covered with a mosaic of sessile organisms, such as hydroids, anemones, sponges and, occasionally, corals (M. Lincoln Smith pers. comm.).

10.5 HUMAN IMPACTS TO ROCKY SHORES, REEFS AND WRECKS

There have been several studies of the effects of human perturbations on local reef habitats (e.g. Borowitzka 1972; SPCC 1983; 1986; Fairweather 1990; Roach 1992; Lincoln Smith and Smith in press). Studies are also underway to assess the effects of Sydney's new deepwater ocean outfalls. Borowitzka (1972) and Fairweather (1990) studied the distribution of algae associated with sewer outfalls in the Sydney region. They found very marked differences between algal assemblages at outfalls compared with control areas. For example, Fairweather (1990) found that the cover of ulvoid algae increased dramatically with decreasing distances to three large outfalls.

Several studies have been done on the disposal of dredge and tunnel spoil on or near rocky reefs (SPCC 1983; 1986; Roach 1992; Lincoln Smith and Smith in press). Between January and July 1980, 2.2 Mm^3 of dredge spoil from Port Kembla Harbour were dumped in the ocean near the Five Islands (SPCC 1983; 1986). The designated dump site was about 2 km from Bass and Martin Islets, but it is believed that spoil was dumped much closer to the islands (SPCC 1983). Surveys were done of the macrobenthos and reef fish on reefs believed most likely to be affected by spoil (SPCC 1986). Unfortunately, there were inadequate spatial and temporal controls and therefore conclusions about the effects of the spoil on macrobenthos and fish are ambiguous. Changes were noted in assemblages of macrobenthos and fish (SPCC 1986), but these were within the range of natural variability noted in later studies (Roach 1992). Thus, even if there had been an impact, the disturbance caused by the disposal would have been similar to those observed from natural sources.

Between October and January, 1985, approximately 1 Mm^3 of spoil from Port Kembla Harbour were dumped off the Five islands, but in deeper water and further away from the 1983 dump site, hence further from the Five Islands (Roach 1992). Sampling done on this occasion included temporal and spatial controls. For both macrobenthos and fish, significant variability was found through time and among sites surveyed, but there was very little evidence of any spoil-related effects (Roach 1992).

Between September 1986 and February 1990, approximately 0.06 Mm^3 of rock spoil was discharged onto a rocky reef at Bondi (Lincoln Smith and Smith in press). 78% of the material consisted of sandstone, the remainder was claystone. Surveys were done of epibenthos and fish at the dump site and at three control sites before, during and after the disposal operation. During much of the disposal operation, a turbid plume spread, mostly to the north, from the dumpsite. Also, while it had been predicted that the spoil would be transported rapidly into deeper water and off the reef (Lincoln Smith and Smith in prep.), it was in fact observed that spoil remained on the reef and eventually smothered much of it.

Significant impacts were observed for macrobenthos, including sea urchins and fish (Lincoln Smith and Smith in prep.). Some fish, which are normally cryptic (e.g. eels) were seen over sand. These fish were often in poor condition and covered with parasites. Other fish, notably Sparidae (e.g. snapper) increased in number at the dump site compared with controls, possibly because these fish often feed on soft substrata. Many of the effects observed were not seen until late in the study, when much of the reef had been covered by spoil.

10.6 CONCLUSIONS

On the basis of existing information, it is clear that rocky shores and reefs provide an important and complex habitat utilised extensively by humans. The ecological significance of shipwrecks is less clear, but wrecks are also utilised extensively utilised by humans. Studies have shown that the assemblages of rocky shores and reefs are structured by a mixture of physical and biological processes and that variability among different places may be very great through time. This variability affects our ability to detect significant changes to species occurring on reefs (e.g. Lincoln Smith et al. 1991).

Far less is known of the ecology of deep reefs, due to the difficulties with sampling this habitat. Recent work done in the Sydney region (Roberts and Henry 1992) is developing sampling procedures that may allow detection of impacts to sessile macrobenthos of deep reefs. Work done using longlining for fishes (FRI 1992) also shows promise, although the technique needs to ensure that it is known when the lines are set over reef and not sand.

One interesting observation that has emerged from several of the studies (Jones 1977; Roach 1992; Roberts and Henry 1992) is that siltation often occurs naturally on reefs, particularly on the deeper margins of reefs and on deep reefs. This may be a significant factor in structuring these communities.

As reefs and wrecks occur in the vicinity of the proposed extraction areas, the potential for effects on the reefs as a result of the extraction operation will need to be assessed and procedures for monitoring these habitats will need to be considered. Part IV of this report deals with these issues.

CHAPTER 11. ASSEMBLAGES OF SANDY BEACHES

11.1 INTRODUCTION

The surf-zones of exposed sandy beaches have been described as harsh, structurally homogeneous environments for nektonic (i.e. shelf-dwelling) organisms (Robertson and Lenanton 1984). This view is generally reinforced by most reviews of this environment (e.g. CSIRO 1989).

In NSW, sandy beaches comprise about 65% of the coastline (Fairweather 1990c) and therefore represent a very common habitat type. Many features of beaches, however, such as the degree of exposure to waves and particle size of sand, can affect the habitat (CSIRO 1989). Beaches on the east coast of Australia have been classified as dissipative, reflective or intermediate (i.e. between reflective and dissipative) (Short and Wright 1981; Wright and Short 1983). on the basis of their morphodynamics. Reflective beaches are characterised by relatively deep water close to the shore, a steep beach face and low shorebreak (Short and Wright 1981; Wright and Short 1983). Dissipative beaches are characterised by a wide surf-zone where wave energy is dissipated. They usually only occur in NSW during high waves on fine sand beaches. Intermediate beaches are the most common beaches on the coast of NSW and they are characterised by sandbars and rips in various configurations.

Beaches between Maroubra and Wattamolla occur in the vicinity of the proposed extractions areas (Fig. 11.1). Those near the proposed Cape Banks extraction area include the intermediate beaches at Maroubra and Southern Bate Bay (Wanda, Elouera and Cronulla) and the low to moderate energy, reflective beaches at Long Bay, Little Bay and the beaches on the northern shore of the entrance to Botany Bay (Congwong, Frenchmans and Yarra Bays) (Geomarine 1993). Near the proposed Providential Head extraction area are small pocket beaches, including Marley and Little Marley Beaches and Wattamolla. Marley Beach is an intermediate, high energy beach whereas Little Marley Beach and Wattamolla are low energy, reflective beaches, due to protection from swells offered by surrounding headlands and reefs (Geomarine 1993).

Preservation of beaches has been a major factor considered in the formulation of the extraction plan for the current proposal (Mining Tenement Management 1993; Geomarine 1993). In preserving the beaches near the proposed extraction areas, the design criteria adopted for the extraction plan include the following (Geomarine 1993):

1. The extraction plans were designed so that any long term perturbations to the long term nearshore wave climate occurring as a result of the extraction would be an order of magnitude smaller than natural variations in the average wave climate that are experienced annually on the sandy shorelines

of the region.

That is, the proposed extraction plans would have no measurable effect on the long term wave climates of the beaches.

2. The proposed extraction plans would cause no measureable change to the effects that storms may have on the beaches of the study region.

3. The proposed extraction plans would have no discernible effect on the wave climate across the entrances to Botany Bay or Bate Bay-Port Hacking and, hence, to the beaches within Botany Bay, Bate Bay and Port Hacking.

Given this rigorous set of design criteria and the peer review process for evaluating the methods used in designing the extraction plans, it was decided that the description of the biota of sandy beaches could be adequately addressed from existing information. Should specific issues arise during the review process, these could be addressed as part of a monitoring programme, should the proposal proceed.

Flora and fauna of sandy beaches include the interstitial flora and fauna and invertebrate macrofauna living in or on the beach sands, phytoplankton, zooplankton and fishes of the surf zone and birds (see Chapter 12) . This review concentrates on the invertebrate fauna and fishes.

11.2 ALGAE AND INVERTEBRATES

Off protected beaches, such as in Botany Bay, there may be seagrass meadows and associated epiphytes. Along the open coast opposite the proposed extraction areas there are no seagrasses. Macrophytic algae do not grow on the unconsolidated beach sediments, but are common on nearby rocky reefs. Detached macrophytes can be important on beaches, however, where they provide shelter and food for fishes (Robertson and Lenanton 1984). We next describe interstitial flora and fauna and invertebrate fauna of sandy beaches based on McLachlan (1983) or Brown and McLachlan (1990), unless otherwise indicated.

11.2.1 Interstitial Flora and Fauna

The spaces between sand grains provide habitat for many small invertebrates. The porous, interstitial system averages approximately 40% of the sediment volume. The major process that affects the physical and chemical structure of the interstitial system is the filtration of seawater through the sediment. On very sheltered beaches and sand-flats, reduced layers of sediment may occur close to the surface and the interstitial organisms may be concentrated in the uppermost, oxygenated layers. On more exposed beaches, most of the sediment is oxygenated due to flushing of the sediment by waves.

Organisms such as bacteria, algae, protozoans and meiofauna live in interstitial habitats. Assemblages of interstitial flora that may include diatoms and dinoflagellates usually only develop on sheltered beaches. Bacteria are abundant in beach sediments where they live attached to grains of sand. Representatives of the protozoa include ciliates and foraminiferans.

The most abundant components of the meiofauna on sandy beaches are generally nematodes and harpacticoid copepods. Other meiofaunal taxa include turbellarians, oligochaetes, ostracods, mystacocarids, gastrotrichs, mites, tardigrades, gnathostomulids, hydrozoans and bryozoans. In general, the relative proportion of nematodes and copepods depends on grain size. Nematodes tend predominate in fine sediments whereas copepods tend to be most abundant in coarser sediments. These taxa tend to be similarly abundant in sediments with a median grain size of 300-350 μm. Meiofauna feed on diatoms, bacteria, protozoa, detritus and other meiofauna and they may congregate in areas containing large amounts of food. Meiofauna generally reproduce all year and have generation times of 1 to 3 months.

Temporal changes in the distribution and abundance of meiofauna have been observed on sandy beaches. Meiofauna may be least abundant and occur deeper in the sediments during winter. Changes in the vertical distribution of meiofauna may also occur after heavy rains, with increased wave disturbance, and with changes associated with tides.

Abundance and biomass of bacteria and meiofauna tends to be greatest in the intertidal zone of sandy beaches exposed to wave action. The physical environment of these beaches provides a large amount of habitat and the relatively great rate of water percolation through the sediment supplies adequate dissolved and particulate food. Distinct assemblages of meiofauna, mainly large oligochaetes and nematodes, may congregate high on the shore if sufficient drift algae (wrack) is present on the beach.

Dispersal of meiofauna may occur via passive transport with sediments or active emergence into the water column followed by dispersal (Palmer 1988). Passive dispersal may dominate in habitats such as beaches where hydrodynamic processes are active (Palmer 1988). Meiofauna may redisperse up and down the beach with the tide.

Little is known about biological interactions among meiofauna on sandy beaches, especially those beaches exposed to strong wave action. Reise (1985) demonstrated that predation and structure provided by the lugworm <u>Arenicola</u> may affect the distribution and abundance of meiofauna on sheltered sand flats. Similar studies have not been done on exposed sandy beaches.

Little work has been done of meiofauna in Australia. Alongi (1988a,b, cited in Alongi 1990) examined the meiofauna of sandflats and mangrove muds in the dry tropics of northern Queensland (see Section 8.1.1.2). We know of no work on meiofauna of exposed sandy beaches in Australia.

11.2.2 Invertebrate Macrofauna

The invertebrate macrofauna is the most conspicuous marine life on most sandy beaches, where polychaetes, molluscs and crustaceans tend to predominate. Crustaceans may be most abundant at the upper tidal levels whereas molluscs tend to be most abundant lower on the shore. Polycheates are generally only present on sheltered sandy shores (e.g. sand-flats), although an important exception is genus Australonuphis, or giant beach worms, which are important bait species in eastern Australia (Paxton 1979).

A pronounced characteristic of the invertebrate macrofauna is a high degree of mobility, including the ability to burrow rapidly. Many species of macrofauna undergo tidal migrations moving up and down the beach with the tide in order to stay in the swash zone where there may be good conditions for feeding and a reduced risk of predation by fish and birds. Tidal migrations may be more complex and, for crustaceans (amphipods, isopods and mysidaceans), may include entry into the plankton at night.

Macrofauna inhabiting a beach may be affected by the physical characteristics of the beach. Abundance and numbers of species tend to increase from reflective through intermediate to dissipative beach states and from steep to flat slopes. Individual size, however, may increase with exposure to waves, leading to large biomass on exposed beaches with large populations of filter-feeders (e.g. pipis, Donax) (Bally 1981, cited in Brown and McLachlan 1990).

The distribution of macrofauna within a beach is usually patchy. The causes of this patchiness may include movement of animals and sorting by swash, congregations around localized concentrations of food, and biological aggregations of fauna. Filter-feeders may migrate to the sections of the beach were the action of the swash is gentle and best for feeding. Temporal changes in assemblages and populations of macrofauna have also been observed.

Experiments examining competition and predation have only been performed on low-energy sand flats (e.g. Reise 1985) and not on exposed sandy beaches. Some authors (e.g. Reise 1985; Brown and McLachlan 1990) assume that physical processes are the most important processes structuring assemblages on exposed sandy beaches and that biological interactions would only be of minor importance. Predation by fish, birds and crabs, however, has been studied little on exposed shores and may be an important process.

Recruitment is also likely to be an important process structuring assemblages of macrofauna on sandy beaches. Recruitment has been shown to be important for structuring assemblages on rocky shores (Chapter 10). The same may be true for sandy beaches because many macrofauna there may also have a planktonic stage in their life-cycle.

There have been some studies of the sandy beach macrofauna on the east coast of Australia (e.g. Dexter 1983; 1984; 1985; Paxton 1979; Jones *et al*. 1991) and in Western Australia (McLachlan and Hesp 1984). Dexter (1983) sampled sandy beaches around Sydney ranging from exposed, oceanic beaches such as Maroubra to protected estuarine beaches and sand-flats. Amphipods and isopods were abundant on most beaches whereas polychaetes were only abundant on the more sheltered beaches and sand-flats (Dexter 1983). In general, more species and more animals were collected from the lower tidal levels than higher on the shore. The number of species and the abundance of animals decreased with increasing exposure to wave action (Dexter 1983). Semi-exposed beaches had greater abundances and more species of macrofauna than exposed, ocean beaches (Dexter 1983).

Different assemblages were collected on exposed shores compared with semi-exposed shores and sheltered shores (sand-flats) (Dexter 1983). Intermediate beaches were characterized by the amphipod *Tittakunara katoa* (Platyischnopidae), the cumacean *Gephyrocuma pala*, the isopod *Pseudolana concinna* (Cirolanidae) and the pipi *Donax deltoides* (Bivalvia) (Dexter 1983; 1984). Reflective beaches in bays were characterised by the amphipod *Exoediceroides* (as *Exoediceros*) *maculosus* (Exoedicerotidae), the isopod *Pseudolana concinna* and the polychaete *Scolelepis carunculata* (Spionidae) (Dexter 1983; 1984).

Dexter (1984) studied four beaches on the coast, including Congwong Bay (La Perouse Beach) in the entrance of Botany Bay which is near the proposed Cape Banks extraction area. Of the twelve species collected, the isopod *Pseudolana concinna* and the amphipod *Exoediceroides maculosus* contributed 98% of the total abundance of macrofauna on this beach in 1980-1981. *Pseudolana* was abundant at the high tide mark on the beach in Congwong Bay whereas *E. maculosus* was most abundant toward the low tide mark (Dexter 1984). Numbers of species on this beach tended to increase from the level of high to low tide (Dexter 1984).

Dexter (1984) found large temporal variation in the abundance of *Pseudolana* and *Exoediceroides* at Congwong Bay. From August to November 1980 *E. maculosus* made up 88% of the total abundance of the macrofauna (Dexter 1984). Gravid, female, *E. maculosus* were present on the beach at Congwong Bay from July to October 1980 and April to June 1981, but were present during each month from June 1980 to July 1981 on other beaches (Dexter 1985). Juvenile *E. maculosus* were abundant during December 1980, January and February 1981 (Dexter 1984). From December 1980 to May 1981, *Pseudolana* comprised 94% of the total abundance of macrofauna

(Dexter 1984). Gravid females of Pseudolana were collected between December 1980 and February 1981 and by the end of February, the population of Pseudolana consisted entirely of juveniles (Dexter 1984, 1985).

Paxton (1979) studied the taxonomy of Australian beach worms (Family Onuphidae). She obtained monthly samples of beach worms Narrabeen Beach at Sydney and less frequently from other beaches in eastern Australia. Two species are likely to occur within the study region, Australonuphis teres and A. parateres (Paxton 1979). Where they occur together, the species appear to occupy different microhabitats. A.parateres occur from half-tide to low-tide levels, but in greatest numbers on sand flats or spits. A.teres is distributed according to size: the smallest are found highest up on the beach and the largest extend so far out that they may only be collected at the lowest tides. Paxton (1979) reported observations of A.teres occurring in great numbers some 200 m from the beach in a depth of 1.5 m.

Jones et al. (1991) studied patterns in the abundance of the amphipods Exoediceroides maculosus and Exoediceros fossor on several sheltered sandy beaches near Sydney between July 1988 and May 1989. These amphipods were most abundant in the swash zone and were thought to migrate with the tide (Jones et al. 1991). The two species of amphipod tended to occur on different beach types (Jones et al. 1991). E. fossor tended to be most abundant on sheltered beaches (lagoons) with narrow swash-zones whereas E. maculosus tended to be most abundant on beaches with wider swash zones (Jones et al. 1991).

Significant interactions between beaches and months sampled occurred in abundance of both species (Jones et al. 1991) indicating different patterns of temporal variation among beaches. Abundance of E. maculosus tended to be large at most beaches from August 1988 to January 1989, probably due to recruitment of juveniles from July 1988 to September 1988 (Jones et al. 1991). Abundance of E. maculosus tended to be small in July 1988 and from March to May 1989 (Jones et al. 1991). Small numbers from March to May 1989 may have been due to the death of the July/September 1989 cohort (Jones et al. 1991).

11.3 FISHES

Reviews of the ichthyofauna of sandy beaches often conclude that the fauna is depauperate compared to other habitats. For example, Robertson and Lenanton (1984) assert that the fishes of surf-zones constitute low diversity faunas, dominated by small planktivores and benthic feeding fishes and their larger but rare fish predators. They also assert that most surf-zone fishes are represented solely by immature individuals and that year to year variations in abundance and species composition of these assemblages are probably tied to fluctuations in recruitment success (Robertson and Lenanton 1984 and references therein).

CSIRO (1989; 1990) reviewed the literature on fishes of sandy beaches and concluded that, overall, the shallow waters off sandy beaches contain a highly mobile fauna, whose distribution and abundance may vary at several spatial scales. Most species are mobile and tend to migrate between shallow sandy areas and other habitats. CSIRO (1989) also concluded, from the literature, that many species, including those of value to humans, occur off sandy beaches only during the early part of their life history. In this respect, man-made disturbances and pollutants could have major effects on the value of sandy beaches as nursery habitats.

There are several studies of the fishes off sandy beaches in estuaries and embayments, some of which include moderately exposed or unstable shores (Planning Workshop 1987; CSIRO 1989; 1990; 1991). Workers at the Australian Museum have recently completed (but not yet published) a study on beaches in the Sydney region (T.Trnsky, Australian Museum, pers. comm.). Preliminary results indicate that beaches can be nursery areas for species of fish of economic importance. Moreover, sheltered beaches in Sydney Harbour supported a diverse and abundant fish fauna than on an exposed beach (Manly). Apart from this study, there are no data on the fishes of highly exposed sandy shores in the Sydney region.

Surveys done on sandy shoals in Port Hacking showed that fishes discriminated between stable and unstable shoals and between the tops of the shoals and deeper dropovers Planning Workshop (1987). In particular, sand whiting (<u>Sillago ciliata</u>) appeared to recruit to stable shoal tops in preference to unstable ones (Planning Workshop 1987). Moreover, the species richness and abundance of fishes (excluding sand whiting) tended to be higher on dropovers than shoal tops. It was suggested that one reason for this may have been the avoidance of predatory birds (Planning Workshop 1987). Robertson and Lenanton (1984) suggest that fish aggregating around detached macrophytes on sandy beaches may also be, in part, avoiding birds.

Surveys of fishes on sandy beaches in Jervis Bay indicated a remarkably diverse ichthyofauna (CSIRO 1991). The fauna there was dominated numerically by several species collectively termed 'baitfish'. These included members of the Atherinidae, Clupeidae, Ambassidae and Notocheiridae. At least 45% of the fish species taken in any sampling period were of commercial or recreational fishing value. These included sand whiting, sand mullet (<u>Myxus elongatus</u>), yellowfin bream (<u>Acanthopagrus australis</u>) and garfish (<u>Hyporhamphus australis</u>) among others. There were very few fish species considered to be resident on beaches, most were classified as transients.

In general, the richness and abundance of fishes was greatest on more sheltered shores, although some larger species tended to predominate on more exposed beaches (CSIRO 1991). Also, nine species of fish were caught in greater numbers at night; only two (garfish and sand mullet) were more abundant in the day (CSIRO

1991). Overall, catches off the sandy beaches in Jervis Bay (CSIRO 1991) and Port Hacking (Planning Workshop 1987) were extremely variable.

11.4 CONCLUSIONS

Dexter (1983; 1984; 1985) showed that the abundance and taxonomic richness of assemblages of macrofauna on beaches around Sydney may vary with exposure to wave action. Macrofauna were more abundant and more taxonomically rich on sheltered beaches than on the exposed beaches near to the proposed extraction areas (Dexter 1983). There is also evidence to suggest that fishes may show a similar preference for sheltered or stable sandy shores and shoals (Planning Workshop 1987; CSIRO 1991). In relation to the proposal to extract marine aggregate, beaches such as Maroubra, Marley and Garie could be considered to be very exposed and would probably have a relatively depauperate fauna, but may have large numbers of transient fishes at certain times. Other beaches, such as Wattamolla and possibly Long Bay, are more sheltered and may therefore support a relatively more diverse fauna.

The literature suggests that the organisms inhabiting sandy beaches are affected by, among other things, exposure to wave activity. Thus, significant changes in the wave regime may affect local populations. The design criteria for the extraction plans have been linked to what can be measured in the field and, more importantly, to a criterion much less than the measured natural variability in wave exposure on beaches throughout the study region. An assessment of the likely effects of the proposal on the biota of sandy beaches is given in Part IV of this report.

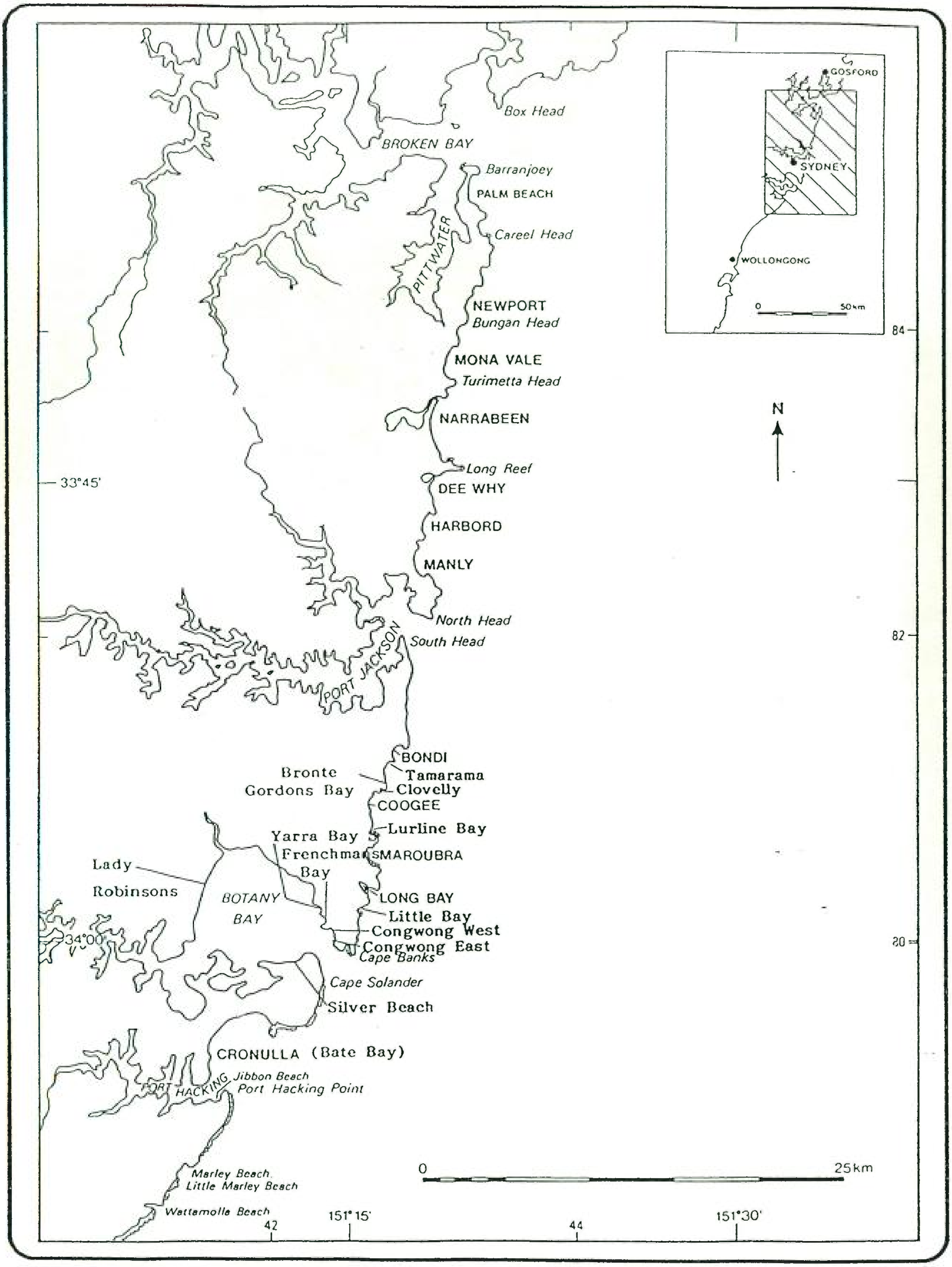


Figure 11.1 Beaches of the Sydney region. Source: Geomarine 1993.

CHAPTER 12. SEABIRDS, MARINE MAMMALS AND MARINE REPTILES

12.1 INTRODUCTION

Seabirds and marine mammals are often a very conspicuous feature of the coastal environment. Some species are resident while others undergo long and well-defined migrations. Most are protected by legislation ranging from state laws to international agreements. Moreover, boats are chartered to view seabirds and whales off the Sydney and Wollongong coasts. The marine reptiles, which include turtles and sea snakes, generally occur in our waters as vagrants from warmer areas. Many are also protected. This chapter summarises distributional and some biological information on these groups, as well as current legislation which may apply.

The study region defined in this chapter encompasses the area between Port Jackson and Kiama, some 100 air km of coastline (approximately 9% of the NSW coast), and extends broadly from the shoreline to the edge of the continental shelf.

12.2 SEABIRDS AND SHOREBIRDS

12.2.1 Introduction

Seabirds may simply be thought of as birds which are able to utilise sea water habitats, from intertidal areas to open ocean. This group of avifauna covers a wide range of bird types. Several limits have been placed on the definition of an Australian seabird. Serventy et al. (1971) included the continental shelf to the 100 fathom (183m) contour, the Australian Biological Resources Study of Australian Birds recommends the 200 m depth line (Mount King Ecological Surveys 1988). Blakers et al. (1984) used a limit of 50 km to sea. The most recent definition of the limit of Australian seabirds is the 200 nautical mile Australian Fishing Zone (AFZ). Most observations of offshore birds are well within this limit (Mount King Ecological Surveys 1988).

Species considered as seabirds in this study belong to the orders Sphenisciformes (penguins), Procellariformes (albatross and other petrels), Pelicaniformes (tropic-birds, frigate-birds, gannets, cormorants and pelicans) and to the families Stercorariidae (skuas) and Laridae (gulls and terns).

Many seabirds obtain their food at or just above the surface by skimming over the water. Others dive to varying depths for their food. More than half the seabird species feed upon fish (Mount King Ecological Surveys 1988). These are mainly the larger seabirds such as albatross, cormorants and petrels. Smaller seabirds, such as penguins, storm-petrels and prions, feed on small fish as well as zooplankton (e.g. shrimp, crab larvae and jellyfish).

Shorebirds, or waders, comprise about 10% of Australia's species of birds (Mount King Ecological Surveys 1988). Most breed in the Northern Hemisphere and migrate to Australia via Asia and the Pacific Islands. They live on coastal and/or inland wetlands. Shorebirds belong predominantly to the following families: Ardeidae (herons), Burhinidae (thick knees), Rostratulidae (painted snipe), Haematopodidae (oystercatchers), Charadriidae (lapwings and plovers), Recurvirostridae (stilts and avocets), Scolopacidae (sandpipers, snipes, godwits, curlews etc), Glareolidae (pratincoles) and Phalaropodidae (phalaropes).

12.2.2 Protection

The arctic jaeger, pomarine jaeger, common tern, little tern, wedge-tailed and short-tailed shearwaters are among the 70 species listed in the Japan-Australia (JAMBA) and China-Australia (CHAMBA) Migratory Bird Treaties and, thus, are included in the Endangered Species Schedules of the National Parks and Wildlife Act, 1974 (Morris 1989). Also in the NPWS Act Endangered Species list are wandering albatross, flesh-footed shearwater, sooty shearwater, streaked shearwater, wilson's storm-petrel, and brown booby.

Shorebirds which occur in the region and are listed in JAMBA and CHAMBA are include the grey plover, lesser golden plover, eastern curlew, wimbrel, wood sandpiper, grey-tailed tattler, wandering tattler, common sandpiper, greenshank, marsh sandpiper, black-tailed godwit, bar-tailed godwit, red knot, sharp-tailed sandpiper, red-necked stint, curlew sandpiper and sanderling. The ruddy turnstone is listed in JAMBA only, and the Asian dowitcher is listed only in CHAMBA.

In addition to the species above, there are two shorebirds included on Schedule 12 of the NSW National Parks and Wildlife Act, 1974. There are the pied oystercatcher and the sooty oystercatcher.

12.2.3 Occurrence

Lists of seabirds and shorebirds recorded from the study region have been compiled by several authors (Jones 1977; Milledge 1977; Hoskin 1977; Morris 1989 - see Tables 12.1 and 12.2). The occurrence of many seabirds on the mid NSW coast is related closely to changes in ocean currents and other seasonal factors (Gibson and Sefton 1959, Milledge 1977, L. Smith pers. comm.). The oceanic dynamics of the water mass off this coastal area are complex. The surface temperature, salinity, and nutrient levels are a function of the East Australian Current (EAC) and upwellings of colder sub-surface water masses (Milledge 1977; Tranter et al. 1982). Many seabirds congregate to feed at the edge of the continental shelf (L. Smith pers. comm.), about 35km offshore, and hence are found mainly beyond the area of interest.

In summer the EAC flows relatively close inshore along the central NSW coast. This current brings warm water from the Coral Sea to the region and with it come tropical seabird species, e.g. Sooty Terns, Grey Ternlets, and Tropicbirds (L. Smith pers. comm.). During the winter the arrival of a cold water mass brings with it birds from the southern oceans, including albatross and prions.

The Australian Museum surveyed seabirds on a monthly basis from May 1973 to April 1974 (Jones 1977; Milledge 1977). Birds were identified and counted from a vessel which travelled over a fixed path from Sydney as far south as Botany Bay, mostly about 5 km offshore. Seabirds characteristic of cold, southern zones and subtropical zones were well represented at different times during the year (Fig. 12.1). Unfortunately, transects were not replicated through time, so we cannot confirm the generality of the conclusions.

Rocky shores, tidal reefs and ocean beaches are used by many species of birds, including gulls, waders and cormorants. Many of these birds (e.g. eastern reef heron, sooty oystercatcher, ruddy turnstone, wandering tattler) feed along the inter-tidal zone of exposed shores, others (e.g. silver gull, white-fronted tern, common tern, black cormorant) feed in waters adjacent to the coast and roost on rocky shores and beaches.

Boat Harbour (in Bate Bay) and nearby shores are important areas for rocky shore birds. The beaches and relatively unspoilt, extensive, rock platforms are excellent feeding grounds. A non-tidal rock shelf there provides a comparatively secure high-tide roost; no other comparable area is available around Botany Bay (SPCC 1979a).

A major seabird habitat to the south of the proposed extraction areas is the Five Islands Nature Reserve, off Port Kembla. The Nature Reserve is a breeding station for little penguin, wedge-tailed shearwater, short-tailed shearwater, white-faced storm petrel, Australian pelican, silver gull, kelp gull, southern black-backed gull, crested tern, eastern reef heron and sooty oystercatcher (Gibson 1976; Battam 1976a, 1976b; Lane 1979; Morris 1989).

The silver gull is the most common seabird in the study region. It is notable for its lack of habitat preference. It feeds both inshore and offshore, and often follows humans, feedings at sewage outfalls, garbage dumps and recreational areas. The Sydney area (including Botany Bay) is the major feeding area for silver gulls on the mid NSW coast (SPCC 1979a).

Table 12.1. Seabird species recorded between Sydney and Kiama, and extending out beyond the continental shelf. Sources: L. Smith (undated), Hoskin (1977), Morris (1989). Assessment of relative abundance provided by Smith (undated) and Morris (1989), denoted by *.

Common Name	Scientific Name	Relative abundance
Little Penguin	Eudyptula minor	Mod. common
Wandering albatross	Diomedea exulans	Mod. common
Royal Albatross	Diomedea epomophora	Rare
Black-browed Albatross	Diomedea melanophrys	Common
Buller's Albatross	Diomedea bulleri	Rare
Grey-headed Albatross	Diomedea chrysostoma	Rare
Yellow-nosed Albatross	Diomedea chlororhynchos	Common
Shy Albatross	Diomedea cauta	Uncommon
Sooty Albatross	Phoebetria fusca	Rare
Light-mantled Sooty Albatross	Phoebetria palpebrata	Rare
Southern Giant Petrel	Macronectes giganteus	Uncommon
Northern Giant Petrel	Macronectes halli	Uncommon
Southern Fulmar	Fulmarus glacialoides	Rare
Cape Petrel	Daption capense	Uncommon
Great-winged Petrel	Pterodoma macroptera	Common
White-headed Petrel	Pterodoma lessonii	Uncommon
Providence Petrel	Pterodoma solandri	Common
Kermadec Petrel	Pterodoma neglecta	Rare
Herald Petrel	Pterodroma arminjoniana	Rare
Tahiti Petrel	Pterodroma rostrata	Rare
Kerguelen Petrel	Pterodroma brevirostris	Rare
Soft Plumaged Petrel	Pterodroma mollis	Rare
Mottled Petrel	Pterodroma inexpecta	Rare
Gould's Petrel	Pterodroma leucoptera	Uncommon
Black Petrel	Procellaria parkinsoni	-
Black-winged Petrel	Pterodroma nigripinnis	Rare
Cook's Petrel	Pterodroma cookii	Rare
White-necked Petrel	Pterodroma externa	Rare
Blue Petrel	Pterodroma caerulea	Rare
Broad-billed Prion	Pachyptila vittata	Unknown
Lesser Broad-billed Prion	Pachyptila salvini	Unknown
Antarctic Prion	Pachyptila desolata	Scarce
Slender-billed Prion	Pachyptila belcheri	Rare
Fairy Prion	Pachyptila turtur	Common
Black Petrel	Procellaria parkinsoni	Rare
Westland Black Petrel	Procellaria westlandica	Rare
White-chinned Petrel	Procellaria aequinoctialis	Rare
Pink-footed Shearwater	Puffinus creatopus	Rare
Flesh-footed Shearwater	Puffinus carneipes	Mod. common
Wedge-tailed Shearwater	Puffinus pacificus	Common
Buller's Shearwater	Puffinus bulleri	Scarce
Sooty Shearwater	Puffinus griseus	Uncommon
Short-tailed Shearwater	Puffinus tenuirostris	Common
Streaked Shearwater	Calonectris leucomelas	Rare
Fluttering Shearwater	Puffinus gavia	Common

Table 12.1, continued

Common Name	Scientific Name	Relative abundance
Hutton's Shearwater	Puffinus huttoni	Uncommon
Little Shearwater	Puffinus assimilis	Rare
Wilson's Storm Petrel	Oceanites oceanicus	Unknown
Grey-backed Storm-Petrel	Oceanites nereis	Rare
White-faced Storm-Petrel	Pelagodroma marina	Uncommon
Black-bellied Storm-Petrel	Fregetta tropica	Rare
White-bellied Storm-Petrel	Fregetta grallaria	Rare
Common Diving-Petrel	Pelecanoides urinatrix	Rare
South Georgian Diving-Petrel	Pelecanoides georgicus	Rare
Australian Pelican	Pelecannus conspicillatus	Mod. common
Australasian Gannet	Morus serrator	Mod. common
White-faced Heron	Ardea novaehollandiae	Unknown
Brown Booby	Sula leucogaster	Rare
Little Pied Cormorant	Phalacrocoranx melanoleucos	Common
Great Cormorant	Phalacrocorax carbo	Common *
Pied Cormorant	Phalacroranx varius	Uncommon #
Little Black Cormorant	Phalacrorax sulcirostris	Common *
Least Frigatebird	Fregata ariel	Rare
Red-tailed Tropicbird	Phaethon rubricauda	Rare
White-tailed Tropicbird	Phaethon lepturus	Rare
Great Skua	Catharacta skua	Scarce
Arctic Jaeger	Stercorarius parasiticus	Uncommon
Pomarine Jaeger	Sterncorarius pomarinus	Mod. common
Long-tailed Jaeger	Sterncorarius longicauda	Uncommon
Silver Gull	Larus novaehollandiae	Very common
Pacific Gull	Larus pacificus	Rare *
Kelp Gull	Larus dominicus	Uncommon
Sabine's Gull	Xema sabini	Rare
Whiskered Tern	Chlidonias hybrida	Rare *
White-winged Black Tern	Chlidonias leucoptera	Rare
Caspian Tern	Hydroprogne caspia	Uncommon
Gull-billed Tern	Gelochelidon nilotica	Rare
Common Tern	Sterna hirundo	Scarce
Arctic Tern	Sterna paradisaea	Rare
Common Tern	Sterna hirundo	Mod. common
White-fronted Tern	Sterna striata	Uncommon
Sooty Tern	Sterna fuscata	Rare
Little Tern	Sterna albifrons	Mod. common
Saunder's Tern	Sterna a. saundersi	Accidental
Crested Tern	Sterna bergii	Common
Common Noddy	Anous stolidus	Rare
Grey Ternlet	Procelsterna albivittata	Rare
White Tern	Gygis alba	Rare

Table 12.2 Shorebirds recorded within the region between Port Jackson and Kiama. Sources: Hoskin (c.1977), Gibson (1977), Mount King Ecological Surveys (1988), Morris (1989). Assessment of relative abundance as per Mount King Ecological Surveys (1988), SPCC (1979a), denoted by *. Status from Kinhill (1991) denoted by **, from NSW NPWS (c. 1980) by #.

Common Name	Scientific Name	Relative abundance
Pacific Heron	Ardea pacifica	Common #
Eastern Reef Heron	Egretta sacra	Uncommon *
Great Egret	Egretta alba	Uncommon #
Little Egret	Egretta garzetta	Rare #
Intermediate Egret	Egretta intermedia	Mod. common **
Rufous Night Heron	Nycticorax caledonicus	Mod. common **
Little Bittern	Ixobrychus minutus	Uncommon **
Black Bittern	Dupetor flavicollis	Uncommon #
Sacred Ibis	Threskiornis aethiopica	Common #
Straw-necked Ibis	Threskiornis spinicollis	Abundant **
Yellow-billed Spoonbill	Platalea flavipes	Mod. common **
Royal Spoonbill	Platalea regia	Mod. common #
Pied Oystercatcher	Haematopus ostralegus	Mod. common
Sooty Oystercatcher	Haematopus fuliginosus	Uncommon
Masked Plover	Vanellus miles	Common
Banded Lapwing	Vanellus tricolor	Uncommon **
Grey Plover	Pluvialis squatarola	Common
Lesser Golden Plover	Pluvialis fulva	Common
Red-kneed Dotterel	Erythrogonys cinctus	Mod. common **
Ringed Plover	Charadrius hiaticula	Rare **
Mongolian Plover	Charadrius mongolus	Uncommon **
Double-banded Plover	Charadrius binictus	Uncommon **
Oriental Plover	Charadrius veredus	Scarce **
Hooded Plover	Charadrius rubricollis	Uncommon
Red-capped Plover	Charadrius ruficapillus	Mod. common
Black-fronted Plover	Charadrius melanops	Uncommon #
Large Sand Plover	Charadrius leschenaultii	Scarce **
Black-winged Stilt	Himantopus himanopus	Mod. common
Red-necked Avocet	Recurvirostra novaehollandiae	Mod. common **
Ruddy Turnstone	Arenaria interpres	Mod. common-rare
Eastern Curlew	Numenius madagascariensis	Uncommon-common
Whimbrel	Numenius phaeopus	Mod. common-scarce
Little Curlew	Numenius minutus	Rare **
Wood Sandpiper	Tringa glareola	Uncommon
Grey-tailed Tattler	Tringa breviceps	Mod.common-rare
Wandering Tattler	Tringa incana	Rare*
Common Sandpiper	Tringa hypoleuscos	Mod.-Uncommon
Greenshank	Tringa nebularia	Mod. Common
Marsh Sandpiper	Tringa stagnatilis	Uncommon
Terek Sandpiper	Tringa terek	Uncommon **
Latham's Snipe	Gallinago hardwickii	Mod. Common **
Asian Dowitcher	Limnodromus semipalmatus	Unknown
Black-tailed Godwit	Limosa limosa	Mod. common-rare
Bar-tailed Godwit	Limosa lapponica	Mod. common
Great Knot	Calidris acuminata	Common **

Table 12.2, continued

Common Name	Scientific Name	Relative abundance
Red Knot	Calidris canutus	Rare - Uncommon
Sharp-tailed Sandpiper	Calidris acuminata	Common
Pectoral Sandpiper	Calidris melanotos	Scarce **
Baird's Sandpiper	Calidris bairdii	Rare **
Western Sandpiper	Calidris mauri	Rare **
Red-necked Stint	Calidris ruficollis	Common
Curlew Sandpiper	Calidris ferruginea	Common
Broad-billed Sandpiper	Limicola falcinellis	Scarce **
Sanderling	Calidris alba	Uncommon-rare
Buff-breasted Sandpiper	Tryngites subruficollis	Scarce **

Most silver gulls in the study area would roost at the Five Islands, a major breeding location, and during the breeding season they may travel to and from Sydney each day (SPCC 1979a).

Of the 25 species of shorebirds found in the region, 19 are non-breeding migrants from the northern hemisphere (Mount King Ecological Surveys 1988). The remainder breed in Australia and are considered sedentary, with some movement between wetlands.

12.3 MARINE MAMMALS

The animals considered in this section include cetaceans (whales and dolphins), pinnipeds (seals and sea lions) and sirenians (dugongs).

12.3.1 Protection

Under Commonwealth legislation, cetaceans are protected by the Whale Protection Act, 1980. The Act prohibits the killing, capturing, injuring or interfering with cetaceans in the Australian Fishing Zone (AFZ), i.e. waters between the 3 nautical mile State limit and the limit of Commonwealth waters, 200 nautical miles seaward of any Australian land or territory. Both proposed extractions are within the 3 nm limit and therefore not subject to the Commonwealth legislation. The Commonwealth legislation has never been ratified by the NSW Government and therefore has never applied to NSW waters (L. Llewellyn, NSW NPWS, pers. comm.). NSW legislation, however, has been amended to provide similar protection.

All cetaceans are listed in either Appendix II (Australian populations) or Appendix I (all other populations) of the Convention on International Trade in Endangered Species of Wild

Fauna and Flora, (CITES) (Tucker and Puddicombe 1988). CITES is given effect by the Wildlife Protection (Regulation of Exports and Imports) Act 1982 which prohibits the import and export of protected animals without a permit.

In addition to CITES, several marine mammals which can occur in NSW waters are listed under the Convention on the Conservation of Migratory Species of Wild Animals (the Bonn Convention, 1979). These include humpback whales, southern right whales, blue whales, humpback dolphins and dugongs.

Pinnipeds became protected under Commonwealth law in 1987 with the amendment of the National Parks and Wildlife Conservation Act, 1975 (Tucker and Puddicombe 1988). The regulations prohibit the killing, taking, keeping, selling or purchase of pinnipeds between State/Territory waters and the edge of the Australian continental shelf (i.e. waters 200m deep or less). Australian seals are listed on Appendix II of CITES.

Since 1977 amendments to the Commonwealth Fisheries Act 1952 have prohibited the fishing, taking, or processing of dugong in the AFZ north of the 50°S parallel by non-indigenes (Tucker and Puddicombe 1988). Dugongs are listed on Appendix I and Appendix II of CITES.

The Whale Protection Act, 1980, and the National Parks and Wildlife Conservation Act, 1975 do not apply under the following circumstances:

* the action was undertaken in accordance with a permit;

* the action was necessary to prevent loss of human life, injury to any person, or damage to any vessel, aircraft or structure affixed or resting on the seabed;

* the action occurred during the course of licensed commercial fishing operations and the action was unavoidable and reasonably necessary to avoid damage to a vessel or equipment used in those operations;

* the action was done in a humane manner and was necessary to relieve or prevent suffering of a protected animal; or

* in the case of treating a protected animal, the action was necessary to prevent risk to human health.

In NSW waters, cetaceans, pinnipeds, and dugongs are protected under the National Parks and Wildlife Act, 1974 and the National Parks and Wildlife (Marine Mammals Protection) Amendment Act, 1986. All marine mammals are considered of special importance in the NSW legislation because they are rare or vulnerable to exploitation.

The NSW 1986 Amendment Act(Part 5; schedule 12 - Marine

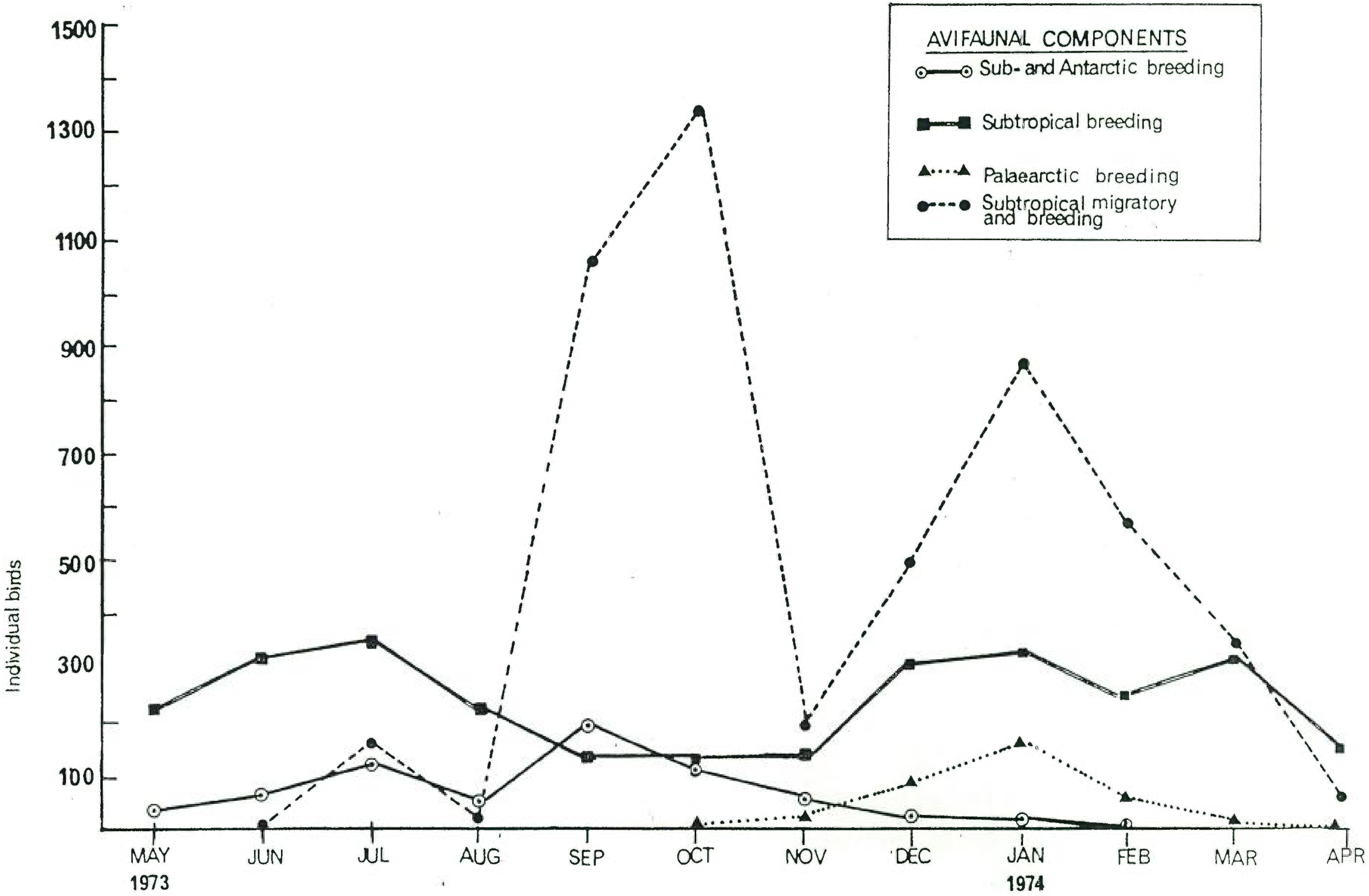


Figure 12.1 Abundance of seabirds recorded off southern Sydney (reproduced from Jones 1977)

Mammals) allows a penalty of $10,000 and/or 2 years imprisonment, or if convicted of commercial operations relating to killing or taking of marine mammals a maximum fine of $100,000.

Section 112 of the Amendment Act constituted the Marine Mammals Advisory Committee, consisting of the Director, or an appointed officer of the NSW National Parks and Wildlife Service, a member nominated by the Minister administering the Fisheries and Oyster Farms Act 1935, Amended 1979, one person representing the Australian Museum Trust, one person representing the Zoological Parks Board of NSW and two people representing conservation organisations. While this committee has been set up, we understand that it has not met to date.

The Marine Mammals Advisory Committee has a number of specific tasks (Section 112B) including advising the Minister on conservation and protection of marine mammals, plans for dealing with strandings and plans of management for marine mammals.

Section 112C provides for the preparation of plans of management for dealing with marine mammals, including:

- population distribution and abundance;
- threats to survival of species, populations or individuals;
- research and strategies related to the conservation and protection of marine mammals;
- educational activities promoting the value and/or protection of marine mammals; and
- international agreements or agreements between the State and the Commonwealth.

12.3.2 Occurrence

Sightings and strandings of marine mammals have been recorded by the Australian and NSW National parks and Wildlife Services. On these basis of these records, twenty-two species of marine mammals have been reported in and around the study region (Table 12.3). For a large number of records, we cannot determine if the animal stranded on the shore or was merelt sighted (Table 12.3).

Most of the species recorded in the region are inhabitants of temperate to cool temperate waters (e.g. bottlenose dolphins). Some are of tropical or sub-tropical origin (e.g. dugongs, striped dolphins, dense beaked whales, whilst others are migrants (southern right whales, humpback whales) or vagrants (crabeater seals) from Antarctic waters (Robinson 1984).

12.3.2.1 Cetaceans

Of the 80 species of whales and dolphins described worldwide, at least 40 species are thought to frequent Australian waters (Baker 1983). Unfortunately, information on the preferred distribution of most species and their habitat usage is limited. From stranding records alone, at least 25 species have been recorded from the NSW coastline and at least 21 species within the study region (Australian National Parks and Wildlife Service 1986, 1987, 1988; NSW National Parks and Wildlife Service Register of Marine Mammal Strandings).

The most common cetaceans of the inshore waters of southern NSW are the Common Dolphin (*Delphinus delphis*), the Bottlenose Dolphin (*Tursiops truncatus*), and the Long Finned Pilot Whale (*Globicephalus malaena*) (Baker 1983). The Humpback Whale (*Megaptera novaeangliae*) and the Southern Right Whale (*Balaena glacialis*) occur seasonally in small numbers.

There is little information on dolphins in NSW, particularly from the study area. It has therefore been necessary to rely on information on dolphin biology from studies done in Queensland and overseas.

The common dolphin is a pelagic species that frequents coastal waters around Australia, often occurring in schools of up to several thousand individuals.

There is some confusion within the scientific literature regarding the taxonomic status of bottlenose dolphins. General consensus is that there is one species of *Tursiops* worldwide, separated into geographical races (Shane *et al*. 1986). However, some authors, such as Wells *et al*. (1980) distinguish 3 species: the Atlantic bottlenose dolphin (*T. truncatus*), the Indian Ocean Bottlenose Dolphin (*T. aduncus*) and the Pacific bottlenose dolphin (*T. gilli*) - which would be the local species. For this study we recognise one species; *T. truncatus*, but acknowledge the possibility that separate species may exist.

Distinct inshore and offshore forms have been found for bottlenose dolphins (Leatherwood and Reaves 1983, Shane *et al*. 1986). There seems to be no association between the coastal and offshore types (Wells *et al*. 1980; Shane *et al*. 1986). Most research has focused primarily on the inshore forms (movements up to a few kilometeres from shore) and so relatively little is known about the offshore form (Shane *et al*. 1986). The inshore form of Bottlenose Dolphin usually occurs in small groups of up to 30. They enter embayments and estuaries, and sometimes travel several kilometers up into rivers. They appear to have limited home ranges (Lear and Bryden 1980, Baker 1983). The home range is the area used by an individual or groups in the course of performing normal daily routines (Shane *et al*. 1986).

Dolphins are gregarious mammals. Social associations and individual movements are based on the age and sex of individuals

(Shane et al. 1986). Group composition changes frequently, although certain associations seem more common. Shane et al. (1986) identified two group types:

1) primary groups = "pods", are the smallest units of dolphins associated closely for days or weeks at a time;

2) secondary groups = "herds", are temporary aggregations (minutes to hours) of primary groups.

Shane (1986) also noted that, in general, group population size tends to increase with increasing water depth or openess of habitat.

The behaviour of bottlenose dolphins is highly variable, and these dolphins can be active both day and night. Food resources are important factors affecting movements. Movement patterns are highly variable between locations, but reasonably predictable within a given location.

Coastal dolphins are opportunistic feeders. Their diet consists of benthic fish, school fish and cephalopods. Individual feeding and co-ordinated feeding strategies are employed, depending largely on the food resource (Wells et al. 1980). Seasonal movements may be attributed to changing food supply. The fact that dolphins take advantage of many different food items may explain why their patterns of movement are not as clearcut as those of some other cetaceans.

During the field studies for the marine aggregate proposal, we observed common and bottlenose dolphins in the proposed extraction areas and the reference areas.

Humpback Whales migrate annually along the east and west Australian coasts, moving north to the tropics where they calve and mate before returning to their feeding grounds in Antarctic waters. Even during periods of extreme exploitation humpback whales appeared to maintain this pattern of migration (Paterson and Paterson 1984). Humpbacks tend to remain close to shorelines while migrating, a fact utilised by whalers in many oceans of the world. Humpbacks migrating along the east coast of Australia are closest to shore in the northern regions (e.g. north of Byron Bay) and tend to be further offshore in southern waters. On the mid NSW coast, Humpbacks are most often seen between May and August moving north, and between September and November on their return southward (Fig. 12.2). An unknown, but probably small, proportion of the population would therefore pass around or through the study region twice a year.

During the field studies for the Metromix proposal, we observed humpbacks passing through the proposed extraction areas and reference areas on two occasions.

In New Zealand and southern Australia during the early nineteenth century, southern right whales were hunted to the verge of extinction (Paterson and Paterson 1984). Prior to this they were abundant on the southern coasts of both countries. Right Whales seem to be gradually increasing in numbers (Ling 1987) but they have not recovered to their former abundance and are still rare off eastern Australia (Dawbin 1983).

Southern right whales often frequent very shallow water. They rarely strand. They have been known to rest on sandy bottoms in depths which allow the blowhole to be above the surface (Baker 1983).

Southern right whales occur in sheltered bays as far north as Sydney (Fig. 12.3). Pregnant females calve in the bays, staying for a few weeks before returning to the open ocean.

In recent years females with calves have been seen more regularly on the NSW coast. In August 1988 a pregnant female entered Bate Bay, and although close to calving she is thought to have been driven away after harassment from sightseers (Daily Mirror, 31 Aug. 1988). Southern right whales also resided for about two weeks off Sydney's northern beaches in June, 1993.

Apart from the rare beaked whales, the temperate species of cetaceans recorded as strandings in the study area feature in strandings elsewhere in south eastern Australia (Robinson 1984).

12.3.2.2 Pinnipeds

Several species of pinnipeds have been recorded along the NSW coast, the most common being the Australian Fur Seal, with colonies at Seal Rocks and Montagu Island (Table 12.3; Figs. 12.4 and 12.5). Leopard Seals are migrant visitors from the Southern Oceans which are frequently sighted along the NSW coast (Robinson 1984). Three species of seal have been recorded within the stretch of coastline being studied; the Australian fur seals, leopard seals and a single crabeater seal. Unlike cetacean strandings, seal landings are often brief, with seals returning to the sea once they have rested.

12.3.2.3 Sirenians

Dugongs are rare on the mid NSW coast, those occurring are vagrants from the north, where they are more common (Marsh 1988). The nearest established dugong population to the study area is in Moreton Bay, Queensland. Dugongs are not considered further in this study.

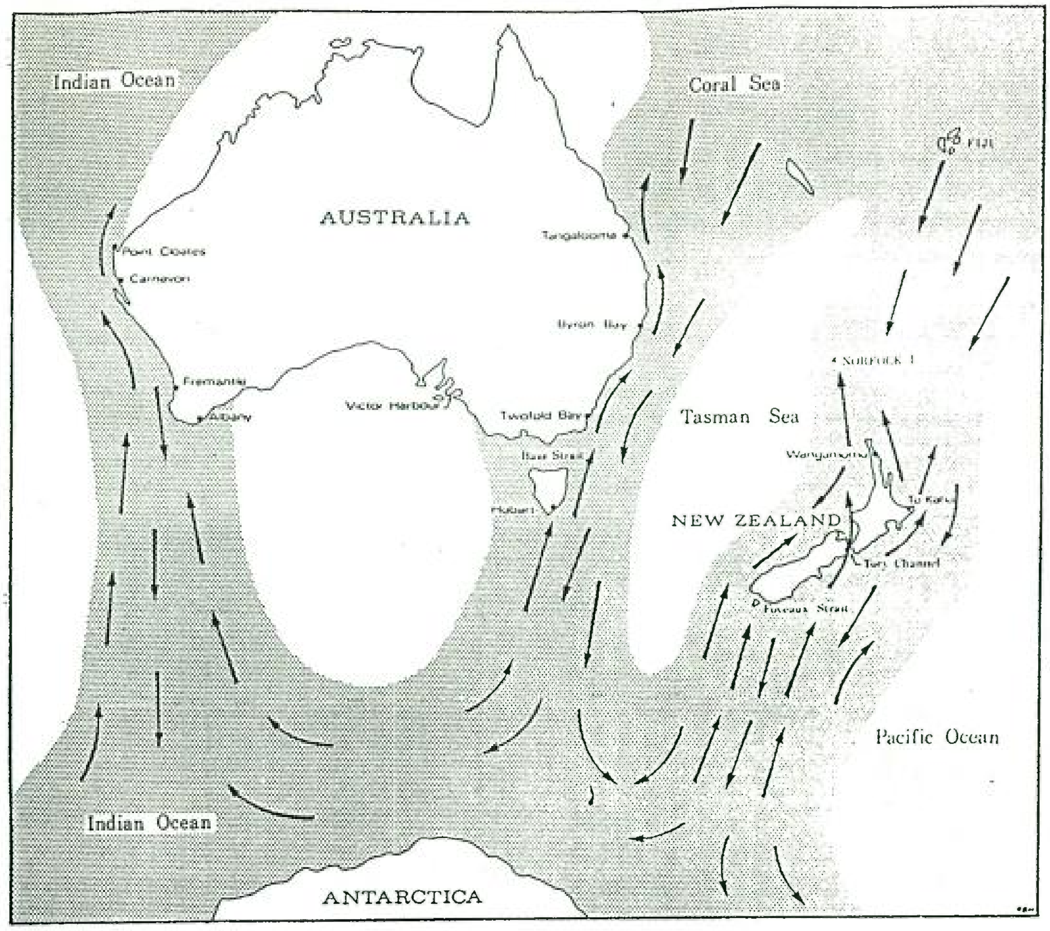


Figure 12.2 Migration routes of Humpback Whales (*Megaptera novaeangliae*) in the Australasian region. (reproduced from Baker 1983)

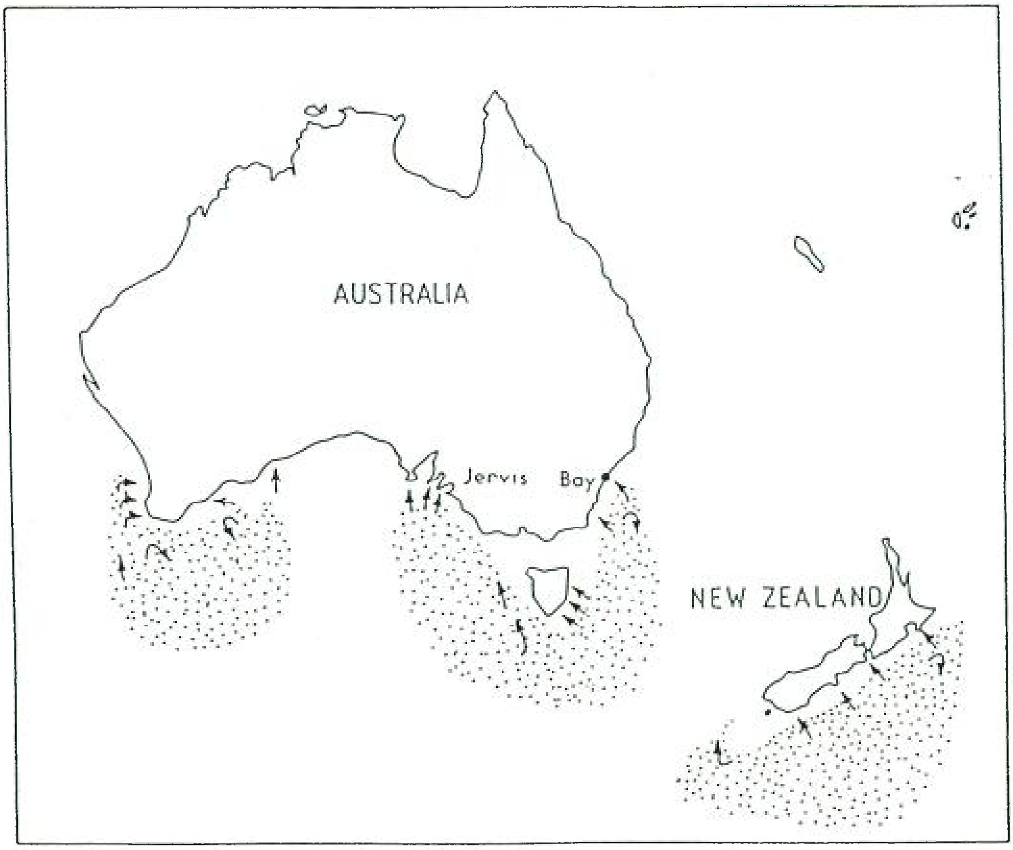


Figure 12.3 Migration route of Southern Right Whales (*Balaena glacialis*) in the Australasian region. (reproduced from Dawbin 1983)

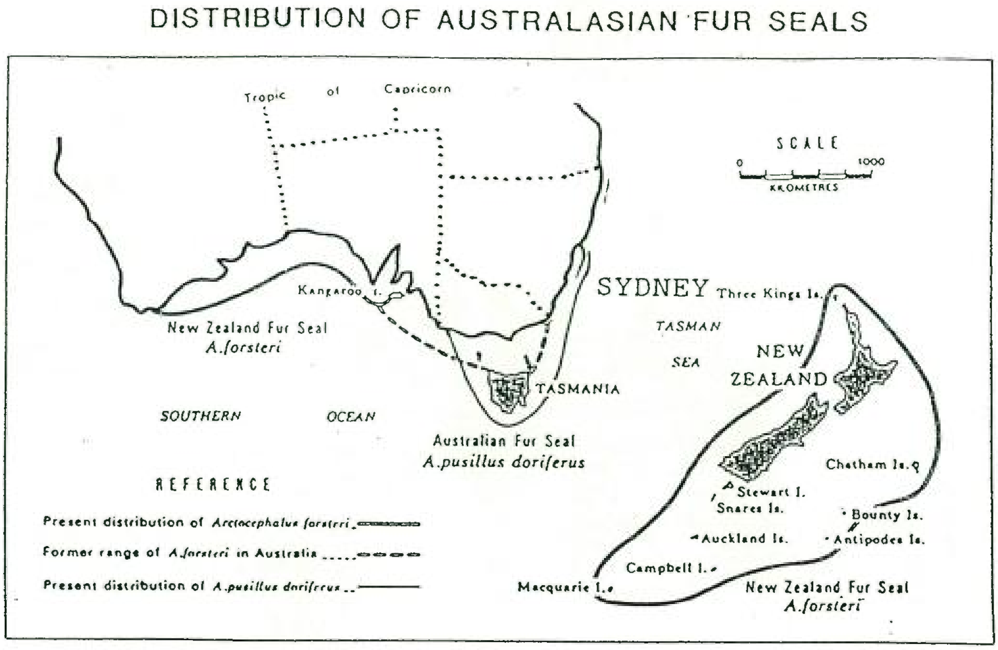


Figure 12.4 Approximate distribution of seals in the Australasian region (reproduced from Ling and Aitken 1981).

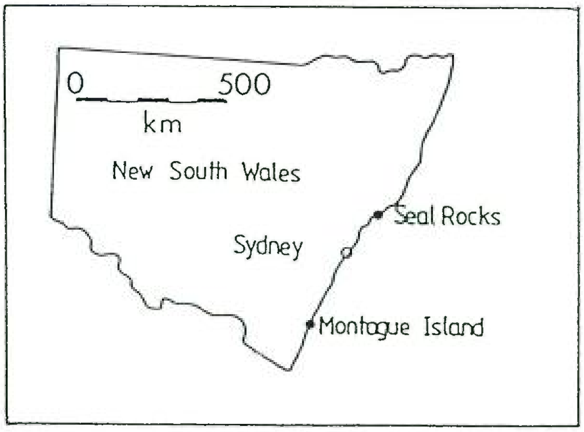


Figure 12.5 Colonies of Australian Fur Seals (*Arctocephalus pusillus doriferus*) on the NSW coast (o), showing proximity to Sydney.

Table 12.3 Reported Strandings/Sightings of Marine Mammals within the Study Area. (ANPWS 1986, 1987, 1988; NSW NPWS Provisional Summary of Recorded/Reported Cetacean (includes other Marine Mammals) Strandings in NSW, NSW NPWS South Metropolitan District records).

Date	Number and Species	Location and Comments	Stranding	Sighting	Uncertain
?	1 Sperm Whale (_Physeter macrocephalus_)	Off Sydney			*
?	1 Bottlenose Dolphin (_Tursiops truncatus_)	Dee Why			*
?	1 Common Dolphin (_Delphinus delphis_)	Port Jackson			*
?	1 Common Dolphin	Neutral Bay, Sydney			*
?	1 Risso's Dolphin (_Grampus griseus_)	Manly			*
?	1 Pygmy Sperm Whale (_Kogia breviceps_)	Botany			*
?	1 Humpback Whale (_Megaptera novaeangliae_)	Little Bay, Sydney			*
?	1 Strap-toothed Beaked Whale (_Mesoplodon layardi_)	Little Bay			*
?	1 Sperm whale	Wollongong			*
?	1 Bottlenose Dolphin	La Parouse			*
?	1 Bottlenose Dolphin	Port Jackson			*
?	1 Rorqual (_Balaenoptera_ sp.)	Manly Beach			*
?	1 Rough-toothed Dolphin	Wollongong			*
c.1800's	1 Humpbacked Dolphin (_Sousa chinesis_)	Wollongong, skull at Cambridge Museum	*		
1918	1 Sperm Whale	North Beach, Wollongong skeleton with museum[a]	*		
18/2/1929	1 Risso's Dolphin	Dee Why Beach	*		
3/3/1929	1 Pygmy Sperm Whale	Dee Why Beach	*		

Table 12.3, continued

Date	Number and Species	Location and Comments	Stranding	Sighting	Uncertain
10/1929	1 False Killer Whale (*Pseudorea crassidens*)	Bulli Beach skeleton with museum[a]	*		
12/2/1959	1 Dugong, adult male (*Dugong dugong*)	Port Hacking found dead	*		
17/7/1959	1 Humpback Whale	Port Kembla	*		
12/1960	1 Dugong	Port Kembla, died	*		
3/4/1962	1 Strap-toothed Beaked Whale	Curl Curl			*
7/8/1968	1 Leopard Seal (*Hydrurga leptonyx*)	Brighton Beach shot	*		
7/10/1968	1 Pygmy Sperm Whale	Wollongong Beach			*
2-9/11/1968	1 Leopard Seal	Bellambi Beach appeared to have been shot but recovering	*		
7/2/1969	1 Pygmy Sperm Whale	Avalon			*
19/2/1969	1 Longfinned Pilot Whale (*Globicephala melaena*)	Thirroul Beach dead	*		
6/7/69	1 Fur Seal (*Arctocephalus pursillus doriferus*)	Corrimal Beach killed	*		
26-27/7/69	1 Fur Seal	Barrack Point very thin, on rock shelf	*		
28/7/1969	1 Fur Seal	Port Kembla landed on beach	*		
8/1969 to 9/1969	small group of Fur Seals	Five Islands live			*
1971	1 Bottlenose Dolphin	Newport Beach			*
1971	1 Common Dolphin	Manly Beach			*
5/10/1971	1 Fur Seal	Port Kembla, on rocks	*		
23-25/10/73	1 Fur Seal	Wollongong Beach			*
12/8/1974	1 Bottlenose dolphin (*Tursiops truncatus*)	Coledale Beach drowned in shark net		*	

Table 12.3, continued

Date	Number and Species	Location and Comments	Stranding	Sighting	Uncertain
25/2/1975	1 Pygmy Sperm Whale (Kogia breviceps)	Garie Beach taken to zoo, died	*		
11-14/9/75	1 Leopard Seal	Corrimal Beach			*
4/1/1976	1 Leopard Seal	Port Kembla-Windang Beach			*
27/2/1976	1 Gray Beaked Whale (Mesoplodon grayi)	Warilla Beach skull to museum[a]	*		
?/12/1977	1 Beaked Whale (female) (Mesoplodon bowdoini)	Windang Beach found dead	*		
21/4/1978	1 Beaked Whale (male)	Corrimal Beach buried in sand	*		
11/10/1978	2 Southern Right Whales	Swam past Wollongong		*	
11/3/1979	1 Pygmy Sperm Whale (female)	North Beach, Wollongong died	*		
15/7/1979	2 Humpback Whales	sighted off Stanwell Park		*	
5/5/1980	1 Dense Beaked Whale (female) (Mesoplodon densirostris)	Stanwell Park Beach found dead	*		
13/7/1980	1 Fur Seal (immature)	Brighton Beach			*
30/7/1980	1 Fur Seal	Wombarra Beach			*
29/8/1980	2 Southern Right Whales	swam past Wollongong (female + calf)		*	
11-12/8/81	1 Southern Right Whale	East Beach Kiama		*	
17/8/1981	1 Southern Right Whale	Austinmer (possibly the same whale as above)		*	
31/10/1981 to 3/12/81	1 Leopard Seal	Windang to at least Corrimal		*	
11/7/1982	1 Crabeater Seal (Lobodon carinophagus)	Port Hacking taken to zoo	*		
18/1/1983	1 dolphin (no details)	Corrimal Beach - killed	*		
18/2/1983	1 Striped Dolphin (female) (Stenella coeuruleopa)	Towradgi Beach dead	*		

Table 12.3, continued

Date	Number and Species	Location and Comments	Stranding	Sighting	Uncertain
4/9/1983 to 3/10/83	1 Fur Seal	Minnamurra Headland injured	*		
19/9/1983	2 Southern Right Whales	Coledale Beach			*
18/2/1984	1 Pygmy Sperm Whale	Garie Beach rescue attempts failed	*		
3/7/1984	8 Humpback Whales	swam past Port Hacking/ Cronulla Beach		*	
?/9/1984	1 juvenile Fur Seal	Cronulla Beach			*
?/5/1985	1 Pygmy Sperm Whale	Wanda Beach, Cronulla animal decomposed	*		
26-31/7/1985	1 Australian Fur Seal	Middle Harbour		*	
14/10/1985	1 Pygmy Sperm Whale	Wanda Beach (with advanced foetus) rescue failed	*		
8/7/1986	1 Common Dolphin	Silver Beach, Kurnell			*
8/8/1986	1 Minke Whale (<u>Balaenoptera acutorostrata</u>)	Coledale Beach, Wollongong dead	*		
13/8/1986	1 Southern Right Whale	100m off Maroubra Beach		*	
13/8/1986	1 Seal (no details)	Collaroy			*
13/12/1986	1 False Killer Whale	Pussycat Bay, Botany Bay		*	
8/5/1987	1 Bottlenose Dolphin	Manly - dead	*		
13/7/1987	2-4 Humpback Whales	0.5km off Whale Beach		*	
28/8/1987	2 Risso Dolphins (<u>Grampus griseus</u>)	20nm off Wollongong		*	
13/2/1987	1 Striped Dolphin	20nm off Wollongong		*	
1/5/1988	1 Pygmy Sperm Whale	Taken to Taronga Zoo	*		
31/8/1988	1 Southern Right Whale	Bate Bay, pregnant headed south to calve		*	
10/1/1989	1 Pygmy Sperm Whale (juv.)	Coalcliff Beach, died of shark wounds	*		

Table 12.3, continued

Date	Number and Species	Location and Comments	Stranding	Sighting	Uncertain
15/1/1989	1 Striped Dolphin	Coledale Beach			*
17/1/1989	1 Striped Dolphin	Coledale Beach			*
15/9/1989	1 Minke Whale	Wanda Beach			*
21/11/1990	1 Common Dolphin	Maroubra Beach			*

[a] Museum not specified in stranding records.

12.4 MARINE REPTILES

Approximately ten species of marine reptiles may occur in the study region. These include five species of sea turtles, particularly the luth or leatherback turtle (Dermochelys coriacea) and about five species of sea snakes.

12.4.1 Protection

All marine reptiles are protected in NSW waters under Section 98(1) of the NSW National Parks and Wildlife Act, 1974. The luth turtle is listed under Schedule 12, Part 1, as endangered fauna of special concern.

12.4.2 Occurrence

Turtles that may occur in the study region include the loggerhead turtle, Caretta caretta, green turtle Chelonia midas, hawksbill turtle Eretmochelys imbricata, olive ridley turtle, Lepidochelys olivacea, flatback turtle, Natator depressus and luth turtle (Marquez 1990). All these species are most common in tropical waters and only the luth turtle, which is likely to be the most common off Sydney, is considered in detail here.

The luth turtle occurs in tropical and, to lesser extent, temperate waters world-wide. The world population is regarded as small and vulnerable, and the IUCN Red Data Book lists it as an endangered species (Honeggar 1975). Luth Turtles have been recorded in most coastal waters of Australia and are relatively common on the central eastern coast, particularly during the summer months (Limpus and McLachlan 1979). They occasionally enter bays and estuaries.

Luth turtles nest widely in the tropics, but also range into temperate zones. Australian nesting records exist only for the central Queensland coast (Limpus and McLachlan 1979), but the observed nesting density is considered to be too low to account for the relatively high abundance of this species along the coast. Colonies further north may account for the numbers visiting the east Australian coast.

Up to five species of sea snake may occur within the study region, mainly during the summer months. The yellow-bellied sea snake (Pelamis platurus) is the most likely to occur.

The yellow-bellied sea snake occurs from eastern Africa to Australia, Japan and across the Pacific to the west coast of the Americas (Heatwole 1987). It is most common in coastal waters and around reefs, and is rarely found in deep waters. The species has been collected along the east coast of Australia as far south as Tasmania (Cogger 1975).

Cogger (1975) suggested that the population off the central NSW coast is probably permanent. He supports this with a review of the Australian Museum Records of the species' occurrence, and cites literature suggesting that a minimum temperature of 20°C is necessary to maintain permanent (i.e. feeding and breeding) populations of yellow-bellied sea snakes.

Other species which may occur in the study area, especially during the summer months, are Hydrophis elegans, Hydrophis ornatus, Distereita major and Astrotia stokesii. H. elegans is normally found in northern Australia and southern New Guinea, extending down the coast to about Sydney. H. ornatus, most common in northern Australia, has been recorded as far south as Tasmania (Cogger 1983). D. major usually occurs as far south as southern Queensland, but stragglers may occur down the NSW coast. Although most common in waters of tropical Australia and New Guinea, A. stokesii may occur as far south as Jervis Bay.

12.5 CONCLUSIONS

The region in which the extraction areas occur is visited by seabirds, shorebirds, marine mammals and marine reptiles. In particular, humpback whales migrate past Sydney twice a year. Southern right whales also migrate along the east coast, although they are more common further south. There are also several species of birds which migrate to and from the region, and the Five Islands Group off Port Kembla is an important roosting and nesting area for several other species of birds.

Many of the animals described in this chapter are protected under various laws and agreements. In addition, there are also bird watching and whale watching boat trips.

General issues that should be addressed in relation to the extraction proposal include:

1) The extent to which any changes in marine environment brought about by the extraction operation may affect the these organisms; and

2) The extent to which the aggregate extraction might disrupt the migration of birds, marine mammals and marine reptiles. Moreover, the extent to which the noise of the extraction vessel and pumping machinery might disrupt birds or affect the hearing of marine mammals is an issue which is addressed in Part IV of this report.

CHAPTER 13. CONTAMINATION OF COASTAL FISH AND INVERTEBRATES

13.1 INTRODUCTION

Sediments are well known as sinks and therefore potential sources for trace elements and hydrophobic (i.e. water-insoluble) organic contaminants (Burton 1992). Disturbance of these sediments can, under certain circumstances, cause the mobilisation of contaminants, which can lead to toxic effects in marine biota and bioaccumulation of toxins in biota which may be eaten by humans (Engler et al. 1991; Burton 1992; Pollution Research 1993). At the commencement of the marine aggregate studies, it was considered important that the potential for contamination of aquatic organisms as a result of the proposed extraction operation be evaluated.

As part of the studies done for the marine aggregate proposal, Dr Ian Irvine (Pollution Research 1993) reviewed the literature on contaminants associated with dredging and aggregate extraction, and compiled information on water and sediment chemistry in the Sydney region. Part of his work involved summarising other studies done in the region and collecting data on water and sediments from within the proposed extraction areas. Pollution Research (1993) should be referred to for further details of those studies.

The focus of this chapter is to review information on sources of contaminants in the Sydney region and on levels of contaminants in marine biota in the region. Part IV of this report predicts the likelihood of any toxic effects or bioaccumulation in marine biota and the potential for any effects on human health.

Pollution studies use many technical terms to deal with the specific issues involved. In this chapter several terms are used regularly and should be defined. In particular, "contamination" refers merely to the presence of substances in the sediment or water which either do not occur naturally (e.g. organochlorine pesticides such as chlordane) or occur in concentrations above which would normally be expected (e.g. trace elements such as copper, selenium or mercury). If sediments are identified as being contaminated, the question becomes: are the contaminated sediments causing, or do they have the potential to cause, biological effects (Power and Chapman 1992)? "Bioaccumulation" refers to the uptake and storage of contaminants in biota. Contaminants can be stored in a variety of tissues, such as liver and muscle. Bioaccumulation may occur via two processes, bioconcentration (uptake via respiratory surfaces such as gills) and biomagnification (uptake via the food chain) (Lincoln Smith and Mann 1989a). The Maximum Recommended Limit (MRL) is the largest concentration of a contaminant in the edible portion (normally the muscle tissue or flesh) of an animal that is recommended for consumption by humans. In Australia, the MRL is determined by the Australian National Health and Medical Research Council (NHMRC). MRL's have been set individually for a wide range of contaminants.

13.2 SOURCES OF CONTAMINATION

13.2.1 The Sydney Region

The Environmental Protection Authority (EPA 1992c) identified three potential sources of contaminants in coastal waters off Sydney. These are summarised (EPA 1992c) as follows:

1. Sewage outfalls. Organochlorines (OC's) and trace elements have been identified in sewage influent, effluent and sludges from the major ocean outfalls at Malabar, Bondi and North Head. The EPA (1992c) predicted that commissioning of the deepwater ocean outfalls would cause a decrease in OC's discharged to Sydney's nearshore environment. Sludge from the Malabar, North Head and Bondi treatment plants is disposed of on land (G. Henry, EPA, pers. comm.).

2. Urban Runoff. EPA (1992c) identified urban runoff as a source of OC's in Sydney's marine environment. OC's attached to particulate matter may enter waterways following heavy rain and be transported into coastal waters via estuaries and drains. OC's including lindane, heptachlor, heptachlor epoxide, dieldrin and chlordane have routinely been present in runoff within the Sydney catchment (Rowlands et al. 1990, cited in EPA 1992c).

3. Airborne OC's. These constitute another potential source of contamination in the nearshore environment, but no data are available for the Sydney region (EPA 1992c).

Another potential source of contaminants is disposal of contaminated materials, typically spoil from harbour dredging programmes, into the sea (SPCC 1983; 1986; The Ecology Lab 1992; Roach 1992). Dredge spoil from Port Kembla Harbour has been dumped seaward of the Five Islands Group, to the southeast of Port Kembla Harbour in depths ranging from about 22-50 m (SPCC 1983; 1986; Roach 1992). The history of dumping includes 2.5 Mm^3 for harbour works in 1973-75; 0.02 Mm^3 dumped from maintenance dredging during the mid to late 1970s; 2.2 Mm^3 dumped after dredging for construction of a coal loader facility in 1980; 0.04 Mm^3 dumped for maintenance dredging in April 1981; and 0.96 Mm^3 dumped after dredging for construction of a grain terminal in 1985/6 (Roach 1992). Some of this spoil was contaminated with trace elements (SPCC 1986; Roach 1992).

Dredge spoil from Sydney Harbour is dumped at a designated dump site 7 Nm (13 km) east of the harbour in a depth of about 110 m (The Ecology Lab 1992). This site has been used for disposal of spoil from dredging operations since 1984, following the passing of the Commonwealth Protection (Sea Dumping) Act, 1981. It has been used as a repository for spoil from several locations in Sydney Harbour, such as Darling Harbour, Woolloomooloo Bay, Mosman, Cremorne, Glebe Island and Hunters Hill (The Ecology Lab 1992). Recently, some 0.027 Mm^3 of spoil from Johnstons Bay were dumped at the site. This spoil was contaminated with trace elements and it was estimated that there were about 60 kg of mercury in the dumped spoil. This spoil was capped with relatively uncontaminated spoil from the Sydney Harbour Tunnel project (The Ecology Lab 1992).

13.2.2 The Status of Sediments Within the Study Region

In reviewing existing information, Pollution Research (1993) found that levels of trace elements in sediments off Sydney were generally low and within acceptable limits. However, the Water Board has found elevated levels of some trace metals off Sydney Harbour (I.Irvine, pers. comm.) and there appear to be naturally-high concentrations of arsenic in the sediments off the mid-NSW coast (Davies 1979).

The EPA (1992d) surveyed contaminants in sediments at six locations: Terrigal, Turimetta Head, North Head, Bondi, Malabar and Marley Beach. Within each location, three replicate samples of sediment were collected from four zones. The data for Terrigal were unavailable at the time of the report (EPA 1992c).

The EPA (1992d) found that levels of trace elements were in general accord with results found elsewhere in the world and on the NSW coast. In comparing the locations and zones within locations, the study found that there was usually as much variability at the level of zones as at locations, suggesting a high degree of natural variability in the spatial distribution of contaminants in the sediments. OC's were usually less than the analytical limit of detection, but were detected in 10% of the 60 samples analysed. The Water Board has found levels of several OC's in sediments on the continental shelf off Sydney, including some samples from the northern part of the Cape Banks area. The samples from Cape Banks were generally below sediment/soil criteria (I.Irvine, pers. comm.).

Pollution Research (1993) described several studies done as part of the marine aggregate proposal, including analysis of water and sediment samples and elutriate testing of sediment samples collected from the proposed extraction areas. Within each of the proposed extraction areas, water samples were collected from the surface and near the bottom at two sites within three sections of the areas - north, central and south. Collections were made three times at Cape Banks and twice at Providential Head (Pollution Research 1993).

Sediments were obtained from Providential Head and Cape Banks initially by vibracoring, as part of the geological survey for the study (Pollution Research 1993; Mining Tenement Management 1993). Additional surface samples were collected later in both of the proposed extraction areas using a grab sampler. Separate samples were taken from each of the proposed extraction areas for elutriate testing.

Pollution Research (1993) found that levels of contaminants in the water from the extraction areas were typical of those from coastal waters in the vicinity of large cities, but were above the levels expected in pristine coastal waters. This was attributed to low-level pollution from a variety of sources, such as atmospheric fallout, ocean outfalls and movement of water from bays and estuaries to the sea. At Providential Head, zinc, cadmium, lead, chromium and copper levels were all below water quality criteria (e.g. SPCC 1990a,b) but mercury concentrations ranged from below to more than twice the criterion (Pollution Research 1993). OC's were detected in one water sample, but this was attributed to experimental error (Pollution Research 1993). At Cape Banks, one of the samples exceeded water quality criteria for copper, and mercury levels ranged from below to over twice the criterion. No OC's were detected in the water samples collected from Cape Banks.

Samples of sediment from both study areas had no OC's at the level of detection for the analyses (Pollution Research 1992). Concentrations of trace elements were low and typical of sandy sediments on the NSW inner shelf, as found in other studies (Pollution Research 1992). At Cape Banks, the concentrations of trace elements, particularly mercury, tended to increase in mid-shelf sediments (not the proposed extraction area) opposite Botany Bay, compared with samples obtained to the north and south. According to Pollution Research (1992), these concentrations were still within the normal range of background variation. The sediments from both areas had no detectable levels of hydrocarbons and low levels of nutrients.

Elutriate testing resulted in no OC's or hydrocarbons being released from any of the samples from either of the proposed extraction areas (Pollution Research 1993). Some cadmium was released in excess of the background levels, but the elutriate concentrations were below the water quality criterion (Pollution Research 1993).

In summary, there are several potential sources of contaminants which may enter into the coastal waters and sediments of the Sydney region. The analysis of water samples indicated that the waters off Sydney have low levels of contaminants (Pollution Research 1993). Analyses of sediments (Pollution Research 1993 and references cited therein) indicated very low or undetectable concentrations of OC's and relatively low concentrations of trace elements. Some samples of sediment from Cape Banks had elevated levels of some contaminants, including mercury, particularly opposite the entrance to Botany Bay. These levels were still well below current international quality criteria for sediments (Pollution Research 1993).

13.3 CONTAMINANTS IN COASTAL BIOTA

Studies of contaminants in biota in the Sydney region fall into two main categories: work done in association with sewage outfalls which discharged into shallow water and work done in deeper water as part of the monitoring programme for Sydney's deepwater ocean outfalls. Results of studies done prior to the commissioning of the deepwater outfalls are now available (EPA 1992a,c,d,e), but there were no data available, at the time of this report, on the effects of the deepwater outfalls on contamination of biota since they were commissioned.

In addition to the above, there are two other sources of information. First, there are studies on the effects on biota of disposal of contaminated sediment in ocean waters (SPCC 1983; 1986; The Ecology Lab 1992; Roach 1992). Second, there are studies on contaminants in estuarine biota (e.g. Mackay et al. 1975; SPCC 1979b; Scammell 1987; Batley et al. 1992). The estuarine studies present limited data or are limited to studies of commercially-grown oysters, and are not discussed further.

13.3.1 Bioaccumulation Studies in Shallow Waters (< 25 m)

Several studies have been done on reef organisms from Sydney and nearby areas, including studies done in association with disposal of contaminated dredge spoil off Port Kembla (SPCC 1986) and with the Sydney ocean outfalls (Scribner et al. 1987; Lincoln Smith and Mann 1989a,b; McLean et al. 1991; Andrijanic 1991; EPA 1992e). These studies basically encompassed the period when Sydney's outfalls discharged effluent from cliff-face outfalls.

As part of the study of the effects of ocean disposal of dredge spoil, the SPCC (1986) determined levels of heavy metals in muscle tissue of red morwong (Cheilodactylus fuscus), collected at Bass Islet, one of the Five Islands (SPCC 1986). Samples taken after spoil disposal showed a slight increase from those taken before, although no statistical comparison was made between the samples.

Scribner et al. (1987) analysed OC's in fish muscle from several species of fish collected around Sydney's major ocean outfalls. The samples were collected in 1979. Species were collected by spearing and included red morwong, blue groper (Achoerodus viridis) and rock blackfish (Girella elevata). OC's were recorded in many of the samples, but these were considered to be at acceptable levels (Scribner et al. 1987).

Lincoln Smith and Mann (1989b) collected three species of fish and three species of invertebrates from three sites: off the cliff-face sewer outfall at Malabar and from two 'reference' sites - off Terrigal and off Royal National Park, near the southern entrance to Port Hacking. Muscle and liver tissues were analysed for OC's and trace elements. The fish species were red morwong, blue groper and rock cale (Crinodus lophodon); the invertebrates were red bait crab (Plagusia chabrus), black-lip abalone (Haliotis ruber) and sea tulip (Pyura gobbosa). Concentrations of OC's in fish muscle were very high at the outfall site: levels of BHC and HPTE in muscle tissue were up to 112 and 52 times greater than the MRL at Malabar (Lincoln Smith and Mann 1989b). Levels at the control sites were either much lower (Port Hacking) or below the detection limit (Terrigal). OC's in the invertebrates were either very low or not detected.

Trace elements showed a more complex pattern among species and sites (Lincoln Smith and Mann 1989b). Some elements (e.g. copper and zinc) were significantly lower in fish collected from Malabar compared with the control sites, but invertebrates showed the opposite effect. Other metals, such as mercury, occurred in higher concentrations at the outfall site. Mercury was the only trace element occurring at levels above the MRL: this was in the muscle tissue of blue groper and red morwong collected from Malabar. In addition to the large variability among sites observed in trace elements, there were also highly significant differences among species. For example, rock cale accumulated more copper and zinc than the other fishes, while red bait crabs accumulated more of these metals than the other invertebrates. Similarly, abalone accumulated more nickel and chromium than the other invertebrates. Subsequent studies by McLean et al. (1989) showed that concentrations of mercury were high in the muscle of red morwong at many locations along the Sydney coast.

Lincoln Smith and Mann (1989a) studied OC's in red morwong from sites to the north and south of each of Sydney's major shoreline outfalls, Malabar, Bondi and North Head. They found that each of the outfalls was a significant source of bioavailable OC's in the nearshore marine environment. Malabar appeared to be the most significant source, followed by North Head and Bondi.

Recent work done by the EPA (1992e) supports findings of Lincoln Smith and Mann (1989a) that the shoreline outfalls at Malabar, North Head and Bondi represent major sources of OC's into the coastal environment off Sydney. In addition to red morwong, the EPA (1992e) used bivalve molluscs as indicators of pollution in the coastal environment. Bivalves were deployed, with appropriate spatial controls, in inshore areas near (the then) cliff-face outfalls. The uptake of OC's and trace elements by bivalves near the shoreline outfalls was confirmed by the study, although the results of the analyses for trace elements were considered to be ambiguous (EPA 1992e).

13.3.2 Bioaccumulation Studies in Deeper Waters (≥ 25 m)

Studies done by The Ecology Lab (1992) and the EPA (1992c,e) investigated bioaccumulation of contaminants in fish and invertebrates collected from deeper waters off Sydney. The Ecology Lab (1992) collected seven species of fish at a spoil-dumping site located in 110 m depth off Sydney Harbour and at numerous control sites. Samples were collected by trawling from three depth ranges: 25-55 m, 80-125 m and 235-270 m. Analysis of fish muscle for trace elements indicated large variability among depths and sites in the concentrations of trace metals in fish in the Sydney region. For most of the contaminants, levels were below the NHMRC MRL, with the possible exceptions of selenium and arsenic. As only total arsenic was analysed, there were no data on concentrations of inorganic arsenic to compare with the published MRL, which applies only to the inorganic form. None of the analyses identified the dump site as a source of contaminants. During the study, samples of fish were taken from the seabed within the proposed extraction areas (The Ecology Lab 1992). Chemical analyses indicated higher levels of some contaminants in fish off Botany Bay, suggesting a source of contaminants in that area.

As part of the monitoring programme for Sydney's deepwater ocean outfalls, the EPA (1992c) studied bioaccumulation in fish collected at depths of 30 m, 60 m and 100 m. Thirteen species of fish and one species of invertebrate were tested, but there were only sufficient data for detailed analysis of two species, snapper (Pagrus auratus) and rubblerlip or blue morwong (Nemadactylus douglasi). The highest concentrations of OC's were found in fish from the 30 m sites nearest to the (then) existing cliff-face outfalls. OC's were also detected in fish collected from deeper water. For example, 11% of the blue morwong collected from 60 m had OC's in concentrations above the NHMRC MRL (EPA 1992c).

Statistical comparison of the data indicated large variation in levels of contaminants in species within and among sites, depths and collection times (EPA 1992c). There are at least two factors, however, that may have confounded interpretation of the results. First, there were differences in the sizes of fish obtained from different sites and these may have affected concentrations of contaminants independently of the sites sampled. In fact, the P.auratus collected tended to be larger in deeper water. Second, there is little or no information on the mobility of the species. Thus there is no certainty that fish showing elevated levels of contaminants from a site actually accumulated those contaminants there.

In another study, bivalve molluscs deployed over 60 m water depth showed significantly less bioaccumulation of contaminants compared with those deployed closer to the shore (EPA 1992e). Moreover, there were no significant differences among offshore sites in the concentrations of contaminants in bivalves.

13.4 CONCLUSIONS

There are several potential sources of contaminants to the marine environment off the coast of Sydney. Studies indicate slight contamination of sediments, particularly adjacent to estuaries. In the areas proposed for aggregate extraction, there are few contaminants and elutriate testing has shown that there is very little likelihood that any risk of contamination of biota would be associated with the extraction process (Pollution Research 1993).

Studies of contamination in fish and invertebrates have shown that there is significant contamination in some marine biota off Sydney and that the cliff-face outfalls were major sources of these contaminants prior to their decommissioning (Lincoln Smith and Mann 1989a,b; EPA 1992c,e). Commissioning of the deepwater ocean outfalls has brought the potential source of contaminants closer to the proposed extraction area at Cape Banks. Thus, assessment of the impacts of the proposed aggregate extraction needs to be considered, among other things, in relation to these outfalls. This question has been addressed by Pollution Research (1993) and will be discussed in Part IV of this report.

CHAPTER 14. COMMERCIAL FISHING, ANGLING AND DIVING

14.1 INTRODUCTION

The waters off Providential Head and Cape Banks are utilised by a number of user groups. In the Sydney region, it is apparent that there is conflict among some of these groups for the resources available, for example, between commercial fishers and anglers (e.g. Henry 1984), between anglers and spearfishers or between SCUBA divers and spearfishers (Lincoln Smith et al. 1989). The initiation of an extraction proposal would add another user to Sydney's coastal waters, with potential concerns raised by existing user groups (see Chapter 4).

Utilisation of the coastal waters off Sydney is treated in two broad categories: 1) commercial fishing and 2) angling and sport diving. Commercial and recreational fishers use several fishing methods, while diving includes SCUBA diving and snorkelling. The aims of the study with respect to other users in the areas proposed for extraction of marine aggregate were to:

1. provide a description of the various activities that are known to, or may, occur in and around the proposed extraction areas;

2. assess the significance of these activities;

3. predict the effects of the proposed extraction operation on other activities and suggest ways in which any potential conflict between extraction operations and other users may be removed or minimised (Part IV); and

4. formulate a proposal for monitoring the effects of the proposal on other user groups (Part V).

While there are some data on fishing activities within estuaries (e.g. Henry 1984), there is little or no information readily available on the extent of fishing and diving in Sydney's coastal waters, let alone the proposed extraction areas. Moreover, in contrast to the very detailed biological research done for the deepwater ocean outfalls (see Chapters 8 and 9), there have been, to our knowledge, no surveys of fishing or diving activities in relation to these outfalls.

Information provided in this chapter was obtained from limited published data, unpublished data supplied by NSW Fisheries and from discussions with scientists, local fishers, divers, clubs and interest groups. All of these sources have limitations. The available data are regionalised on a much larger scale than the proposed extraction areas. Thus, trends apparent in the data may be caused by factors outside the specific areas of interest. In contrast, anecdotal information can focus on very small scales, but may be subject to personal biases or to inaccuracies arising due to reliance on memory. These limitations should be considered in interpreting the findings presented here.

14.2 COMMERCIAL FISHING

Commercial fishing occurs in oceanic, coastal and estuarine waters along the length of NSW. It is regulated by both NSW Fisheries and Commonwealth regulations. Fisheries considered in relation to the marine aggregate proposal include:

1) pelagic fishing with fishing lines and traps for fishes such as tuna and kingfish and, to a lesser extent, with beach seines to collect sea mullet and Australian salmon;

2) demersal fisheries using otter trawl and danish seine for fish and prawns on soft substrata (e.g. sand, gravel or mud); and

3) reef fisheries using traps and lines for fish and crayfish, or diving to collect abalone.

A brief description of each fishery is provided here, emphasising aspects of the fishery that may be affected by the proposal.

14.2.1 Pelagic Fisheries

Pelagic fisheries in NSW generally target relatively large, mobile, surface fishes that are often occur seasonally off Sydney. Pelagic fishes are caught using a variety of methods, including lines, traps and nets. Line fishing includes the following activities:

1. Longlining, principally for tunas, with the aim usually to sell sashimi-quality product, which is very valuable. This type of fishery is most common in surface waters well off the coast, typically at the edge of the continental shelf or beyond. It is not done within, or in the vicinity of, the proposed extraction areas.

2. Polefishing for tunas and kingfish. Polefishing is used to catch southern bluefin tuna (Thunnus mccoyii) in South Australia and, until recently, southern NSW. Southern bluefin are caught as they migrate to the south and west around Australia. Polefishing for other tunas (e.g. skipjack, Katsuwonus pelamis, yellowfin, Thunnus albacares and bonito, Sarda australis) and kingfish (Seriola lalandi) is less popular, but areas to the south of Sydney, such as the Sir Joseph Young Banks, off Greenwell Point, are polefished for tuna and kingfish. Little or no polefishing occurs in the areas proposed extraction areas.

3. Trolling. Another type of line fishery involves trolling over rocky reefs and around headlands to catch small species of tuna (e.g. bonito and frigate mackerel, Auxis thazard), kingfish and tailor (Pomatomus saltarix). It is done from small licenced fishing boats; typically these fishers also fish by other methods. Popular trolling areas occur in the vicinity of the Providential Head extraction area (see Section 14.3.1).

In recent years, trapping of kingfish has become popular in coastal waters. Large traps with a wooden frame and wire mesh are suspended at depths of about 2-10 m beneath buoys. The traps have a sheet of shade cloth (typically hessian) fixed on the upper surface of the trap. The traps and buoys are anchored over reef. Kingfish swim into the traps, presumably because they offer shelter. Kingfish traps are deployed off rocky reefs such as the Five Islands (off Port Kembla) and the Gap (off Sydney Heads). They may be deployed over reefs adjacent to the proposed extraction areas, although discussions with local fishers from Wollongong suggest that these areas are not preferred.

In NSW, pelagic fishes are taken in nets by several methods. First, inshore species such as sea mullet (Mugil cephalus) and Australian salmon (Arripis trutta) are taken by beach hauling as they migrate along the coast. Beach hauling is restricted to the surf zone of ocean beaches (and in estuaries), and is thus well inshore of the proposed extraction areas. Advice from NSW Fisheries inspectors suggests that some hauling is done on Jibbon Beach in Royal National Park (i.e. just inside the entrance to Port Hacking), but not on the ocean beaches of the park. There are no beaches available for hauling adjacent to the proposed Cape Banks extraction area. There is, however, a well developed haul fishery within Botany Bay, with important haul grounds along the northern shores and at Towra Point and Silver Beach, on the southern side of the bay (Kinhill 1991). Second, purse seines are used to catch southern bluefin tuna and Australian salmon. This fishery occurs in southern NSW, hence is remote from the areas under consideration here. Third, midwater trawling is used to catch pelagic fishes, mostly offshore and in more southern waters. A fourth method is the catching of pilchards (Sardinops neopilchardus) and yellowtail (Trachurus novaezelandiae) by small purse seines ("lamparas") in Jervis Bay.

In summary, there are several pelagic fisheries in coastal waters off NSW. Most of these do not occur near the proposed extraction areas and so would not be affected by the proposal.

14.2.2 Soft-bottom Demersal Fisheries

Fisheries occurring on soft substrata, such as the shelf sand bodies proposed for extraction of marine aggregate, are exploited mainly by otter trawl and to a much lesser extent danish seining. No Danish seining occurs Sydney now and will not be described in detail. Otter trawling involves the towing of a large net over the seabed. The net is held apart by the use of large wood and/or steel boards which are oriented perpendicular to the seabed and at a slight angle to the trawler. The net is also held against the seafloor by the use of heavy chains at the base of the net. It is held open by the positioning of floats on the top of the net. The nets are trawled for variable periods of time, depending on several factors, including the size of the trawl ground and location of obstructions, sea state and the size of the catch, often inferred from sounder readings.

It is crucial for the operation of the trawl net that the seabed be free of obstructions (e.g. reefs, wreckage or debris) and that it be topographically even. Because of this, the "pit method" of aggregate extraction (Chapter 4) was considered and discounted early in the study, as it has the potential to adversely affect the operation of trawl nets.

Trawl grounds within NSW territiorial waters (i.e. within 3 Nm of the coast) are regulated by NSW Fisheries. Trawl grounds beyond the state limit in waters south of Barrenjoey Head (i.e. the southern entrance to the Hawkesbury River) constitute the South East Trawl Fishery (SET), which is regulated by the Commonwealth Government. Some vessels which operate from Sydney and Wollongong ports are licenced to work in the SET, others are licenced only to fish in NSW waters, others still may fish in both. Thus, fishers who are licenced to fish only in SET waters are excluded from the proposed extraction areas.

14.2.2.1 The Development of Trawling in Waters off NSW

Trawl fishing has been an important activity on the NSW coast since about 1915, but there is compelling evidence that commercial fishing itself has had significant effects on exploited stocks and in this respect it likely that the areas proposed for extraction have already been affected by human activities (see Chapter 9). The following paragraphs provide a brief overview of trawling activities, which is one of the major fisheries that needs to be considered in relation to the present proposal, on the NSW coast.

Exploratory otter trawl fishing off NSW was first done from 1898 to 1914. Commercial trawling began in 1915 when three trawlers and their crews were brought from England (Roughley 1955). These boats fished near Sydney and made large catches, consisting mainly of tiger flathead Neoplatycephalus richardsoni, john dory Zeus faber, redfish Centroberyx affinis, chinaman leatherjacket Nelusetta ayraudi, red gurnard Chelidonichthys kumu, latchet Pterygotrigla polyommata, and barracouta Thyrsites atun (Colefax 1934). Four more trawlers joined the fishery in 1920. By 1928 the fishing fleet had increased to 19 and had been privatised (Roughley 1955). Although the NSW trawl fishery was profitable during the 1920's it was already in decline by 1930 (Roughley 1955). The 'home grounds', that is, those within one days' steaming from Sydney, had been overfished, forcing trawlers to move further afield (Roughley 1955).

Danish seining commenced in NSW waters in 1933 (Roughley 1955). It differed from otter trawling in that it enabled boats to fish in shallower waters, and the method allowed fishing in localities where space prohibited other types of trawling, such as small pockets of sand surrounded by rocks (Roughley 1955). Access to different grounds may explain the initially large catches made and their subsequent decline (Roughley 1955). The rapid increase in the number of boats entering the danish seine fishery quickly led to overfishing, and by 1940 this fishery was also in decline (Houston 1955; Roughley 1955).

The NSW trawl fishery closed for 3-4 years during the Second World War (Roughley 1955). This closure may have benefitted NSW fish stocks, as large catches were made on all grounds following the war in 1945. Once again, this led to a rapid expansion in the fishing fleet and by 1948 fish stocks had been depleted and the fishery was in decline (Houston 1955; Roughley 1955).

Danish seine vessels dominated the NSW trawl fishery during the 1960's (Rowling 1979). The main fishing grounds were on the mid to outer continental shelf, in depths from 80-200 meters, between Crowdy Head and Gabo Island (Rowling 1979). In the 1970's there was a marked shift in fishing effort to deepwater trawl fisheries located on the continental slope, initially in depths of about 400-500 metres (Rowling 1979). This trend has continued in the 1980's as further exploratory deepwater trawling, in depths ranging from 1000-1300 meters, has revealed new resources of trawl fish (e.g. Gorman and Graham 1983; 1985).

14.2.2.2. The Current Status of Trawling in the Sydney/Wollongong Region

Information on the current status of trawling in the Sydney region, particularly in or near the proposed extraction areas, was obtained from discussions held with officers from NSW Fisheries and with local fishermen, including Mr Gratz Lammachia from Wollongong and Mr Paul Bagnato from Sydney.

Sydney is not a major centre for trawl fishing in NSW, although most of the catch is sold through the Sydney markets (i.e. it is transported by truck from other NSW ports). There are three main types of trawling done: deepwater trawling within the SET, and usually well beyond the outer boundary of the proposed extractions areas (i.e. below 100 m depth); nearshore trawling within NSW waters, which includes the areas considered for the proposed extraction of marine aggregate; and prawn trawling in estuarine waters of Botany Bay, Sydney Harbour and, much further north, in the Hawkesbury River/Broken Bay. Commercial fishing (other than bait gathering) is not permitted in Port Hacking.

In 1988, there were 144 boats fishing in the SET (Tilzey et al. 1990). According to Mr Bagnato, four trawlers work regularly from Sydney. The Arakiwa (17.7 m long) and the Seaport (18.3 m) are licenced to fish in SET and NSW state waters. In summer, they work nearshore waters to the north of Sydney, particularly in trawl grounds off Broken Bay. They also work very close to the shore (just beyond the surf zone) in Bate Bay where they catch estuarine fishes, particularly yellowfin bream (Acantopagrus australis). In winter, these trawlers often work south of Sydney in state and SET waters. When they fish in state waters, one trawl ground worked is off Botany Bay and it includes the proposed extraction area off Cape Banks. Species caught include trevally (Pseudocaranx dentex), john dory, squid (e.g. Sepioteuthis australis) and flathead. They rarely, if ever, trawl in the Providential Head extraction area.

According to Mr Bagnato, there is currently little or no trawling for prawns (apart from royal red prawns, Haliporoides sibogae, taken in deep shelf waters) on trawl grounds off Sydney (i.e. outside the estuaries), although some trawling has been done in the past.

The other vessels which fish from Sydney are the Antonia (21.3 m) and the Francesca (22.4 m), both of which are licenced to trawl only in SET waters and therefore are excluded from the proposed extraction areas. A fifth vessel, Winkles, is not licenced to trawl for fish south of Broken Bay (V. Blaslov, pers. comm.).

According to Mr Lammachia, there are 4 large trawlers (up to 25.3 m long) currently based in Wollongong. These trawlers fish primarily in deeper shelf waters, well beyond the outer limit of the proposed extraction areaa. There is little trawling done in waters inshore of the state boundary. In his view, there is little or no trawling done in the area at Providential Head proposed for aggregate extraction.

Our field observations support these conclusions. During the entire study (over more than 1 year) we never observed trawlers fishing commercially in either of the proposed extraction areas. During that time, however, we did observe trawlers working in depths shallower than, or comparable to, the proposed extraction areas in Bate Bay and in waters well offshore from the outer boundaries of the proposed extraction areas.

Prawn trawling is an important fishery within Botany Bay and, to a lesser extent, Sydney Harbour. According to Dr S. Kennelly (FRI), there are 40-50 trawlers operating in Botany Bay, most of which are moored in the Cooks River. Trawling is restricted to the period between sunset and sunrise from November to March. The most significant species taken is the eastern king prawn (Penaeus plebejus), mostly as juveniles. Small catches of school prawns (Metapenaeus macleayi), greasyback prawns (Metapenaeus bennettae), crabs (mostly Portunus pelagicus) and Balmain bugs (Ibacus peroni) are also taken. Trawling is done over much of the bay extending (rarely) to the bay's entrance. The fishery is essentially confined to the bay, however, as the trawlers are relatively small and are geared typically to trawl only in shallow waters (e.g. < 30 m). In contrast, the proposed extraction area at Cape Banks extends from about 43-65 m depth.

Of the three types of trawling described, nearshore trawling, which has the greatest potential to be affected by the proposal, is the least important. On the basis of our discussions with fishers, it is concluded that the ground at the proposed Providential Head extraction area currently makes little or no direct contribution to the local commercial catch, while that at Cape Banks is one of a number of grounds worked by a few nearshore trawlers, but it is excluded from the trawlers licenced only for the SET.

14.2.3 Reef Fisheries

Reefs are fished commercially in the Sydney region by handline, setline and trap. All these techniques may be done from small boats and we have no data on the number of boats that may commercially exploit reefs. Handlining targets species such as mulloway, also known as jewfish (Argyrosomus hololepidotus), snapper (Pagrus auratus), blue morwong (Nemadactylus douglasi), kingfish and leatherjackets (Monacanthidae). It may be done on any reef in the coastal waters off Sydney.

Setlining involves laying a line of baited hooks over the seabed. This is normally done by day and the hooks are left in the water for 1-4 hours. Within 3 Nm of the coast, setlines may have a maximum of only six hooks. Beyond the state limit, there is no limit to the number of hooks that may be used and lines with up to 600 hooks are frequently employed. The limit of 6 hooks per set line virtually excludes setline fishing within 3 Nm of the coast in the Sydney region. The principal species taken include snapper, sharks, mulloway and blue morwong. The size of the hook is also limited to 5/0 or larger, thus excluding many of the smaller reef fishes.

Two main groups are targeted with traps: reef fish and crayfish. Fish are taken in large wood and wire traps baited with fish. The traps are marked with buoys, often with colourful flags so they may be seen from a greater distance. The traps are usually left overnight, but sometimes they may not be recovered for days (or even weeks), if strong currents force the marker buoys underwater. Deeper reefs away from the coast (e.g. up to 80 m depth) are fished frequently with traps, although shallower reefs are also sometimes fished. The traps catch a range of reef species, including wobbegong sharks (Orectolobus spp.), snapper, blue morwong and leatherjackets. Fish are trapped year round.

During the field studies for this project, we frequently observed trap buoys over rocky reefs off Cape Banks, often extending toward the outer margin of the reef and therefore close to the outer edge of the buffer for the proposed extraction area. We also occasionally observed trap buoys on shallow reefs off Providential Head.

Trapping of crayfish (predominantly Jasus verreauxi) off Sydney is done on shallow coastal reefs, often less than 10 m deep. The crayfish occur seasonally, usually from late August to about November/December. Smaller traps are used; these are baited with fish and usually left overnight. Discussions with fishers suggest that trapping of crayfish occurs along the entire coast of Sydney, including the reefs adjacent to the proposed extraction areas.

Because reef fishing is often done by small boats it is difficult to determine the size of the local fishery. Licenced fishing boats are registered according to size, but no distiction is made between boats fishing inland, estuarine or coastal waters. According to Mr Rob Allen (NSW Fisheries, pers. comm.), a total of 3,281 boats are registered currently as licenced fishing boats in NSW. Only 15% of these are ≥10 m long, thus most of the boats fishing on rocky reefs form a subset of the 2,800 or so of the remaining boats.

14.2.4 Collection of Abalone

A small but very valuable fishery exists for abalone (Haliotis rubra) in NSW waters. In 1991/2 the value of the catch statewide was $5.112 million (source: NSW Fisheries). Abalone are collected by divers working on shallow reefs, often less than 10 m deep (although abalone do occur in much deeper waters in southern NSW). The fishery is centred in southern NSW, where the largest populations of abalone occur. A small but significant portion of the catch comes from the central coast of NSW. According to fisheries inspectors based at Botany Bay, there are two to three divers who collect abalone commercially between Botany Bay and Wollongong.

14.2.5 Trends in Catch Data for Commercial Fisheries

14.2.5.1 South East Trawl Fishery (SET)

As already described, vessels licenced to trawl only in the SET are excluded from the proposed extraction areas. The SET is offshore from these areas, however, and some fishes dominating the SET catches occur in these areas (Tilzey et al. 1990). Data provided by Tilzey et al. (1990) extend to shallow waters which, off Sydney, are within state waters. These data came from SET fishers licenced also to fish in NSW waters (R. Tilzey, pers. comm.). Compared with deep strata, shallow strata probably underestimate the catch, although estimates of catch per unit of effort (CPUE) may be more accurate.

Tilzey _et_ _al_. (1990) identified differences in the weight of the catch and CPUE among depth strata within the SET. Total catch weight was greatest at depths of 100-149 m, with other peaks at 350-399 m and 900-949 m. The largest CPUE occurred in the stratum between 850-899 m. Between 0-49 m and 50-99 m, CPUE was low and the total catch weight moderate. Minor species comprised almost half the catch in the 50-99 m stratum.

Catches and CPUE for most of the major species occurred in strata deeper than the proposed extraction areas, although this must be qualified by a possible lack of data for shallow water in the Sydney region (see above). An exception was _Sillago bassensis flindersi_, which had the greatest proportion of the catch in waters shallower than 100 m.

14.2.5.2 Data from NSW Waters

Data compiled recently on the commercial catch of fish and prawns from various zones along the NSW coast (Fig. 14.1) were provided by FRI. The data cover the period 1987-1991 or less and therefore represent only a relatively short time period. Moreover, these data were qualified by FRI as follows:

1. The species designations are complicated by the fact that a number of species were added to the monthly catch return forms in mid 1990.

2. An unknown proportion of the SET catch is not included because the fishers in the SET are not required to report species information to NSW Fisheries. It is possible to assume that the proportion is constant from year to year, but there is no evidence to support this assumption.

3. Prior to mid-1990, only one principal fishing method was required to be reported, even though more may have been used. Thus, accurate data on fishing effort cannot be extracted from the FRI database, although these data may be used as a relative index. The most meaningful effort is provided by the totals for all methods combined.

4. Some of the data were put into a combined "multiple zone" category, in which information is provided only on the catch from several zones fished. In these cases, it is not possible to determine the relative significance of any zone of interest. This problem arises mainly with the trawl fishing and constitutes only a small proportion of the catch data for other fishing methods.

14.2.5.2.1 Fishing Effort

Figures 14.2-14.7 (reproduced in Appendix D, Volume II) summarise the data provided by FRI on fishing effort in NSW on a monthly basis. Zones 6 and 7, the areas in which the proposed extraction areas occur, show a similar amount of effort to most other zones, when all methods are combined (Fig. 14.2). For specific methods, zones 6 and 7 tended to show similar or slightly lower levels of effort to many of the other zones. Zones 2 and 5 typically showed the greatest effort in fish trawling, while zones 6 and 7 tended to have intermediate levels of trawling effort. Effort expended in fish trapping was relatively high in zones 6 and 7 (Fig. 14.4). Similarly, levels of fish trolling were also high in zones 6 and 7, with possible peaks in effort during the spring and autumn (Fig. 14.5).

Effort expended in handlining was relatively large in zones 1-3 (Fig. 14.6). Effort expended in handlining in zones 6 and 7 was similar to that for zones 5 and 9. Finally, prawn trawling was greatest in zones 1, 2 and 5, including the coastline adjacent to the northern rivers area and large trawl grounds off Stockton Bight and Port Stephens (Fig. 14.1, 14.7). Zones 6 and 7 had relatively little effort expended on prawn trawling, but with distinct seasonal peaks during the spring to autumn period.

14.2.5.2.2 Catch Records for Selected Species

Figures 14.8-14.22 (in Appendix D) show monthly catches for a range of species or species groups that may occur within the proposed extraction areas. Many of these species were collected during the field studies (Chapter 9) and groups such as flathead, yellowtail, john dory and red spot whiting were often abundant in the samples. The figures often show distinctive trends in the catch along the NSW coastline, but rarely, if ever, do zones 6 and 7 stand out in comparison with other zones.

Catches of all specified shark in the 1990-1991 period were very low in the north of the state and tended to peak around the central part of NSW, particularly zone 5 (Fig. 14.8). Catches of john dory and redfish were also very low in northern NSW (Figs. 14.9-10). The catch of these species showed greater numbers in autumn, winter and early spring in zone 5, but this was much less clear in the southern zones. Red gurnard were also rare in catches from northern NSW, but similar numbers occurred in zones 5-10 (Fig. 14.11). Catches of latchet were also rare in the north, peaked in zone 5 and declined in zone 10 (Fig. 14.12).

Catches of sand and blue-spotted flathead (Platycephalus caeruleopunctatus) peaked in zones 1, 2, 5, 9 and 10. The catch from zones 6 and 7 was relatively consistent, but low (Fig. 14.13). Catches for NSW may be explained by the presence of more than two species in the records. In northern NSW, northern sand flathead, Platycephalus arenarius may constitute the sand flathead component of the catch, while in southern NSW it may be southern sand flathead, Platycephalus bassensis. In the field studies for the proposal, blue-spotted flathead were the most common species of this group in the study region; only a few southern and northern sand flathead were recorded (Appendix B1).

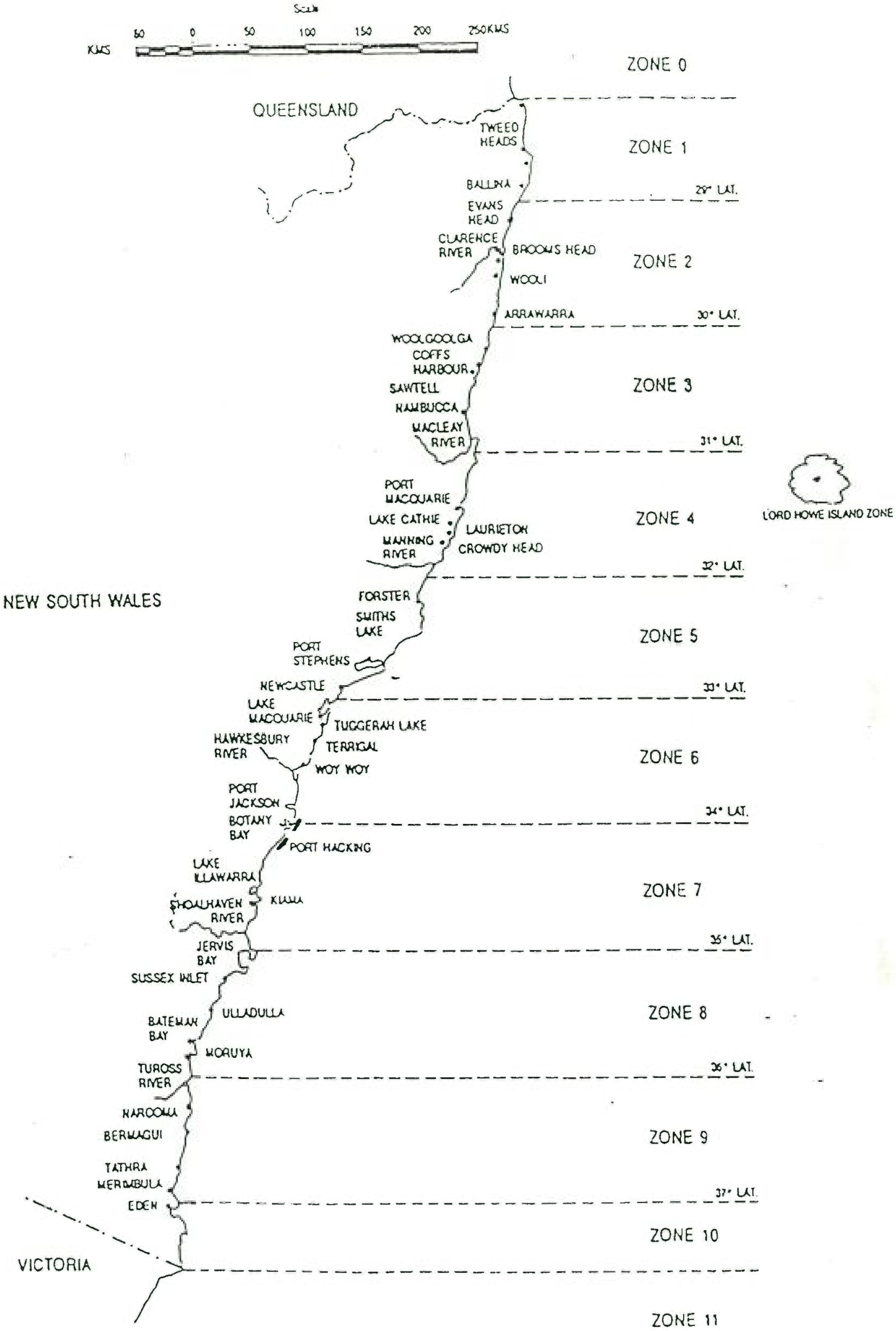


Figure 14.1 Ocean fishing zones and NSW ports of landing. Note Zones 6 and 7 contain the proposed extraction areas, shown by shading (Source: Fisheries Research Institue, NSW Fisheries).

Very small catches of tiger flathead were made in zones 1-4 (Fig. 14.14). In zone 5 there appeared to be a seasonal peak in the catch during the winter and spring. Consistently low catches were made in zones 6 and 7. In zones 8 and 9 there was a peak in the catch during spring, while zone 10 showed a peak from late spring to early autumn.

The catch of red spot whiting was greatest in northern NSW, particularly zone 2 (Fig. 14.15). The catch was very small in zones 6 and 7. The largest catch of yellowtail occurred around zones 5, 6 and 7 (Fig. 14.16). Most snapper came from the north coast, with a gradual decline to the south (Fig. 14.17). In contrast, most tarwhine (Rhabdosargus sarba) came from zone 5 (Fig. 14.18), with small catches recorded elsewhere. Catches of leatherjackets showed a possible seasonal trend for greater catches in winter in zones 1-4. Over much of the state, however, catches of leatherjackets were small and consistent throughout the year (Fig. 14.19). The catch within zones 6 and 7 was small.

Figures 14.20-22 (Appendix D) show catches of three species of invertebrates. Zones 1 and 2, and to a lesser extent zone 3, dominated the total catch of eastern king prawns for NSW (Fig. 14.20). The relative contribution made by the other zones, including zones 6 and 7, was very small. For calamari squid, zones 5 and 10 had the largest catches in the period for which data were supplied (Fig. 14.21). Small, but consistent, catches were recorded from zone 6. The catch of cuttlefish (Sepia spp.) was greatest in the mid to north coast (Fig. 14.22). Minor catches came from other zones.

Despite their limitations, the catch data suggest several trends in the catches among zones for some important coastal fishes and invertebrates of NSW. Trends through time are difficult to interpret, as these trends may reflect seasonal occurrences of species or seasonal variability in the effort expended by fishers in catching those species. Zones 6 and 7, which are of interest for the present proposal, do not stand out in the records. This contrasts with the catches for some species in the northern and southern sections of the state. Further, zone 5 also appears to stand out for many species, although there is no ready explanation for this.

14.2.6 Value of Fin-fish

According to Corkery (1993), the value of commercial fin-fish to the economy of NSW varies from $77 million to $85 million per year. About 2% of the catch comes from the sea area off Sydney (NSW Fisheries, pers. comm. to R.W. Corkery). On the basis of our discussions with fishers and our field observations, it is unlikely that the proportion of fish caught commercially from both proposed extraction areas exceeds 5% of the total catch of fin-fish for the Sydney region. On this basis, the revenue from fin-fish from both proposed extraction areas would be less than

$85 000 per year (Corkery 1993).

14.3 ANGLING AND DIVING

Given the close proximity of the proposed extraction areas to the large population centres of Sydney and Wollongong, it is not surprising that there is extensive recreational use of the coastal waters in the study region. People fish and dive from boats (both private and chartered) and from numerous points along the shore. Unlike many parts of the NSW coast, which have treacherous bars at the entrances to estuaries, Sydney's four major estuaries provide ready access to coastal waters.

14.3.1 Types of Fishing

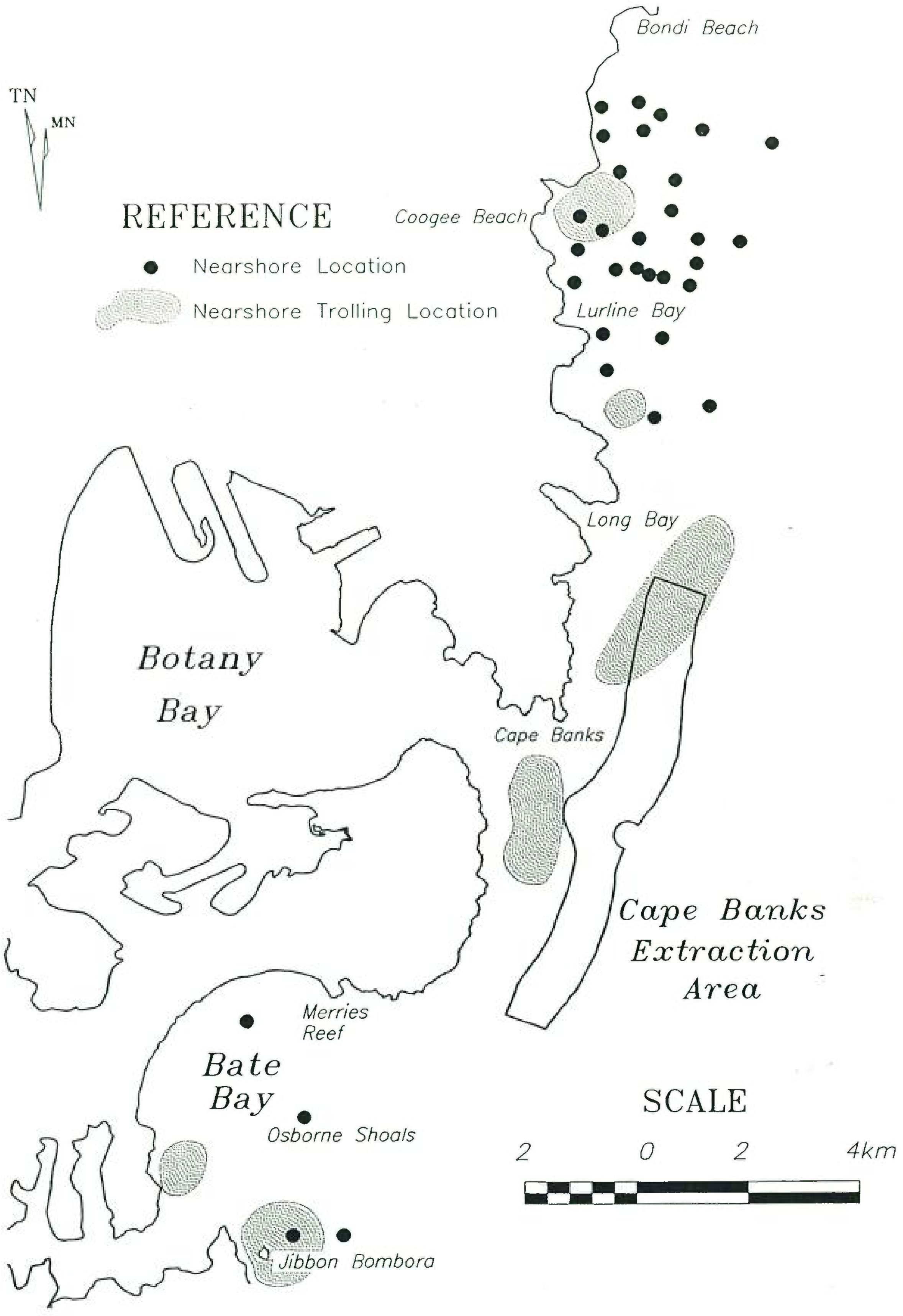
Most recreational fishing in coastal waters of NSW involves the use of monofilament fishing lines. In this section fishing is described under three main categories, gamefishing and fishing for pelagic fishes, reef fishes and fishes on soft substrata.

14.3.1.1 Gamefish and Pelagic Fish

Pelagic fish, including sharks, tunas, billfish (Istiophoridae and Xiphidae), kingfish, dolphin fish (_Coryphaena hippurus_) and wahoo (_Acanthocybium solandri_) are the main species sought after by gamefishers. The major species of sharks sought after are Carcharhinidae (whaler, blue and tiger sharks), Lamnidae (mako and white sharks) and Sphyrnidae (hammerheads) (see Stevens 1984). The most common tunas are yellowfin and striped tunas, although bigeye tuna (_Thunnus obesus_), southern tuna, longtail tuna (_Thunnus tonggol_), mackerel tuna (_Euthynnus affinis_) and albacore (_Thunnus alalunga_) are also taken. Other pelagic species, such as bonito, frigate mackerel, tailor and Australian salmon are also caught by recreational fishers.

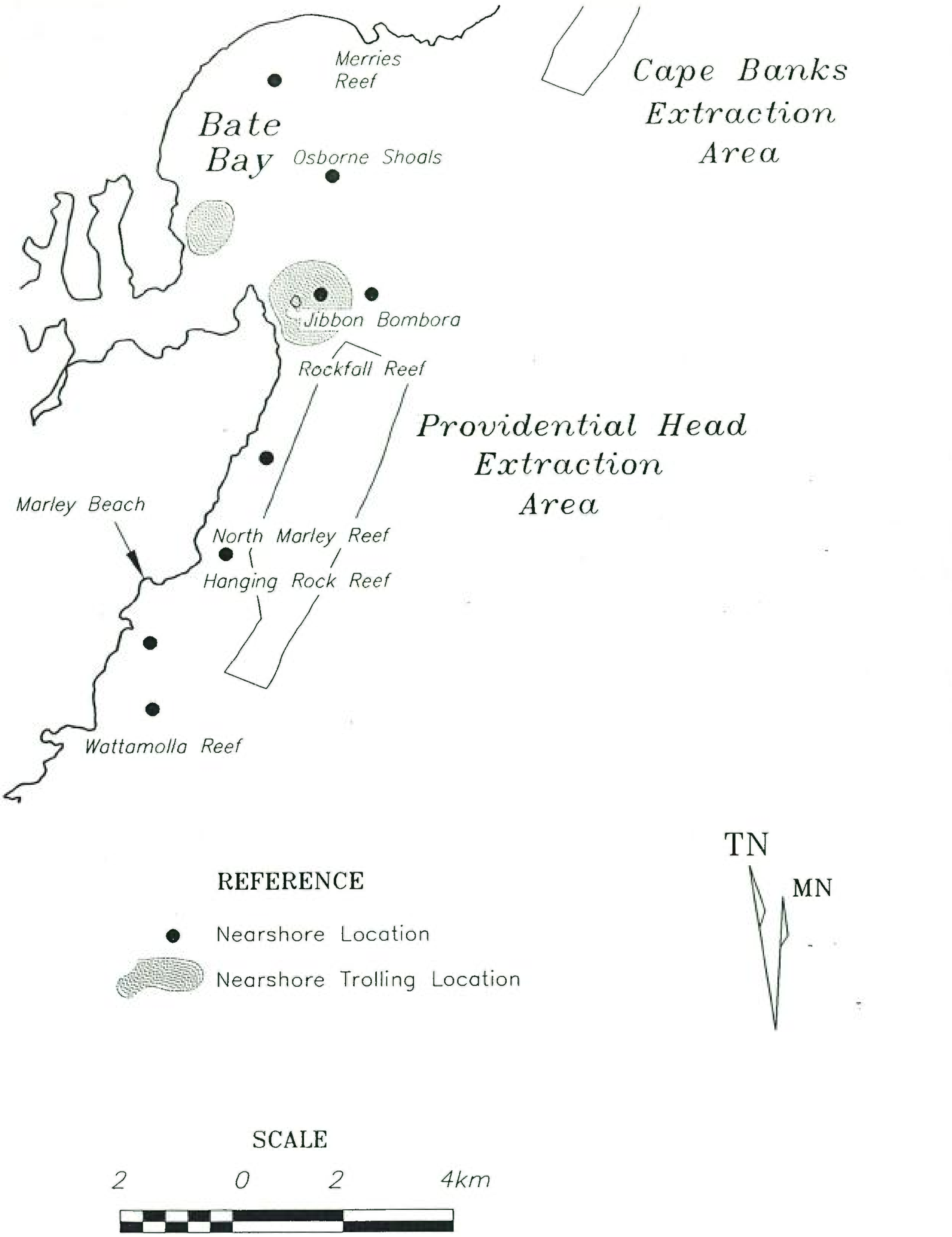
Most gamefishing off Sydney occurs towards the edge of the continental shelf, although gamefish can, and often are, caught anywhere beyond the estuaries. One very important gamefishing spot is a pinnacle reef known as The Peak, located off Maroubra, which rises from about 82 m to 59 m. According to Goadby (1970), this reef is fished for a variety of gamefish, such as large kingfish, yellowfin tuna and sharks. The Peak is northeast of the proposed Cape Banks extraction area, about 1 km further offshore than the outer boundary of the proposed extraction area.

Smaller pelagic species, as well as kingfish and small tunas (e.g. bonito and frigate mackerel) are caught in shallow coastal waters, usually over reefs adjacent to rocky headlands. Figures 14.23 and 14.24 show popular trolling areas off southern Sydney (Anon 1992).



Source : Anon 1992

Figure 14.23
RECREATIONAL FISHING SITES NEAR CAPE BANKS



Source : Anon 1992

Figure 14.24
RECREATIONAL FISHING
AREAS NEAR PROVIDENTIAL HEAD

Gamefishing may be done by trolling, drifting with baits or anchoring and using baits. While drifting or at anchor, large quantities of berley, also known as chum (e.g. fish or offal) are often released into the water to attract the gamefish to the boat. Other popular methods include saltwater flyfishing or casting small lures into schools of fish. With the exception of fishing for broad billed swordfish, virtually all gamefishing in NSW is done by day.

14.3.1.2 Ground or Demersal Fish - Reefs

Fishing for ground fish is a popular form of recreational fishing. It is relatively inexpensive and may provide fish of good eating quality. Fishing on reefs may be done either by anchoring on a reef or drifting over one or more reefs. Species sought include snapper, mulloway, leatherjackets, pigfish (Bodianus sp.), trevally, kingfish and redfish, although there is a wide range of species that may be taken incidentally, such as maori wrasse (Opthalmolepis lineolatus), sweep (Scorpis lineolatus), long-finned seapike (Dinolestes lewini) and red rock cod (Scorpaena cardinalis). Fishing is done by day or night, although most drift fishing is done by day.

Discussions with charter boat operators suggest that all of these species are commonly taken on reefs in the vicinity of the proposed extraction areas. Off Cape Banks, there are reported to be very productive reefs in waters beyond the outer limit proposed for extraction. The reefs inshore of the area are also considered good for reef fish. Similarly, the reefs fringing the proposed Providential Head extraction area provide good reef fishing, although there are very popular fishing reefs at Jibbon Bombora and at the Osborne Shoals, which are to the north of the Providential Head area.

Angling over the s.s. Tuggerah and s.s. Undola shipwrecks also yields good catches of reef fish, particularly kingfish and redfish. Byron (1986) stated that the s.s. Tuggerah is a popular site for weekend fishers and it is not uncommon to see as many as 15 small fishing craft anchored over the wreck on Sundays.

14.3.1.3 Groundfish - Soft Substrata

Fishing for groundfish on sandy substrata is usually done by drifting. The most sought after fishes are flathead, although other species often taken include flounder (e.g Pseudorhombus jenynsii), gurnards, latchets, fiddler rays (Trygonorhina fasciata) and shovelnose rays (Aptychotrema rostrata). Charter boat operators indicated that the proposed extraction area off Cape Banks is an important ground for flathead, particularly during the winter and early spring, when westerly winds provide a good "drift" across the sand body. The field study showed that at least seven species of flathead occur in the study region - all of these are sought after by recreational fishers.

Our discussions with fishers suggest that virtually all of the fishing done over soft substrata is done by day.

14.3.1.4 Shore Fishing

Angling from rocky shores and beaches is also popular in the Sydney region. Fishers target species such as yellowfin bream, luderick (Girella tricuspidata), blue groper (Achoerodus viridis), rock blackfish (Girella elevata), trevally, tailor, kingfish, salmon and mulloway from rocky shores, while they catch whiting (Sillago ciliata), bream, flathead, tailor, dart (e.g. Trachinotus spp.) and mulloway from beaches. Fishing is done by day or night. Anglers also gather bait from the shore. Bait collected from rocky shores includes cunjevoi (Pyura spp.), sea lettuce (Ulva) and crabs (e.g. Plagusia chabrus), while pipis (Donax) and beach works (Onuphis) are taken from beaches.

14.3.2 Fishing Clubs, Associations and Charter Operators

Whilst many fishers prefer to fish privately, there are numerous clubs which cater for various types of fishing. There is a gamefishing club based in each of Sydney's four main estuaries, and at Wollongong. There are also two major angling organisations, the NSW Fishing Clubs' Association (Inc.) (NSW FCA) and the Australian National Sportsfishing Association (ANSA). The Recreational Fisheries Advisory Council (RFAC) advises NSW Fisheries on issues that could affect recreational fishing in NSW. The Applicant has advised RFAC of the present proposal to extract marine aggregate.

The 1991-1992 yearbook of the NSW FCA lists about 42 affiliated clubs from Sydney to Wollongong which are located in suburbs near the proposed extraction areas. There are also about 11 ANSA clubs similarly located. No data were available on the active membership of these clubs. All of these organisations have regular fishing competitions, often with various categories, such as estuarine, beach, rock and offshore competitions.

There are numerous boats available for charter for fishing in the Sydney region. About 8, 6 and 3 charter boats for fishing operate from Botany Bay, Port Hacking and Wollongong, respectively. These boats often take from 10-20 passengers. Charter rates are structured in several ways, for example, one operator charges $45 per passenger per day (with a minimum number of passengers per trip); another charges $100 per hour for the boat, with a minimum trip of 6 hours. In most cases the operator includes bait and tackle in the cost of the charter. Most charters are done during the weekend, although midweek charters are common in summer. Most operate exclusively during daylight hours. Some charters undertake whale and bird watching cruises.

Discussions with charter boat operators suggest a distinct seasonality associated with their activities. In summer, many charter boats fish for reef species over reef or gravel in offshore waters (e.g. depths of 60-140 m) which is at or beyond the outer limit of the proposed extraction areas. Species taken are snapper, blue morwong, redfish and pigfish. In winter, operators fish in shallower waters - either on shallow reefs for species such as trevally, snapper, redfish, red rock cod and sweep; or they drift for flathead over sandy substrata, including the areas proposed for extraction of marine aggregate. The sand body off Cape Banks is considered to be popular because of its accessibility from Botany Bay. Similarly, reefs and sandy areas in Bate Bay are also popular because of their ready accessibility from Port Hacking. Discussions with charter operators from Sydney suggest that they usually fish only as far south as The Peak (off Maroubra).

14.3.3 SCUBA Diving and Skindiving

Recreational diving is a rapidly growing aquatic leisure activity throughout the world (Hughes, 1985; Hornsby, 1988). More than half of the SCUBA divers in Australia are in NSW and this state has the most established selection of diving services and locations (Harding, 1989). The principal attractions of SCUBA diving are sightseeing, training and photography (Henry _et_ _al_. 1990). Snorkel divers require less equipment and their principal underwater activities are spearfishing, sightseeing and collecting (Henry _et_ _al_. 1990).

Recreational diving involves SCUBA and snorkel diving. SCUBA divers breathe compressed air. As there are some risks associated with SCUBA diving, divers must undergo a training programme to obtain a diving certificate. The three main training organisations for amateur SCUBA diving in NSW are PADI (Professional Association of Diving Instructors), FAUI (Federation of Australian Underwater Instructors) and SSI (SCUBA Schools International). Under the training programme provided by PADI, limits are imposed on the depths to which sports divers should descend. The basic open water certificate awarded by PADI recommends a maximum depth of 18 m for divers. The advanced open water certificate recommends a maximum depth of 30 m. PADI specifies that no sports diver should go below 40 m depth. We understand that the other training organisations have similar standards. Thus, shipwrecks such as the _s.s. Woniora_, _s.s.Tuggerah_ and _s.s. Undola_, which are all at depths greater than 45 m, would be undivable following locally-accepted standards of certification.

Diving generally occurs on coastal rocky reefs or shipwrecks and rarely on sand. The popularity of some dive locations may be due to accessibility, normally clear water or the occurrence of special features such as dramatic topography, or an abundance and richness of marine life. Diving is a year round activity off Sydney. Most diving is done during the day, although some diving is done at night with torches, particularly in calm waters inside or at the entrances to estuaries.

Reviews of SCUBA diving and spearfishing locations in the Sydney region are provided by Byron (1986) and Andrewartha and Montcalm (c. 1969), respectively.

Byron (1986) described the coastline from Botany Bay to Garie Beach as containing undoubtedly the most popular areas in Sydney for SCUBA diving and spearfishing. He noted that there were about 22 dive shops in the Sydney region equipped to train SCUBA divers. Many of these shops also run organised dive trips to reefs and wrecks on a regular basis. Byron lists 20 locations for diving within the Sydney region. None of these dive sites is within the areas proposed for extraction of marine aggregate, but some occur relatively close to these areas. They are described briefly (on the basis of Byron (1986)) as follows.

There are numerous dive sites between Botany Bay and Wattamolla (Figs. 14.25 and 14.26). A long reef running southwest from Boat Harbour in Bate Bay provides a series of popular dive sites, culminating in the Osborne Shoals. The shoals are about 3 km east of Cronulla and cover an area of about 2 km² (Byron 1986). Jibbon Bombora near the northern boundary of the proposed extraction site at Providential Head (Fig. 14.25). The bombora is a submerged rocky outcrop about half a kilometre offshore which runs for a further kilometre offshore and dropping to 30 m depth (Byron 1986). Byron described the bottom growth as being sparse at times, but improving with depth. Invertebrate growth of interest to divers includes gorgonians, hydroids, soft corals and finger sponges.

Two popular dive sites are Barrens Hut and Rockfall, about 1 km south of Jibbon Head, and shoreward of the proposed extraction area at Providential Head (Fig. 14.25). Barrens Hut was described as occurring about 450 m offshore, featuring gullies, caves and a vertical wall dropping 10 m to a beautiful sponge garden laden with sea whips (Byron 1986). It was also described as having excellent fish life and as being a good for photography. Rockfall is 150 m offshore at a depth of 20 m. It has vertical walls rising 3-5 m from sand. It was described as good dive for inexperienced divers.

Byron (1986) listed three dive sites near Marley Head: North Marley Reef, Rock Perch Reef and Hanging Rock Reef (Fig. 14.25). Marley Reef is about 1 km north of Marley Head and extends from about 130 m to 550 m offshore. Marine life there is described as very prolific. The site features caves and vertical walls ranging from 1-10 m high (Byron 1986). Rock Perch Reef occurs off Marley Head and extends to a depth of 21 m. Byron also considered this a good site for underwater photography. Hanging Rock is just south of Marley Head and offers vertical walls 6-12 m high, with huge boulders. The final reef described by Byron (1986) along this

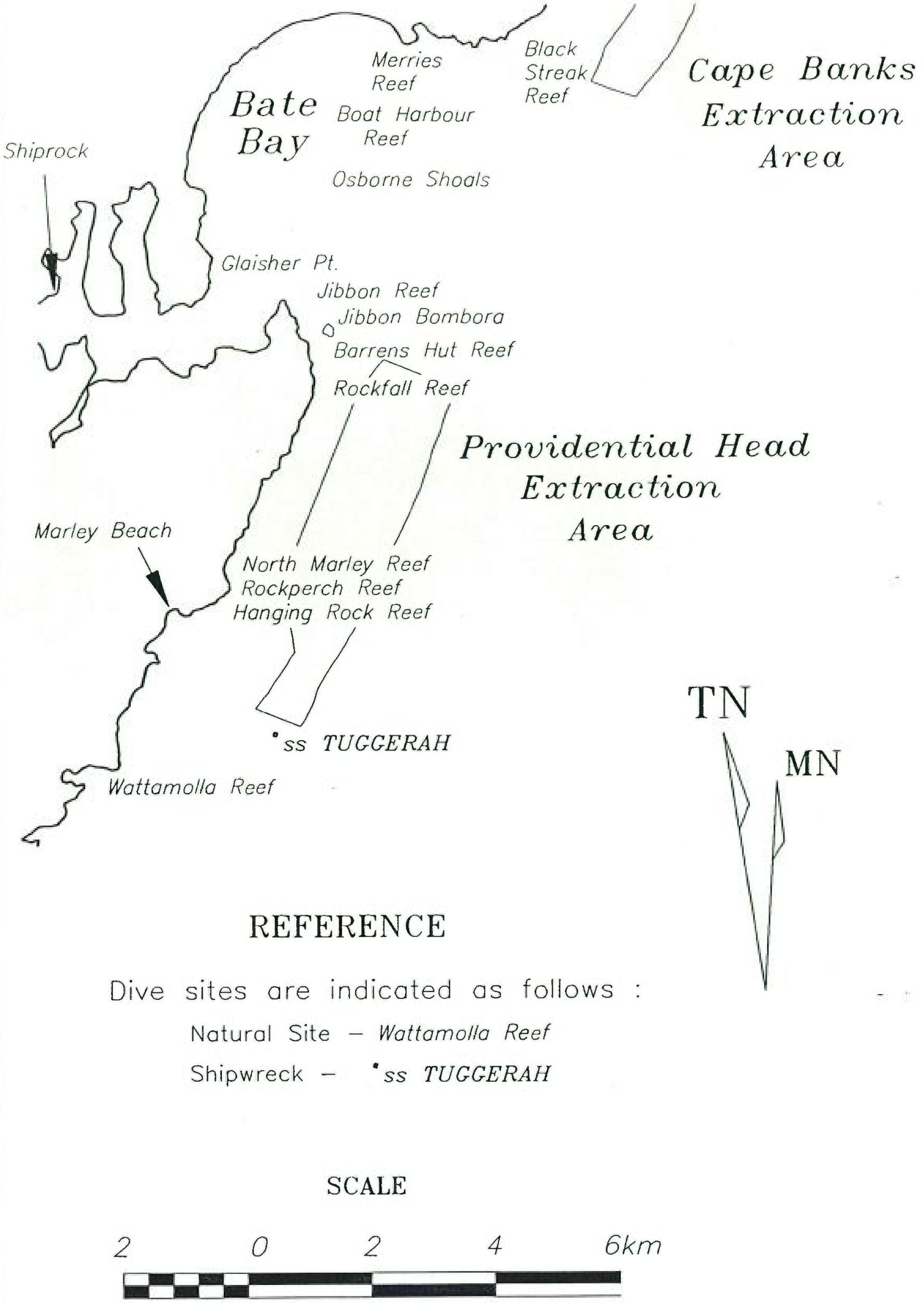
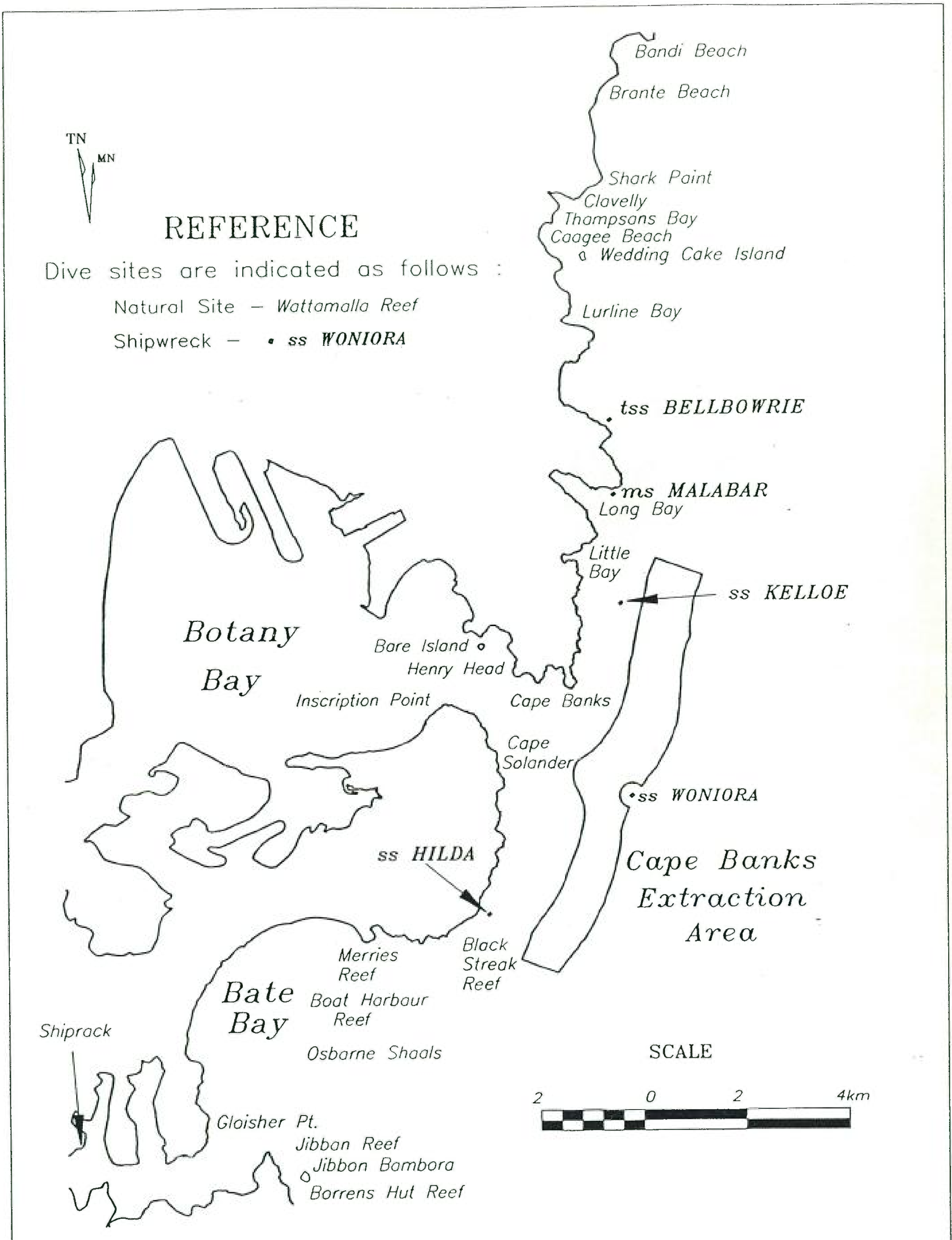


Figure 14.25
RECREATIONAL DIVING
AREAS NEAR PROVIDENTIAL HEAD

Source : Byron 1986



Source : Byron 1986

Figure 14.26
POPULAR DIVE SITES
IN SOUTHERN SYDNEY

section of the coast was Wattamolla Headland (Fig. 14.25). This site is to the south of the southern boundary of the proposed extraction area. It covers a large area some 700 m offshore. It has excellent marine life and fish (Byron 1986).

Byron (1986) provided little description of the diving around Botany Bay, although rocky shores fringe most of the coastline there (Fig. 14.26). The northern headland of Botany Bay (Inscription Point to Cape Solander) is described a often having poor water visibility due to the tidal flow from Botany Bay and the presence of the nearby oil refinery (which discharges effluent at Yena Gap). Estimates of water visibility at Inscription Point and Henry Head support this observation (M. Lincoln Smith, unpubl. data). Another popular dive site is Bare Island, on the northern side of Botany Bay (Fig. 14.26). The average water visibility was described as being no more than about 3 m (Byron 1984).

In addition to diving on rocky reefs, diving on shipwrecks is popular with experienced divers. The s.s. Tuggerah and s.s. Undola, to the south of the proposed extraction area at Providential Head, are at depths of 45-48 m. Discussions with local divers suggest that there are at least 6 charter boats that take divers to these wrecks and, when the weather is good, it is likely that there will be divers at the wreck on most days, especially during weekends and holidays. The attraction of the wrecks includes the prolific marine life, the backdrop of the wrecks as a photographic subject, the cultural heritage, the prospect of discovering an artifact and the thrill and challenge of deep diving.

Andrewartha and Montcalm (c. 1969) discussed spearfishing locations from Mallacoota (Victoria) to Sydney. The coastline fringing Royal National Park was considered to be good for spearfishing, although a number of locations were outstanding. Jibbon Bombora was described as being the best spearfishing area close to Sydney and its southern suburbs. It can only be reached by boat. Andrewartha and Montcalm stated that the actual diving sites may vary from day to day, but the best area seems to be approximately half way between Jibbon Bombora and Marley Point at a place known as "Tumble Downs" (this is very close to the site described as "Barrens Hut" by Byron (1986), and both may refer to the same place - see Fig. 14.25).

Boat Harbour was described as a good location for learners (Andrewartha and Montcalm c.1969). The coastline from Cape Bailey to Cape Solander was also known as a good area for spearfishing.

Andrewartha and Montcalm (c.1969) state that the water off Cape Banks and extending to Long Bay often has poor water visibility, due to the outflow of tidal waters from Botany Bay. Despite this, they concluded that it was still a popular spearfishing area, with a wide variety of reef species being taken.

Fish sought after by spearfishers include reef species, such as rock blackfish, red morwong (Cheilodactylus fuscus), yellowfin bream, luderick and leatherjackets, and several pelagic species, such as kingfish, Australian salmon and bonito (Lincoln Smith et al. 1989).

14.3.4 SCUBA Diving Clubs and Spearfishing Competitions

There are numerous clubs and associations for SCUBA diving and spearfishing. Many of the Sydney diving shops also provide charters for divers. Most of this diving is done on weekends and holidays.

There are four spearfishing clubs in the Sydney region, two based on either side of Sydney Harbour (Chard 1988). At the time of Chard's paper, there were about 250-300 divers participating in organised spearfishing along the NSW coast. About 100 divers belong to the Sydney clubs (A. Smith, pers. obs.). According to Chard (1988), the popularity of spearfishing is declining, probably due to increases in the popularity of SCUBA diving and to an increase in awareness about conservation.

A monthly spearfishing competition, the Alliman Shield, is held in the Sydney region. Each month the venue changes, with the competition being held from Gunnamatta Bay, La Perouse, Little Manly, Long Reef, Watsons Bay, Wollongong or Palm Beach. Most of the diving is done from boats and the competitors may cover much of the Sydney coastline. In addition to the Alliman Shield, there are regular zone, state and other representative championships, but these competitions are held only occasionally in Sydney.

14.4 CONCLUSIONS

This chapter reviewed fishing and diving activities in the study region, with emphasis on the areas proposed for extraction of marine aggregate. Indications are that commercial fishing within the proposed extraction areas is not very significant in terms of the catch of most species. In particular, trawling is rare within the depth range of interest off Providential Head, while Cape Banks is one of a number of trawl grounds fished. Similarly, commercial fisheries for pelagic species are of little importance within or near the proposed extraction areas.

Trap and line fishing on reefs, however, may be significant near the proposed extraction areas. This is a parsimonius conclusion based on our sightings of trap buoys during the study and the presence of well developed reefs in the area. Moreover, the data provided by FRI showed consistently large effort expended on trap fishing and, to a lesser extent, handlining, in zones 6 and 7, which include the proposed extraction areas.

Recreational fishing appears to be very popular in and around the proposed extraction areas. Gamefishing and trolling for pelagic fishes is probably the least important in the areas under consideration, while drifting for fishes over soft substrata is probably the most, particularly in winter and early spring. Assessment of impact will need to consider effects on stocks of fish and the benthic organisms upon which many fish feed, potential increases in sedimentation on reefs and the potential for disruption of fishing activities by the extraction vessel (see Part IV).

Similarly, diving is also an important activity in the study region, although this is most important on reefs and wrecks which are outside the proposed extraction areas. Thus, assessment of impact must consider whether there are likely to be any indirect effects on diving, for example from the creation of sediment plumes following release of excess water into the sea (Part IV).

CHAPTER 15. RESEARCH, EDUCATION AND CONSERVATION

15.1 INTRODUCTION

Extensive scientific research is done along the coastline of Sydney. In addition, there are several aquatic reserves in the Sydney region and a draft proposal to reserve the oceanic and estuarine waters adjoining Royal National Park for nature conservation and passive recreation (NSW NPA 1991). Boat charters also undertake cruises to observe whales and seabirds.

In this chapter we describe:

1. Major areas for research and education in marine ecology;

2. Monitoring of marine organisms to assess the effects of the deep water ocean outfalls recently commissioned off Sydney; and

3. Aquatic reserves and reserve proposals.

15.2 RESEARCH AND EDUCATION

The coastal aspect of Sydney provides great opportunity for marine studies. Most of Sydney's universities and Wollongong University have courses in marine biology.

The University of Sydney administers the Cape Banks Scientific Marine Research Area, where many studies have been done on rocky intertidal and subtidal ecology. The research area is located at the northern entrance to Botany Bay (Fig. 15.1). It fringes the shoreline adjacent to the proposed extraction area at Cape Banks, lying about 1.25 km from the eastern boundary of the proposed extraction area.

A report was prepared by Underwood and Astles (1991) for the Applicant describing the significance of the Cape Banks Marine Research Area (Appendix C). Westoby (1991) pointed out that the research at Cape Banks provides one of the few areas for long term ecological research within Australia. This research could be beneficial for determining the effects of long term change (e.g. as a result of the Greenhouse Effect) on marine ecosystems.

15.3 MONITORING THE EFFECTS OF THE DEEPWATER OCEAN OUTFALLS

Research being done for the deepwater ocean outfalls environmental monitoring program (EMP) includes studies of ichthyoplankton, demersal fish of soft substrata and reefs, macrofauna of soft substrata and algae and invertebrates of rocky substrata (EPA 1992f). Related studies are investigating the accumulation of contaminants in bivalves deployed at the deepwater outfalls, control sites and at the previous cliff-face outfalls; and contaminants in fish and invertebrates caught around the deepwater outfalls, at or near the former cliff-face outfalls and reference areas.

Most of the studies began about a year before the first of the deepwater outfalls (Malabar) was commissioned. These studies, along with the use of control or reference sites, provide a baseline against which the effects of the outfalls may be measured.

The Fisheries Research Institute (FRI), which is part of NSW Fisheries, is studying ichthyoplankton, macrofauna of soft substrata and demersal fish (FRI 1992 - see also Chapters 8 and 9). During pre-commissioning studies for the outfalls, samples were collected from up to three depths: 30, 60 and 100 m near the sites for the deepwater ocean outfalls at North Head, Bondi and Malabar. Samples were also collected at reference locations at Long Reef, Port Hacking and Marley Beach (Fig. 15.1).

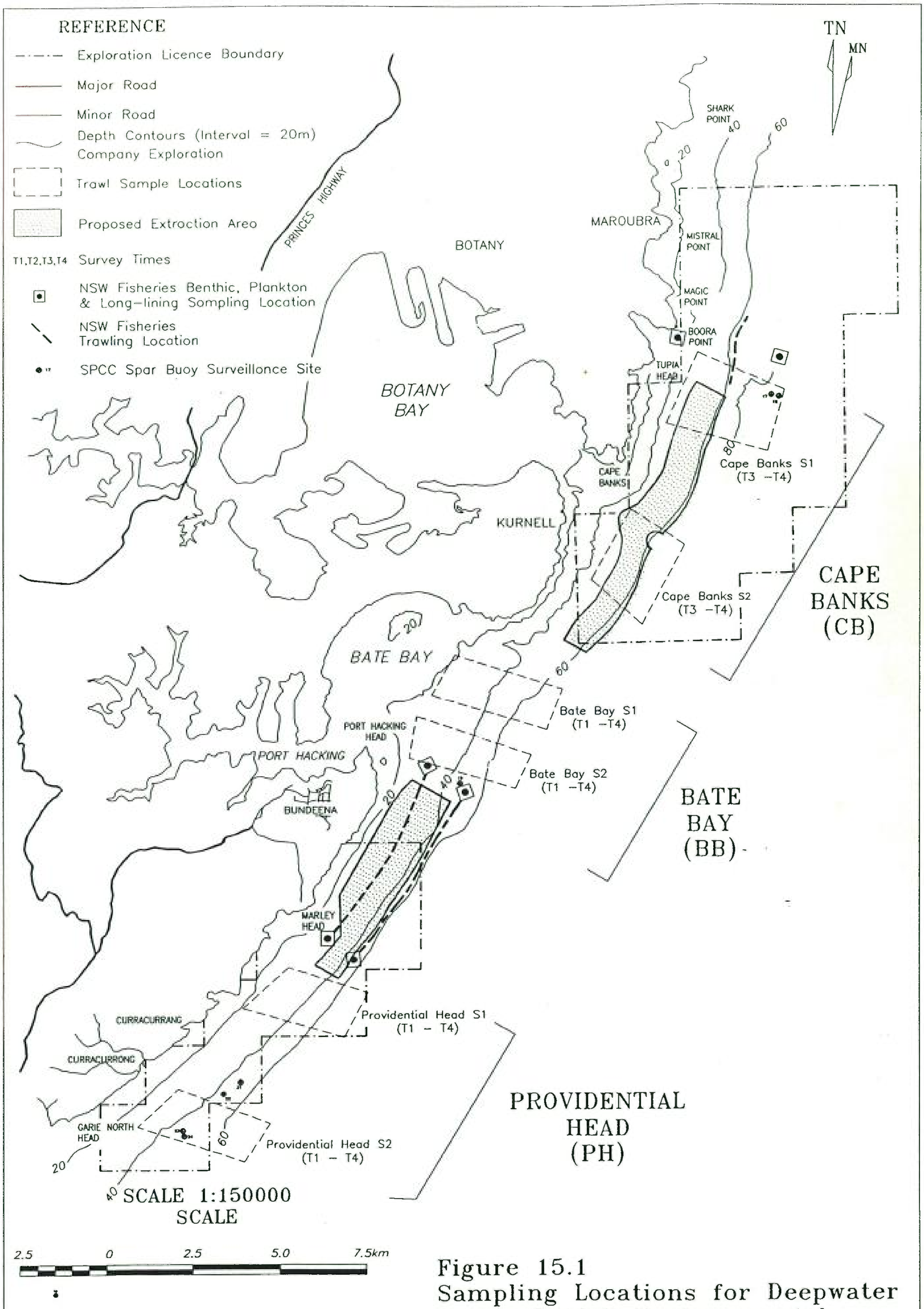
Several sampling locations used by FRI are within, or close to, the proposed extraction areas (Fig. 15.1). Benthic macrofauna, ichthyoplankton and fish collected by longlining sampled at 30 m and 60 m at Port Hacking and Marley Beach are near the boundary of the proposed extraction area at Providential Head. Fish collected by trawl at 30 m are within the proposed extraction area, while those collected at 60 m depth are close to the seaward boundary of the proposed extraction area.

At Cape Banks, the sample locations selected by FRI ("Malabar") are north of the proposed extraction area and centred around the deepwater ocean outfall or the former cliff-face outfall.

Thus, with respect to the research being done by FRI for the EMP, the proposed extraction areas are near to or encompass two of three reference locations and one of three outfall locations.

We understand that, under the terms of the present study (N. Otway, FRI, pers. comm.), monitoring ended in mid-1993. A decision is yet to be made about continuing the monitoring programme beyond this period.

The EPA is studying bioaccumulation of fish and invertebrates as part of the EMP (EPA 1992f). Oysters are being deployed for 3-monthly periods in 60 m depth of water at each of the deepwater ocean outfalls and at control locations. Oysters are deployed around each of the outfalls from three spar buoys. One of the spar buoys off Malabar borders the outer boundary of the Cape Banks extraction area (Fig. 15.1). The reference locations are divided into two groups, 'near controls' and 'far controls'. A



SOURCE : R.W.CORKERY & CO. PTY. LIMITED
3rd September, 1993

Figure 15.1
Sampling Locations for Deepwater Ocean Outfall Environmental Monitoring Program

near control occurs along the outer boundary of the proposed extraction area at Providential Head (EPA 1992e).

As part of another experiment, oysters are deployed at the old cliff-face outfalls and at 3 control locations, one of which is on reef in 10 m water depth near Jibbon. At the same locations, red morwong (Cheilodactylus fuscus) are collected as an indicator of contaminants in fish.

The EPA also examined contaminants in fish collected by the FRI as part of its demersal fish programme (EPA 1992c). Samples were obtained from the same locations, as described above. In the post-commissioning phase of monitoring, the EPA initiated a different study design whereby the references were relocated to Terrigal and Jervis Bay. Thus, there are three sites in each of three locations: three sites near to Sydney's outfalls and three sites each at far controls. Sampling in 30 m and 60 m depth is done quarterly, while sampling in 100 m is done on a 6-monthly basis.

Finally, the EPA is studying the effects of the deepwater ocean outfalls on the biota of hard substrata using photographic techniques (EPA 1992b; Roberts and Henry 1992). Reefs are being studied in 60 m water depth off North Head, Long Reef and Bungan Head. These sites are all north of Sydney Harbour and therefore remote from the proposed extraction areas.

As with the FRI studies, the pre-commissioning phase of the EPA studies extended for up to two years and the post-commissioning phase is currently scheduled to extend to mid-1993.

15.4 EXISTING AND PROPOSED AQUATIC RESERVES

There are three aquatic reserves, both within estuaries, in the vicinity of the proposed extraction areas. Towra Point Aquatic Reserve occurs at Towra Point in Botany Bay, while the Shiprock Aquatic Reserve occurs at the entrance to Burraneer Bay, Port Hacking. Cabbage Tree Basin, which is on the southern side of Port Hacking and fringes the Royal National Park, is also protected (Ivanovici 1984). It is managed by NSW NPWS and NSW Fisheries.

To the north, there are aquatic reserves at Long Reef and North Head, Sydney Harbour. The Long Reef Aquatic Reserve fringes the open coastline. Within this reserve, collecting of invertebrates up to 500 m seaward from the high water mark is prohibited. The North Harbour (Sydney) Aquatic Reserve includes the southern edge of North Head and extends into Sydney Harbour. Spearfishing is prohibited within this area.

One special interest group, the NSW National Parks Association (NPA), recently proposed the declaration of a marine and estuarine protected area (MEPA) at sites adjoining Royal

National Park. The limits of the proposed MEPA were divided into three areas, the Port Hacking estuary, the open ocean and the area within Bate Bay joining these two areas together (NPA 1991; see Fig. 15.2).

It is not within the brief of this study to provide a critique of the MEPA proposal. Insofar as the proposal to extract marine aggregate at Providential Head is concerned, however, this study has obtained detailed information against which the criteria may be applied more objectively to the proposed MEPA. In particular, a measure of the ecological significance of the sandy substratum off Royal National Park has been obtained by reference to other locations. Moreover, studies done by Geomarine (1993) allow the issue of shoreline stability and sediment mobility, which were important factors in the determination of the seaward boundary of the proposed MEPA (NPA 1991).

Much of the proposed MEPA is incorporated within Port Hacking, where there are already two aquatic reserves. Thus, many of the criteria apply only to the estuarine portion of the proposal. However, the MEPA would have as its eastern (i.e. seaward) boundary the 50 m bathymetric contour (NPA 1991), which would incorporate virtually all of the proposed extraction area at Providential Head. Conversely, the proposed extraction area fringes less than 25% of the shoreline of Royal National Park (Fig. 15.2).

The eastern ocean boundary of the proposed MEPA would, according to NPA (1991), protect the coastline from any alteration of the environment that could occur on the inner continental shelf. The selection of the 50 m boundary appears based on the following arguments:

1. Based on research on wave refraction into Broken Bay and the Wollongong coast, south of Royal National Park, Dr E. Bryant (University of Wollongong) recommended that extension of the marine boundary to approximately the 50 m contour would ensure protection of the seabed and existing beaches from alterations to seabed topography (NPA 1991).

2. The 50 m bathymetric contour would provide a buffer between the intertidal zone and nearshore waters, including important diving sites off Jibbon, Marley and Wattamolla from any "dredging, mining or pollution" of inshore waters (NPA 1991).

Four major questions that arise with respect to the marine aggregate and MEPA proposals. First, how worthy is the sand body, in terms of its biological characteristics, of being included within the MEPA proposal? Based on the studies done by The Ecology Lab and, as part of the Deepwater Ocean Outfalls study, by the Fisheries Research Institute, the sand body itself satifies few of the criteria adopted by NPA (1991).

Second, how valid is the assertion that alteration of seabed topography within the 50 m depth contour would enhance erosion of beaches and seabed mobility? Based on the detailed studies presented by Geomarine (1993), selection of the 50 m depth contour to ensure protection of the shoreline and seabed is, under the extraction plan proposed, irrelevant.

Third, is a buffer out to the 50 m depth contour appropriate for protecting the nearshore areas? Based on the studies of plume dispersion and the initiation of a 250 m buffer from fringing rocky reefs and shipwrecks under the proposed extraction plan, a buffer of several kilometres appears to be grossly excessive.

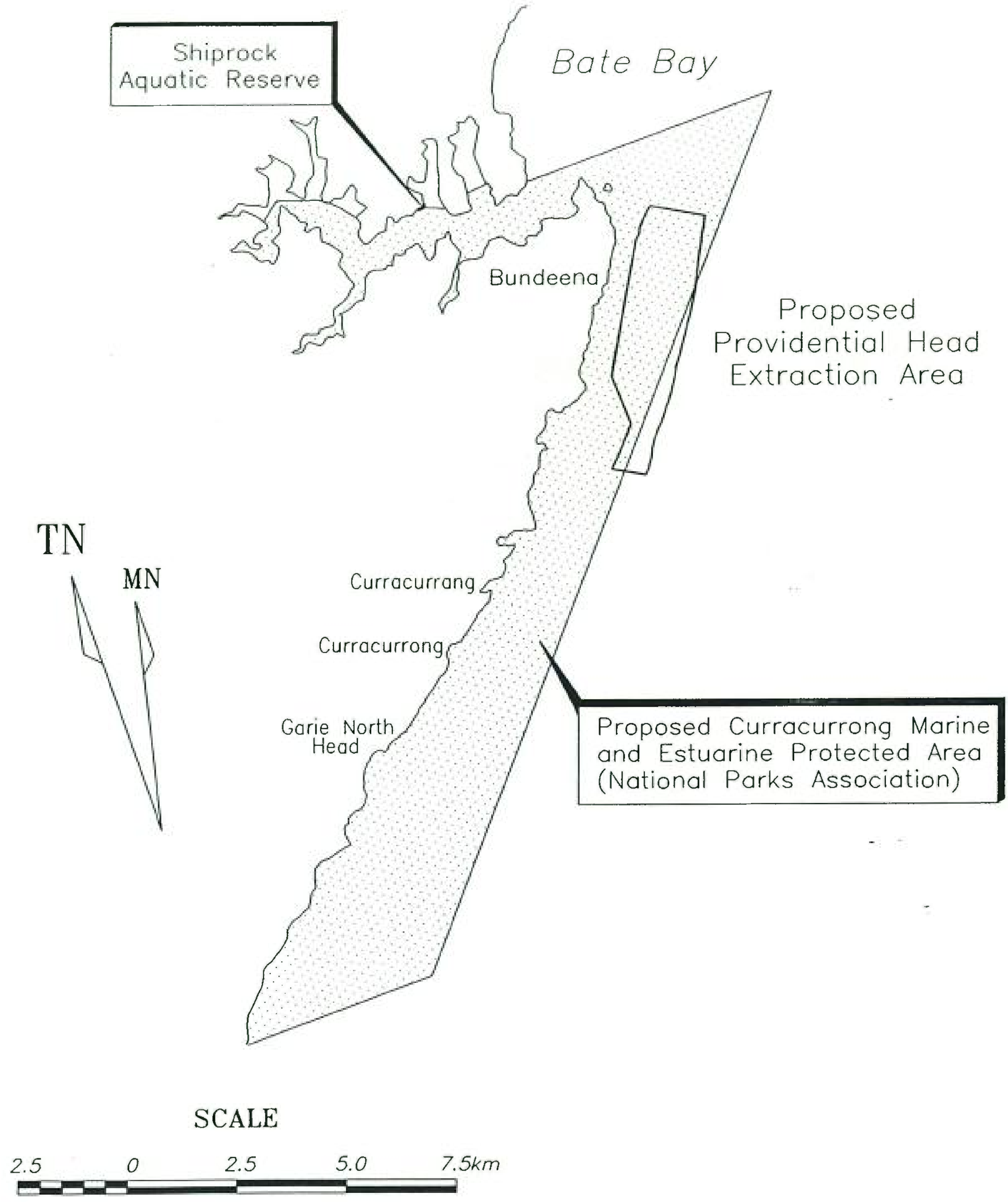
Fourth, given that the proposed extraction area at Providential Head fringes less than a quarter of the length of the coastline proposed for incorporation in the MEPA, in what ways could the extraction and MEPA proposals both be accomodated? The studies done by The Ecology Lab found that the sandy seabed off the Royal National Park supports similar assemblages to other areas between Botany Bay and Bass Point. The use of a portion of the seabed for extraction would leave large areas of similar habitat within the proposed MEPA undisturbed. Part of the monitoring programme initiated for the extraction operation would address this issue. Moreover, the information gathered as part of the monitoring programme in the region - both inside and outside the proposed extraction areas - is likely to be much greater than if extraction did not proceed. Thus, monitoring of the extraction operation would also provide monitoring of the MEPA.

These questions are addressed further in Part IV of the report.

15.5 CONCLUSIONS

There are significant areas of scientific research and education that should be considered in relation to the proposal to extract marine aggregate at Providential Head and Cape Banks. In particular, the Cape Banks Marine Scientific Research Area, administered by the University of Sydney, is opposite the proposed extraction area at Cape Banks. Also, there are monitoring stations for the deepwater ocean outfalls EMP near the Cape Banks area and near to and within the proposed Providential Head extraction area.

The future of the EMP for the deepwater ocean outfalls beyond 1993 is unclear. If the sampling locations near the proposed extraction areas are no longer required, then no potential for conflict between the extraction operation and the sampling locations for the EMP would arise. If monitoring is continued for the EMP, changes to the communities monitored caused by the proposed extraction operation may confound interpretation of outfall-related impacts. This could lead to adverse effects being attributed to the extraction of aggregate which may, if fact, have been caused by the outfall, and <u>vice versa</u>. The monitoring programme for the aggregate proposal should seek to distinguish these potential sources of impact (see Part IV of the report).



Source : NSW NPA (1991)

Figure 15.2
PROPOSED MARINE & ESTUARINE PROTECTED AREA ADJOINING ROYAL NATIONAL PARK, SHOWING PROPOSED PROVIDENTIAL HEAD EXTRACTION AREA

PART IV: ASSESSMENT AND MONITORING

CHAPTER 16. ASSESSMENT OF IMPACTS

16.1 INTRODUCTION

In this Chapter, environmental impacts associated with the proposal to extract marine aggregate at Providential Head and Cape Banks are considered under three broad categories:

1. Disturbance of the marine biota seabed and coastline as a consequence of the movement and suction of the extraction head;

2. Disturbance of the water column from the disposal of excess water containing fine-grained material; and

3. Disturbance from operations/accidents associated with the extraction vessel (e.g., noise associated with the vessel and extraction head).

Finally, the predicted impacts of the proposal are considered in relation to other users of the coastal resources, such as fishers and divers.

Issues associated with the assessment of impact of the proposal were discussed at a workshop sponsored by the Applicant in April 1992. This chapter draws upon some of the discussions held for the workshop and reported by Underwood (1992b). Professor Underwood's paper is reproduced in Appendix E, Volume II.

16.2 DISTURBANCE OF MARINE BIOTA IN RELATION TO THE SEABED AND COASTLINE

16.2.1 The Seabed within the Proposed Extraction Areas

16.2.1.1 Benthic Macrofauna

The passage of the extraction head over seabed would remove the upper layer of substratum over an area of 2.0-5.0 km^2 annually or 1 ha per trip each at Providential Head or Cape Banks (Tables 3.1 and 3.2). If approval is given for extraction at both areas, the number of trips to each area over a given period would be halved approximately, but the total period over which extraction occurred would be doubled. The following sections discuss the predicted effects of extraction over different spatial and temporal scales.

16.2.1.1.1 Small-scale, Short-term Responses

This section predicts the effects of the proposal over the scale of the track made by the extraction head and over periods of months following extraction.

Most of the living benthic organisms occur in the top 30 cm or so of the seabed, so the extraction would also remove most of the live benthos occurring under the track of the extraction head (i.e. up to about 1.7 m wide). Given the powerful suction generated at the extraction head, some benthic organisms, for example meiofauna which may occur within a floc just above the seabed, would be sucked into the extraction head from the side.

Some macrofauna could probably avoid the extraction head. For example, large, burrowing bivalves may be able to burrow beneath the extraction head, while active swimmers, such as some amphipods, may be able to swim away. Organisms such as penaeid prawns would probably be capable of swimming to avoid the extraction head, but they may, as an escape response, bury in the substratum, making them more vulnerable (Chapter 9). Groups such as polychaetes, ophiuroids and tube dwelling amphipods and tanaidaceans may not be able to avoid the extraction head. These organisms constituted a large proportion of the benthos in the study region (Chapter 8).

The time of day and occurrence of storms may also be a significant factor in determining the mortality of benthic invertebrates as a result of the extraction operation. For example, prawns may better avoid the extraction head at night, when they may tend to be more active on or above the substratum. Similarly, during storm activity (assuming that the extraction vessel were working), some organisms may be mobilised above the substratum (cf. Dobbs and Vozarik 1983) and hence may be more able to avoid the extraction head.

Section 8.3 examined the effects of storms on benthic infauna. During a relatively severe storm, the seabed would have been disturbed to a depth of 100 mm within the substratum at water depths to 70 m. Thus, natural mechanisms are known to cause disturbances of the seabed in the depth range of interest under the present proposal.

The findings of our study of macrofauna before and after a severe storm suggested that the storm's effects may have affected the biota to water depths of 70 m. The findings also suggested that assemblages living in shallower water may be more resilient to storm effects than those in deeper water. A similar response may occur following the extraction of marine aggregate.

Once an organism had been sucked into the extraction head, it would pass up the pipe and into the hopper of the extraction vessel. Some organisms would be returned to port with the aggregate. The remaining organisms would be returned to the sea with the excess water. These would probably include organisms which were physically small and had low biomass. Of these organisms, some would be killed by abrasion of the aggregate, change in water pressure or impact with the screens. Other organisms, such as small bivalves and gastropods, may survive this process and be eaten by fish and other animals when put back into the water or redispersed back to the seabed alive (where they may or may not survive, depending on whether they arrive at suitable habitat).

On the basis of existing information, it is not possible to quantify the extent to which benthic organisms would be able to avoid the extraction head or survive the extraction process. In the worst case, mortality of organisms within the path of the extraction head (and a smaller surface component sucked in from the sides) would approach 100%. It would be possible, as part of a monitoring programme, to investigate the true extent of mortality associated with the extraction operation. Experiments are currently underway to estimate the proportion of animals that may be returned to the sea with the return water (K. Lee, Metromix, pers. comm.). Experimental monitoring of the extraction operation would allow estimation of the loss of organisms from the seabed. Preliminary results indicate that many benthic organisms would be returned to the sea, where they may or may not survive.

The direct loss of organisms destroyed by the suction head may then lead to: 1) ecological changes such as changes in the structure of assemblages or changes in the sequences of recovery from natural disturbance (e.g. storms); and 2) net loss in productivity with indirect effects on fish productivity.

It is predicted that, under the proposal, impacts to macrofauna would be extreme but highly localised in space and time. This prediction is based on four factors: the scale of impact; natural turnover and the ability of macrofauna to recolonise cleared areas; the type of substratum remaining after extraction; and the small amount of settlement of fine materials back onto the seabed.

1. Scale of Disturbance

The areas of the seabed occupied by the proposed extraction represent only about 11% of the sandy habitat within a similar depth range in the Sydney region (MTM pers. comm.). Moreover, within the extraction areas, a large proportion (i.e. > 75%) of the area of the seabed would be undisturbed at any one time (Chapter 3, and below, Section 16.2.1.1.2).

2. Turnover and Recolonisation

The extraction operation would have a long return interval (Chapter 3) relative to the recolonisation rates of macrofauna, which are predicted to be of the order of 2-3 months (Section 8.4).

This estimate of recolonisation was based on an experiment done as part of the study and it is possible that recolonisation rates of disturbed areas may vary among taxa and through time. Recolonisation rates are unlikely to be similar for all taxa within macrobenthic assemblages. In the extreme short term, there may be a rapid influx of scavengers to the tracks left by the extraction head (Oliver and Slattery 1985). In the longer term, long-lived organisms such as large bivalves are likely to recolonise much less rapidly than short-lived organisms such as many amphipods and polychaetes (R.M. Warwick, pers. comm.).

It is possible that some of the larger, deep-burying organisms would be able to avoid the extraction head by burying deeply into the substratum. Also, recall that during the physical disturbance experiment some of the plots in which simulated extraction occurred still retained macroinvertebrates immediately after extraction, even in the plots extracted to 30 cm depth (Section 8.4).

It also appears that variability in benthic macrofauna within the extraction areas and reference locations varies naturally over time-scales of 2-6 months or even less (Chapter 8). Thus, it appears that there are already processes causing significant change, or turnover, in macrofaunal assemblages and populations. The changes, however, are not consistent among locations.

Recolonisation of disturbed areas would mainly be via two mechanisms: movement of organisms into the available space from adjacent areas and settlement of larvae or small juveniles dispersed from variable distances. The physical disturbance experiment suggested that, at the time of the experiment, small, disturbed plots were colonised largely by animals from adjacent areas.

3. Characteristics of the Substratum

The sediment exposed during extraction would, minus the living organisms, be the same as, or very similar to, that presently occurring on the surface of the sand body. A major impact of aggregate extraction in the North Sea is considered to be the exposure of a different substratum following extraction, such as removal of gravel to be replaced by sand or *vice versa* (e.g. Cressard 1975, de Groot 1979b). This is not the case in the present proposal.

It is possible, however, that there may be less organic matter in the exposed substratum. This may favour, to a certain extent, colonisation by filter feeders compared to deposit feeders.

4. Settlement of Fines

Resettlement of fines in the excess water returned to the sea would be very small, thus the potential for mortality of organisms due to smothering would be minimal. Geomarine (1993) estimated that the amount of sedimentation of fines on the seafloor from the return waters to be less than 1 mm per year.

This amount of settlement would have negligible effects on the biota of the sandy substrata for the following reasons. First, studies of the ability of macrofauna to withstand sedimentation found that many organisms can burrow through spoil material (Engler et al. 1991). Second, the ability to survive burial is greatly enhanced when, as in this case, the settling material is similar to that of the substratum. Third, the amounts of sediment re-settling on the seabed as a result of storm disturbance would often exceed the amounts settling as a result of the return of fines from aggregate extraction. Thus, it is expected that the benthic infauna would be adapted to this form of disturbance.

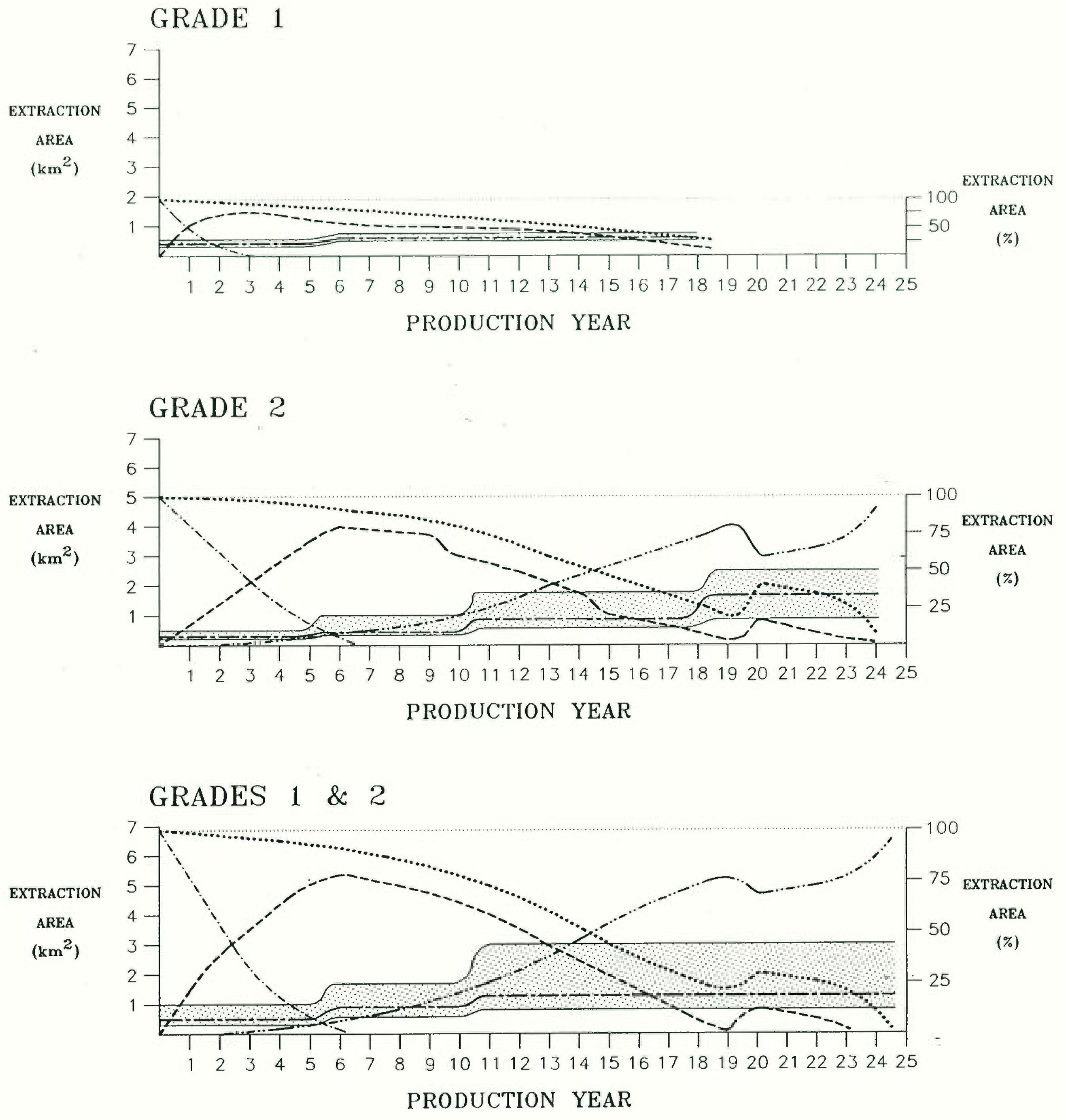
Poiner and Kennedy (1984) suggested that settlement of fines from dredging in Moreton Bay led to an increase in the production of benthic infauna. It is plausible that a similar effect would occur as a result of the present proposal.

16.2.1.1.2 Large-scale, Mid- to Long-term Responses

At any given time, large sections of the proposed extraction areas would not be disturbed. During the project, any patch of the substratum within the extraction area would be in one of four conditions: substratum which had never been disturbed by extraction; substratum which had been disturbed but would never be disturbed by extraction again; substratum which had not been disturbed for some time (nominally set at 3 months) which is predicted to have been largely recolonised; and substratum which had been recently disturbed and hence was in a state of recolonisation. The proportion of substratum in the entire extraction area exhibiting each condition would vary predicably through time (Figs. 16.1 - 16.3). At any one time, the total area occupied by the four conditions would equal the size of the extraction area.

The total area of marine aggregate resource would decrease relative to the total extraction area throughout the life of the project (Figs. 16.1 - 16.3). At Cape Banks, Grade 1 marine aggregate would be removed over approximately the first 18 or so years, whereas Grade 2 material would be extracted over the life of the project (Fig. 16.1, see also Chapter 3). At Providential Head, extraction of marine aggregate from water depths of <35 m would be concentrated only during the first decade of the project (Fig. 16.2). Thereafter, extraction would be confined more to deeper water.

If extraction were approved in both areas, extraction of Grade 1 aggregate at Cape Banks would be similar to that if extraction only in the Cape Banks area were approved (Fig. 16.3). The life of the extraction of Grade 2 at Cape Banks, and target



REFERENCE

SEA BED CONDITIONS

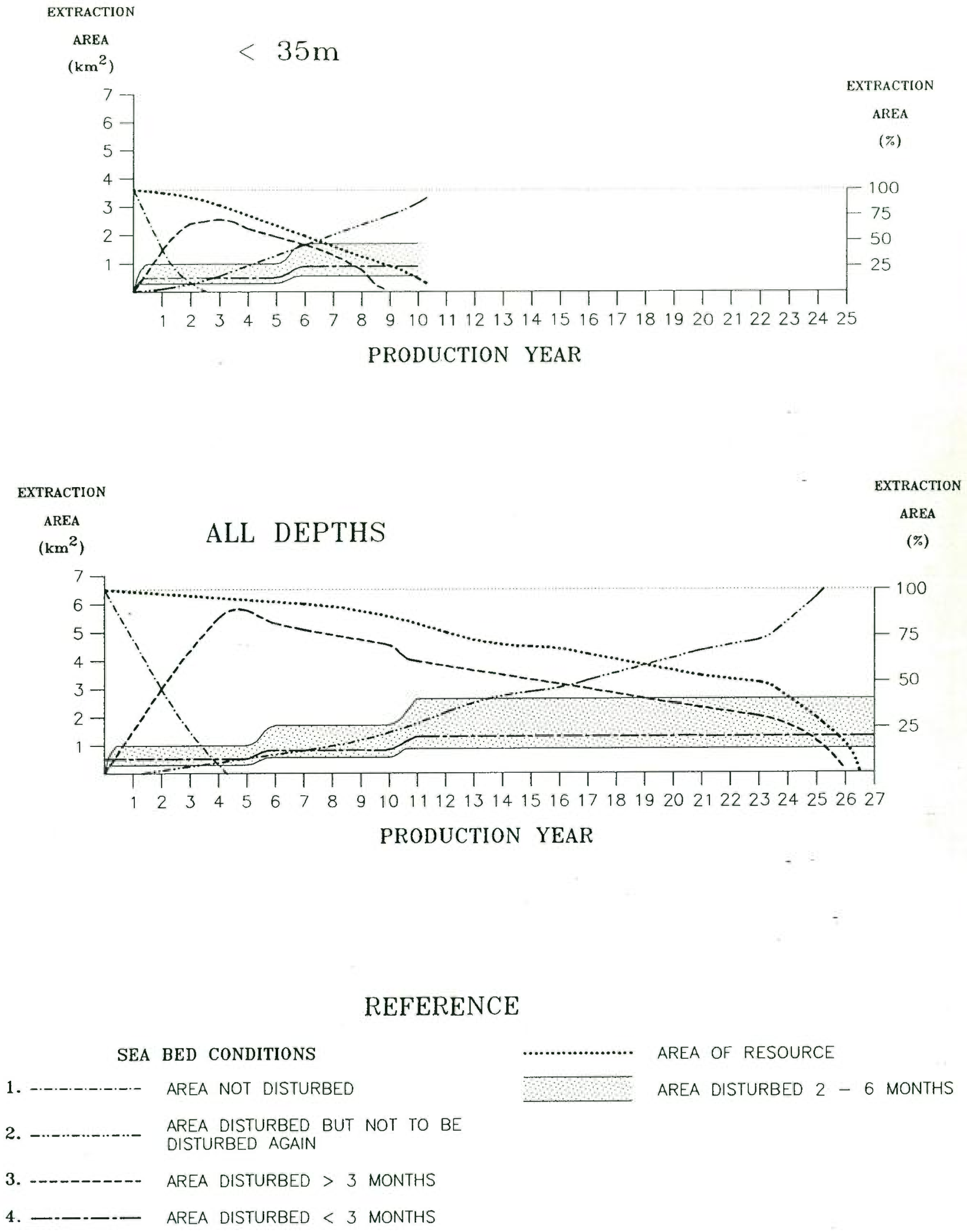
1. -·-·-·-·-·- AREA NOT DISTURBED
2. -··-··-··- AREA DISTURBED BUT NOT TO BE DISTURBED AGAIN
3. ----------- AREA DISTURBED > 3 MONTHS
4. —·—·—·— AREA DISTURBED < 3 MONTHS

·················· AREA OF RESOURCE

▨ AREA DISTURBED 2 – 6 MONTHS

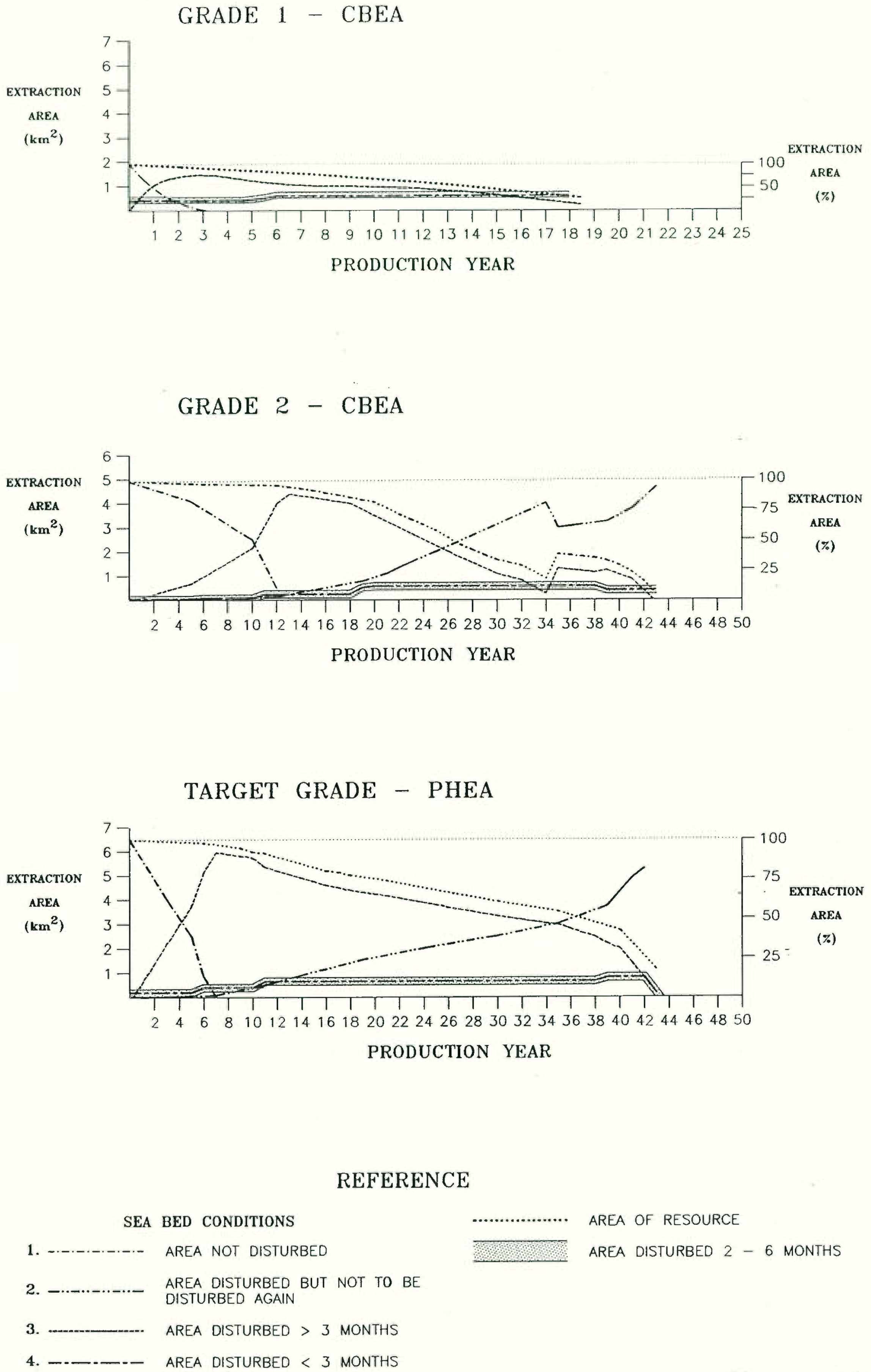
SOURCE : R.W.CORKERY & CO. PTY. LIMITED

Figure 16.1
AREAS OF DISTURBANCE : CAPE BANKS



SOURCE : R.W.CORKERY & CO. PTY. LIMITED

Figure 16.2
AREAS OF DISTURBANCE : PROVIDENTIAL HEAD


GRADE 1 - CBEA

GRADE 2 - CBEA

TARGET GRADE - PHEA

SOURCE : R.W.CORKERY & CO. PTY. LIMITED

Figure 16.3
AREAS OF DISTURBANCE

grade material at Providential Head, would increase to about 43 years (Fig. 16.3).

The first condition of the seabed would be substratum which had never been disturbed by extraction, but would obviously decrease to zero during the life of the project. At Cape Banks, it would take about 6 years for the extraction head to pass over all of the extraction area at least once (Fig. 16.1). At Providential Head, it would take a little over 4 years (Fig. 16.2). If extraction were approved in both areas, it would take about 12 years to disturb all of the Cape Banks area and about 7 years to disturb all of the Providential Head area (Fig. 16.3).

The second condition would consist of substratum which had been disturbed but would not be disturbed again. This condition would occur because the total area of the resource to be extracted would be diminishing gradually (Figs. 16.1 - 16.3).

The third condition would consist of substratum which had been extracted from over an intermediate period (i.e. after intervals of, say, greater than three months) and which is predicted to have been largely recolonised (Figs. 16.1 & 16.2). This condition would increase rapidly until all the extraction area had been passed over at least once (i.e. after about 6 y at Cape Banks and 4 y at Providential Head; or 12 and 8 years, respectively, for Cape Banks and Providential Head, if approval were given for both areas). Thereafter, the area of the seabed under this condition would decline roughly in parallel with the total area of the resource.

The fourth condition would comprise sediment that had been recently disturbed and which was being recolonised. This condition would increase rapidly at the beginning of the project and would then constitute a relatively constant proportion of the substratum until the rate of production increased. Then the proportion of recently disturbed substratum would increase to secondary and tertiary plateaux (Figs. 16.1 - 16.3).

The proportion of the seabed under condition 4 in either proposed extraction area, would always be less than 25% (i.e. <1.5 km²). Note, however, that we have also plotted the area disturbed over an interval of between 2 and 6 months, to provide some indication of the area disturbed taking into account the likely variability in recolonisation by macrofauna. Even assuming a recolonisation rate of 6 months, less than half of either extraction area would be in state of recolonisation at any one time. If approval were given to extract from both areas, the proportion of the seabed being recolonised at any one time would be much less than 25% of each area, even assuming a recolonisation period of 6 months (Fig. 16.3).

At the end of the project, the proportion of recently disturbed substratum would decline until three months after the end, when there would obviously be no more recently disturbed substratum.

There are two issues that must be considered for conditions 3 and 4. First, the rate of recolonisation has been estimated on the basis of the physical disturbance experiment, the reported literature and the large temporal variability observed during the field studies. It can only be verified for the actual extraction operation after monitoring of the operation has been done.

Second, the rate of recolonisation may change as the area of the resource diminishes. It was explained previously that settlement of furrows could occur by two mechanisms, movement of organisms from adjacent areas and settlement of larvae or small juveniles from inside and outside the extraction areas. As the resource area decreased and production levels increased, the amount of adjacent, undisturbed seabed available to provide a source of organisms moving into disturbed areas would decrease. Therefore, as the resource area decreased and the return time decreased, the rate of recolonisation due to migration of organisms from adjacent areas may also decrease <u>within</u> the diminishing resource area and a larger proportion would come from outside the area. The extent to which this occurs can only be determined as part of a monitoring programme.

It should be noted, however, that as the area of the resource would be diminishing through time, the overall area of disturbance would also be diminishing. In fact, the overall area of the seabed disturbed by the extraction operation would be very small compared to the amount of sandy habitat available within the Sydney region, which is estimated to be about 140 km^2.

At the end of the project, the seafloor would be up to 5 m deeper than at the start. Because the shelf sand body is about 30 m thick in the areas proposed for extraction, there would be no bedrock exposed by the extraction. The sediment itself would consist of very similar material in many places (where the target grade extended to depths of greater than 5 m). In other places, there would be a slightly finer grade of sediment exposed. It should be noted, however, that this finer material already occurs on the surface in some parts of the shelf sand body (Mining Tenement Management 1993).

The increase in depth in the proposed extraction areas may cause a change in the structure of benthic assemblages. This prediction is based on the findings in Chapter 8, which showed that depth was an important determinant of assemblage and population structure. Note that benthic assemblages in deeper water tended to be more taxonomically rich, with more animals, than in shallower waters.

In summary, the effects of the extraction of marine aggregate on benthic infauna may be considered at several spatial scales, ranging from the individual tracks of the extraction head to the whole of the resource area. Even at the scale of the resource area the amount of seabed disturbed would be small relative to the area of similar habitat which is available in the region. Several sources of information suggest that recolonisation of disturbed areas would be of the order of 2 to 3 months. For much of the project, return intervals are likely to be much greater than 3 months (Chapter 3). Moreover, it is highly unlikely that there would be any mortality of benthic organisms due to smothering from resettlement of fines from the water column, because of very low rates of settlement (< 1 mm per year), the type of material would be similar to that already in the substratum and there is already considerable settlement of sediment suspended by storms.

16.2.1.2 Demersal Fishes

During the extraction of marine aggregate, the extraction vessel and the extraction head would travel at a speed of about 1 knot (approx. 1.8 km h^{-1}). This is much less than the speed that many trawlers operate at and about half the speed at which trawling for this study was done (Chapter 9). Most fish and mobile invertebrates would avoid being sucked into the extraction head. Species which may not generally avoid the head include small, relatively sedentary fish such as small flatfish (e.g. <u>Lophonectes gallus</u>) and sand dwellers (Family Creediidae). The extent of impact to fish assemblages would therefore depend upon whether the benthic food source became limiting as a result of the loss of benthic macrofauna which was removed by the extraction operation, by the behavioural responses of fish to the extraction operation, or by changes to habitat or water quality.

Given the relatively small area of the seabed that would be recently disturbed (Figs. 16.1 & 16.2), and was therefore being recolonised, we predict that a reduction in food supply would not be limiting to fishes within the extraction area. If there were a shift in community structure to a predominance of smaller, rapidly-colonising organisms (as discussed in the last section), Warwick (pers. comm.) suggested that this could be beneficial to consumers such as fish, as the smaller animals are probably more readily eaten than larger, deeply-burying ones. Moreover, discharge of the excess water containing benthic macrofauna would probably may attract fish to the area. Visual observations of a discharge pipe returning a sand slurry laden with macrofauna at Wallis Lake (M. Lincoln Smith pers. obs.) supports this view.

Studies done in estuarine habitats have shown that most habitats are used by some species as nursery and or spawning areas (e.g. SPCC 1981c). It would be surprising if the extraction areas did not fulfil this rôle to some extent. None of the data collected, however, showed that the species cited preferred the proposed extraction areas to the reference areas studied (Chapter 9).

Moreover, there are no species from the inshore sand habitats known to have specific requirements for spawning grounds, as described for the Atlantic herring on gravel banks in the North Sea (Chapter 4).

From our field studies, the studies done by FRI (Chapter 9) and discussions held with local fishers, there was no evidence to suggest that the proposed extraction areas were significant spawning areas for fishes. It is likely, however, that the sandy habitat along the coastline is used as both a breeding and/or nursery area by some species. Length frequency data collected during the study suggest that angel sharks may use the shallow inshore areas throughout their life cycle, while other species, such as small-tooth flounder, red gurnard, redfish and john dory probably use these nearshore areas as spawning and/or nursery areas (Chapter 9).

In the long term, there would be an increase in the depth of water by up to 5 m. This may lead to a slight shoreward extension of the assemblages of fish sampled in the deeper parts of the proposed extraction areas. As these assemblages included species of economic value such as red spot whiting and tiger flathead, these changes may have some benefits to local fisheries.

In summary, as with the benthic infauna, the area of seabed that would be disturbed as a result of the proposal would be small compared to the available habitat in the region. Most fish would be able to avoid the extraction head while others may be attracted to the area to feed on organisms which had been disturbed by the extraction operation. The proposed extraction areas appear to be no more important as nursery areas than other areas in the region.

16.2.1.3 Fishes Associated with Reefs and Shipwrecks

No extraction would occur within 250 m of any rocky reefs or shipwreck that had been identified (in fact, the distance from any shipwreck would be much greater during the early years of the operation). Thus, there would be a buffer zone for reefs and shipwrecks. Buffers are recommended for dredging in NSW estuaries, for example, a buffer of 50 m is recommended between dredging and seagrass beds and 30 m between saltmarshes and mangroves and dredging operations (Pollard et al. 1991).

Russell (1975) observed that most reef fish rarely stray beyond visual contact with reefs (e.g. < 20 m). In NSW, the boundary between reefs and sand has been identified as being important for settlement of reef fishes from the plankton (Lincoln Smith et al. 1988, 1990), but reef fish have rarely been observed more than a few metres away from reefs (M. Lincoln Smith, pers. obs.). It is possible, however, that some nocturnal fish may move away from reefs to forage over sandy areas at night, although the extent of any such movements is unknown.

In summary, buffers are proposed between the extraction of marine aggregate and reefs or shipwrecks. This is in accord with the management guidelines in NSW estuaries, although the distance of 250 m proposed by the Applicant is much greater than any buffers recommended by NSW Fisheries between dredging or extraction and sensitive estuarine habitats. Without any precedent, it is impossible to decide accurately what the optimum size of the buffers should be. The proposed buffers, however, would leave a wide strip of sand undisturbed by extraction which could be utilised by reef organisms. An important part of any monitoring programme would be to assess the optimal size of buffers.

16.2.2 Changes to the Marine Biota of the Shoreline

16.2.2.1 Beaches

A large part of the study done by Geomarine (1993) considered the effects of the proposal on the coastline and on movement of sediment on the seabed. Their studies concluded that there would be no measurable increase in coastal erosion (or indeed, any measurable changes to beaches) as a result of the proposal. It is therefore concluded that, if the physical environment of the coastline is unlikely to change as a result of the proposal, it is highly unlikely that any measurable effects on biota of beaches would occur.

16.2.2.2 Rocky Shores

Geomarine (1993) predicted that there would be no measurable change in wave energy on rocky shores. In particular, the coastal studies modelled the effects of the proposal on the rocky shores of the Cape Banks Scientific Marine Research Area and Geomarine (1993) concluded that there would be no measurable changes to coastal processes there.

One issue of concern raised (see Chapter 4) was that the extraction operation would expose reef or mud areas (see also Carey and Talbot 1980). The physiography of the sand bodies considered for extraction suggests that reefs or other substrata would not be exposed as a result of the extraction operation.

16.3 SEDIMENT PLUMES

The return of excess water and fine sediments from the extraction operation would form a plume in the receiving waters. The extent and fate of this plume was discussed by Lawson and Treloar (1993) and Geomarine (1993), and the potential for release of any contaminants during this process was discussed investigated by Pollution Research (1993).

Excess water would be discharged through numerous ports at high speed, similar to the discharge of sewage effluent through the diffuser ports in deep water off Sydney (Lawson and Treloar 1993). The return of excess water via the diffusers would be modelled at depths of about 12-15 m (Lawson and Treloar 1993). In most dredging and estuarine extraction operations done in Australia, discharge of excess water occurs at the surface of the water, where the plume is most visible. The following subsections discuss the potential effects of the plume on the water column, the sandy seabed and on nearby reefs and shipwrecks.

16.3.1 Effects in the Water Column

Two plumes could be associated with the extraction operation, one generated as a result of the discharge of excess water returned to the ocean, the other generated as the extraction head passes along the seabed. Because of the strong suction generated at the extraction head, the plume near the head would be negligible (Lawson and Treloar 1993). This is not discussed further.

According to Lawson and Treloar (1993), plumes from successive trips to the extraction areas would be very unlikely to merge. Even when the extraction vessel had two passes on the same run, the plumes are predicted to never come closer than 200 m from each other (Lawson and Treloar 1993). This differs from static dredging operations, where a continuous plume may be generated.

The turbidity of the plume associated with extraction (Lawson and Treloar 1993) would be initially greater than the natural background for coastal waters off Sydney (EPA data, cited in Pollution Research 1993). At the outlet pipe, the concentration of suspended fines may approach 9,000 mgL^{-1}, but this would only represent 0.01% or 0.005% of the volume of water occurring over the proposed extraction area at Cape Banks or Providential Head, respectively (Lawson and Treloar 1993). Thus, the plume would occupy only a very small portion of the water volume of the proposed extraction areas.

With increasing distance from the extraction vessel and increasing time after discharge, the plume would sink and disperse. Using diffuser ports, dispersion would be very rapid. Within 35 m of the discharge points the plume would become diluted by a factor of 18 and there would be a dilution of the plume to levels of suspended solids of 9 mgL^{-1} or less at a distance of 1.5 km behind the extraction vessel (Lawson and Treloar 1993). According to Lawson and Treloar (1993), plumes would impinge upon the coastline very rarely. If they did, concentrations there would be less than 5 mgL^{-1} in all parts of the plume (Geomarine 1992). These levels are approaching background levels that may occur of Sydney's coastal reefs (EPA data cited in Pollution Research 1993). Similarly, lawson and Treloar (1993) concluded that the plumes would never pass directly through the s.s. Woniora, s.s. Tuggerah or s.s. Undola shipwrecks.

As identified from the literature (Section 4.1.2.2), plumes generated as a result of the return of excess water could have the following general effects:

1) Reduction in primary productivity due to reduction in light intensity or changes to spectral quality, which could affect organisms within the plankton as well as macroalgae on reefs.

In comparison with dredging, plumes associated with the extraction of marine aggregate typically are not problematic, because of the low levels of fines generally present in the resource (Packer 1987).

Due to the relatively rapid dispersal of the plume over a large area and the size of the coastal water body compared with that of the plume, it is unlikely that there would be detectable differences in primary productivity as a result of the extraction operation, except possibly on very small spatial and temporal scales. This conclusion was also reached by Chan and Anderson (1981), in predicting the effects of discharge of turbid water from the mining of manganese nodules in the equatorial Pacific. Moreover, subsurface release of the plumes would expose less of the water column to turbid water, thus further reducing the potential for impacts to the plankton. Recall that phytoplankton, however, may occur throughout the water column (Chapter 7), thus there may be some, albeit very small-scale, effects on phytoplankton regardless of the depth of discharge.

2) Increases in primary productivity caused by the release of nutrients into the water column. Pollution Research (1992) found that there would be little increase in the concentrations of nutrients as a result of the plume. Thus, there would probably be no detectable increase in primary productivity arising from increased concentrations of nutrients.

3) Increased potential for bioaccumulation of contaminants released from the sediment. Elutriate testing suggested that there would no significant release of contaminants from the plume into the water column (Pollution Research 1992).

4) Clogging of sensitive feeding and breathing organs by fine particles of sediment. Very high concentrations of suspended materials are required before gills and other sensitive organs become clogged (e.g. Moore 1977; Hirota 1981; Matsumoto 1984; Jokiel 1989; Engler et al. 1991). Such effects may occur at the highest concentrations of the plume (i.e. within a few metres of the discharge ports), but would be very limited in space and time.

An example of the effects of suspended solids on fish is provided by Jokiel (1989), who tested the effects of several types of suspended solids to the mahi mahi, Coryphaena hippurus (Coryphaenidae). This species is marine and pelagic, and considered to have very delicate larvae (Jokiel 1989). Four aspects of the response of mahi mahi to suspended solids were examined: egg mortality and normality of larvae at hatching; larval mortality; larval feeding; and larval behaviour. Concentrations tested were from 0 mgL^{-1} (i.e. a control treatment), 500, 1000, 4000 and 8000 mgL^{-1}. No egg mortality was observed in any of the treatments when eggs were exposed for 24 h. After 96 h exposure, 10% of the eggs in 8000 mgL^{-1} had died, but 5% of the eggs in the control treatment had also died. None of the surviving eggs in any of the treatments was considered to be abnormal after 96 h exposure. Mortality of larvae exposed to very high concentrations of suspended solids was also very low. For example, larvae exposed to spoil from harbour dredging for 2 h at 8000 mgL^{-1} showed 11% mortality, compared with 8% mortality for the control treatment.

In the context of the present proposal, these findings suggest that mahi mahi present in the proposed extraction areas may show a small effect at the discharge ports itself, but there would be no measurable effect within tens of metres, nor after the vessel had left the extraction areas on its return trip. Given the likely sensitivity of mahi mahi to stress (Jokiel 1989), it is probable that many local coastal species would be at least as tolerant as the mahi mahi.

5) Interference with migratory patterns of fish, invertebrates (e.g. prawns) and marine mammals. In this case, migration needs to be considered both vertically (through the water column) and horizontally (along the coast).

Jokiel (1989) noted that feeding by larvae was affected by high concentrations of suspended sediments. He argued that even over short time periods this could contribute to mortality of fish larvae. He also noted, however, that larvae tended to migrate vertically away from the sediment plume. Zooplankton would be able to migrate above or below the plume which, at 15 m depth, would be < 10 m thick (Lawson and Treloar 1993). Even if this prediction were incorrect, the scale of the plume relative to the receiving waters suggests that the effects on the distribution and abundance of zooplankton would be negligible.

There are few data on the effects of plumes on the horizontal migration of aquatic organisms. Insofar as the plume would be relatively small compared with the receiving waters, that it would disperse relatively rapidly and that turbidity along the Sydney coastline may often be highly variable due to plumes associated with runoff from estuaries, it is predicted that migrations of aquatic organisms would be unaffected by extraction of aggregate.

Changes to water clarity as a result of suspended solids may affect feeding in seabirds (Moore 1977). It is unlikely that there would be any significant effects to bird feeding as a result of the plume due to the relatively small size of the plume. Moreover, subsurface disposal of the excess water would remove any plume from surface waters and well below the depths at which most birds occurring in Sydney's coastal waters feed.

6) Effects on fishing and diving activities (see Section 16.5).

16.3.2 Settlement of Fines onto Sandy Substrata

Lawson and Treloar (1993) estimated that, in the worst case, the maximal annual average siltation on the seabed associated with settlement of fines would be < 1 mm of sediment deposited as a result of extraction at either of the proposed extraction areas. Given the very small amount of settlement of fine sediments, the fact that the settling fines would have been derived from the site (cf. Engler et al. 1991) and that the Sydney coastline has a relatively high energy (Geomarine 1993), it is predicted that there would be minimal effects associated with the settlement of fines onto the sandy substrata of the proposed extraction areas (see also Section 16.2.1.1.1).

It is further predicted that the long term fate of the fines within the plume would be to settle in an energy environment which already experiences natural settlement of similar-sized particles, namely, further offshore in the mid-shelf region (Lawson and Treloar 1993).

16.3.3 Rocky Reefs and Shipwrecks

Sediments from the plume may settle on reefs or shipwrecks adjacent to the proposed extraction areas. There is a growing body of evidence suggesting that reefs in central NSW are subjected to natural sedimentation, even deep reefs (e.g. to 60 m) (Jones 1977; Roberts and Henry 1992; Roach 1992). Moreover, a recent study found that it was only after massive sedimentation on a reef in the Sydney region that macrobenthos and fish showed a measurable change compared with the reef prior to the disturbance and with several control sites (Lincoln Smith and Smith in press). In this case, over 60,000 m^3 of spoil (consisting of particle sizes ranging from fines to boulders) were dumped on a reef over 3½ years (Lincoln Smith and Smith in press).

According to Lawson and Treloar (1993), the large turbulence associated with the nearshore area suggests that there would be very little settlement of silt on shallow reefs. Deeper reefs, however, may show slightly more sedimentation.

McLeod (1993) noted that the loss of encrusting organisms from the hull of an iron shipwreck may lead to increased corrosion of the exposed parts and therefore an increased the rate of deterioration. Thus, it is possible that the s.s. Tuggerah and s.s. Woniora, in particular, may be subject to increased deterioration if the extraction operation were to cause the loss of encrusting organisms on the shipwrecks. Increased deterioration of these wrecks would then reduce the diving amenity and may reduce their effectiveness to function as artificial reefs.

Given the very small degree of sedimentation likely to occur and the prediction that there would be no increased scouring around the edges of the shipwrecks as a result of the proposal (Geomarine 1993), it is unlikely that there would be significant impacts to the biota of shipwrecks.

According to Lawson and Treloar (1993), release of the plume via discharge ports at an average depth of 15 m below the water surface would prevent the plume passing directly through any of the shipwrecks near the proposed extraction areas. If the plume were released 10 m above the seabed anywhere at Cape Banks, it would never directly pass through the s.s. Woniora (Lawson and Treloar 1993). At Providential Head, it would be possible to vary the height of the discharge to minimise the chances of the plume impinging on the s.s. Tuggerah. It is possible, though unlikely, that the plume could, after passing out of the extraction area, be transported back through a shipwreck by changing currents. By the time this occurred, however, the plume would have been significantly dispersed and probably have suspended solids within the range observed naturally (D. Treloar, pers. comm.).

16.3.4 Marine Mammals, Marine Reptiles and Seabirds

The relatively small size of the plume, subsurface discharge and rapid dispersal and dilution of the plume associated with excess water suggest that there would be minimal effects on marine mammals, marine reptiles and seabirds.

16.3.5 Predicted Effects of the Discharge of Excess Water on Marine Biota

In considering the fate of the excess water associated with the extraction of marine aggregate, the Applicant has considered a number of innovative design options which address the types of impacts on marine organisms that have been reported previously in the literature. These include subsurface disposal of the plume and discharge via a series of diffusers, similar to the principle adopted for Sydney's deepwater ocean outfalls.

Given that the amount of fines would be relatively small compared to the amount of aggregate extracted, that the receiving waters are vast compared to the amount of water discharged, that the water could be discharged at depths well below the surface and via a series of diffuser ports, and that all of these factors would combine to cause the rapid dispersal of the plume, it is predicted that there would be negligible effects from the excess water on marine biota.

16.4 DISTURBANCE FROM OPERATIONS OR POTENTIAL ACCIDENTS ASSOCIATED WITH THE EXTRACTION OPERATION

16.4.1 Noise

No seismic testing or general blasting would be required for the proposal, so that noises would be limited to the day-to-day running of the extraction vessel, which is similar to many other coastal vessels, and the generation of suction to obtain the aggregate slurry (Corkery 1993).

Heggie (1993) examined the levels of noise likely to be associated with the operation of an extraction vessel and extraction head and reviewed the literature on the effects of noise on marine organisms. A distinction was made between the noise of the extraction machinery and the vessel. The noise propagated underwater by dredges is mainly of low frequency (20 Hz - 1000 Hz) due to the strong tones associated with the rotating machinery on board (Heggie 1993). An extraction vessel extracting marine aggregate would emit continuous, relatively constant noise. Noise would decrease with distance, but some noise may be weakly detectable up to 20 km away (Heggie 1993). In the Sydney region, which has extensive shipping, the noise of dredging machinery may be attenuated by the background of other shipping noises.

Heggie (1993) concluded that the noise of an extraction vessel steaming to and from the extraction area each day would be unlikely to cause any significant change in existing ambient underwater noise levels.

Heggie (1993) cited references which show that fish may be repelled or attracted by underwater noise. Similarly, studies with marine mammals showed that inter- and intra-specific differences occurred in response to noise. Hazard (1988) cites studies in which it was concluded that a 20 dB increase in underwater noise could cause a tenfold reduction in marine mammal communication range. She stressed, however, that the frequency at which sounds are transmitted, in addition to the volume of the sound, may be critical in disrupting behaviour of marine mammals. For example, Hazard (1988) found that outboard motors, especially when operated at high speed, had the greatest potential for interfering with communication and echolocation of Beluga whales.

Heggie (1993) concluded that, due to the relatively high density of shipping activity near the proposed extraction operations and the route to and from port, there are always likely to be other vessels present within the possible zone of influence or audibility of the extraction vessel. It is therefore predicted that noise from the extraction vessel is unlikely to change significantly existing underwater ambient noise conditions (Heggie 1992).

16.4.2 Vessel Movements and Potential Accidents

While travelling to and from the extraction area(s), the extraction vessel would move at speeds of about 12 knots and would behave like many other vessels of similar size operating in the coastal waters off Sydney. During extraction, the vessel would be travelling slowly enough (i.e. about 1 knot) that most animals, particularly marine mammals, reptiles and seabirds, would be able to avoid the vessel. Moreover, many of these animals are most common in waters further offshore (Chapter 12).

One important exception is the southern right whale, which migrates northwards along the NSW coast to calve, travelling as far north as Sydney. Another exception is the humpback whale which migrates along the NSW coast, but usually further offshore than the proposed extraction areas. These animals, like all marine mammals, are protected by commonwealth and state laws and it would be the responsibility of the Applicant and the captain of the vessel to avoid any disturbance to them.

As with any seafaring vessel, it is possible that there could be an accident or loss of the vessel. The discarding of wastes, occurrence of spillages, etc. all have the potential to cause impacts. The extent to which they are likely to occur, however, can be moderated by management practice.

16.5 EFFECTS ON OTHER USERS OF THE AREA

Apart from the potential for alteration to natural communities, there is also the potential for conflict with other users of the coastal areas considered for extraction of marine aggregate (Chapters 14 and 15). These are discussed below.

16.5.1 Commercial Fishing

Although there is some commercial fishing within or near the proposed extraction areas, much of this was relatively minor compared with fishing in deeper water or along other parts of the coast (Chapter 14). Possible exceptions to this may be trap fishing for fish and crayfish and diving for abalone. Otter trawling has the greatest potential for being disrupted by the extraction operation, yet it is rarely done at Providential Head and Cape Banks.

Despite this, there is the potential to manage the extraction operation to avoid or minimise any potential conflict in the future.

16.5.1.1 Otter Trawling

The literature from overseas indicates that trawl fishing and the extraction of marine aggregate can operate together (see Chapter 4). For example, the extraction operation would employ the "strip" rather than the "pit" method of extraction (Chapter 4, Section 4.1), which would not render the seabed unsuitable for trawling and therefore would not remove a potential fishing ground.

ANON (1978) reported that trawlers often worked in the tracks of extraction vessels off the United Kingdom. It was argued that the disturbance of the seabed suspended benthic organisms in the water column which attracted fish to the area. Another possibility is that the turbid water from the plumes generated by dredging may assist the trawlers, as it is believed that fish are less able to avoid nets in turbid water. Given the rapid dispersion of the excess water that is achievable, however, it is likely that the plume associated with the extraction vessel would make little difference to trawling activities.

16.5.1.2 Trap Fishing

Trap fishing is restricted to reefs and there would be a buffer of at least 250 m between any trapping and the extraction operation. Moreover, traps are usually marked by buoys and so would be readily avoided by the extraction vessel. It is unlikely that there would be direct conflict between trap fishers and the extraction vessel.

16.5.1.3 Abalone Diving

Diving for abalone is done on shallow reefs (mostly less than about 10 m deep) and therefore would be well inshore of the 250 m buffer between the extraction operation (25-70 m) and reefs. However, because the collection of abalone relies on vision, it is possible that plumes impinging on the coast could affect the efficiency of collection. Given the very intermittent nature of the occurrence of plumes on the shoreline, it is predicted that the extraction operation would not prevent the collection of abalone, but that, on very rare occasions, the efficiency of collection may be reduced.

16.5.2 Recreational Fishing

There is the potential for significant conflict to arise between anglers and the extraction operation. Recreational fishing is common in both proposed extraction areas because sites are readily accessible from launching ramps in Botany Bay and Port Hacking and, according to discussions with local fishers, the proposed extraction areas include sites that are important for certain fishes, such as flathead (Chapter 14).

The greatest potential for conflict would be in the navigation of the extraction vessel and recreational craft. Fishers may also object to viewing a large vessel working nearby, although large ships passing into and out of Botany Bay are a regular feature of the seascape at Cape Banks. These potential conflicts could be minimised by not extracting aggregate at peak recreational times, such as weekends and public holidays. It is therefore recommended that, if the extraction operation proceeds, no extraction be done on weekends until the extent of any putative conflict between recreational fishers and the extraction operation is determined.

16.5.3 Diving

The effect of the proposed extraction operation should be considered separately for diving on shipwrecks, such as the s.s. Tuggerah, and diving on shallower reefs. The extraction plan has been formulated so that excess water from the extraction process would be returned to the ocean at an average depth of about 15 m. Plumes may pass over the wreck, but it is most unlikely that they would pass through the wreck. In the rare case where the plume passes through the wreck, it would have had to travel out of the extraction area, been subject to a change in the currents and then pass back through the wreck. Thus, the plume would be very dilute (D. Treloar, pers. comm.).

A plume generated from extraction at Providential Head would mostly pass over the s.s. Tuggerah at a depth of 14-20 m below the water surface. It would be < 10 m thick and would take from 4 to 60 min to pass over the wreck, depending on the current at the time and the location within the extraction area that the vessel was working (D. Treloar, pers. comm.).

The s.s. Undola is located further to the south of the s.s. Tuggerah. Return of the excess water at 15 m depth would make it most unlikely that the plume would pass through the s.s. Undola, but it could pass over the wreck. According to D. Treloar (pers. comm.), the plume would be very dilute by the time it passed this wreck. It would be at a depth of 15-20 m below the water surface and it would be < 10 m thick, but with levels of suspended solids approaching background.

If divers encountered a plume, they would pass through it in the order of 10 to 15 seconds as they descended and 12 to 24 seconds as they ascended, following normal SCUBA diving guidelines for ascending and descending. According to D. Treloar (pers. comm.) there would be a slight reduction of light beneath the plume, but it is not possible to predict its extent. As the divers ascended, they may stop to decompress. These stops are typically held at depths of 9 m, 6 m and/or 3 m below the surface, which are above the predicted depth of the plume.

Plumes associated with the extraction operation would impinge infrequently upon the coastline (Geomarine 1992). The mechanisms of upwelling, downwelling and turbulence on the coast would disperse and dilute the plume. By using a series of ports for the return of excess water, the plume would never have concentrations of suspended sediments above 5 mgL^{-1} after initial dilution (Lawson and Treloar 1993). This may be visible to a diver, but is approaching levels which may be found for waters off Sydney.

According to D. Treloar (pers. comm.), it would be very difficult to predict the duration that the plume would persist on the coast, but it could persist over several hours and up to about one day. Timing of the extraction operation to occur outside weekends and public holidays would reduce but not eliminate the potential for recreational divers to dive in waters over shallow reefs which contained some of the fines from the extraction operation.

In summary, the level of enjoyment associated with diving relies largely on the clarity of the water. Creation of a turbid plume from extraction of marine aggregate could reduce the pleasure and safety of diving. The extraction operation has been developed so that effects to divers visiting shipwrecks should be eliminated in most cases and minimal in the more rare event of divers passing through a plume. The plumes are expected to impinge rarely upon shallow rocky reefs, and turbulence and other processes associated with the nearshore zone should ensure that the plume is rapidly diluted. Any public concerns about the effects of the extraction operation on diving may be mitigated by the avoidance of dredging on weekends and public holidays until monitoring of the plume provides empirical data on the fate of the plume under varying conditions; and by the initiation of a code of practice whereby divers are informed of the schedule of the extraction vessel.

16.5.4 Research and Conservation

The development of the extraction plan and the modelling of the physical impacts of the proposal has, in part, been done to assess and minimise any effects on the Cape Banks Marine Research Area. On this basis, it is considered, that this area would not be affected by the extraction proposal.

Some of the research being done as part of the environmental monitoring programme for the deepwater ocean outfalls is close to or within the proposed extraction areas. If the monitoring ends with the current contract, in mid-1993 (or even if it were extended up to the time the extraction began), there would be no conflict between the EMP studies and the extraction proposals. If, however, monitoring of the effects of the outfalls continued beyond the commencement of extraction, there would be a strong possibility that the extraction could affect the results of the monitoring.

The outer boundary specified by the draft proposal for a marine extension of Royal National Park (NPA 1991) currently includes most of the proposed extraction area at Providential Head. Recall, however, that the proposed extraction areas incorporates only about a quarter of the proposed park extension, is limited to only a single demersal habitat - sandy substratum - which is very common elsewhere along the coast (including other parts of the proposed extension) and avoids, by at least 250 m, any rocky reefs or shipwrecks. Moreover, if plumes were found to impinge upon the reefs or shoreline, management practice could be altered to minimise this occurrence. On the basis of these considerations, it is concluded that the proposal to extract marine aggregate could be accommodated within a proposal to extend Royal National Park to adjacent marine waters.

One positive benefit of accommodating the two proposals is that there would be a large information base generated on the biota of the area, as part of the monitoring programme for the aggregate extraction, which would realistically not be generated elsewhere (with the possible, and limited, exception of the monitoring for the deepwater ocean outfalls). This information would not be limited to the extraction area alone, as there would be a need to study control or reference areas (see Chapter 18). Thus, information may become available to NSW NPWS for education and long term understanding of the marine processes in the area.

16.6 CONCLUSIONS

16.6.1 Distinction Between the Proposal and Terrestrial Mining and Typical Dredging Operations

The extraction of marine aggregate under the present proposal is very different from other dredging operations and from terrestrial mining activities. Underwood (1992b) drew a very clear distinction between these activities using the following points:

> "1. The time-scale of disturbances for the amount of material to be removed is much longer, making the rate of disturbance much smaller than any previous Australian project.
>
> 2. There is no insertion of toxic materials or wastes, as in most terrestrial mining and extraction. This is important, because it means that only physical

> disturbances to the habitat matter. These are small individually (removal of 20-30 cm sand in an approximately 1 m wide strip at each pass).
>
> 3. The material left after each dredging is essentially identical (physically) to the original habitat. This is, again, unlike any terrestrial (and most marine dredging) extractions.
>
> 4. The recovery of supplies of food in the habitat is expected to be very rapid (if not immediate) because food is almost exclusively from planktonic microscopic plants. The water-column producing these will not be affected in any way that would alter the distribution of such food-supplies.
>
> 5. The rates of mobility of adult benthic organisms in soft-sediments are such that considerable, rapid immigration into disturbed patches will occur throughout the project. larval recruitment of planktonic offspring is the major mode of reproduction of marine organisms. Breeding populations outside the area will continue to be extensive.
>
> 6. No rare or endangered species are known from benthic marine habitats in coastal waters of New South Wales. This is largely the case throughout the world, which is a major difference from the situation in terrestrial and riverine habitats." (Underwood, 1992b, p.2).

The proposals to extract marine aggregate at Providential Head and Cape Banks would cause disturbances to some marine assemblages and have the potential to affect the activities of other users of the area, specifically some recreational fishing and diving and some of the research done for the deepwater ocean outfalls monitoring programme. The plumes generated by the extraction process would be intermittent, pass from the area rapidly and are unlikely to merge. It is predicted that plumes would have little impact on biota, particularly if discharged at a depth of 15 m below the surface of the sea.

16.6.2 Significance of the Proposed Extraction Areas

The areas proposed for extraction have not been found to be outstanding in their marine communities compared to control or reference areas. They also represent only a very small proportion of this type of habitat within the Sydney region and NSW. Reviews of the literature and an experiment on recolonisation of disturbed areas suggest that the extraction "tracks" will be rapidly recolonised.

16.6.3 Other Users

There are some areas where conflict with current users of both areas proposed for extraction may occur. These include recreational fishing over the sand bodies, diving and possibly research associated with the deepwater ocean outfalls. Trap fishing, linefishing over reefs and otter trawling are predicted to be little affected by the proposal. In most cases, potential conflicts could be minimised by appropriate management practice.

Another area of potential conflict is with respect to the operation of Sydney's deepwater ocean outfalls and the monitoring programme studying the effects of the outfalls on the marine environment. Given that both proposed extraction areas are to the south of the Malabar outfall, it is unlikely that the extraction operation would directly interfere with the operation of the outfall and its diffusers. Also, the effect of the extraction proposal on movement of sediment is predicted to be negligible (Geomarine 1993), thus transport of sediments and currents are unlikely to be affected around the outfall. Finally, it is possible, but we consider unlikely, that there would be combined effects of the outfall and the extraction operation on marine ecology. This possibility could only be examined as part of a monitoring programme.

With respect to the monitoring of the deepwater ocean outfalls, conflict may arise if the research is extended, in its present form, beyond 1993.

16.6.4 Legislation

As described in Chapter 4, the proposal to extract marine aggregate is governed by State and Commonwealth legislation and, in the case of marine mammals, avifauna and marine reptiles, by international agreements. These are discussed broadly by Corkery (1993); here we discuss the implications of the proposal in terms of two important pieces of legislation, the NSW Fisheries and Oyster Farms Act and the NSW National Parks and Wildlife Act.

Under the NSW Oyster Farms and Fisheries Act, there are four main areas which should be complied with. These relate to obstruction of fishing grounds, dispersal of school or shoal fish, interference of fishing operations and placement of liquid or solid matter that could affect fish.

1. Obstruction of fishing in recognised fishing grounds. The proposed extraction would occur within fishing grounds in NSW waters, although the significance of these grounds to commercial fishers is small (Chapter 14). Nevertheless, the method of extraction, which employs the strip rather than the pit approach (Chapter 4), would not adversely affect the operation of trawl nets. Furthermore, the buffer of 250 m between reef and any

extraction will minimise the potential for the extraction vessel or the extraction head to interfere with fish traps.

2. Dispersal of fish. The movement of the extraction head over the substratum would cause most fish to move away to avoid the head. We predict that these movements would be at a very small scale, hence they would be insignificant. No seismic testing or blasting would be required (J, Hann, pers. comm.) which could disperse or harm fish over a large scale.

3. Interference with fishing operations. The extraction vessel would be within the extraction area for only a small proportion of the time. Moreover, the Applicant would develop a code of practice to ensure that the activities associated with extraction of marine aggregate do not interfere with fishing operations (Corkery 1993).

4. Place any liquid or solid matter into the water which is injurious to fish, spawning grounds, their spawn, or food. The information collected by The Ecology Lab for the study suggests that fish, spawning and food would be affected only a very small scales, if at all.

Many of the seabirds, marine mammals and marine reptiles likely to be encountered in the proposed extraction areas are protected by law, as they are considered to be rare and/or endangered. The nature of the extraction operation, subsurface release of excess water and the development of a code of practice in which marine mammals are avoided by the extraction vessel, should ensure that the Applicant can comply with the legislation.

16.6.5 Ecologically Sustainable Development

In recent years a concept (and political strategy) used to relate human development with the natural environment has been termed "ecologically sustainable development" or simply ESD (e.g. ANON 1990b; Butler 1991; Green et al. 1991, 1992; Hammer et al. 1993). Green et al. (1992) chaired a Commonwealth committee on ESD whose objective was provide a policy strategy for the Australian Community for the longer term, defined by them as up to 40 years. This section reviews aspects of ESD in relation to marine ecological issues for the proposal to extract marine aggregate.

According to Green et al. (1991)..."The concept of ecologically sustainable development (ESD) has grown out of the definition of sustainable development provided in the report of the World Commission on Environment and Development (WCED 1987).... The WCED report is founded on the notion that economic development and environmental well-being are not mutually exclusive but mutually enhancing goals. It thus firmly broke with the view that there is an inherently antagonistic relationship between the protection and maintenance of the environment and the goal of economic growth expressed in such publications as the Club of Rome's Limits to Growth (Meadows et al. 1972)." (page 5).

ANON (1990b) defined ESD as follows: "Ecologically sustainable development means using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased." Green et al. 1992, however, considered that it is very difficult to define ESD and preferred to address directly 6 principles of ESD:

1. intergenerational equity,
2. intragenerational equity,
3. conservation of biodiversity,
4. dealing cautiously with risk,
5. global issues,
6. economic diversity/resilience.

Insofar as they affect issues related to marine ecology and current users of the coastal ecosystem, these principles are discussed in relation to the present proposal. It must be recognised that these principles apply at many different levels across the marine aggregate proposal, ranging from land issues to the economic matters on which the proposal is based. For further information on these, see Corkery (1993).

The first 2 principles deal with equity within and among generations. Within generations, the proposal has been designed to minimise conflict with other users. At the end of the project, there would be similar habitat (albeit up to 5 m deeper) at both extraction areas. It is therefore predicted that the proposal would not be inequitable with respect to future users of the ecological resources of the proposed extraction areas.

Conservation of biodiversity is seen as one of the crucial measures of maintenance of ecosystems (Green et al. 1992), although there are many ways in which biodiversity can be defined. For example, Hammer et al. (1993), asserted that biodiversity must be considered in terms of species diversity, genetic diversity, functional diversity and spatial and temporal diversity. This wide definition implies diversity of species and of ecological processes. Butler (1991) also discussed the concept of the capacity of an ecosystem to be ecologically sustainable.

On a large scale (e.g. the Sydney or NSW region), there are extensive areas of shelf sand bodies (Ferland 1990). Thus, in the context of the proposal, this type of habitat is not limited. Our field investigations also showed that the proposed extraction areas are similar to other areas. On this basis, biodiversity using the wide definition of Hammer et al. (1993), would be maintained.

At smaller spatial scales, we cannot define what the capacity of the proposed extraction areas is to extraction of marine aggregate and, unless we exceed that capacity by extracting marine aggregate at very large rates, it is unlikely that we would ever know. In this study, the proposal has been linked to a maximal rate of extraction (i.e. 1.5 $Mt.y^{-1}$) which will, on the best estimates available, allow macrofauna of the disturbed patches to recolonise. The macrofauna of the recolonised patches would, along with propagules from outside the extraction area, provide the animals which would recolonise newly extracted patches.

The literature suggests that meiofauna recolonise at very rapid rates (Chapter 8), so the 3 month recolonisation period adopted should allow for recolonisation of macrofauna and meiofauna. Moreover, the actual area which is being recolonised at any one time represents only a small proportion of the extraction area (Figs. 16.1-16.3) which, in turn, represents a small proportion of similar habitat over a similar depth range in the Sydney region.

Our studies of macrofauna and fish suggest that the assemblages of the shelf sand bodies are highly variable in time and space at scales of months and to less than 1 km (Chapters 8 and 9). It is also likely that the assemblages are affected by physical (e.g. storms which can penetrate to 70 m or more below the ocean surface) and biological factors. Connell's (1978) intermediate disturbance hypothesis is, among others, one model that may account for a large diversity of species in an area undergoing intermediate levels of disturbance. If such a model applied (and there are arguments against it - see Chapter 8), we do not know at what point of the disturbance continuum the sand bodies exist. The rapid rate of recolonisation observed (which was limited by the depth of the experiment - Section 8.4) does suggest that the macrofauna are adapted to disturbance. Thus, even at the scale of the proposed extraction area, it is likely that biodiversity would be maintained during and after the project.

As in all environmental impact statements, predictions about effects are made and there is, inevitably, an element of risk associated with these predictions. The fourth principle of ESD requires that risk be dealt with cautiously.

Green _et al_. (1992) described three approaches to risk in relation to human developments. First, the "reactive approach" relies on some technological measure in the future to repair the damage caused by development. Green _et al_. (1992) suggest that many developments in the past have adopted this approach and that it is inadequate. Second, the "anticipatory approach" promotes research, environmental evaluation, long term integrated planning and the application of new technology. Third, the "precautionary approach" seeks to modify the manufacture, use of products or services, or the conduct of activity, consistent with scientific and technical understanding, to prevent serious or irreversible environmental degradation. Green _et al_. (1992) argued that the latter two apporaches will best serve the ESD principle of dealing cautiously with risk.

Throughout the pre-approval phase of the project, the latter two approaches to risk have been adopted. For example, in terms of the anticipatory approach, the studies done by The Ecology Lab have evolved as the project progressed, leading from pilot studies investigating the effect of depth, mesh size and taxonomic resolution on biota of the proposed extraction areas, to studies of the effect of a storm and sediment characteristics on macrofauna, culminating in an experiment which examined rates of recolonisation of macrofauna. The implementation of an appropriate monitoring programme would continue this approach (Chapter 17).

One example of the precautionary approach is the design of subsurface release of excess water, which was subsequently modified to include dispersers to assist in dilution of plumes. Another is linking the extraction plan to recolonisation of the seabed by macrofauna.

The last two principles of ESD do not relate directly to the marine ecological studies. In terms of global issues, however, it could be argued that the methodology and findings of the study can be applied to other extraction operations, which may help ultimately to ensure the sustainability of this type of development elsewhere. A discussion of the economic justifications for the proposal is provided by Corkery (1993). In terms of present users of the proposed extraction areas, the project has been designed to minimise any effects on their livelihood (Corkery 1993).

16.6.6 Adaptive Ecological Management of the Project

An important and favourable aspect of the proposal is that the extraction plan could be modified in several respects once the project had commenced. Thus, unlike many projects, it is adaptive. In particular, it may be possible to vary the location within the extraction area of the extraction head over the seabed to maximise the rate of recolonisation of benthic organisms. Or, the depth at which the excess water is returned to the sea may be varied in accordance with the location of the extraction vessel within the resource area and the prevailing oceanic conditions at the time. In many dredging operations such choices are not available. Finally, the timing of extraction could be varied to minimise conflict with other users of the area.

The ability of the Applicant to make adjustments to the extraction plan is, however, <u>totally</u> dependent upon having a monitoring plan which allows accurate estimates to be made of the effects, if any, of the extraction operation. The next and final chapter provides a framework in which the predicted effects may be monitored.

Chapter 17. DEVELOPING A MONITORING PROGRAMME

17.1 INTRODUCTION

17.1.1 Requirements and Aims of Monitoring

The Requirements of the Director of the Department of Planning specify that the EIS should formulate a proposal for monitoring the effects of the proposed extraction (see Chapter 4). In this chapter, general monitoring programmes are described for Providential Head and Cape Banks. There would be significant advantages for monitoring if extraction occurred simultaneously from both areas.

The aims of the monitoring programme for the extraction proposal are defined as follows:

1. to test predictions of the effects of extraction made in the EIS;

2. to assist in formulating strategies to mitigate any unforeseen impacts after the proposal has commenced (i.e. to improve the extraction plan); and

3. to distinguish impacts associated with the extraction operation from natural variation (e.g. el Niño events) or other man-made impacts (e.g. offshore ocean outfalls).

This type of extraction has never been done in coastal waters off Australia, apart from the removal of sand for beach nourishment off Gold Coast beaches (Neilsen _et al_. 1991). The biological effects for this operation were not monitored until after the sand had been removed. Thus, a well designed and implemented monitoring programme would also allow managers to predict better the effects of future proposals of a similar nature, which has been a notable shortcoming of EIS's in NSW (Buckley 1989; Fairweather 1989).

Issues associated with monitoring were discussed at a workshop sponsored by the Applicant in April 1992. This chapter draws upon some of the discussions held for the workshop and reported by Underwood (1992b - reproduced in Appendix E). The various components of the ecosystem that may be affected by the proposal should each be considered for monitoring, but the strategy adopted for each would vary according to the extent and timing of effects. For example, parts of the sandy seabed would be disturbed by extraction from the very beginning of the extraction project, whereas any changes in wave energy which may affect rocky shores could not occur until after extraction had been occurring for several years, if at all.

In either case, the basic elements of monitoring would be the same: wherever possible, the putative impact site should be compared with appropriate spatial and temporal controls. That is, the putative impact site would be surveyed before and during and/or after extraction and compared with control sites which were surveyed in the same way, at the same times. This conforms to the optimal impact study design proposed by Green (1979) and modified by later authors (Bernstein and Zaliniski 1984; Stewart-Oaten et al. 1986; Underwood 1991, 1992a). It is also similar to the approach adopted by FRI for monitoring the effects of the deepwater ocean outfalls on ichthyoplankton, demersal fish and benthic macroinvertebrates.

In addition to this quantitative approach, consideration should also be given to the observations of other users in the areas, including fishers, divers and other scientists, insofar as they may make important observations which could then be followed up objectively (see Section 17.2.6).

17.1.2 Establishing a Monitoring Framework: Data Needs and Determination of What Constitutes an "Impact"

During the pre-approval, or EIS phase of the proposed extraction operation, data were gathered to provide a description of the environment against which an assessment of impacts could be made (see Table 5.1, Section 5.2). These data were also very useful in helping to formulate a monitoring programme and, in some cases, providing part of the baseline against which the putative effects of extraction could be compared.

If the project proceeds to the next phase (i.e. the pre-extraction phase), it would be necessary to obtain further data, prior to the commencement of extraction, to complete two tasks, establishment of the baseline which would provide an adequate temporal control and, in some cases, obtaining information which would allow us to specify the optimum sample sizes for the various habitats studied.

Thus, a distinction should be drawn between the data gathered for the EIS, the data gathered to provide information on sample sizes required and a baseline against which changes can be measured and, finally, the data gathered on the changes which occur within the extraction and control areas during and, if necessary, after the period of extraction.

A further distinction also needs to be made on the kinds of effects that were predicted in Chapter 16. Some assemblages, particularly those of the sand bodies, are expected to show changes as a result of the extraction operation. Clearly, wherever the extraction head passed over the seabed, a change would take place. Other assemblages, however, are not expected to change, based on predictions of physical and chemical changes resulting from the extraction operation. Examples of these include rocky shore biota and levels of contaminants in biota.

In the case of the assemblages of the sand bodies, monitoring would be used to measure the magnitude of change and the rate of recolonisation at different spatial scales within the extraction areas (see Section 17.2.2). Two obvious questions arising from this are 1) what level of change would be considered to constitute a significant or unacceptable impact? and 2) would the monitoring programme be powerful enough to detect the level of change posited as being unacceptable?

There is no precedent to allow us to decide, from past experience with aggregate extraction, what a significant impact is. It would require discussions between the Applicant and government authorities to decide on an acceptable level of impact and, as a start, it could be based on the levels of natural variability already observed in the studies done for the EIS.

For example, if a family of amphipods were found to vary among locations through time by, say, 40% during the EIS and pre-extraction phases, a hypothetical change of 60% at the extraction area(s) during extraction may be considered to constitute a significant impact. Alternatively, if that taxon failed to recolonise disturbed areas to within 20% of the original levels, or the levels recorded at control locations within a specified period, hypothetically over,say, 6 months, then that may be considered to constitute a significant impact.

In the cases of rocky shores and contaminants, the prediction that there would be little or no change as a result of aggregate extraction implies that <u>any</u> detectable change relative to control areas could be seen an a significant impact. Unfortunately, this approach is simplistic, as it is still necessary that the size of an effect be posited (i.e. predicted), with the appropriate statistical power (Cohen 1988) so that the monitoring programme can be appropriately designed. For biota in which no change is predicted, it may well be that the size of the change considered to constitute a significant impact is small. In that case, the monitoring programme will need to be very intense, with large sample sizes, or the level of significance for statistical tests reduced (i.e., in statistical terms, alpha may be reduced to, say, 0.10, rather than the conventional 0.05).

If approval is given for the extraction of marine aggregate, an important part of the pre-extraction phase would be to address these issues and to collect any further data required for the monitoring programme. The next section provides a framework for monitoring each habitat, assemblage or current user groups of concern, including the information that would be required as part of the pre-extraction phase.

17.2 HABITATS, COMMUNITIES AND HUMAN ACTIVITIES BEING CONSIDERED

17.2.1 The Water Column

Monitoring of the plumes created by return of excess water should focus on monitoring of physical and chemical characteristics of the water (e.g. light attenuation, suspended solids, nutients, contaminants), compared with at least two areas near to, but not within, the plume. Concentrations of chlorophyll should also be measured inside and outside the plume.

There are two possible sampling strategies that could be considered. First, the fate of the plume could be followed until it disperses to a pre-determined concentration expressed as mgL^{-1} or as a percentage above the ambient concentration of the water (as measured from controls sampled at the same time, but outside the plume). This would require the use of equipment on the sampling vessel to allow the plume to be identified.

Second, record the physical and chemical characteristics of interest at key points (i.e. shipwrecks, reef boundaries) and/or at fixed distances from the discharge point of excess water. Permanent control sites would also be sampled.

Sampling of the water column would not necessarily need to be done over long time periods. Sampling could be done over a number of extraction cycles - say three or four cycles - and within seasons over, say, two years. The seasonal component is considered important because of the large degree of seasonal variability in nutrients and phytoplankton noted off Sydney (see Chapter 7). Once the fate of the plumes and their effects on phytoplankton had been identified, there may be no need for further monitoring, unless weather conditions changed (e.g. due to an el Niño event), or the method of extraction changed (e.g. the depth of discharge changes).

17.2.2 The Sandy Seabed

17.2.2.1 Benthic Macrofauna

The effects of the extraction operation on benthic macrofauna could occur at three spatial scales (Underwood 1992b): the small-scale tracks along which the extraction head passes; the medium-scale portion of the extraction area being targeted at any one time; and the large-scale of the entire extraction area, whose surface would be entirely disturbed after 6 years of operation at Cape Banks or 4.5 years at Providential Head (assuming extraction at one area or the other, but not both).

17.2.2.1.1 Small-scale Disturbance

Given that the passage of the extraction head would kill something approaching 100% of the benthic macrofauna in its path, the emphasis of monitoring at the small-scale would be on the ability of the assemblages to recolonise disturbed areas. This is similar to the scale at which the physical disturbance experiment was done (Chapter 8) and would help to further verify the results of that experiment.

Monitoring would be done by divers identifying, marking and subsequently sampling the actual track made by the extraction head. Replicate samples of sediment would be collected using a hand-held corer. This would determine the spatial extent of removal of macrofauna, by sampling at chosen distances normal to the centre of the track (Underwood 1992b). Some sampling should also be done of meiofauna, by seiving the samples through a smaller mesh.

Measurements that would be taken include counts of organisms (sorted to family) and biomass of families. Also, it is recommended that sediment samples be taken to determine the characteristics of the sediment.

17.2.2.1.2 Medium-scale "Patch" Disturbance

Because the extraction operation would extract aggregate from sectors within the total extraction area, it is recommended that the Applicant attempt to extract intensively from at least two replicate patches in one of the proposed extraction areas (Underwood 1992b). Extraction should be at an intensive rate over a relatively small area, probably determined by the manoeuverability of the extraction vessel. Replicated sampling in the patches, outside the patches in the extraction area and outside the extraction area would reveal responses to the disturbance. Sampling over a period of 1 to 6 months should be sufficient to indicate the scale and magnitude of disturbance and the rate of recovery (Underwood 1992b).

At this spatial scale, the effects of extraction would be much more realistically similar to the actual extraction than the physical disturbance experiment, although somewhat more intense than would be expected under a normal extraction plan. Results are predicted to show very rapid responses by the invertebrate fauna (Underwood 1992b). If not, some change in extraction procedures may be possible to reduce the frequency of disturbance.

The suggested monotoring plan for disturbing the patch would be far more effective if approval were given to extract from both Providential Head and Cape Banks. This is because commercial extraction of marine aggregate can continue while the "experimental" area is left undisturbed.

During the EIS studies, most sampling was done using a Smith MacIntyre grab (Chapter 8). At the workshop held in April 1991, it was suggested that a box-corer might be useful for sampling benthic infauna, particularly if we wish to sample meiofauna (Underwood 1992b). As part of the pre-extraction phase, it is recommended that the relative efficiency of the box-corer and the grab be evaluated and the most suitable sampler used.

17.2.2.1.3 Large-scale Disturbance Associated with the Total Extraction Area

Due to the long-term nature of the proposed extraction operation, benthic macrofauna should be sampled over the entire extraction area, including controls, on an infrequent basis, say every 3 to 5 years (Underwood 1992b). The sampling design would be similar to that used for the EIS study, namely, samples would be taken from sites, selected at random, from the extraction and control areas. The studies conducted for the EIS suggest that Bate Bay and Bass Point would be suitable as external references. Sampling would also be stratified according to depth.

If extraction were approved for only one of the proposed extraction areas, it is recommended that a comparison be made between the extraction area for which approval had been given and three control locations, namely, the original control locations at Bate Bay and Bass Point and the proposed extraction area for which no approval was granted (i.e. either Providential Head or Cape Banks). This sampling design is termed an asymmetrical design.

If extraction were approved for both areas, the monitoring programme could compare the two extraction areas with the two original controls, but it could also compare the two extraction areas to determine if the magnitude of any putative effects were the same in both extraction areas. This is a symmetrical or balanced design.

Note that the balanced design can only apply to extraction occurring in depths of 45 m or more, because at Cape Banks no extraction would occur in shallower water. Thus, any comparison of the effects of extraction in water depths of, say, 35-45 m at Providential Head would utilise the asymmetrical design (but at this stage there would only be two controls available for comparison).

A crucial component of monitoring at the large scale is time. Samples must be available from before extraction commences to compare with samples taken during (and, if necessary, after) extraction. So far, sampling has been done on four occasions over one year at Providential Head and twice over 6 months at Cape Banks. If approval for extraction is given, it is recommended that sampling be done for a year during the pre-extraction phase.

Once extraction had commenced, the monitoring would focus on the small- and medium-scale disturbances in the first 6-12 months of operation. In the third year of extraction, assessment of the large-scale disturbance would be repeated. Further sampling at this scale would be determined after the third year.

As with the monitoring at other spatial scales, macrofauna would be identified to family and counted and weighed at the family level. At the workshop held in April 1991, it was considered that if justifiable public concern were expressed about particular benthic species, they could be examined specifically (Underwood 1992b). There is, however, no obvious scientific reason for this for most benthic macrofauna, given the sparse knowledge of their taxonomy, life cycles, ecology, etc.

17.2.2.2 Demersal Fishes and Mobile Macroinvertebrates

Due to the mobility of fish and mobile macroinvertebrates, it would be inappropriate to follow the same monitoring strategy as described for the benthic macrofauna. It is recommended that the sampling strategy adopted for the large-scale disturbance be used for the fish and mobile macroinvertebrates.

This approach would allow the Applicant to monitor any large-scale and long term changes. The methodology used would be the same as for the EIS study, namely, an otter trawl would sample the seabed in the sites within the extraction area(s) and reference sites. Sampling would also be stratified according to depth.

Fish would be identified to species and counted. Species of economic value would be measured to obtain length-frequency data. Other data that could be obtained include biomass of individuals and species, reproductive condition and some limited work on their food. A comparison of populations occurring by day and night could also be considered.

17.2.3 Rocky Shoreline and Sandy Beaches

The assessment of impact concluded that any physical changes to rocky shores and beaches would be minimal (Geomarine 1992), as the extraction plan had been designed to minimise any erosion of beaches or changes to patterns of exposure, particularly at the Cape Banks scientific research area. Notwithstanding this, it is still considered that monitoring should be done to determine whether the predictions are verified.

Monitoring of physical processes would be done to allow a distinction to be made between natural changes and any changes brought about by the extraction operation.

With respect to rocky shores, it is highly unlikely that any impacts from alteration of wave energy would be apparent for a number of years, if ever, depending on whether the seabed topography had been altered (note that no such change is predicted - Geomarine 1992). Despite the very low risk of any effects, monitoring of biota is recommended for two reasons. First, the rocky shores and particularly the Cape Banks area, are considered to be of very high conservation and scientific value, and therefore monitoring is warranted, despite the very strict design criteria adopted by the Applicant.

Second, by initiating a well-designed study with appropriate spatial and temporal controls, it would be possibe for the Applicant to distinguish between any affects due to the extraction operation and those which may be due to large-scale processes, such as abnormal storm activity, El Niño cycles, etc. Thus, the Applicant would be in a strong position to refute or confirm any assertions made by others, using more limited data sets, about the effects of the extraction operation.

It is recommended that, if approval for extraction is given, a monitoring programme be intiated as follows. Prior to commencement of extraction, surveys should be done of the intertidal organisms adjacent to the proposed extraction area(s) and at control locations, stratified according to the level on the shore and to degree of exposure. It would also be desirable to obtain information on the inshore wave climate and extent of any sedimentation.

A two year study should be done, with sampling over seasons. This baseline could then be used as a temporal control to compare against similar surveys done at any time during the life of the extraction operation. For example, it may be advisable to repeat the survey at 5 or 10 yearly intervals, or if monitoring of physical processes (e.g. sand transport) varies from the predicted effects.

17.2.4 Rocky Reefs and Shipwrecks

17.2.4.1 Shallow Rocky Reefs

Shallow rocky reefs (< 20 m) can be readily surveyed by divers. Monitoring should be done on rocky reefs in relation to the possible movement of silt onto reefs associated with the return of excess water. A monitoring programme should be initiated to assess this, with two major components. First, silt traps should be deployed on reefs adjacent to the proposed extraction area(s) and at control locations, to determine the extent of siltation associated with the extraction operation. The traps should be replicated and stratified according to depth. Sampling should also commence prior to commencement of extraction.

Second, surveys of sessile biota (e.g. kelp and sponges), mobile invertebrates (e.g. abalone and sea urchins) and fish would be done. Standard procedures are available for these and sampling would be straightforward. Sessile biota would be sampled using photoquadrats (e.g. Roach 1992). These can also provide an indication of the amount of silt covering reef areas (Roach 1992). Fish and mobile invertebrates would be sampled by visual census, using transects and quadrats (e.g. Lincoln Smith et al. 1991, Lincoln Smith and Smith in press). The basic elements involved in the programme would be the selection of sites adjacent to the extraction operation and at control areas, stratification according to depth and sampling before and after commencement of extraction.

17.2.4.2 Deep Reefs and Shipwrecks

Deeper rocky reefs (to about 45 m depth) and shipwrecks are far less accessible to divers. Deep reefs may be sampled remotely by using photoquadrats for sessile biota and by traps, gill nets and longlines for fish and some mobile invertebrates.

As with the shallow reefs, it is recommended that deep reefs be sampled using silt traps (to determine the extent of settlement of silt onto reefs) and photographically. For logistical reasons, FRI (1992) abandoned the use of gill nets and traps for sampling fish as part of the monitoring programme for the deepwater ocean outfalls. Longlining was more successful and it is recommended that this be investigated for monitoring the effects of the extraction operation. The basic elements involved in the programme would be the selection of sites adjacent to the extraction operation and at control areas, stratification according to depth and sampling before and after commencement of extraction.

Sampling the biota associated with shipwrecks is problematic, because of the relatively great depth involved, the relatively small size of the wrecks and the lack of suitable control locations. Rather than expending a large amount of effort and expense attempting to monitor the biota of shipwrecks, it is recommended that monitoring be limited to investigating physical matters, such as the frequency (if at all) that plumes impinge on shipwrecks that have been identified, such as the s.s. Tuggerah, s.s. Woniora and s.s. Undola (see Section 17.2.1) and the stability of the seabed surrounding the wrecks.

17.2.5 Marine Mammals and Seabirds

Due to their relatively infrequent occurrence on the coast and great mobility, it is recommended that no specific monitoring studies be done on marine mammals and reptiles. It is recommended, however, that contact with specialist scientists be maintained as part of the monitoring programme to allow the Applicant to alter the extraction plan in response to changed migration paths, changes in abundance and so forth. Also, it is recommended that, as part of the vessel's operating practice, any incident involving marine mammals be recorded and reported to the Applicant and NSW NPWS. In particular, if southern right whales are observed with calves in areas such as Bate Bay, observations should be made of any interaction between the extraction vessel and the whales. Such interactions should be minimised.

Monitoring of seabirds is not warranted given the very small potential for impact. It is recommended, however, that close liasion be maintained with NSW NPWS, the Royal Ornithological Society and the Australian Museum to identify any trends in populations of seabirds that should be accounted for in the extraction plan.

17.2.6 Contaminants

Testing for contaminants in the marine aggregate and in the water column should be done routinely. Testing biota should only be considered if contaminants are found in the aggregate or water column, or if testing of biota as part of the deepwater ocean outfalls monitoring programme ceases.

17.2.7 Other Users

17.2.7.1 Commercial Fishing

The survey of demersal fish and macroinvertebrates recommended as part of the monitoring programme would provide a guide to the effects of the extraction proposal on commercial fishing. It would be limited, however, in that the net used would be smaller, the trawl times shorter and the frequency of sampling likely to be less than commercial fishing activities. It would therefore be necessary to maintain close liaison with commercial fishers to monitor the frequency of commercial trawling within the proposed extraction areas and any observations about the catch.

17.2.7.2 Recreational Fishing

Similarly, the demersal trawl study would provide a rough guide as to the relative abundance of species, particularly flathead, often sought by recreational fishers. Given that recreational fishing is very popular on the coastline around Sydney and that the extraction of aggregate is expected to be a very sensitive local issue, the following measures are recommended.

First, contact should be established and maintained with local fishing clubs and the Recreational Fishermens Advisory Committee (RFAC). The Applicant should advise these groups of its short- and long-term extraction plans and seek to obtain information from fishers regarding any conflict arising from the operation.

Second, a survey of anglers fishing from boats should be done during the pre-extraction phase to determine the distribution of fishers with respect to the proposed extraction areas, the catch per unit of effort (CPUE) of fishers inside and outside extraction areas and the species composition of the catch. It is suggested that the survey be done in the area from Maroubra Beach to Garie Beach and the coastline within this area be divided into a series of zones, including the proposed extraction areas.

Sampling should be stratified according to depth (or distance from the coast), season, holiday/weekend vs weekday and time of day. The survey of the distribution and abundance of fishers could be done from a boat. Information on CPUE may be more difficult to obtain. Interviewing fishers at sea may be very difficult in all but the calmest sea conditions. Interviews at boat ramps may prove wasteful because there are many ramps that could be utilised and many boats using the ramps would be likely to fish within estuaries. An alternative approach would be either to enlist the assistance of local fishers to provide their catch for examination, or simply to fish, using local gear and bait, in the areas of interest.

Sampling should be done at least one year prior to commencement of extraction and continue for at least one year after. The use of zones would provide for several control areas as well as the extraction area(s). The decision to end monitoring of fishing would be based on the survey results and discussions with fishers.

17.2.7.3 SCUBA and Skin Diving

Two approaches to the SCUBA and skin diving are recommended. Although the Applicant should seek to extract aggregate at times of the day least likely to conflict with divers, there should also be a system of notification whereby divers can obtain information on the expected location of sediment plumes under a range of conditions.

Second, the Applicant should liaise with a consultative group comprising representatives from dive clubs and shops. Part of this liaison would include the provision of a log on water visibility that dive club operators could fill in and give to the Applicant and the regular distribution of a questionnaire to divers from shops requesting information on the water visibility. Such a questionnaire should be distributed to all the dive shops in Sydney and Wollongong, so that some indication of the perception of water visibility from the region generally can be obtained.

Both the questionnaire and the log should be distributed for a year prior to the commencement of extraction and at least one year after.

17.2.7.4 Research, Education and Conservation

The monitoring programme described above would provide information which could be used to interpret the effects of the operation on other research. In particular, monitoring of rocky shores would provide information relevent to the Cape Banks research area. Also, information on rocky reefs and the biota of the sand body would be relevant to the proposed marine and estuarine protected area (NPA 1991).

17.3 CONCLUSIONS

In considering the requirements for monitoring well before the commencement of any extraction, the Applicant is well placed to initiate a monitoring programme that can incorporate the essential elements of spatial and temporal controls, which are vital to determining the effects of aggregate extraction. This chapter is concluded by summarsing and further discussing the various monitoring programmes suggested, and by discussing the benefits for monitoring if ectraction is done at both Cape banks and Providential Head

17.3.1 Summary of Approaches to Monitoring

Monitoring of the effects of the plume associated with the return of excess water would involve modelling the plume characteristics under various conditions and conducting field studies to observe the fate of the plume.

The field studies done for the EIS have shown that the control areas at Bass Point and Bate Bay would be appropriate as external references for the assemblages of benthic invertebrates and fish occurring in the areas of interest. The approach of monitoring benthos at three spatial scales would permit an assessment of effects early in the extraction operation (i.e. < 1y) but would also allow the Applicant - and those auditing the results of monitoring - to obtain an indication of the effects of extraction over medium and large scales.

Due to the very strict design criteria adopted by the Applicant, there are no predicted changes expected to the coastline. In the unlikely event that there were changes as a result of the extraction operation, these would happen in the long term. Thus, the monitoring programme suggested for sandy beaches and rocky shores relies on studies of physical processes (for beaches), or obtaining a pre-extraction baseline at putative impact sites and controls which can be compared with the same sites at any time during and after the extraction operation. The programme suggested for reefs requires that a baseline be compiled before extraction commenced on the amount of silt deposited on reefs (impact and control) and the biota present. Surveys would continue after extraction commenced.

No monitoring of biota is recommended for shipwrecks because of the logistical difficulties and because of the difficulties in finding adequate controls. Monitoring of the plume and sand transport, however, will provide an indication (albeit without control locations) of the physical effects of the extraction operation on shipwrecks.

Similarly, although marine mammals, reptiles and seabirds have a high conservation status, no direct monitoring of them is recommended at this stage, either because they would be logistically difficult to monitor (marine mammals and reptiles) or because the impacts likely to occur to these groups are considered to be negligible (marine mammals, reptiles and seabirds).

17.3.2 Monitoring if Extraction Occurs at Both Cape Banks and Providential Head

There are two major advantages for monitoring if extraction occurs at both Providential Head and Cape Banks. First, it would allow the Applicant to conduct experimental monitoring in one area, particularly of the macrobenthos of the sand body, while commercial extraction proceeds in the other area. This is relevant to the small and medium-scale monitoring of the extraction operation described in Section 17.2.2.1.

Second, it would allow the use of a balanced design for several of the habitats being monitored. This would allow a more sensitive test of the effects of extraction and it would assist in the interpretation of results. For example, if statistical analyses show similar effects occurring in both of the extraction areas compared with control areas, then we can be much more confident that the effects were actually caused by the extraction operation. If there are any unacceptable disturbances, an advantage of this procedure is that it can efficiently identify differences in the intensity of disturbances between the two areas. This would allow greater opportunity for improved future extraction because the sampling would also have helped to identify in what ways one of the areas had been less disturbed.

On the other hand, if approval is given for only one area, then the monitoring would conform to an asymmetrical design. In this case, the extraction area would be compared with two or three control areas.

If, using the asymmetrical design, it were found that the extraction area was different from the controls, we may not be as confident that the extraction operation was the cause of the effect. For example, if extraction were approved only at Cape Banks, it is possible that differences between Cape Banks and the controls could be due, to some extent, to the discharge of sewage from the deepwater ocean outfall off Malabar.

An important part of the monitoring programme should be the interaction between the Applicant and other users of the proposed extraction areas. Initially, the Applicant should seek to measure any effects of extraction on other users. This can be done by discussions with commercial and recreational fishers, the use of questionnaires and even by field surveys. In the long term, the Applicant should ensure that there is a system of communication available to allow other users to know when and where extraction is taking place, if necessary, on a day-to-day basis.

PART V: REFERENCES

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