Technical Report A

PEA and Location Selection and Constraints Mapping Report

Report to:

NSW Department of Primary Industries

Pilot Offshore Artificial Reefs

Preliminary Environmental Assessment



FINAL

February 2008

The Ecology Lab Pty Ltd
Marine and Freshwater Studies

Offshore Artificial Reefs
Preliminary Environmental Assessment

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EXECUTIVE SUMMARY

The New South Wales Department of Primary Industries (DPI, Fisheries), with funding from the Recreational Fishing Trust, aims to improve recreational fishing opportunities in NSW through the development of Offshore Artificial Reef structures (OARs) at selected locations along the NSW coast. DPI already has implemented a program of deployment of Fish Aggregating Devices (FADs) for enhancement of pelagic fishing and has underway a program of deployment of artificial reefs (using reef balls) in estuaries.

The design and deployment of the reef units for OARs has drawn on systems designed and used overseas, particularly in Korea and Japan. Whilst many designs have been used, the preferred type is tending towards relatively open steel structures which are placed on sedimentary habitats. Local coastal processes (e.g. current and wave climate) and seabed characteristics play a major role in the design of the reef units. At this preliminary stage, it is proposed that up to four individual artificial reef units will be used to construct the OARs and will be fabricated from steel, and be deployed in areas of moderately firm sandy seabed remote from existing natural rocky reefs at water depths of approximately 25 m to 40 m.

DPI proposes to install OARs at three locations along the mid coast of NSW off Newcastle, Sydney and Port Kembla. This will require assessment under Part 3A of the *Environmental Planning and Assessment Act* 1979. This report is a preliminary environmental assessment of the proposal and is based on a desktop study used to identify prospective sites and map potential constraints. DPI commissioned The Ecology Lab Pty Ltd, who in turn teamed-up with Worley Parsons Pty Ltd (incorporating Patterson Britton & Partners) to undertake the study.

Once the constraints mapping was completed, representatives of DPI, The Ecology Lab and Worley Parsons undertook a risk assessment workshop in which potential impacts at a generic level were identified. The likelihood of such impacts occurring was estimated; and the consequence (environmental harm) assessed. The constraints mapping was prepared as a stand-alone report, which is appended to this preliminary assessment. Matrices prepared from the risk assessment are also appended here.

Within the section of coast considered, three regions were selected, corresponding to the Newcastle, Sydney and Wollongong areas. Within each region, two sub-regions were identified as being prospective sites for installation of OARs. These include locations in Stockton Bight and south of Nobby's Head (Newcastle); offshore of Broken Bay and Bate Bay (Sydney) and south of Stanwell Tops and offshore of Perkins Beach (Wollongong). Subject to discussions with port authorities, a third sub-region was identified just to the south of Sydney Harbour.

Preliminary consultation with commercial fishers in the Newcastle region has further narrowed down the site selection to a suitable site located between Red Head to the north and Moon Island (Swansea) to the south.

Other potential areas that were excluded were constrained by the presence of coastal infrastructure (e.g. ocean outfalls, telecommunications exclusion zones, shipping routes and anchorages, spoil disposal grounds) and known historical shipwrecks and natural reefs. The risk assessment identified 50 environmental receptors, with impacts ranging from alteration of currents or wave climate, scouring effects, potential for contamination, changes to habitat and biodiversity, interference with migration of fish and cetaceans and potential for conflict among commercial and recreational fishers. Generally, it was found that impacts operated

only over a small spatial scale and that many impacts could be anticipated and mitigated by the design of the reef units.

The detailed assessment of the proposal will require a close consideration of all relevant legislation, including state (e.g. *Environmental Planning and Assessment Act*, *Fisheries Management Act*, *Threatened Species Conservation Act, Coastal Protection Act*) and commonwealth (e.g. *Environment Protection and Biodiversity Conservation Act* and *Environment Protection* (*Sea Dumping) Act)* legislation.
There will also be a need for detailed consultation with government authorities and stakeholders (e.g. commercial and recreational fishers, conservation groups, port authorities).

It is also recommended that further site-specific information be collected, including data on sediment characteristics (which would also assist in refining the design of reef units), biodiversity (e.g. benthos and demersal fishes) and potential proximity to reefs or shipwrecks that may not be charted or known. Acquiring this information would require a focused field program and should include, where relevant, surveys through time at prospective OAR sites and at control sites. This information would enhance the assessment process and contribute to a baseline that could be used to monitor the OARs following installation.

1.0 INTRODUCTION

The Ecology Lab Pty Ltd and Worley Parsons Pty Ltd (formerly Patterson Britton Pty Ltd) have been commissioned by the NSW Department of Primary Industries (DPI) to prepare this Preliminary Environmental Assessment (PEA) of DPI's proposed offshore artificial reefs (OAR) project to seek approval under Part 3A of the *Environmental Planning and Assessment Act 1979* (EP&A Act).

The purpose of this document, together with consultation from the Planning Focus Meeting (PFM) is to assist in establishing the Director General's Requirements (DGR's) for a detailed Environmental Assessment of the proposal.

Aims of this PEA are to provide:

- A description of artificial reefs and their use in NSW;
- An outline identifying the need for the project;
- Project objectives and description;
- Maps including the sites proposed for the project;
- A description of the existing environment at proposed sites;
- An environmental risk analysis of the project, identifying key issues and issues of moderate and/or low significance;
- A proposal of how these issues will be addressed.

Prior to this PEA, The Ecology Lab was commissioned by DPI to undertake a desktop location and constraints mapping study to identify potential sites for deployment of artificial reef structures at defined regions in Newcastle, Sydney and Wollongong (Appendix 1). The initial report identified and addressed the major physical, oceanographic and biological constraints associated with siting of Artificial Reefs at these locations and as such already addresses a number of requirements of the PEA.

1.1 Artificial Reefs Overview

Artificial reefs have been defined as "any material purposely placed in the marine environment to influence physical, biological, or socio-economic processes related to living marine organisms" (Sutton and Bushnell, 2007). Up to 40 countries around the world have constructed artificial reefs (Baine, 2001). Objectives for the deployment of artificial reefs include the enhancement of recreational and commercial fishing, coastal protection and mitigation of habitat loss and damage (Seaman and Jensen, 2000).

The materials used to build artificial reefs vary and have evolved considerably over time. A variety of 'waste' material has historically been used in artificial reef construction. These are collectively known as 'materials of opportunity', which have included discarded automobile tyres, scuttled ships, concrete pipes, railway cars, and surplus military equipment (Figure 1). However, the use of specially designed prefabricated reef structures is now used in many countries including Japan and Korea, who are considered world leaders in artificial reef technology (Kim, 2001; Sutton and Bushnell, 2007). Primarily made from concrete or steel (Figure 2a&b), 'design specific' structures have been demonstrated to be more appropriate in achieving specific fisheries management objectives (Sherman *et al*. 2002). When deployed

together, these artificial reef units are collectively known as 'multi-component' reefs which form reef groups (Pollard, 1989) (Figure 3).

Figure 1: An artificial reef made from tyres in Borneo, Malaysia. 'Materials of opportunity' such as tyres have historically been the material of choice in artificial reef construction (image: Heath Folpp)

(a)

(b)

Figure 2: Examples of 'design specific' artificial reef units used in South Korea - **(a)** individual concrete cube units have been used extensively; **(b)** using steel means greater complexity in artificial reef unit design can be achieved (images: NSW DPI).

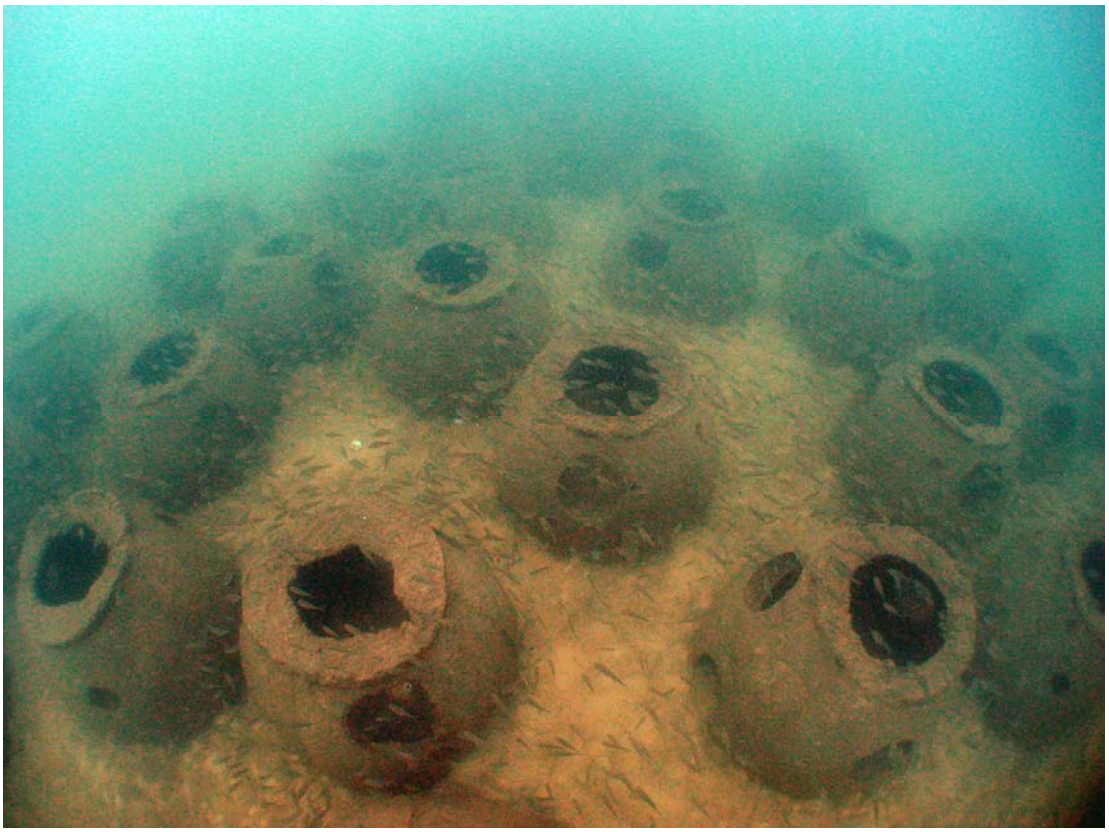


Figure 3: Individual concrete 'Reef Ball' artificial reef units deployed together in Lake Macquarie in December 2005 form a reef group (image: NSW DPI).

Artificial reefs are believed to enhance the productivity of designated areas by providing substrate for the settlement and subsequent growth of marine organisms and can play an important role in providing food and refuge for juveniles of commercially and recreationally important species (Pollard and Mathews, 1985). With improved designs and structural integrity, artificial reefs may contribute significantly to environmental and fish habitat enhancement (Branden *et al*, 1994). However, there has been considerable debate over the effectiveness of artificial reefs to produce more fish, rather than just attracting existing fish to a new location. This has become known as the 'attraction-production question'. Attraction is simply defined as the net movement of individuals (eg fish) from natural to artificial habitats; whereas a simplified definition of production is the change in biomass over time (Carr and Hixon, 1997). In reality, it is a very complex question and extensive research has failed to provide a definitive answer (Grossman *et al,* 1997; Pickering and Whitmarsh, 1997; Osenberg *et al*, 2002). The benefit of artificial reefs on fish stocks will likely depend on the management objectives of their use (Lindberg, 1997). Although artificial reefs may have the potential to increase a fishers catch, management strategies have been implemented by all Australian state fisheries agencies to regulate the impact of fishing. These regulations can be varied to prevent overfishing and to ensure that targeted species are not taken before they are sexually mature (Branden *et al*, 1994). However, the impact of artificial reefs on fish stocks requires further scientific study (Branden *et al*, 1994).

1.2 History of NSW Artificial Structure Use

There have been at least four detailed reviews of artificial reefs in Australia (Pollard and Mathews, 1985; Kerr, 1992; Branden *et al*, 1994; Coutin, 2001). Collectively these reviews detail the development of Australian artificial reef design, construction, deployment and monitoring from 1965 to 2001. The main purpose of artificial reefs in Australia is for recreational fishers and divers (Branden *et al*, 1994) and historically, materials of opportunity (waste material) have been the main materials used in their construction (Pollard, 1989; Kerr, 1992).

In NSW, the use of artificial reefs began in 1966, with the deployment of a series of multi-component artificial reefs in Lake Macquarie using car bodies and tyres (Pollard and Mathews, 1985; Pollard, 1989). Augmentation of these reefs continued in the 1970's with additional reefs constructed in Batemans Bay, Port Stephens and Port Hacking using car tyres (Coutin, 2001). In addition to these tyre and car body reefs, up to 12 vessels were scuttled beginning in the mid 1970's to create single-component artificial reefs in NSW coastal waters, beginning with the retired-ferry the 'Dee Why' in 1976 (Pollard and Mathews, 1985; Pollard, 1989; Coutin, 2001).

From the mid 1980's lack of funding and increasingly stringent environmental legislation meant that artificial reef construction in NSW effectively ceased until the introduction of the general recreational fishing fee in 2001, when funds became available for the further investigation of the use of artificial structures as a fisheries enhancement tool. In 2002, a fish aggregating device (FAD) program was established in NSW to provide additional fishing opportunities for recreational sport and offshore fishers. FADs provide a target location where fast growing pelagic fish species can be targeted by recreational fishers (source: NSW DPI). The FADs consist of a single 600mm float, moored to the sea-bed at varying depths and distance from the coast (Figure 4). Monitoring of recreational catch composition and factors effecting catch rates of dolphinfish (*Coryphena hippurus*) (Folpp & Lowry, 2006) has been conducted on the FADs. This project has developed into a long running recreational fisheries enhancement program, with 21 FADs deployed from October to June annually from Byron Bay to Eden (source: NSW DPI).

Figure 4: A FAD (Fish Aggregation Device) located off Laurieton on the NSW mid north coast deployed between October and June annually by NSW DPI (image: NSW DPI).

In 2004, DPI began investigations into artificial reefs in coastal estuaries, progressing earlier work done by the Department in the 1970's (Pollard and Mathews, 1985). Using design specific artificial habitat modules developed in the United States (known as 'Reef Balls'), a number of small multi-component artificial reefs were deployed in Lake Macquarie in December 2005, followed by Botany Bay in June 2006 and St. Georges Basin in February 2007 (Figure 5). Each multi-component reef complex consists of 6 individual reefs (180 reef balls in total in each estuary) and has an associated long term monitoring program to evaluate the effectiveness of the reefs. Preliminary results indicate that the artificial habitat has been successful in maintaining an increase in fish abundance and diversity, accompanied by extensive marine plant growth on the surface of the Reef Balls units (source: NSW DPI).

The reefs have also been a success in terms of enhancing recreational fishing opportunities. Eight months after construction, catch abundance, catch diversity, and catch rates of recreational species on the artificial reefs were found to be as good as or better than control sites (naturally occurring reefs) within Lake Macquarie (University of Newcastle, *unpublished data*).

The pilot estuarine artificial reefs project has provided the necessary monitoring and management experience required for the investigation of the potential implementation of large multi-component artificial reefs in NSW coastal waters.

Figure 5: A barge loaded with Reef Balls ready for deployment in Lake Macquarie by NSW DPI in late 2005 (image: NSW DPI).

1.3 Need for the Project

The proposed development of the offshore artificial reefs project complements existing recreational fishing enhancement projects including the fish aggregating devices (FADs) and estuarine artificial reef (EARs) programs.

DPI manages recreational fishing in ocean waters off NSW out to 200 nautical miles under the *Fisheries Management Act 1994* (FM Act). A primary objective of the FM Act 1994 is "to conserve, develop and share the fishery resources of the State for the benefit of present and future generations". Further objects under the Act include promoting "ecologically sustainable development, including the conservation of biological diversity" and promoting "quality recreational fishing opportunities".

The deployment of artificial reefs as a fisheries enhancement tool is consistent with these objectives. The creation of new, high quality fishing areas through the deployment of artificial reefs will provide alternative fishing grounds that may divert fishing effort from existing heavily fished locations.

1.4 Objectives

- undertake an environmental assessment of the proposed deployment of offshore artificial reefs to examine biological, biophysical, economic, social and environmental impacts that may arise from their deployment

- investigate statutory obligations for the deployment of artificial reefs in NSW coastal waters
- investigate suitable and effective artificial reef designs for NSW coastal environmental conditions
- deploy artificial reefs in 3 metropolitan zones in NSW, namely Newcastle, Sydney and Wollongong to enhance recreational fishing opportunities by providing additional fishing locations
- implement a long-term scientific monitoring program to assess the effectiveness and impacts of the artificial reefs over time

1.5 Project Description

Four individual 'reef units' made from steel are proposed to be deployed in offshore waters at water depths between 25 m and 40 m at each of the three proposed locations (Newcastle, Sydney and Wollongong). The combination of the four 'reef units' will collectively create a 'reef group' (i.e. the multi-component artificial reef). The units would sit directly on the seabed and would not require additional anchorage other than the weight of the unit itself. It is estimated that an area of seabed between 0.5 km^2 to 1 km^2 would be required per reef group.

Figure 6: A 10 m tall, 35 tonne design specific steel artificial reef unit waiting for deployment on Cheju Island, South Korea (image: NSW DPI).

Although artificial reefs can enhance fishing opportunities, creating a successful reef entails more than placing miscellaneous materials in ocean or estuarine environments. Planning, long term monitoring, and evaluation measured against project goals and objectives must be incorporated to ensure that the maximum anticipated benefits are derived from artificial reefs.

2.0 PRELIMINARY DESIGN OF OFFSHORE ARTIFICIAL REEFS

Prior to commencing the Offshore Artificial Reefs project two key DPI staff visited Korea and Japan to investigate progress in artificial reef technology. In both countries artificial reefs have been used to enhance commercial fisheries for more than 30 years. Over this period many refinements to design and deployment have increased the effectiveness of the structures and a diverse range of designs are utilised for the production of fish, seaweed, abalone, rock lobsters and molluscs (including octopus and squid). Design refinements such as the inclusion of natural materials embedded in concrete and the development of patented ceramics to promote settlement of algae have boosted seaweed, mollusc and shellfish production. Innovative species specific designs, and purpose built multi-species reefs are now commonplace. A key feature of all reef designs has been the inclusion of the stability and structural strength requirements to withstand severe sea conditions. There has been a transition to steel reef construction allowing greater sophistication in design to take advantage of the extensive biological and behavioural research conducted by government, universities and private companies.

The key points learned from the study trip were:

- Artificial reefs must be designed specifically to suit the target species; thus, one size or design does not fit all.
- Using general purpose artificial reef designs may lead to sub-optimal results.
- There is a large body of published and unpublished research into the effectiveness of various reef designs on species identical or similar to those found in Australia such as snapper (Sparidae), yellowtail kingfish and yellowtail scad (Carangidae).
- Reef units must be designed for the bottom sediments, currents, prevailing sea conditions and potential for extreme weather events.
- Extensive commercial expertise in reef design and manufacture based on decades of experience and research exists in both Japan and Korea.
- Very little of the research and development literature is published in English.
- Artificial reef design and manufacturing companies are keen to expand their operations to Australia.
- Many of the most effective designs are patented.
- Artificial reef designs are rapidly increasing in sophistication.
- Steel reef modules allow more sophisticated designs and are increasing in popularity.
- Japanese and Korean commercial and recreational fisheries have benefited enormously from decades of well funded research and development programs on reef design and biological interactions.
- The national and provincial governments in both countries have recognised the benefits of artificial reefs in increasing fisheries production and continue to expand their programs from the consolidated revenue of governments.

3.0 PLANNING AND LEGISLATIVE REQUIREMENTS

As part of the detailed environmental assessment a thorough consideration of all relevant legislation at state and commonwealth levels would be required. Key areas of legislation relate to sea dumping, environmental planning controls, navigation, maritime heritage, coastal protection, fisheries management, conservation, ecologically sustainable development and climate change. A brief overview of some of the key legislation is provided here and in Appendix 1.

3.1 State Legislation

3.1.1 Environmental Planning and Assessment Act 1979

Developments considered a major project are assessed under Part 3A of the EP& A Act where the Minister for Planning's approval is required. Part 3A projects are generally assessed by the Department of Planning.

Under clause 75B 2(b) of the EP&A Act, Part 3A projects include 'an activity for which the proponent is also the determining authority (within the meaning of Part 5) and that, in the opinion of the proponent, would (but for this Part) require an environmental impact statement to be obtained under that Part'.

3.1.2 Conservation Legislation

Threatened Species Conservation Act 1995 (TSC Act) and the *Fisheries Management Act 1994* (FM Act)

In NSW the *Threatened Species Conservation Act 1995 (TSC Act) and* the *Fisheries Management Act 1994* (*FM Act*) include provisions to declare threatened species, populations, ecological communities and key threatening processes. Provisions for the protection of fish and marine plants are administered through the Department of Primary industries (NSW DPI) and those for marine birds, mammals and reptiles are administered through the NSW Department of Environment and Climate Change (DECC). Part 2 (19) of the *FM Act* also allows for the declaration of 'protected species', which, though not currently declining, must be protected so they do not become threatened in future. Species protected under NSW and Commonwealth legislation relevant to this review are listed in Table 1 of Appendix 1. In addition to the conservation of threatened species, populations and ecological communities (of fish and marine vegetation) the FM Act also aims to conserve fish stocks and key fish habitats and to promote ecologically sustainable development, including the conservation of biological diversity.

3.1.3 Coastal Protection Legislation

Coastal Protection Act 1979

The objects of this Act are to provide for the protection of the coastal environment of the State for the benefit of both present and future generations. In accordance with the Coastal Protection Regulation 2004 made under the *Coastal Protection Act 1979*:

- a person (including a public authority) must not, without the concurrence of the Minister, carry out development of any part of the coastal zone to which the regulation applies;
- a public authority must not, without the concurrence of the Minister, grant any right or consent to a person to use or occupy any part of the coastal zone to which this regulation applies, or to carry out development on any part of the coastal zone to which this regulation applies.

The "coastal zone" is defined in the Act and would include the regions proposed for installation of the OARs. Accordingly, it would be necessary for DPI to seek the concurrence of the Minister administering the *Coastal Protection Act* prior to installation of the OARs.

Crown Lands Act (1989)

The Crown Lands Act is to ensure that Crown land is managed for the benefit of the people of NSW and to provide for proper assessment and management in regard to development and conservation. It also regulates conditions under which Crown land is permitted to be occupied, used, sold, leased licensed or otherwise dealt with. The Act also provides for the reservation and/or dedication of Crown land for public purposes and the management and use of the reserved or dedicated land. Provisions for the collection, recording and dissemination of information in relation to Crown land is also outlined within the Act.

Submerged land is generally classified as a type of Crown land. This includes area below the mean high water mark encompassing coastal estuaries, many large river beds, wetlands, and the State's territorial waters, which extend 3 nautical miles (5.5. km) out to sea. Principles of Crown land management are:

- that environmental protection principles be observed in relation to management and administration of Crown land;
- that natural resources of Crown land (including water, soil, flora, fauna and scenic quality) be conserved where possible;
- that public use and enjoyment of appropriate Crown land be encouraged
- that, where appropriate, multiple use of Crown land be encouraged
- that, where appropriate, Crown land should be used and managed in such a way that both land and its resources are sustained in perpetuity;
- that Crown land be occupied, used, sold, leased, licensed or otherwise dealt with in the best interests of the State consistent with the above principles.

3.2 Commonwealth Legislation

3.2.1 Environment Protection (Sea Dumping) Act 1981

The placement and construction of Artificial Reefs would be regulated under the Commonwealth *Environment Protection (Sea Dumping) Act 1981* (the Sea Dumping Act) and is administered through the Department of the Environment, Water, Heritage and the Arts (DEWHA). The Sea Dumping Act applies to Australian Waters, from the low water mark to the limit of the Exclusive Economic Zone (EEZ). This does not apply to internal waters within the limits of a state or territory (such as Sydney Harbour). A permit must be obtained for placing materials on the seabed to create an artificial reef. Applications for

Artificial Reefs would also be circulated to relevant stakeholders, government and industry for comment.

Issuing of a permit would require that:

- appropriate sites are selected;
- suitable materials are used and properly prepared;
- no significant adverse impact on the marine environment occurs;
- the reef structure does not pose a danger to navigation or a threat to the safety of humans.

Once a permit has been issued the Artificial Reef would then be marked on nautical charts.

3.2.3 Environmental Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is administered by the Commonwealth Department of Environment, Water, Heritage and the Arts (DEWHA) and assesses actions that are likely to have a significant impact on matters of national environmental significance (NES). Matters of NES relevant to this project include: listed threatened species and ecological communities, migratory species and the Commonwealth marine area.
In the aquatic environment, the Act lists threatened species, ecological communities and key threatening processes; migratory species; cetaceans; marine species and Ramsar areas of national significance. The Act applies to waters in the Australian jur isdiction, which includes tidal waters of Australian States (see also Appendix 1).

3.2.4 The Historic Shipwrecks Act (1976)

The *Historic Shipwrecks Act (1976)* is administered by the Commonwealth Department of Environment and Water and protects historic wrecks and relics in Commonwealth waters, extending from below the low water mark to the edge of the continental shelf. In NSW all shipwrecks over 75 years of age are automatically protected from disturbance under the state NSW Heritage Act 1977. Some historic shipwrecks lie within protected or no-entry zones. These zones may cover an area up to a radius of 800 m around a wreck site, and may be declared where circumstances place it at particular risk of interference. This declaration prohibits all entry into this zone without a permit. Permits are also required to undertake any activities otherwise prohibited or restricted by the Act.

4.0 SITE SELECTION AND CONSTRAINTS MAPPING

4.1 Constraints Mapping

Suitable siting is essential to the success of an artificial reef. Improper positioning could, for example, result in a number of negative impacts, such as hazards to navigation, damage to bottom habitat and damage to submerged cables or wrecks. Broadscale constraints mapping and investigation of suitable locations is therefore imperative at an early stage of the project development. NSW DPI commissioned The Ecology Lab to undertake location selection and constraints mapping – using GIS – as part of the preliminary assessment. The findings of that assessment are presented in Appendix 1 and summarised briefly here.

Constraints mapping focused on three areas on the mid coast of NSW (Figure 7):

a) Newcastle (from Stockton Beach south to Swansea).

b) Sydney (from Barrenjoey Head south to Bundeena, Port Hacking)

c) Wollongong (from Stanwell Tops south to Port Kembla)

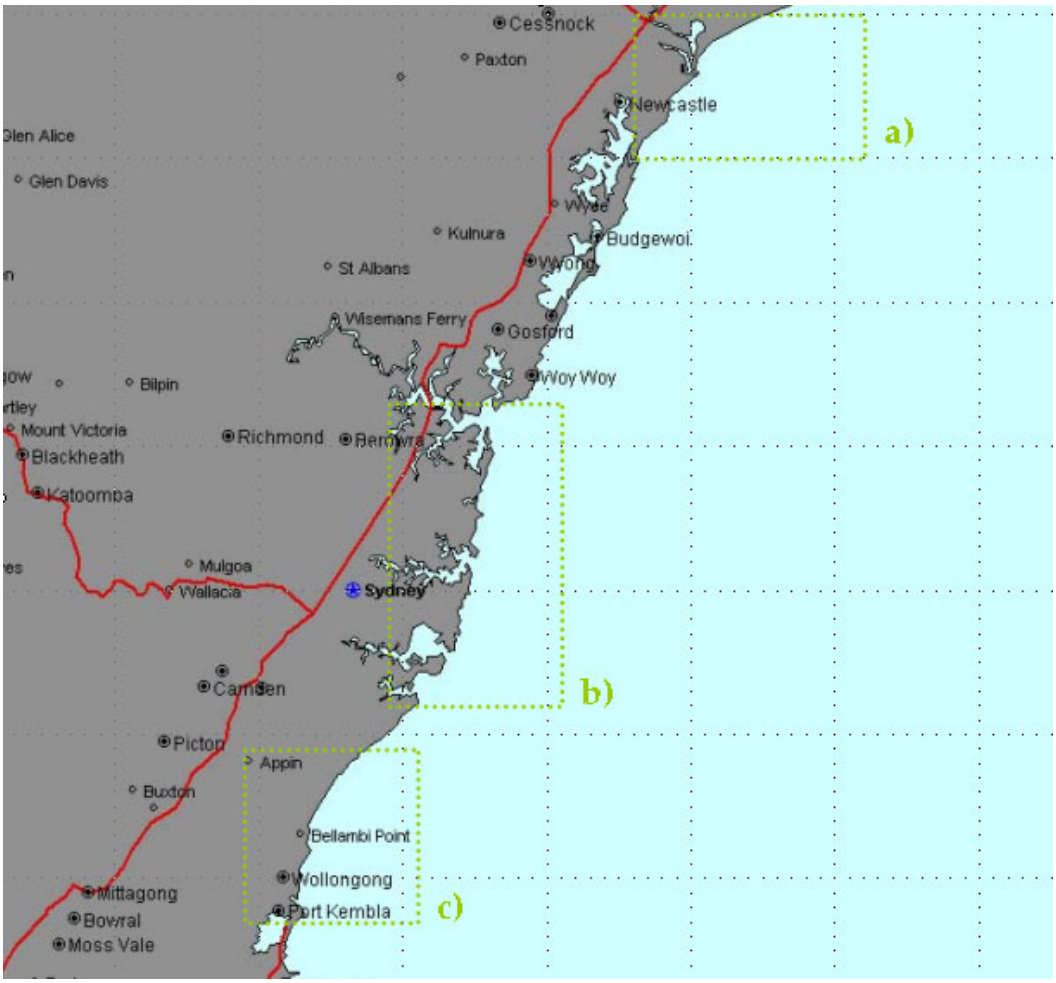


Figure 7: Overview map of the Newcastle, Sydney and Wollongong Study Regions.

The following issues were identified as major constraints in site selection and addressed for each of the study regions:

1. Depth. As the tower structures of the OARs may reach 10 m in height, a depth range between 25 m – 40 m on the continental shelf is a major requirement to avoid creating a navigational hazard. Suitable depth will also be important for the stability of the structures (in terms of ability to withstand certain hydrodynamic forces), accessibility to recreational fishers (via boat) and will also influence the type of fish which will aggregate around the structure.
2. Exclusion zones, including:
    - ACMA cable exclusion zones
    - Deepwater ocean outfalls
    - Designated commercial shipping lanes/port restrictions
    - Marine protected areas (state and commonwealth)
    - Mining exploration leases
    - Historical ship wrecks
    - Spoil grounds
3. Other potentially restricting features e.g.
    - Commercial Fishing Areas (e.g. trawl and trap)
    - FADs (Fish Aggregation Devices)
    - Desalination plants
4. Distribution of substrata and suitability of substrata to support reef structures. Artificial reefs are typically designed to maintain their structural and functional integrity for many years without deteriorating or being permanently covered by sediment (Marshall *et al*, 2003). Underlying sediments should have the ability to easily support the reef structure and generally soft sediments such as clays, silts and loosely packed sands should be avoided. Reliable and detailed seabed characterisation data are therefore necessary to properly site the OARs.
5. Distribution of habitats, flora and fauna. On positioning OARs, existing natural reef habitats, habitats unique within an area, or locations known to support diverse benthic/epibenthic communities should be avoided. Habitats critical to the survival of a particular species are generally protected under NSW legislation and should therefore be avoided. It should also be considered that protected habitats may require an additional buffer zone around them where fishing or development activity is restricted. Specific legislative requirements with regards to Marine Protected Areas (MPA's) are addressed in section 1.4 of Appendix 1. In addition, DPI has specified that placement of the OARs should be a distance away from existing reefs in order to create new reef habitats, rather than adding to existing reef-fishing areas.
6. Threatened species issues, including fish, invertebrates, marine mammals and marine reptiles. Constraints pertaining to the location of critical habitat areas were the main consideration for threatened species as information on the occurrence and distribution of threatened species is often sparse and may be limited to predictions based on presence of suitable habitat and/or records of a species occurring at near by locations. It is especially difficult to predict where

highly mobile individuals (such as fish or migratory marine mammals) occur due to their itinerant nature.

7. Coastal and Oceanographic processes. Artificial structures placed on the ocean floor are subject to forces due to waves and ocean currents, which are variable in speed and direction and differential hydrostatic pressures. In combination, such phenomena can produce stresses on the seafloor and artificial reef structures (Sheng, 2000). Excessive physical forces may lead to erosion of benthic sediments, leading to instability or movement of the reef structures. Spatial information on near-shore hydrodynamics is therefore essential in order to avoid potentially high energy areas with bottom stresses unsuitable for reef placement. Oceanographic processes relevant to the study regions (including wave climate, water levels, coastal storms and oceanographic effects) have been addressed by Worley Parsons within Appendix 1.

The three Study Areas were evaluated in terms of constraining features to identify specific sub regions where constraints are minimal and have potential for Artificial Reef deployment. The sub regions identified are outlined in Section 4.2 below.

4.2 Sub-Regions

The location selection and constraints mapping exercise has led to the identification of two potentially suitable areas (sub-regions) within each Study Region:

- Newcastle (Figure 2 in Appendix 1)
    a) North (Stockton Bight).
    b) South (south of Nobby's Head and spoil grounds).
- Sydney (Figure 3a/b in Appendix 1)
    a) North (Broken Bay, off Barrenjoey Headland, south to Palm Beach).
    b) South (offshore, Bate Bay)
- Wollongong (Figure 4, in Appendix 1)
    a) North (Stanwell Tops to Bulli)
    b) South (south of Port Kembla off Perkins Beach)

Distribution/characteristics of substrata (mainly presence of unsuitable sub-tidal reef surfaces) and designated exclusion zones (such as port restrictions, cable exclusion zones and spoil grounds) were the main factors in isolating the sub-regions.

For each sub-region a summary table has been constructed to list key issues and their relevance in context with that sub region (Tables 4-6, in Appendix 1).

4.3 Existing Environment

The main physical, biological and social characteristics known for each of the six sub-regions are outlined in Appendix 1 (Tables 4 -6). This includes information on exclusion zones in the vicinity of the sub regions, types of substratum expected, habitat characteristics, biological communities, threatened species, coastal oceanography and issues associated with commercial and recreational fishing.

4.3.1 Newcastle Region

4.3.1.1 North (Stockton Bight)

Offshore of Stockton Bight is a good potential region for siting of an OAR in terms of physical characteristics such as depth, seabed morphology, and few physical obstructions and/or exclusion zones (Figure 2 of Appendix 1). Substratum is mostly sand with likely patches of reef. It is expected that the community of invertebrates and demersal fish found in the area would be typical of those associated with natural shelf sand. Approximately 15 either endangered, vulnerable or protected species are known or expected to occur in the vicinity of Stockton Bight.

Shipping movement to and from the Port of Newcastle is exceptionally high, although anchoring is not permitted in the selected sub region. Newcastle Port Corporation consider Stockton Bight a relatively suitable location for placement of the OARS as it is not considered safe for vessels to anchor. Stockton Bight itself is a well known trawling area. The Ocean Prawn Trawl, Ocean Fish Trawl, Ocean Hauling, Ocean Trap and Line, Lobster and Abalone fishery may operate within this sub region. Coastal erosion along Stockton Beach near the township of Stockton has also been an issue according to the Newcastle Coastline Management Study.

4.3.1.2 South (south of Nobby's Head)

The southern study region has been selected as physical characteristics such as depth, seabed morphology and few physical obstructions and/or exclusion zones make this suitable for OAR deployment. Substratum is mostly sand although there may be isolated patches of reef. It is expected that the community of invertebrates and demersal fish found above and within the sediments would be typical of those associated with natural shelf sand. Approximately 15 either endangered, vulnerable or protected species are known or expected to occur in the vicinity of the sub region. The Belmont and Burwood beach deep ocean outfalls and two wrecks (The Byron and Bonnie Dundee) are potential constraints to be avoided in site selection. Commercial fishing is likely to be a significant issue in the sub region although preliminary consultation with commercial fishers in the Newcastle area have narrowed the potential site to an area in approximately 35 m water depth located between Red Head and Moon Island/Swansea (Figure 2 of Appendix 1).

4.3.2 Sydney Region

4.3.2.1 North (Broken Bay to Palm Beach).

The north Sydney sub region is a relatively small area (roughly 6 km^2) consisting predominantly of medium to coarse orange sand with a small patch of rocky reef at the southern end of the area (offshore from Little Head). It is expected that the community of invertebrates and demersal fish found above and within the sediments would be typical of those associated with natural shelf sand. Approximately 16 either endangered, vulnerable or protected species are known or expected to occur in the vicinity of the sub region. The Barrenjoey Head Aquatic Reserve extends 100 m offshore and is located just to the north of the sub region. Uncharted shipwrecks may also present an issue in the region (Figure 3a of Appendix 1).

4.3.2.2 South (Bate Bay)

The south Sydney sub region is defined by the southern limit of Port Botany port limits to the southern limit of the study region (within the specified depth range), where an area approximately 10. 8 km^2 consists of medium to coarse grain orange sand substrata (Figure 3b of Appendix 1).

It is expected that the community of invertebrates and demersal fish found above and within the sediments would be typical of those associated with natural shelf sand and rocky reef. Approximately 16 either endangered, vulnerable or protected species are known or expected to occur in the vicinity of the sub region. A limiting feature of the sub region is the already popular recreational fishing locations (such as off Port Hacking Point and Glaisher Point) and the presence of rocky reefs such as Osbourne Shoal and Jibbon Bombora amongst others although this could also represent a positive need for alternative locations. Exact positioning of OARs in this sub-region, however, would be limited to remain separated from existing reef habitats.

4.3.2.3 Alternative (South Head to Bondi)

Should the Sydney Port Corporation agree to OARs being positioned at the radial extremes of port limits then potential locations would be significantly broadened. This would also open up the possibility of a third suitable location between South Head and Ben Buckler, which is the northern end of Bondi Beach (Figure 3b, Appendix 1).

4.3.3 Wollongong

4.3.3.1 North (Stanwell Tops to Bulli)

The northern sub region covers approximately 36 km^2 comprising predominantly sandy substrata apart from two known reef shoals offshore from Stanwell Park and Brickyard Point (Figure 4 of Appendix 1). It is expected that the community of invertebrates and demersal fish found above and within the sediments would be typical of those associated with natural shelf sand and rocky reef. Approximately 14 either endangered, vulnerable or protected species are known or expected to occur in the vicinity of the sub region. Commercial and recreational fishing is likely to take place within the sub region.

4.3.3.2 South (offshore from Perkins Beach)

The southern sub region is defined by the southern line of Port Kembla port limits, south to the reef at the southern end of Perkins Beach (this area has been extended just south of the Wollongong study region originally identified by DPI). An area between roughly 7 km^2 and 8 km^2 has been identified where constraints are minimal (Figure 4 of Appendix 1). The Five Islands Nature Reserve is situated at the north of this area and a critical grey nurse shark habitat is located approximately 5.5 km to the south at Bass Point. The biological community assemblage is otherwise likely to comprise typical invertebrate infauna associated with soft sandy sediments and rocky reef habitats. Recreational fishing is popular off The Five Islands Nature Reserve and Perkins Beach. It is possible that commercial fishers may operate in the sub region.

5.0 PRELIMINARY ENVIRONMENTAL ASSESSMENT

The Preliminary Environmental Assessment is based on the outcomes of the constraints mapping (Appendix 1) and discussions between DPI, The Ecology Lab and Worley Parsons. Part of these discussions entailed a risk assessment exercise, described as follows.

5.1 Environmental Risk Analysis

5.1.1 Background

Environmental or ecological risk assessment has become a favoured means for identifying the likelihood and relative consequence of potential hazards associated with human activities. It is also now being widely advocated as a beneficial process in fisheries management (Fletcher 2005).

Typically, assessment of risk entails the identification of a potential hazard (i.e. some aspect of the activity that could affect the environment), a judgment of the likelihood that the hazard has of occurring and a judgement of the consequence of that hazard, if it did result from the proposed activity. Frequently, scientists and managers also consider those aspects of the environment that might be subject to the hazard; such aspects are often referred to as receptors.

As part of the Preliminary Environmental Assessment, a risk analysis workshop was held on 17 January 2008 attended by representatives of DPI, The Ecology Lab and Worley Parsons. The aim of the workshop was to identify potential issues/hazards associated with the Offshore Artificial Reefs program, to assess the likelihood of occurrence of these hazards and assess the consequence to key receptors if these hazards eventuated. This would then help to focus in key issues for the Planning Focus Meeting and the subsequent detailed environment assessment. Five key points need to be recognised in relation to this risk assessment:

- The risk assessment benefited greatly from the constraints mapping, which had been completed and reviewed by all groups prior to the workshop. The constraints mapping was an important means of identifying environmental receptors and of filtering some receptors that could otherwise be subject to significant risk in relation to the activity. For example, prospective sites had been selected to exclude features such as major natural reefs, telecommunications routes, key shipping corridors, etc and these will not require further detailed consideration as part of the next stage of the assessment process.
- The risk assessment was done at a generic level, that is, without particular emphasis on any of the locations identified during the constraints mapping. Notwithstanding this, particular locations were discussed during the risk assessment and where a concern may have been identified for a region a more conservative approach was taken overall.
- Risk is very often scale-dependent, therefore the risk assessment considered the potential effects of the artificial reefs at three spatial scales:
    - small (<1 km^2)
    - interim (1 -10 km^2)
    - large (> 10 km^2)

- The risk assessment focused on the artificial reefs once they had been deployed, but it was recognised that the detailed assessment would also need to evaluate the construction, deployment and ultimate decommissioning of the reef units.
- The risk assessment was essentially an "in-house" process, involving only DPI and the study team. It was recognised at the workshop that extensive consultation with stakeholders would be an important part of the detailed assessment.

Table 1 outlines categories and scores of the probability/likelihood of a hazard occurring and of the consequence to the receptor considered if the hazard eventuated. Scores of likelihood and consequence may then be combined into a matrix to provide a subjective judgement of significance (Table 2). At this preliminary stage in the assessment process, assessment of significance does not mean that the project should not proceed (i.e. if the level of risk is high) or that an issue should be ignored in the detailed assessment if the level of risk is considered low, but rather that the issue may need greater or less effort in the design of the reefs or further research on the receiving environment.

Probability/Likelihood			
A	Almost certain	Happens often	> 1/month
B	Likely	Could readily happen	> 1/year
C	Possible	Could happen & has occurred elsewhere	1 to 10 yrs
D	Unlikely	Has not happened but could	10 to 100 yrs
E	Rare	Conceivable in extreme circumstances	< 1/100 yrs

Consequence	
1	Extreme environmental harm (e.g. widespread catastrophic impact)
2	Major environmental harm (widespread substantial impact)
3	Serious environmental harm (widespread significant impact)
4	Material environmental harm (localised and significant harm)
5	Minimal environmental harm (e.g. interference or likely interference)

Table 1. Explanation of methodology for the Offshore Artificial Reef risk assessment exercise

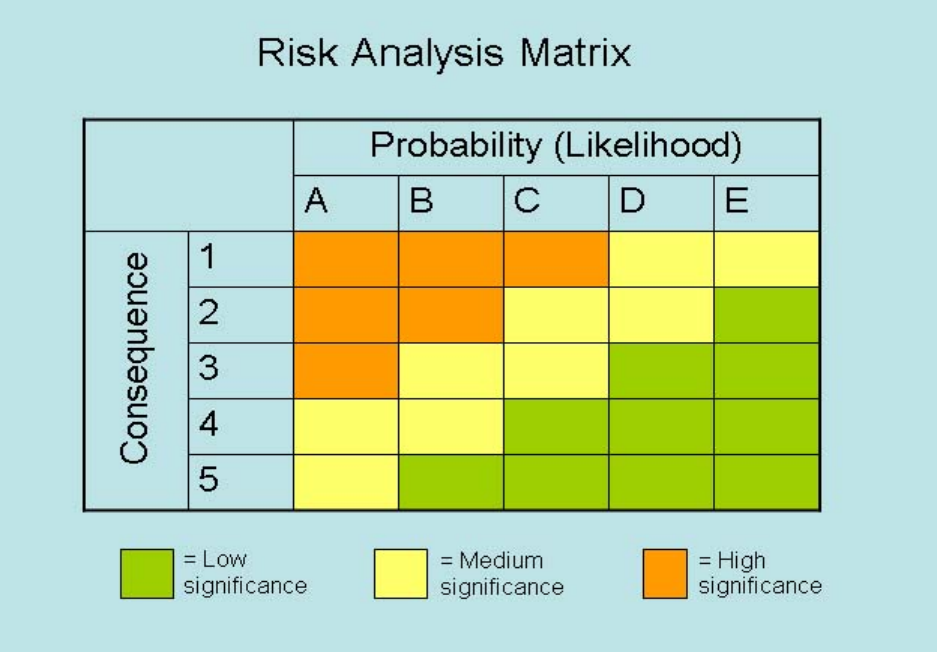


Table 2. Assessment of significance, in accordance to scores of probability (likelihood) and consequence (Table 1).

5.1.2 Results

Risk assessment results are presented in Table 3. Detailed results including scores of likelihood and consequence are in Appendix 3. In total, 50 receptors were identified within six broad categories: coastal processes and oceanography; contamination; ecosystem processes; climate change; fisheries; and coastal infrastructure. Most of the receptors were ranked within the "low significance" range, reflecting the participants' view that impacts occurred with relatively minor consequences. Impacts with a high likelihood of occurrence tended to apply at the smallest spatial scale; for example, localised scouring around the reef structures and potential changes to sedimentary characteristics. With increasing distance from the proposed reefs, frequency of occurrence declines with little environmental consequence.

In terms of the category for coastal infrastructure, receptors include the artificial reefs themselves and a range of existing activities and structures. Without a detailed design for the reef units, there is a risk that they would not function as required, hence an assessment of A3 (of high significance) at the smallest spatial scale (Appendix 3). This issue would, however, be readily addressed during the detailed design and potential risk of failure should be minimised, given the successful design of units elsewhere (Section 2).

As can be seen from Table 3, potential impacts to a range of existing infrastructure have been avoided by the use of constraints mapping to identify optimal areas for placement. The constraints mapping also sought to remove risks to historical shipwrecks. It is likely, however, that further work will be required during detailed assessment to identify with precision known or unknown wrecks in the vicinity of the proposed artificial reefs.

In the category 'ecosystem processes', a number of receptors were identified that are likely to have small-scale consequences, particularly changes to sediment characteristics and local impacts on diversity and productivity. At the broader scale, interruption of movement corridors for fish and marine mammals was identified as a potential risk. Constraints mapping has initially identified areas away from critical habitats and areas of conservation significance which would help minimise possible impacts on threatened, protected and migratory species. However, further assessment of benthos, fish and associated habitat would be required at a local scale to address these issues with ongoing monitoring to assess longer term changes in diversity and/or productivity.

Table 3 also indicates which receptors may, if impacted, also present a risk to human safety. Whilst we are not qualified to provide a detailed assessment of human health risks, we have identified for further consideration these receptors on the basis of our field experience in NSW coastal waters.

A summary of risk scores for the 50 receptors is presented in Appendix 2.

5.2 Further Assessments

The Planning Focus Meeting will provide an opportunity to consider the outcomes of the Constraints Mapping and Preliminary Risk Assessment. At this stage, the following matters are recommended for more detailed assessment.

1. **Detailed Design of Reef Units.** Clearly, the appropriate design of the reef units will be crucial to the success of the program. Various types of units have been developed overseas and there is reasonable information on local coastal conditions that should enable the optimal design to be developed. As part of this

component, detailed consideration should be given to environmental implications of the logistics of construction, installation and ultimately decommissioning and disposal of the units.

2. Planning Issues and Stakeholder Consultation.

a. Commonwealth legislation
b. State legislation
c. Consultation with stakeholders, including commercial & recreational fishers, conservation groups & government authorities.

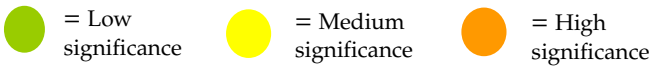
3. Local Aquatic Environment.

a. Coastal Processes. Survey and/or modelling of local conditions (wave climate, sediment transport and oceanographic effects) should be undertaken once a final design has been developed. This would ensure that design, orientation and spatial arrangement of units would be optimised.

b. Distribution of habitat
    i. Reefs, including bathymetry of any reefs located and proximity to the proposed units.
    ii. Soft sediments, including physical characteristics of sediments to assist in assessing the stability of the reef units.
    iii. Historic shipwrecks.
c. Existing biodiversity – benthos and fish. It is recommended that a quantitative assessment of biodiversity and abundance be implemented. The data collected would be extremely valuable in describing the existing ecology of the site(s) and, if properly designed, could form part of a baseline of data for measuring the effects of the OARs, once installed. Key elements of this would include:

    i. Replicated sampling using standardised sampling methodology – for example use of grab samplers and underwater video units.
    ii. Selection of at least two control locations to provide a geographical context for data collected at prospective sites of OARs.
    iii. Sampling at least twice to provide a measure of variability through time in the absence of the OARs.

Table 3. Results of Risk Assessment Workshop (17/1/08) on Offshore Artificial Reefs. See Appendix 3 of main report for explanation of how values were reached). Asterisks (*) identify possible health and safety issues. Risk values are classed as follows:



Potentially constraining feature (receptor)	Hazard/Negative Impact	Scale: Small (< 1 km²)	Scale: Interm. (1-10 km²)	Scale: Large (>10 km²)	
1. Coastal Processes & Oceanography:					
Waves & Currents	Increased wave height, breaking waves				*
	Changed wave direction				
	Changed current direction and magnitude				
	Impact on structure: stability of units				
Coastal erosion/sedimentation	Increased beach erosion				
	Increased deposition (beach or channel)				
Scouring/deposition	Scouring around reefs				
	Deposition on reefs				
	Scouring/deposition around units				
2. Contamination:					
Contamination/pollution issues	Mobilisation of existing contaminants (e.g. from outfalls/ spoil grounds)				*
	Creation of contaminants (steel structures; aluminium anodes)				*
	Contamination from local boats - increased or concentrated boating				
	Gross pollution (lost gear, nylon lines, lead weights, etc)				
3. Ecosystem Processes:					
Substratum type	Change to sedimentary characteristics (e.g. grain size, biota from structures)				
Habitat distribution	Effects of flow by scouring/erosion and emplacement of units				
	Loss of sediments				
Threatened species	Loss of habitat for saw sharks				
	Interruption of movement corridors (e.g. GNS, marine mammals)				

Continued

Table 3. Continued

Potentially constraining feature (receptor)	Hazard/Negative Impact	Scale: Small (< 1 km²)	Scale: Interm. (1-10 km²)	Scale: Large (>10 km²)	
	Increased capture/interactions of threatened species that use reef habitat	●	●	●	
Benthic diversity & productivity	Changes to diversity and productivity of soft sediments	●	●	●	
	Increased predation by fishes from the OAR on benthos	●	●	●	
	Provision of structure for a different assemblage of (attached) benthic organisms	●	●	●	
Demersal fishes/invertebrates	Removal of habitat for demersal biota	●	●	●	
	Increased predation by fishes from the OAR on demersal fishes	●	●	●	
Pelagic fish and invertebrates	Increased predation on pelagic fishes attracted to units	●	●	●	
Introduced species	New habitat for potential utilisation by alien species (e.g. *Sabella*)	●	●	●	
Success of OAR re: biodiversity and abundance	Failure to increase/enhance biodiversity and abundance	●	●	●	
4. Climate change:					
Climate change	Effects of climate change on units affecting stability, etc	●	●	●	
	Effects of climate change on amenity of the units	●	●	●	
	Effects of climate change on ecosystem processes	●	●	●	
5. Fisheries:					
Commercial fishing	Loss of fishing grounds	●	●	●	
	Loss of gear	●	●	●	
	Increased conflict with other users	●	●	●	*
	Safety issues (e.g. gear hookups)	●	●	●	*
Recreational fishing	Reduced availablity of demersal fishes (e.g. flathead)	●	●	●	
	Increased catch of fishes	●	●	●	
	Increased capture of under-sized fish	●	●	●	
	Increased conflict with other users	●	●	●	*
	Safety issues (e.g. anchor hookups)	●	●	●	*
Scuba Diving	Increased conflict with other users	●	●	●	*
	Safety issues (e.g. boatstrike; decompression illness; entanglement)	●	●	●	*

Continued

Table 3. Continued

Potentially constraining feature (receptor)	Hazard/Negative Impact	Scale			
		Small (< 1 km²)	Interm. (1-10 km²)	Large (>10 km²)	
Spearfishing	Increased catch of fishes	●	●	●	
	Increased capture of under-sized fish	●	●	●	
	Increased encounters with dangerous marine animals	●	●	●	*
	Increased conflict with other users	●	●	●	*
	Safety issues (e.g. boatstrike; entanglement)	●	●	●	*
6. Coastal Infrastructure:					
OAR structure	Stability of units; corrosion	●	●	●	
AMCA cables	n/a (see constraints mapping)	-	-	-	
Deepwater outfalls	n/a (see constraints mapping)	-	-	-	
Shipping lanes & anchorages	n/a (see constraints mapping)	-	-	-	
Marine protected areas	n/a (see constraints mapping)	-	-	-	
Mining exploration leases	n/a (see constraints mapping)	-	-	-	
Spoil disposal grounds	n/a (see constraints mapping)	-	-	-	
Historical ship wrecks	Damage to wrecks from unit emplacement	●	●	●	
	Indirect damage due to changes in water & sediment movements	●	●	●	
	Anchor damage from vessels close to units	●	●	●	

6.0 CONCLUSIONS

The OAR program is part of a broad scale approach to fisheries enhancement, other aspects being FADs and estuarine reef balls. Artificial reefs have been installed in coastal waters in many countries and individual reefs can be designed to suit the local conditions. For this preliminary assessment, OAR units are assumed to be made of steel and would be self-anchoring. This design is not mandatory and units could be readily re-designed to suit local conditions. Worley Parsons have advised that there is extensive research available on the design of offshore platforms that could be readily applied to the current proposal.

The constraints mapping has identified up to seven prospective sites for placement of OARs between Newcastle and Port Kembla. The risk assessment did not identify any impacts of major concern and many of the smaller concerns could be mitigated by design of the units and their installation. There would, however, be a requirement for detailed consideration of the procedures for construction, transport and ultimate decommissioning of the units. The detailed assessment of the proposal will require a close consideration of all relevant legislation, including state (e.g. *Environmental Planning and Assessment Act*, *Fisheries Management Act*, *Threatened Species Conservation Act*, *Coastal Protection Act*) and commonwealth (e.g. *Environment Protection and Biodiversity Conservation Act* and *Environment Protection* (*Sea Dumping*) *Act*) legislation. There will also be a need for detailed consultation with government authorities and stakeholders (e.g. commercial and recreational fishers, conservation groups, port authorities).

Finally, there will be a need to collect further site-specific information, including data on sediment characteristics, biodiversity (e.g. benthos and demersal fishes) and potential proximity to reefs or shipwrecks that may not be charted or known. Acquiring this information would require a focused field program and should include, where relevant, surveys through time at prospective OAR sites and control sites. This information would enhance the assessment process and contribute to a baseline that could be used to monitor the OARs after they are installed.

7.0 ACKNOWLEDGEMENTS

This report was written by Dr Marcus Lincoln Smith and Kate Reeds, with assistance from Dr Arthur Dye (The Ecology Lab) and Greg Britton (Worley Parsons). Background information was supplied by NSW DPI.

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APPENDICES

Appendix 1: Offshore Artificial Reefs - Location Selection and Constraints Mapping. Report by The Ecology Lab Pty Ltd to NSW Department of Primary Industry.

Appendix 2: Offshore Artificial Reefs -risk assessment matrix.

Appendix 3: Offshore Artificial Reefs -results of risk assessment workshop (17/1/08).

Report to:

NSW Department of Primary Industry

APPENDIX 1

Offshore Artificial Reefs – Location Selection and Constraints Mapping

FINAL

January 2008

Offshore Artificial Reefs – Location Selection and Constraints Mapping

January 2008

Report Prepared for:

NSW Department of Primary Industries (DPI)

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Report Number – 30/0708 A

Report Status – Final, 23 January 2008

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SUMMARY

The New South Wales Department of Primary Industries (DPI, Fisheries) with funding from the Recreational Fishing Trust, aim to improve recreational fishing opportunities in NSW through the development of offshore artificial reef structures (OAR's) at selected locations along the NSW coastline.

The artificial reefs would be placed on the seabed at depths between 25 m - 40 m and, as a working design, would consist of four, 10 m tall steel tower structures per artificial reef. Each reef unit is expected to weigh in the region of 35 tonnes and will sit directly on the seabed and would be anchored by the weight of the unit itself. In the initial phase of deployment, it is estimated that an area of seabed between 0.5 km^2 to 1 km^2 would be required per reef (consisting of four individual units). Subsequent phases could expand the artificial reefs by adding up to three more groups of reef modules to cover an area of 3 km^2 per site (9 km^2 in total).

DPI has commissioned The Ecology Lab Pty Ltd to undertake a desktop analysis of opportunities and constraints for installing the artificial reefs along the coastline at Newcastle, Sydney and Port Kembla. Worley Parsons (formerly Patterson Britton & Partners) Pty Ltd has collaborated with the Ecology Lab to provide expert advice on the coastal and oceanographic characteristics of the study regions and to assist with mapping of coastal resources. This report aims to:

- Outline major physical, hydrological and biological constraints on site selection, including descriptions and sources of information;
- Map any constraints identified in regard to deployment of the reefs at appropriate spatial scales;
- Use existing information to recommend sites either with potential for deployment of the OAR's or which require further investigations.
- Recommend innovative variations to the broad proposal and future consultations with DPI if required.

Current literature was searched using library resources from the Ecology Lab, Worley Parsons and the internet to produce the main constraints review at each location. Constraint maps were constructed using GIS (Geographic Information Systems) software.

Two sub-regions within each location were identified where constraining issues appear to be manageable and sufficient area is available for placement of the reefs. These sub regions have been identified as follows:

- Newcastle:
    a) North (Stockton Bight).
    b) South (south of Nobby's Head and spoil grounds).
- Sydney:
    a) North (Broken Bay, off Barrenjoey Headland, south to Newport Reef).
    b) South (offshore, Bate Bay)
- Wollongong:
    a) North (Stanwell Tops to Bulli)

b) South (south of Port Kembla off Perkins Beach)

There is also the possibility of a third sub region (between South Head and Ben Buckler) within the Sydney region, although this requires authorisation from the Sydney Port Harbour Master to deploy the structures within port limits.

Further information is still required in some areas to validate the suitability of the sub regions. This includes locations of local commercial trawling grounds (which will be addressed through consultation with relevant cooperatives and fishers at a later stage) and precise locations of ship wrecks or anthropogenic debris on the seabed. In addition, no published data are available on sub tidal rocky reefs in depths greater than 20 m depth in the Newcastle and Wollongong study regions.

It is recommended that acoustic survey techniques and point ground truth sampling are used to provide full coverage information of the seabed within selected sub regions at the 1 km^2 – 3 km^2 scale. This would provide information on the nature (e.g. hardness, roughness, texture) of the sediments, the presence and deposition of seabed features (e.g. sand waves, rock reefs) and would also locate the presence of uncharted ship wrecks or anthropogenic debris. These data together with information obtained from the benthic ground truth survey can be combined to produce detailed seabed habitat maps and ensure that artificial reef units are positioned in the best possible location. It is recommended that data on biological attributes are obtained to give an indication of overall productivity and provide baseline information for future monitoring surveys. As a minimum, this should include sampling of benthos (obtained as part of the ground truth survey) and demersal fish (carried out either by trawl or non-destructive, remote video techniques).

1.0 INTRODUCTION

1.1 Background and Aims

The New South Wales Department of Primary Industries (DPI, Fisheries) with funding from the Recreational Fishing Trust, aim to improve recreational fishing opportunities in NSW through the development of offshore artificial reef structures (OAR's) at selected locations along the NSW coastline.

The artificial reefs are designed to sit offshore at depths between 25 m - 40 m and would consist of four, 10 m tall steel tower structures per reef. Each reef unit is expected to weigh in the region of 35 tonnes and will sit directly on the seabed without requiring additional anchorage other than the weight of the unit itself. In the initial phase of deployment, it is estimated that an area of seabed between 0.5 km^2 to 1 km^2 would be required per reef (consisting of four individual units). Subsequent phases could expand the artificial reefs by adding up to three more groups of reef modules to cover an area of 3 km^2 per site (9 km^2 in total).

DPI has commissioned The Ecology Lab Pty Ltd to undertake a desktop analysis of opportunities and constraints for installing the artificial reefs along the coastline at Newcastle, Sydney and Port Kembla. Worley Parsons (formerly Patterson Britton & Partners) Pty Ltd was sub-contracted by the Ecology Lab to provide expert advice on the coastal and oceanographic characteristics of the study regions and provide GIS data layers. This review aims to:

- Outline major physical, hydrological and biological constraints on site selection, including descriptions and sources of information;
- Provide high quality maps identifying constraints and suitable deployment sites at appropriate scales;
- Recommend sites either with potential for deployment of the OAR's or which require further investigations and/or ground truthing;
- Recommend innovative variations to the broad proposal and future consultations with DPI if required.

1.2 Study Regions

DPI has identified three localities for OAR deployment (hereafter referred to as the 'study regions'), where positioning constraints will be evaluated (Figure 1).

- Newcastle (from Stockton Beach south to Swansea).
- Sydney (from Barrenjoey Head south to Bundeena, Port Hacking)
- Wollongong (from The Stanwell Tops south to Port Kembla)

1.3 Appreciation of Constraining Issues

NSW DPI and The Ecology Lab have identified a number of major constraints which will restrict potential positioning of the artificial reefs. It is therefore essential that these limiting factors are addressed at the initial phase of the project before more detailed investigations

are undertaken. Issues constraining the location of the artificial reef structures are outlined in brief below:

- Depth. As the tower structures of the OAR's reach 10 m in height, a depth range between 25 m – 40 m on the continental shelf is a major requirement to avoid creating a navigational hazard. Suitable depth will also be important for the stability of the structures (in terms of ability to withstand certain hydrodynamic forces), accessibility to recreational fishers (via boat) and will also influence the type of fish which will aggregate around the structure.
- Exclusion zones, including:

  AMCA cable exclusion zones

  Deepwater ocean outfalls

  Commercial fishing areas (e.g. trawl and trap)

  Designated commercial shipping lanes/port restrictions

  Marine protected areas (state and commonwealth)

  Mining exploration leases

  Historical ship wrecks

  Spoil grounds
- Other restricting features e.g.

  FADS (Fish Attraction Devices)

  Desalination plants
- Distribution of substrata and suitability of substrata to support reef structures.

Artificial reefs are typically designed to maintain their structural and functional integrity for many years without deteriorating or being permanently covered by sediment (Marshall *et al*, 2003). Underlying sediments should have the ability to easily support the reef structure and generally soft sediments such as clays, silts and loosely packed sands should be avoided. Reliable and detailed seabed characterisation data are therefore necessary to properly site the OAR's.

- Distribution of habitats, flora and fauna.

On positioning OAR's, existing reef habitats, habitats unique within an area, or locations known to support diverse benthic/epibenthic communities should be avoided. Areas to be avoided should also include beds of macroalgae, oyster reefs and mussel beds. Habitats critical to the survival of a particular species are generally protected under NSW legislation and should therefore be avoided. It should also be considered that protected habitats may require an additional buffer zone around them where fishing or development activity is restricted. Specific legislative requirements with regards to Marine Protected Areas (MPA's) are addressed in section 1.4. In addition, DPI have specified that placement of the OAR's should be a distance away from existing reefs in order to create new habitats where there was originally none, rather than adding to existing fishing areas.

- Threatened species issues, including fish, invertebrates, marine mammals and marine reptiles.

Information on the occurrence and distribution of threatened species is generally sparse and may be limited to predictions based on presence of suitable habitat and/or records of a species occurring at near by locations. It is especially difficult to predict where highly mobile individuals (such as fish or migratory marine mammals) occur due to their itinerant nature.

- Coastal and Oceanographic processes.

Artificial structures placed on the ocean floor are subject to the forces of currents (variable in speed and direction), waves, tides and hydrostatic changes in water levels. Combined, such currents can produce stresses on the seafloor and artificial reef structures (Sheng *et al*, 2000). Excessive physical forces may lead to erosion of benthic sediments, leading to instability or movement of the reef structures. Spatial information on near-shore hydrodynamics is therefore essential in order to avoid potentially high energy areas with bottom stresses unsuitable for reef placement. Detailed discussion of oceanographic processes relevant to the study regions (including wave climate, water levels, coastal storms and oceanographic effects has been compiled by Worley Parsons Pty Ltd (Appendix 1).

1.4 Statutory Requirements

The following statutory requirements are relevant to this review, some of which are directly related to statutory exclusion zones.

The *Environmental Protection and Biodiversity Conservation Act 1999* (*EPBC Act)* is administered by the Commonwealth Department of Environment and Heritage (DEH) and assesses actions that are likely to have a significant impact on a matter of national environmental significance (NES). In the aquatic environment, the Act lists threatened species, ecological communities and key threatening processes; migratory species; cetaceans; marine species and Ramsar areas of national significance. The Act applies to waters in the Australian jurisdiction, which generally includes the coastal waters of Australian States.

In NSW the *Threatened Species Conservation Act 1995 (TSC Act)* the *Fisheries Management Act 1994* (*FM Act*) and the *Fisheries Management Amendment Act 1997* (*FMA Act*) include provisions to declare threatened species, populations, ecological communities and key threatening processes. Provisions for the protection of fish and marine plants are administered through the Department of Primary industries (NSW DPI) and those for marine birds, mammals and reptiles are administered through the NSW Department of Environment and Climate Change (DECC). Part 2 (19) of the *FM Act* also allows for the declaration of 'protected species', which, though not currently declining, must be protected so they do not become threatened in future. Species protected under NSW and Commonwealth legislation relevant to this review are listed in Table 1.

The *Telecommunications Act 1997* and *Telecommunications and Other Legislation Amendment (Protection of Submarine Cables and Other Measures) Act 2005* (the *T&OLA Act*) were enacted to increase protection of fibre optic telecommunications cables of national significance. Under the legislation, the Australian Communications and Media Authority (ACMA) may declare protection zones in relation to submarine cables. In a protection zone, certain activities, such as bottom trawl fishing and dredging, are prohibited and restrictions may be imposed on other activities with potential to damage or break submarine cables. Section 8 of the Act lists activities that constitute a serious threat of damage to a submarine cable, this includes the 'use of, towing, operating or suspending from a ship, a structure moored to the seabed with the primary function of attracting fish for capture, such as a fish aggregating device' (ACMA, 2007a/b).

The *Historic Shipwrecks Act 1976* is administered by the Commonwealth Department of Environment and Water and protects historic wrecks and relics in Commonwealth waters, extending from below the low water mark to the edge of the continental shelf. In NSW all shipwrecks over 75 years of age are automatically protected from disturbance under the state NSW Heritage Act 1977. Some historic shipwrecks lie within protected or no-entry

zones. These zones may cover an area up to a radius of 800 m around a wreck site, and may be declared where circumstances place it at particular risk of interference. This declaration prohibits all entry into this zone without a permit. Permits are also required to undertake any activities otherwise prohibited or restricted by the Act.

2.0 NEWCASTLE (SWANSEA TO STOCKTON BEACH)

2.1 Depth Range

Data Source: Webster, M. A and Petkovic, P. (2005). Australian Bathymetry and Topography Grid, Geoscience Australia. Bathymetry contours are derived from the 250m bathymetry raster grid.
Depth contours (isobaths) have been mapped at 20 m, 40 m and 60 m intervals (Figure 2) although it should be noted that the required depth range for the artificial reef structures (recommended by DPI) is between 25 m and 40 m. At the northern end of the Newcastle study region, depth increases gradually offshore from Stockton Beach, reaching a depth of 20 m at approximately 1 km offshore and a depth of 40 m a further 5km – 6 km seaward. The southern section of the study region, (south of the port entrance) is similar in depth profile, with the exception of steeper inclines off the rocky reef outcrops. Depths suitable for OAR's, (i.e. 25 m) start at around 1.5 km to 2 km offshore, however, as a result many features such as port limits and spoil grounds (sections 2.2.3 and 2.2.7) located in the region would limit potential OAR sites to areas north or south of the port. North of the harbour there is approximately 115 km^2 within the 25 m to 40 m depth range and south of the harbour exclusion zones approximately 70 km^2.

2.2 Exclusion Zones

2.2.1 Deepwater Ocean Outfalls

Data Source: Worley Parsons Pty Ltd and The Ecology lab Pty Ltd

Three deepwater ocean outfalls are operated by Hunter Water within the Newcastle region, from north to south, these are located at Boulder Bay (just south of Port Stephens), Burwood (south of Newcastle Port) and Belmont, 10 km south of Burwood, although the Boulder Bay outfall is located outside of the study region so is not considered further (Figure 2). The Burwood and Belmont deep water ocean outfall extends for approximately 1.6 km offshore and 1.5 km offshore respectively. The outfalls consist of a mild steel pipeline laid on the ocean bed terminating in diffuser (around 120 m long) to prevent entry of seawater and marine sediment into the outfalls (web ref 14).

2.2.2 Commercial and Recreational Fishing Areas

Data Source: Larcombe *et al* (2006) Atlas of Australian Marine Fishing and Coastal Communities, Tanner and Liggins (2000) NSW Commercial Fisheries Statistics, McEnally and McEnally (2004) AFN Fishing Guide to the Central Coast and North Coast of NSW.

Commercial fisheries potentially affected by the proposal are those that can operate in State waters. These include those under the jurisdiction of the State of NSW and also those under the jurisdiction of the Commonwealth of Australia that may operate within the 3 nm limit under a Section 37 permit of the *FM Act* (The Ecology Lab, 2007).

Fisheries permitted to operate within the Newcastle study region include the Ocean Hauling Fishery, the Ocean Prawn Trawl Fishery, the Ocean Fish Trawl Fishery and the Ocean Trap and Line Fishery. The Lobster, Abalone, Sea Urchin and Turban Shell fisheries are also known to operate within these waters although to a much lesser extent. The Newcastle

study region covers mostly catch reporting zone 5 and also overlaps into the northern section of catch reporting zone 6 (Figure 5). The geographical extent of these fisheries, target species and economic values of the fisheries are outlined in Appendix 2.

Stockton Bight is a well known commercial fishing ground and trawling in this area is therefore a significant limiting factor in determining suitable deployment sites. A number of commercial fishing licences are held in Newcastle and commercial fisheries data for the years 1998/99 show there were approximately 189 fishers operating in zone 5 and 124 in zone 6. 54 of these were known to operate out of Newcastle and 10 out of Swansea (Tanner and Liggins, 2000). Data compiled by Larcombe et al, (2006) for the years 2000-02 showed that the main fishing methods in the Newcastle region was by net, with a high percentage of trawling, and a small percentage of trapping. Although there is a substantial amount of statistical data available on catch landings, economic value and species landed, there is a lack of spatial information available to map specific locations where fishing effort is concentrated. This is mostly due to the confidential nature of fisheries log book data. Spatial fisheries information would be required from DPI in order to map areas with a high frequency of trawling activity at a resolution useful to this study.

Recreational fishing in this region is popular, with 3 DPI listed charter vessels operating out of the Hunter (web ref 19) and a number of other vessels operating from the surrounding suburbs (National Oceans Office, 2004). It should be noted however that DPI listed vessels (those wishing to be listed) represent approximately 70% of all registered vessels operating in the area so the actual figure is likely to be greater.

Recreational fishers use hook and line to target demersal reef species such as yellowfin bream (*Acanthopagrus australis*), silver trevally (*Pseudocaranx dentex*), mulloway (*Argyrosomus hololepidotus*), snapper (*Pagrus auratus*) and kingfish (*Seriola lalandi*) on offshore reefs and species such as leatherjackets (Monacanthidae) and flathead (Platycephalidae) on sandy areas. Popular offshore fishing spots include Uralla Reef (North Stockton), Carls Reef, The Gravel (off central Stockton) and further inshore at Stockton around the wreck of the Sygna. Offshore from the port entrance, spots known as Middle Reef and North Reef are targeted for bream (Sparidae), mulloway (*Argyrosomus hololepidotus*) and teraglin (*Atractoscion aequidens*). The dumping ground and around Nobby's Head is also popular for boat fishing. Reefs immediately south of Nobby's Head (in particular a rocky pinnacle known as 'Big Ben') are thought to be good locations for snapper and mulloway. Directly south of Nobby's Head and east of Redhead are several sections of reef productive for a mixture of reef fish. The wreck of the Bonnie Dundee (approximately 5 km offshore from Swansea) is a favoured spot for mulloway and baitfish. GPS Positions, target species and names of known offshore recreational fishing locations are listed in Table 7 and locations marked in Figure 2.

Boat ramp facilities in the region are good as offshore recreational fishing areas are accessible via the Hunter Estuary and from Swansea (Figure 2).

2.2.3 Designated Commercial Shipping lanes/Port Authority Restrictions

Data Source: AUS Chart 207 (positions rectified for use in GIS format) and Newcastle Port Authority.

The Port of Newcastle is one of Australia's oldest ports and also the largest port in Australia in terms of total throughput (tonnage) of exports and import trade. There are approximately 3000 shipping movements per year with coal export representing more than 90 % of the total throughput tonnage (web ref. 5). Newcastle Port Limits are defined by a circular line of 3 nm radius from Nobby's Head Lighthouse, however, it should be noted that on AUS Chart

207, port limits are represented as an arc to a point in line with the northern breakwater. Within this zone vessels are not permitted to anchor or impede the navigation of commercial shipping. Despite the high frequency of shipping traffic in the Newcastle region, no ships are permitted to anchor within 3 nm of the coast (this is at approximately 40 m depth) or north of Little Red Head Point. Shipping would therefore not be a significant constraint if an artificial reef is located outside of the port limits, within the 3 nm limit. The Harbour Master advised that no consideration would be given to the placement of OAR's within the port limit and that any proposed location should be well clear of the 'massive anchorage' for Newcastle ports heavy shipping. Details of discussions with Newcastle port authorities and Worley Parsons are outlined in Appendix 4.

A circular no anchoring zone is also located approximately 7 km south of Newcastle port which encompasses the Burwood deepwater ocean outfall and possibly a historic wreck.

2.2.4 Marine Protected Areas

Data Source: Breen *et al* (2005) Broadscale Biodiversity Assessment of the Hawkesbury Shelf Marine Bioregion and NSW DPI.

There are three types of Marine Protected Areas (MPA's) recognised within NSW, Marine Parks, Aquatic Reserves and National Parks and Nature Reserves (which are generally terrestrial but with associated marine components). MPA's are protected under *The Marine Parks Act 1997* which aims to promote and conserve marine biodiversity, habitats and ecological processes, provide for the ecologically sustainable use of fish and marine vegetation and provide opportunity for public appreciation, enjoyment and education (Breen *et al*, 2005). The Port Stephens – Great Lakes Marine Park is located at the northern limit of the Newcastle study region, extending from Birubi Beach Surf Life Saving Club (North Stockton Beach), north, to Cape Hawke Surf Life saving Club (near Forster). The park encompasses an area of approximately 98,000 hectares and includes waters within the 3 nautical mile state limit. A zoning plan for the park was established in April 2007, aiming to accommodate a range of recreational and commercial fishing activities, while also protecting the marine habitat. Zoning at the southernmost end of the marine park is a habitat protection zone for approximately 4 km offshore where it becomes a general use zone for a further 3 km – 4 km offshore. The northern boundary of the Newcastle study region should therefore be defined by the limit of these zones (off North Stockton beach). No other marine protected areas are designated within this study region apart from the Kooragang Nature Reserve which is not considered a constraining issue as it is located within the intertidal habitat of the Hunter Estuary.

2.2.5 Mining Exploration Leases

Data Source: NSW DPI (2007) Petroleum Projects and Exploration Highlights in NSW (map) and NSW DPI 'TAS Map' minerals mapping online application.

Petroleum Exploration Licence (PEP) 11 is the only current offshore mining exploration area in NSW. The extent of the area is from Port Stephens to Wollongong (200 km) covering 2,000,000 acres, starting from 3 nm offshore. Bounty Oil and Gas NL currently have plans to drill the first exploratory oil rig in the licence area, Biggus – 1. Location of the exploratory oil rig is planned to be 25 km south of Newcastle and approximately 22 km offshore at a depth of 125 m. A 2 nm exclusion zone will apply around the rig for the time that it is in place. Due to the depth and planned location of the exploratory rig, it is unlikely to be a major constraining feature in the region. As the exploration licence area is so large it has not

been mapped in the figures, although the data layer is included in accompanying GIS files. There are no active sand or gravel operations in the study region.

2.2.6 Historical Ship Wrecks

Data Source: NSW Maritime Heritage database/ NSW Heritage Office (web ref 2), The Shipwreck Atlas of NSW (1996) Department of Urban Affairs and Planning (positions rectified for GIS format) and Byron (1997a/b), The Scuba Diving, Snorkelling and Spearfishing Guide to Northern/Southern NSW.

Appendix 3a provides search results for historical shipwrecks located within the radius of the specified study region from the NSW Maritime heritage database. These data provides an indication of the total number of wrecks in the region but does not provide accurate locations. GIS data with accurate positions was therefore obtained directly from the NSW Maritime Office (courtesy of David Nutley) combined with positions obtained from Byron (1997a/b) and the Shipwreck Atlas of NSW . These data (Table 2), although accurate, is limited to more well known wrecks for which exact positions are known. It should therefore be considered that there are a number of wrecks in the region for which accurate positions are unknown and may occur within the 25 m – 40 m depth range.

In total, 34 shipwrecks were found in the Newcastle study region, 7 of which are known with reasonable accuracy. At the northern end of the study region (Stockton Bight), wrecks of the Fitzroy, Osprey and Commodore are known to lie between 25 m and 40 m of water. The Fitzroy wreck site is located off Birubi Point, and is the furthest out of a group of wrecks located either in shallow areas or inter-tidally. One unidentified wreck lies offshore from the centre of Stockton Beach in waters exceeding 36 m. The Osprey, Commodore and Irresistible are located at South Stockton Beach. The Osprey lies in 40 m of water approximately 5 km offshore, with the Commodore located to the southeast of this approximately 4 km offshore from Nobby' s Head at a depth of 35 m. In 1984, the Commodore was declared a historic shipwreck and is therefore protected under the *Historic Shipwrecks Act* and an exclusion zone applies. The Irresistible is located closer to the shore of South Stockton Beach although less is known about the exact depth at which it lies. A number of additional wrecks exist in shallower waters of South Stockton Beach inside the northern harbour breakwater. At the southern end of the Study region (South of Nobby's Head), wrecks of The Byron and Bonnie Dundee are located between 4 km – 5 km off Redhead Point and Moon Island respectively. Both are thought to lie in approximately 35 m of water. The wreck of The Advance also lies approximately 6 km southeast of Moon Island and 3km offshore, at 50 m depth just south of the defined study region.

As a number of wrecks are known to occur within the study region for which no accurate data are available it is recommended that more detailed analysis of wreck locations should be undertaken at a later stage, when more specific, potential sites have been identified.

2.2.7 Spoil Grounds

Data Source: AUS Chart 207 (Positions rectified for use in GIS format). The Ecology Lab (1993).

One main spoil disposal area exists in the Newcastle study region, located approximately 3 km offshore and south east of Nobby's Head just south of the southern port limits. The spoil disposal ground has previously been used for dumping of dredged material from the harbour and covers an area of approximately 3.83 km^2 in 30 m - 45 m of water.

2.3 Distribution and Characteristics of Substrata

Data Source: NSW National Parks and Wildlife Service, 'Near shore Sub-tidal Marine Reef Systems and Soft Sediment Mapping' and University of Sydney, School of Geosciences, GIS marine sediment data.

Near shore sub-tidal reefs have been mapped by the NSW National Parks and Wildlife Service over a range of years from aerial photography provided by NSW Department of Land and Water Conservation's specialist Coastal and Floods Unit. Other than this data set there is little GIS data available for detailed mapping of seabed morphology at depths appropriate to this study. The most complete data set available for near shore reefs in NSW covers reefs to a depth of 20 m up to 1 km offshore, although some reef shoals further offshore have been digitised from Australian Hydrographic Office (AHO) nautical charts. In the Newcastle study region, there are two small reef shoals offshore from South Stockton Beach between 20 m – 40 m depth (Figure 2). As they are located close to the perimeter of Newcastle port limits, the area would already be considered low priority for site selection.

Soft sediments in the study region have been studied by Ruello 1973, Patterson and Britton & Partners 1996 and Birch *et al.* 1997. Sediment around the Port of Newcastle was described to consist of sand, mud and silt. Sediments further offshore on the inner shelf plain were described as typically sandy (Patterson Britton & Partners 1996). It is believed that approximately 12 km offshore at the inner shelf slope there is a large stretch of mud at a depth of approximately 100 m (Patterson Britton & Partners 1996). GIS Sediment data provided by the Department of Geosciences, University of Sydney includes particle size composition of samples collected by dredge pipe off North Stockton and Red Head (Table 3). Samples consisted of a high percentage of sand with some gravel inshore and a mixture of mud and sand at a depth >60 m.

ROV (Remotely Operated Vehicle) investigation of the seabed has also been undertaken at two locations north and south of Newcastle by the Ecology Lab (2001). This study compared biological, chemical and physical characteristics of a dump ground (located outside the harbour entrance) with adjacent control areas. Sediment characteristics during the ROV survey were observed at depths between 25 m – 30 m and showed the seabed at both control locations to consist predominantly of rippled sand and shell fragments. Wavelength and wave height of the sand ripples were estimated at approximately 20 cm throughout the survey, with shells and shell fragments seen to be concentrated in the wave troughs. At some positions in the northern control site small black rocks (probably coal) were observed on the seabed. On average, sediments sampled at both control sites consisted of 98 % sand and 2 % gravel.

2.4 Distribution of Habitats, Flora and Fauna

Data Source: Literature sourced from the Ecology Lab reference library.

Distribution and diversity of macrofauna (invertebrates living on or within sediments) vary in space and time depending on a range of physical and biological factors. Physical factors include water depth and movement, salinity and type of sediment. Biological factors include food availability, competition and predation (McCaulry *et al.* 1977; Jones, 1986; Morrisey *et al.* 1992; Snelgrove and Butman, 1994; Newell *et al.* 1998). The nature of the sediment in particular, has a major influence on the animals living within it (Morrisey *et al*, 1998) and in general, sub tidal sediments support a large variety of invertebrates and fish. The invertebrates may consist of 'infauna' which burrow to depths of about 50 cm into the sediments, and 'epifauna' which live on the surface of the sediments. Sub-tidal rocky reefs

support very different communities to the sandy habitats. They also show some degree of 'zonation', with turfing macroalgae and kelp occurring in shallower waters, bare rock (which is actually covered by encrusting red algae) at intermediate depths and 'sponge gardens' in deeper water (Underwood *et al.* 1991).

A study by The Ecology Lab (2001), investigated benthic community assemblages and sediment characteristics of sites in the vicinity of the Newcastle Harbour spoil ground using benthic grabs and ROV (Remote Operated Vehicle). Two control sites were sampled, one located offshore from South Stockton Beach (outside of port limits) at a depth of around 27 m and the other south of the harbour, offshore from Red Head Point at a depth of 18 m - 28 m. ROV observations at the northern control site showed that the seafloor appeared clean with shells and shell fragments in ripples across the seafloor. Sea urchin tests (skeletons), and small starfish were observed at some locations. Similar habitats were observed at the southern and northern control sites. Assemblages of benthic invertebrates consisted mainly of polychaete worms (family, Cirratulidae), amphipod crustaceans (family, Phoxocephalidae), isopod crustaceans (family, Anthuridae) and bivalve molluscs (family Veneridae). Sediment particle size composition at both control sites was similar and consisted of approximately 98 % sand and the rest gravel. A later study, (The Ecology Lab, 2003) also investigated benthic community structure and sediment particle size composition at similar locations to those investigated in 2001. Results showed that dominant families collected in benthic samples were again isopod crustaceans, amphipod crustaceans, polychaete worms and bivalve molluscs although composition of families were slightly different. Results also showed that in general, higher numbers of individuals were found in deeper sediments. Sediments at the control sites were characterised as 'natural shelf sediments' and were (as expected) composed of a high sand percentage and a small gravel percentage. A small proportion of rock fragments and quartz matter were also found at some locations. Overall, the benthic community assemblage was typical of that expected in sandy offshore habitats.

2.5 Threatened Species Issues, Including Fish, Invertebrates, Marine Mammals and Marine Reptiles.

Data Source: The NSW DPI threatened species database and (web ref 1), the NSW Government BioNet System (web ref 15) and literature sourced from the Ecology Lab reference library. GIS positions of critical habitats were obtained from the Fishery Management Strategy for the Ocean Trap and Line Fishery (NSW DPI, 2006) and NSW DPI.

Table 1 summarises marine species and populations listed under the *FM Act*, *TSC Act* and the *EPBC Act* which occur in the Newcastle Study region (Search criteria was for the Hunter/ Central Rivers Catchment Management Authority). A Total of 15 endangered, vulnerable or protected species were found to occur in the Newcastle study region including three species of reptile, six species of marine mammal and six species of fish. Marine sea-birds (such as petrels, albatross and shearwater) scheduled in the *TSC* and *EPBC Act* were excluded from the search as it is unlikely that their presence in a deployment area would be of significant relevance. Three species, the Loggerhead Turtle (*Caretta caretta*), Blue Whale (*Balaenoptera musculus*) and Southern Right Whale (*Eubalaena australis*) are listed under Commonwealth legislation as 'endangered migratory species' known to occur in the Newcastle region, with the exception of the Blue Whale which has only been 'predicted' to occur in the region. The Grey nurse Shark (*Carcharias taurus*) is listed as 'critically endangered' and is known to occur throughout this coastline with a major aggregation site (designated a critical habitat) north of Port Stephens at Little Broughton Island, although this is some distance out of the Newcastle study region. Southern Right Whales are increasingly

being sighted off the NSW coast within inshore waters whilst travelling between coastal locations (Allen & Bejeder, 2003). Records of Southern Right Whale sightings on the east coast of Australia between 1993 and 2002 were compiled by Allen & Bejeder (2003) and showed a number of sightings of cow-calf pairs were reported off Port Stephens. Distribution and migration maps produced by the Department of Environment and Heritage (web refs 16, 17 and 18), show that although Southern Rights are known to occur along the whole NSW coastline, they are not usually known to aggregate in these waters. Calving females with young are sometimes observed close to the shore within a water depth of between 5 m – 10 m (Web Ref. 3) and it is recommended that placement of infrastructure in this zone is avoided, partly for this reason. Sightings of the endangered Loggerhead Turtle have been recorded approximately 2 km offshore from Swansea Heads by the National Parks and Wildlife Service in 2003, although the majority of records tend to be from northern NSW. Once more specific areas have been identified as potential zones for the deployment of OAR's then it would be possible to assess the likelihood of protected species occurring in the vicinity of the structures in further.

2.6 Coastal and Oceanographic Processes

Data Source: Worley Parsons Pty Ltd

Refer to Appendix 1.

2.7 Gaps in Information

In order to make more informed recommendations on potential deployment sites, further information would be required in the following areas:

- Shipwrecks. There are a number of shipwrecks in the region for which the exact location is unknown. Expert information would be useful at a later stage, combined with detailed seabed surveys (e.g. side-scan sonar) where necessary.
- Nature of the Seabed. No published data are available at depth > 20 m offshore.
- Commercial Fishing. Spatial information on the location of regularly fished areas is highly sensitive and not easily accessed, which is mostly due to the confidential nature of fisheries log book data. Spatial fisheries information would be required from DPI in order to map areas with a high frequency of trawling activity at a resolution useful to this study. Further information of how Artificial Reef deployment will interact with share management fisheries and possible legal advice pertaining to this may be required.

3.0 SYDNEY (BARRENJOEY HEAD TO PORT HACKING)

3.1 Depth Range

Data Source: Webster, M. A and Petkovic, P. (2005). Australian Bathymetry and Topography Grid, Geoscience Australia. Bathymetry contours are derived from the 250m bathymetry raster grid.
Depth contours (isobaths) have been mapped at 20 m, 40 m and 60 m intervals (Figure 3a/b) and it should be noted that the required depth range for the artificial reef structures (recommended by DPI) is between 25 m and 40 m. Depth contours in the Sydney study region are variable and do not closely follow the shape of the coastline in areas, which is a reflection of the heterogeneous nature of the seabed and presence of extensive patches of sub-tidal rocky reefs (section 3.3). In many parts of the study region there are a number of rocky outcrops where the shore profile is relatively steep compared to the gradually sloping profiles of the sandy beach coves in between. From Port Jackson to the southern limit of the study region, the seaward incline is generally steeper than in the north, with the 20 m – 40 m isobaths separated by a distance of 1 km – 1.6 km as opposed to between 0.36 km and 3.14 km. Overall depth is not a major limiting factor in the Sydney region as OAR site selection is mostly limited by the seabed morphology.

3.2 Exclusion Zones

3.2.1 Deepwater Ocean Outfalls

Data Source: Worley Parsons Pty Ltd. NSW EPA (1995) Sydney Deepwater Outfall Environmental Monitoring Program Vol 2. The Ecology Lab Pty Ltd.

Three deep water ocean outfalls operate in the Sydney study region at North Head, Bondi and Malabar. The outfalls extend between 3 km and 4 km offshore to a depth of 60 m with the exception of Malabar which extends to 80 m (Figure 3a/b).

3.2.2 Commercial and Recreational Fishing Areas

Data Source: Larcombe *et al* (2006) Atlas of Australian Marine Fishing and Coastal Communities, Tanner and Liggins (2000) NSW Commercial Fisheries Statistics, Brown (2007) AFN Fishing Guide to Sydney-Hawkesbury.

Commercial fisheries potentially affected by the proposal are those that can operate in State waters. These include those under the jurisdiction of the State of NSW and those also under the jurisdiction of the Commonwealth of Australia that may operate within the 3 nm limit under a Section 37 permit of the *FM Act* (The Ecology Lab, 2007).

Sydney is a major centre for trawl fishing in NSW, with a large percentage of catch sold and distributed through the Sydney markets. Commercial fisheries permitted to operate in the Sydney study region (catch reporting zone 6, Figure 5), are the Ocean Trap and Line Fishery, the Ocean Hauling Fishery, the Ocean Prawn Trawl Fishery and the Lobster Fishery. The Abalone and Turban Shell Fisheries are also permitted in the study area, although these fisheries are closed at present. General information on the geographical extent of these fisheries, target species and economic values of the fisheries are outlined in Appendix 2.

Trap and Line Fishing and Lobster trapping both occur along the Sydney coastline (The Ecology Lab, 1993), although lobster trapping is usually within 10 m depth of water and therefore would not be a constraining factor. The Ocean Hauling Fishery targets approximately 20 finfish species using commercial hauling and purse seine nets from sea beaches and in ocean waters within 3 nautical miles of the NSW coast. Purse seining for garfish (Hemiramphidae), yellowtail scad (*Trachurus novaezelandiae*) and blue mackerel (*Scomber australasicus*) may occur occasionally within the northern Sydney study region. The Ocean Fish Trawl Fishery uses the demersal otter trawl to target a large number of species, such as silver trevally (*Pseudocaranx dentex*), tiger flathead (*Platycephalus richardsoni*), redfish (*Centroberyx gerrardi*), john dory (*Zeus faber*) and numerous species of sharks and rays. A total of 99 fishing businesses hold endorsements to operate in the Ocean Fish Trawl Fishery. Of these, 47 are endorsed to operate in the southern sector of the fishery, south of Barrenjoey Point, near Sydney in State waters. Ocean prawn trawling tends to occur in more estuarine waters of Botany Bay, Sydney Harbour and the Hawkesbury River/Broken Bay. Anecdotal evidence suggests that in the early 1990's there were 4 trawlers operating out of Sydney and that popular trawl grounds were located off Broken Bay (in summer) and within state waters south of Sydney in winter, including one trawl ground from Botany Bay to past Cape Banks.

Recreational fishing from boats occurs throughout the Sydney study region. There are 39 DPI listed chartered fishing boats operating in the study region including those listed in the Hawkesbury, Port Jackson, Port Botany and Port Hacking (web ref 19). It should be noted however that DPI listed vessels (those wishing to be listed) represent only approximately 70% of all registered vessels operating in the area.

Recreational fishers use hook and line to target demersal, reef species such as yellowfin bream (*Acanthopagrus australis*), silver trevally (*Psuedocaranx dentex)*, mulloway (*Argyrosomus hololepidotus*), snapper (*Pagrus auratus*) and kingfish (*Seriola lalandi*) on offshore reefs and species such as leatherjacket (Monacanthidae) and flathead (Platycephalidae) on sandy areas. Trolling for pelagic species such as tailor (*Pomatomus saltatrix*) and kingfish is also common. Game fishing for pelagic fish, including sharks, tunas (Scombridae), billfish (*Scomberesox saurus*), bonito (*Sarda australis*), frigate mackerel (*Auxis thazard*), tailor and Australian salmon (*Arripis trutta*) generally takes place off the Sydney coastline towards the edge of the continental shelf, although they may be found anywhere beyond the estuaries (Ecology Lab, 1993b). Locations of popular offshore recreational fishing spots and reefs are marked in Figures 3a and 3b. Names of the locations, target species and GPS positions are listed in Table 8.

Spearfishing and lobster gathering is popular on headlands and reefs. In NSW, these activities are permitted using snorkel (i.e. no SCUBA or surface air supply) and are restricted to waters of 20 m depth or less. Access for recreational fishing by boat is good in the north of the study region from the confluence of waterways at Broken Bay. Boat access from the south is also good from Port Jackson, Port Botany and Bate Bay.

3.2.3 Designated Commercial Shipping Lanes/Port Authority Restrictions

Data Source: AUS Chart 197 (positions rectified for use in GIS format).

The Sydney study region includes two of Australia's largest commercial shipping ports, Port Jackson (Sydney Harbour) and Port Botany located 12 km southeast of Sydney. Commercial vessels operating to and from Port Jackson consist mainly of container carriers, car carriers, general cargo and a relatively high percentage of cruise vessels, whereas cargo vessels operating to and from Port Botany generally contain bulk liquids and chemicals (web ref 6).

Both ports operate under the jurisdiction of the Sydney Ports Corporation and defined port limits apply (at both locations), restricting movements and anchorage of vessels in the area (Figure 3a/b). Port limits surrounding Port Jackson are defined as the waters of Sydney Harbour and of all tidal bays, rivers and their tributaries connected or leading to Sydney Harbour, bounded by the mean high water mark together with that part of the South Pacific Ocean below the mean high water mark enclosed by the arc of a circle (radius 4 nm) having its centre as the navigation light at Hornby Lighthouse (Sydney Ports Corporation, 2007). The port limits of Botany Bay are defined as the waters of Botany Bay and of all bays, rivers and their tributaries connected or leading to Botany Bay bounded by the mean high water mark and by, the eastern side of the Endeavour Bridge in Cooks River and the eastern side of the Captain Cook Bridge in Georges River together with that part of the South Pacific Ocean below mean high water mark enclosed by the arc of a circle (radius 4 nm), having its centre as the navigation light at Henry Head (Sydney Port Corporation, 2007). Anchorage within the designated port limits and ACMA exclusion zones is prohibited. There are no recommended anchorage zones off the coast for vessels waiting to enter the harbour or Botany Bay, although it is recommended that vessels maintain a distance of at least 3 nm from the coastline and outside port limits in the unlikely event that a vessel is queuing for berth space. Sydney port harbour masters will consider OAR placement within port limits providing they are not at risk to vessels. Sites at the more extreme angles of the radial port limits are also favored as ships generally approach the port entrances directly. Details of consultation with Sydney port authorities are outlined in Appendix 4).

3.2.4 Marine Protected Areas

Data Source: Breen *et al* (2005) Broadscale Biodiversity Assessment of the Hawkesbury Shelf Marine Bioregion and NSW DPI and the Marine Protection Authority (MPA).

There are three types of Marine Protected Areas (MPA's) recognised within NSW, Marine Parks, Aquatic Reserves and National Parks and Nature Reserves (which are generally terrestrial but with associated marine components). No MPA's, National Parks or nature reserves which are relevant to this review occur within the Sydney Study region, however, there are currently ten Aquatic Reserves along the entire stretch of this coastline (Figure 3a/b). These are listed below, from north to south. Total area covered (km^2) is in brackets.

- Barrenjoey Head, Hawkesbury River (0.3)
- Narrabeen Head (0.1)
- Long Reef (0.8)
- Cabbage Tree Bay (0.2)
- North Sydney Harbour (2.6)
- Bronte – Coogee (0.4)
- Cape Banks, La Perouse (0.2)
- Towra Point (14)
- Boat Harbour, Kurnell (0.7)
- Shiprock, Port Hacking (0.02)

The reserves are managed by the NSW Department of Primary Industries under section 194 of the *Fisheries Management Act 1994* and are permanently established to protect biodiversity and representative samples of marine life and habitats, although in some cases they have

been established to protect unique habitats, protected species populations or ecological communities. The offshore boundaries for Aquatic Reserves in the Sydney region is generally 100 m from the mean low water mark and it is unlikely that the area covered by the Aquatic Reserves will be a major constraint to OAR site selection, as depths within the areas are likely to be too shallow.

3.2.5 Mining Exploration Leases

Data Source: NSW DPI (2007) Petroleum Projects and Exploration Highlights in NSW (map) and NSW DPI 'TAS Map' minerals mapping online application.

Petroleum Exploration Licence (PEP) 11 is the only current mining exploration area in NSW. The zone extends for 200 km from Port Stephens south to Wollongong, covering a total 2,000,000 acres from 3 nm offshore. In NSW, sand resources are known to exist between Newcastle and Wollongong, however NSW government policy prohibits offshore mining within 3 nm (web ref 13). Marine sand is, however, permitted to be periodically dredged from the entrance to Narrabeen Lagoon in northern Sydney for replenishment of Collaroy Beach, which is extensively eroded in severe storms. This would be unlikely to impact upon the location of OAR's in that particular region. No other sand mining operations are active in this study area.

3.2.6 Historical Ship Wrecks

Data Source: NSW Maritime Heritage database NSW Heritage Office), The Shipwreck Atlas of NSW (Department of Urban Affairs and Planning, 1996) and The Scuba Diving, Snorkelling and Spearfishing Guide to Northern and Southern NSW.

Appendix 3a provides search results for historical shipwrecks located within the radius of the specified study region from the NSW Maritime heritage database. This data provides an indication of the total number of wrecks in the region but does not provide accurate locations. GIS data with accurate positions was therefore obtained directly from the NSW Maritime Office courtesy of David Nutley, combined with positions obtained from Byron (1997a/b) and The Shipwreck Atlas of NSW (2006). This data (Table 2), although accurate, is limited to more well known wrecks for which exact positions are known. It should therefore be considered that there are a number of wrecks in the region for which accurate positions are unknown and may occur within the 25 m – 40 m depth range.

In total, 105 shipwrecks were found in the Sydney study region. In the northern section of the Sydney study region (Broken Bay south to North Head) there are a significant number of wrecks, only a handful however, are likely to occur in depths suitable for OAR deployment. 'The Valiant' is located approximately 1 km offshore from Barrenjoey Head in about 26 m of water and is a popular dive site marked by buoys at the entrance to Broken Bay (Figure 3a). South of the Valiant, approximately 3 km offshore from Avalon Beach is the Birchgrove Park in 49 m of water. South of this, there are a number of wrecks clustered in a restricted dumping ground between Turimetta Head and Long Reef (directly offshore from the centre of Narrabeen Beach) including wrecks of the Duckenfield, Pyrmont II, Dee Why, Bellubbera, Coolooli, D.H.B 656 and the Himma amongst many other unidentified wrecks. This dumping ground however, is located within two major restricted zones (the Northern Sydney ACMA Cable Zone and a designated dumping ground) so wrecks occurring in the area are not considered a significant issue. The wreck of SS Myola is located just south of both these exclusion zones, over 5 km offshore from Dee Why Head at a depth of 48 m. In the southern section of the Sydney study region (from South Head to Bundeena, Port

Hacking), there are four further wrecks including (from north to south), The Royal Shepard (at 27 m depth, offshore from South Head), Annie M. Miller (approximately 1 km off Rosa Gully at 50 m depth), The Kelloe (northeast of Little Bay at 40 m depth) and the Woniora (off Kurnell, at 63 m depth) (Figure 3b). Wrecks of the Koputai and HMAS Encounter are also located offshore from Coogee Beach although these will occur in the Southern Sydney ACMA Exclusion Zone so have not been considered further.

As there are a number of wrecks known to occur within the study region for which no accurate data is available it would be recommended that more detailed analysis of wreck locations should be undertaken at a later stage, when more specific potential deployment sites have been identified.

3.2.7 Spoil Grounds

Data Source: AUS Chart 197 (positions rectified for use in GIS format)

A significant exclusion zone is located from Turimetta Head south to Long Reef and extends offshore to a depth of 100 m. The area contains a number of wrecks which have either been lost or dumped at sea. This area also overlaps with the Northern Sydney Cable Exclusion Zone (Section 3.2.8). A small spoil ground is located directly offshore from Curl Curl Head in 35 m – 50 m and a further restricted area is located south of this just off North Head, although this exclusion zone overlaps with the port limits of Port Jackson where restrictions already apply (section 3.2.3). A major spoil ground is located south of Port Jackson and directly offshore from Macquarie Light House, although this is found in deep water exceeding 80 m so is not considered a major constraining feature.

3.2.8 AMCA Cable Exclusion Zones

Data Source: ACMA (Australia Communications and Media Authority).

Schedule 3a of the Telecommunications Act 1997 gives ACMA (Australia Communications and Media Authority) power to declare protection zones over submarine cables of national significance. Within these zones, activities which could damage submarine cables (such as trawling and anchoring) are prohibited or restricted. Schedule 3a, subparagraph 10 (4) (a) (viii) also specifies that 'placement of structures moored to the seabed with the primary function of attracting fish for capture, for example, fish aggregating devices' (ACMA, 2007a/b) are prohibited throughout the protection zones.

There are two major cable protection zones in the Sydney study region; The Northern Sydney Protection Zone and the Southern Sydney Protection Zone. The Northern Sydney Protection Zone extends from Narrabeen beach to around 75 km off shore, to the 2,000 metre water depth, covering the northern branches of the Australia Japan Cable, the Southern Cross Cable and the Australia Papua New Guinea 2 Cable. Within the 100 m depth contour, the zone begins at the Southern end of Warriewood beach, covering a distance of 2.4 km south to the southern end of Narrabeen beach. The Southern Sydney Protection Zone extends from Tamarama and Clovelly beaches and extends 57 km offshore, to the 2000 metre water depth, covering the southern branches of the Australia Japan Cable, the Southern Cross Cable and the Tasman 2 Cable. Within the 100 m depth contour the zone begins at Ben Buckler Point (north end of Bondi Beach), covering a distance of 2.4 km south to Honeycomb Bay, South Coogee (Figure 3).

3.2.9 Other Restricting Features

FAD's (Fish Aggregation Devices)

Data Source: NSW DPI

There are 5 FAD's (Fish Attraction Devices) located offshore in the Sydney study region. All of these are located at depths much deeper than the OAR depth range and therefore are not a constraining issue in this region. One device however, is located further inshore sitting at 50 m (8.5 km offshore from Port Jackson) which may require consideration in OAR site selection.

Buoys

Data Source: Manly Hydraulics Laboratories

The Sydney wave rider buoy is located directly offshore from Curl Curl beach, approximately 12 km offshore. Depth at this point exceeds 100 m so it is not considered a constraint.

Desalination Plants

Data Source: The Ecology Lab

Kurnell desalination plant is currently under construction and located on the southern headland of Botany Bay between Cape Solander and Cape Bailey. An exclusion zone has been estimated and mapped around the extent of the development encompassing the location of water intakes and outlets (Figure 3b).

3.3 Distribution and Characteristics of Substrata

Data Source: Public Works Department NSW. Coast and Rivers Branch (based on surveys and interpretation for 'Sydney Coastal Study' by Gordon and Hoffman 1985), courtesy of Worley Parsons Pty Ltd.

Detailed seabed maps for the Sydney region were scanned and digitised for purpose of this study. Characteristics of seabed morphology were classified into the following distinct classes (Figure 3a/b):

- Medium to coarse grained, orange coloured sand with 40 % shell;
- Fine grained, grey coloured sand with 5 % - 20 % mud and 30 % - 40 % shell;
- Fine grained, fawn coloured sand with 30 % shell;
- Fine to medium grained, golden coloured sand with 10 % shell (can be up to 60 %);
- Rock reef;
- Artificial reef (includes shipwrecks)

It should be noted that movement of sand on the seabed can result in changes to rock/sand boundaries over time and that this effect would be more marked in shallow depths and flat reef. These maps are therefore limited to describing average conditions at the time of survey.

Rocky reef is considered a significant constraining feature for OAR deployment. This is because reef is unlikely to provide a stable platform suitable for supporting the artificial reef structures and also because existing reef habitats are likely to be lost or impaired by the disturbance. DPI have also specified that the artificial reef structures should be located

away from existing reefs, in order to create new recreational fishing area (rather than adding to existing areas). In the Sydney study region, rocky reef makes up a significant component of the offshore seabed, although it is patchily distributed along the coastline and interspersed by sand of various grain sizes and types. At the northern end of the study region (from Barrenjoey Head to the southern end of Palm Beach), there is an area of medium to coarse grained sand, free of reef substrata which has potential as an OAR deployment site (Figure 3a). South of Palm Beach, potential for OAR deployment is limited by a network of reef habitat until reaching North Head at the entrance of Port Jackson. From South Head to Ben Buckler, rocky reef is confined to a narrow strip close to the shoreline extending out approximately 0.5 km seaward to a depth of 24 m. Seaward of the narrow reef strip is an area of fine to medium golden sand which (apart from the Port Jackson port limits) is another potential OAR site (Figure 3b). South of Maroubra Beach, rocky reef habitat is again less fragmented and confined to the coastline from Long Bay around Cape Banks and on the southern headland of Port Botany, extending into the 40 m depth zone. Sediment composition data made available via the Department of Geoscience, University of Sydney, indicates that sediments beyond the 60 m depth zone generally consist of a high percentage of sand (between 87 % and 100 %) a small percentage of mud (between 0 % and 13 %) and some gravel (between 0 % and 3 %) (Table 3.).

3.4 Distribution of Habitats, Flora and Fauna

Data Source: Literature sourced from the Ecology Lab reference library.

Distribution and diversity of macrofauna (invertebrates living on or within sediments) vary in space and time depending on a range of physical and biological factors. Physical factors include water depth and movement, salinity and type of sediment or substrata. Biological factors include food availability, competition and predation (McCaulry et al. 1977; Jones, 1986; Morrisey et al. 1992; Snelgrove and Butman, 1994; Newell et al. 1998). The nature of the sediment in particular, has a major influence on the animals living within it (Morrisey, 1998) and in general, sub tidal sediments support a large variety of invertebrates and fish. The invertebrates may consist of 'infauna' which burrow to depths of about 50 cm into the sediments, and 'epifauna' which live on the surface of the sediments. Sub-tidal rocky reefs support very different communities to the sandy habitats. They also show some degree of 'zonation', with turfing macroalgae and kelp occurring in shallower waters, bare rock (which is actually covered by encrusting red algae) in intermediate areas and 'sponge gardens' in deeper water (Underwood *et al.* 1991).

Previous studies have found that the sandy habitats off Sydney support diverse and abundant assemblages of fish and invertebrates and that major changes occur in these assemblages with increasing depth, even over a relatively narrow depth range (eg. 20-30 m). Studies have also found that: a) the invertebrates are, at least within shallower areas (eg. 20-25 m), capable of rapid recolonisation if disturbed; and b) they show detectable responses to storm activity, even at depths of 65 m (The Ecology Lab 1993). This suggests that these assemblages are resilient to physical disturbance. Rocky reefs support very different communities to the sandy habitats. They also show some degree of 'zonation', with turfing macroalgae and kelp occurring in shallower waters, bare rock (which is actually covered by encrusting red algae) in intermediate areas and 'sponge gardens' in deeper water (Underwood *et al.* 1991). These habitats are structured by a variety of physical and biological processes. Reef habitat is likely to be less resilient to disturbance than sandy habitat and is also utilised heavily by humans. In addition to rocky reefs, there are shipwrecks within the area (Section 3.2.6). The wrecks function ecologically in a similar way to rocky reefs and often support similar assemblages of fish and invertebrates. A diverse

assemblage of demersal (bottom dwelling) fish have been recorded in the Sydney area, with stingarees (Urolophidae), flathead (Platycephalidae), gurnards (Triglidae), flounder (Pleuronectidae), box fish (Ostraciidae), school whiting (*Sillago flindersi*), cardinal fish (Apogonidae), bellowsfish(Centriscidae), nannygai (*Centroberyx affinis*) and john dory found to be particularly abundant. Clear patterns in species assemblages related to depth have also been observed.

3.5 Threatened Species Issues, Including Fish, Invertebrates, Marine Mammals and Marine Reptiles

Data Source: The NSW DPI threatened species database (web ref 1) and the NSW Government BioNet System (web ref 15). Literature was sourced from the Ecology Lab reference library.

Threatened species data was obtained from the NSW DPI threatened species database and the NSW Government BioNet System. Table 1 summarises marine species and populations listed under the *FM Act*, *TSC Act* and the *EPBC Act* which occur in the Sydney study region (search criteria was for the Sydney Metro Catchment Management Authority). There are 15 either endangered, vulnerable or protected species occurring in the Sydney study region, including three species of marine reptile, seven marine mammals and five species of fish. Marine sea-birds (such as petrels, albatross and shearwater) scheduled in the *TSC* and *EPBC Act* were excluded from the search as it is unlikely that their presence in a deployment area would be of significant relevance. Three species, the Loggerhead Turtle (*Caretta caretta*), Blue Whale (*Balaenoptera musculus*) and Southern Right Whale (*Eubalaena australis*) are listed under Commonwealth legislation as endangered migratory species known to occur in the Sydney study region, with the exception of the Blue Whale which has only been 'predicted' to occur in the region. Southern Right Whales are increasingly being sighted off the NSW coast within inshore waters travelling between coastal locations (Allen & Bejeder, 2003). Records of Southern Right Whale sightings on the east coast of Australia between 1993 and 2002 were compiled by Allen & Bejeder (2003) and showed a number of sightings reported off Sydney. Distribution and migration maps produced by the Department of Environment and Heritage (web refs 16, 17 and 18), also show that although Southern Rights are known to occur along the whole NSW coastline they are not known to aggregate in these waters. Calving females with young however, are known to remain close to the shore within a water depth of between 5 m – 10 m (Web ref 3) and it is recommended that placement of infrastructure in this zone is avoided partly because of this.

The Grey Nurse Shark (*Carcharias taurus*) is listed as 'critically endangered' and is known to aggregate within the Sydney study region. Grey Nurse Shark observations between 1998 and 2000 recorded by Otway and Parker (2000) and Otway *et al* (2003), were mapped by the Natural Heritage Trust as part of the 'Broadscale Biodiversity Assessment of the Hawkesbury Shelf Marine Bioregion'. Maps showed that South Maroubra (Magic Point) was a significant aggregation site with sharks observed on 50 % of survey occasions in numbers representing 3.5 % of the total observed population (NSW DPI, 2002). A 200 m area of critical habitat has been declared off Magic Point with an 800 m buffer zone extending beyond the critical habitat. This area has been mapped as a potential constraint (Figure 3b). An endangered population of the Little Penguin (*Eudyptula minor*) is known to occur from just north of Smedley's Point to Cannae Point, North Sydney Harbour, Manly and is the only known breeding population on mainland NSW (NSW Parks and Wildlife Trust, 2002). The area has been declared a critical habitat and has a 50 m restriction zone extending outwards from the shoreline although it is unlikely to be an issue in relation to OAR's.

3.6 Coastal and Oceanographic Proceeses

Data Source: Worley Parsons Pty Ltd

Refer to Appendix 1

3.7 Gaps In Information

- Shipwrecks. There are a number of wrecks in the region for which the exact location is unknown. Expert information would be useful at a later stage, combined with detailed seabed surveys (e.g. side-scan sonar) where necessary.
- Commercial Fishing. Spatial information on the location of regularly fished areas is highly sensitive and not easily accessed, which is mostly due to the confidential nature of fisheries log book data. Spatial fisheries information would be required from DPI in order to map areas with a high frequency of trawling activity at a resolution useful to this study. Further information of how Artificial Reef deployment will interact with share management fisheries and possible legal advice pertaining to this may also be required.

4.0 WOLLONGONG (STANWELL TOPS TO PORT KEMBLA)

4.1 Depth Range

Data Source: Webster, M. A and Petkovic, P. (2005). Australian Bathymetry and Topography Grid, Geoscience Australia. Bathymetry contours are derived from the 250m bathymetry raster grid.
Depth contours (isobaths) have been mapped at 20 m, 40 m and 60 m intervals (Figure 4) and it should be noted that the required depth range for the artificial reef structures (recommended by DPI) is between 25 m and 40 m. The northern part of the Wollongong study region (between Stanwell Tops and Bellambi Headland) is characterised by a gradually sloping seaward profile which offers an area (roughly 50 km^2) with depths suitable for OAR deployment (Figure 4). At Bellambi Headland, seabed profile becomes steeper and more variable in relation to the rocky seabed morphology. South of Port Kembla, isobaths become more evenly spaced again following the gradually sloping seaward incline of Perkins Beach where there is a smaller area (up to 10 km^2) at a suitable OAR Depth range.

4.2 Exclusion Zones

4.2.1 Deepwater Ocean Outfalls

Data Source: The Ecology Lab Pty Ltd (2001).

A recently upgraded deepwater ocean outfall is located at the southern end of Wollongong Beach and runs from the sewage treatment plant offshore for approximately 600 m (Figure 4).

4.2.2 Commercial and Recreational Fishing Areas.

Data Source: Larcombe *et al* (2006) Atlas of Australian Marine Fishing and Coastal Communities and Tanner and Liggins, (2000) NSW Commercial Fisheries Statistics. Ross (1998), The New South Wales Fishing Atlas.

Commercial fisheries potentially affected by the proposal are those that can operate in State waters. These include those under the jurisdiction of the State of NSW and those also under the jurisdiction of the Commonwealth of Australia that may operate within the 3 nm limit under a Section 37 permit of the *FM Act* (The Ecology Lab, 2007).

Commercial fisheries permitted to operate in the Wollongong study region (catch reporting zone 7, Figure 5), are the Ocean Trap and Line Fishery, the Ocean Hauling Fishery the Ocean Prawn Trawl Fishery and the Lobster Fishery, Abalone and Turban Shell Fisheries. The geographical extent of these fisheries, target species and economic values of the fisheries are outlined in Appendix 2. A relatively small fishing fleet operates out of Wollongong consisting of around 25 fishers (Tanner and Liggins, 2000). Fishing gear used in the region consists mainly of nets and trawl with a small percentage of trap and line (Larcombe *et al*, 2006). Anecdotal evidence suggests that although there are around 4 large trawlers based in Wollongong, they mainly fish in deeper shelf waters well beyond the limit of the suitable OAR depth range. As commercial fishing effort in the region is relatively low it is unlikely to be a major constraining factor.

7 DPI listed recreational charter boats operate out of Wollongong and Lake Illawarra, offering estuary, nearshore, game and deep sea bottom fishing (web ref 19). Whale-watching excursions are also run by some operators in appropriate seasons. Extensive reefs offshore from Austinmer and Bellambi Point are popular offshore recreational fishing locations, where kingfish (*Seriola lalandi*), bonito (*Sarda australis*) and yellowfin tuna (*Thunnus albacares*) are common catches. Drift fishing for flathead (Platycephalidae) is thought to be productive along the entire stretch of coast. Offshore from Wollongong Harbour (between 1.5 km and 2.5 km) and west of Big Island, patches of gravel substratum and reef provide good fishing for snapper (*Pagrus auratus*). Fishing around the Five Islands (offshore from Port Kembla) is also known for kingfish, snapper and mulloway (*Argyrosomus hololepidotus*), with bream (Sparidae), tailor (*Pomatomus saltatrix*) and salmon (*Arripis trutta*) occurring in shallower waters.

Access for private boat owners is poor in the northern region of the Wollongong study region, however, there are a number of boat ramps located in the south from Bellambi, Flagstaff Point and Port Kembla.

4.2.3 Designated Commercial Shipping Lanes/Port Authority Restrictions

Data Source: Port Kembla Port Corporation and AUS Charts 808 and 195 (positions rectified for GIS format).

Port Kembla is the closest specialist industrial port to Port Botany, traditionally handling bulk goods and commodities such as iron ore, coal and grain. The port is currently undergoing major expansion that will see general and break bulk cargoes, containers and vehicle handling becoming increasingly more important.

The Limits of Port Kembla Harbour are bounded by an arc centered from the northern breakwater, extending out 3 nm miles from a point just of Bulli Head to the northern end of Perkins beach. A number of anchorage zones for different vessel types and sizes are specified by Port Kembla Port Corporation outside of these limits (Figure 4). Although the specified port limits are not represented on the latest AUS Chart (195), an approach channel alignment has been mapped and a total of 17 numbered anchor berths on swinging moorings. Three designated boarding areas have also been mapped (Figure 4). Port Kembla Port Authority do not support the deployment of artificial reef structures within ports limits. Details of discussions between Port Kembla Port Authority and Worley Parsons are outlined in Appendix 4.

4.2.4 Marine Protected Areas

Data Source: NSW National Parks and Wildlife Service (2005) Plan of Management, Five Islands Nature Reserve.

There are currently no Marine Parks or Aquatic Reserves listed in the Wollongong study region, although there is one designated Nature Reserve, which is located at the southernmost end of the study region. Five Islands Nature Reserve (FINR) includes five small islands clustered off the coast of Port Kembla, immediately south of the city of Wollongong. FINR encompasses a combined area of approximately 0.27 km^2, consisting of Flinders ("Toothbrush") Islet (0.0273 km), Bass Islet (0.023 km), Martin Islet (0.0233 km^2), Big ("Rabbit" or "Perkins") Island (0.177 km^2) and Rocky Islet (0.005 km^2). The islands are clustered between approximately 0.5 km and 3.5 km off the coast. Rocky and Martin Islets and Big Island are tightly clustered close to the mainland off Red Point while Flinders and Bass Islets are more distant. FINR is managed by the National Parks and Wildlife Service

(NPWS), part of the NSW Department of Environment and Climate Change (DECC), under the *National Parks and Wildlife Act 1974*. The reserve is a significant habitat for a number of migratory marine birds and two species of seal, the Australian Fur-Seal (*Arctocephalus pusillus doriferus*) and the Leopard Seal (*Hydrurga leptonyx*), both of which are protected under NSW legislation.

Nature reserves such as FINR differ from aquatic reserves and marine parks in that there is no zoning or regulation for multiple use and they do not directly protect fish or aquatic invertebrates from fishing. Under the International Union for the Conservation of Nature and Natural Resources (IUCN), Five Islands Nature Reserve equates to the IUCN Category 1a, "Strict Nature Reserve", that is an area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features, and/or species, available primarily for scientific research and/or environment monitoring. As the islands are located in an area which is already constrained by a number of other issues, such as shipping lanes, Port restrictions and spoil grounds and subtidal reef habitat, it is unlikely that this region would be a high priority for OAR's.

4.2.5 Mining Exploration Leases

'*Data Source*: NSW DPI (2007) Petroleum Projects and Exploration Highlights in NSW (map) and NSW DPI 'TAS Map' minerals mapping online application

Petroleum Exploration Licence (PEP) 11 is the only current mining exploration area in NSW. The north to south extent of the zone is from Port Stephens to Wollongong (200 km) covering 2,000,000 acres. The permit starts from 3 nm offshore. There are no active sand or gravel extraction operations in the study region.

4.2.6 Historical Ship Wrecks

Data Source: NSW Maritime Heritage database NSW Heritage Office, The Shipwreck Atlas of NSW (Department of Urban Affairs and Planning, 1996) and The Scuba Diving, Snorkelling and Spearfishing Guide to Northern and Southern NSW.

Appendix 3a provides search results for historical shipwrecks located within the radius of the specified study region from the NSW Maritime heritage database. This data provides an indication of the total number of wrecks in the region but does not provide accurate locations. GIS data with accurate positions was therefore obtained directly from the NSW Maritime Office (courtesy of David Nutley) combined with positions obtained from Byron (1997a/b) and The Shipwreck Atlas of NSW (1996). This data (Table 2, Figure 4), although accurate, is limited to more well known wrecks for which exact positions are known. It should be considered that there are a number of wrecks in the region for which accurate positions are unknown and may occur within the 25 m – 40 m depth range.

In total, 9 shipwrecks were found in the Wollongong study region, of which only The Bombo was pinpointed within the 25 m – 40 m depth range. The majority of wrecks located in the Wollongong study region are found inshore on reefs at depths less than 18 m and are therefore not a constraining issue. These wrecks are concentrated on the northern side of Bellambi Reef and include the Excelsior, Ocean Queen, Prospector, Reaper, Little Pet, Norman, Aldinga, Resolute, Mount Kembla, Saxania, Aldinga, Munmorah and The Queen of Nations immediately to the south. Offshore from South Wollongong Beach and north of Flinders Islet, lies the wreck of the Bombo. At a depth of 29 m it is a possible constraining feature, however as it is within the boundaries of the port exclusion zone it is not considered an issue. Finally, the 'Waratah' is the only other wreck known to be found in the study

region and is located immediately north of Bulli Point. As this wreck also sits in shallow reef at less than 18 m deep it is also an unlikely constraint.

4.2.7 Spoil Grounds

Data Source: EPA Maps rectified for GIS format and AUS Chart 195

Spoil dumping grounds containing dredged material from Port Kembla Harbour are located between Bass Islet and Big Island (EPA, 1992) and also further offshore at depths between >60 m south of the port exclusion zone (Figure 4).

4.2.8 Other restricting features

Buoys

One wave rider buoy is located in the Wollongong study region however, this is located within the restricted zone of Port Kembla and is therefore not considered an issue.

4.3 Distribution and Characteristics of Substrata

Data Source: NSW National Parks and Wildlife Service, 'Near Shore Sub-tidal Marine Reef Systems and Soft Sediment Mapping' and University of Sydney, School of Geosciences, GIS marine sediment data.

Near shore sub-tidal reefs have been mapped by the NSW National Parks and Wildlife Service over a range of years from aerial photography provided by NSW Department of Land and Water Conservation's specialist Coastal and Floods Unit. Other than this data set there are few GIS data available for detailed mapping of seabed morphology at depths appropriate to this study. The most complete data set available for near shore reefs in NSW covers reefs to a depth of 20 m up to 1 km offshore, although some reef shoals further offshore have been digitised from Australian Hydrographic Office (AHO) nautical charts. At the northern section of the Wollongong study region there are three small reef shoals offshore from Stanwell Park and Brickyard Point (Figure 4). These are the only significant constraining features in the northern part of the Wollongong study region which is otherwise a good potential OAR site.

The Ecology Lab (2001), investigated soft sediments, offshore from Belambi Point and to the north of Bellambi using a Van Veen Grab. Replicate samples were taken from two sites at three depths (10 m, 15 m and 20 m) at each location. Sediment type consisted mainly of fine to medium brown sand, with some samples containing a small percentage of silt and some gravel (as broken shells). No significant differences in grain size were detected between these locations and it is expected that a similar sediment composition exists throughout this study area, excluding the spoil grounds located outside the entrance of Port Kembla and areas adjacent. Sediment data compiled by the Department of Geosciences, Sydney University did not include the Wollongong study area, but did include data from vibro core samples collected to the north of the study area, south east of Bundeena. Results again showed high percentages of sand (95 % on average), a small percentage of mud (4 % on average) and some gravel (1.7 % on average) (Table 3).

4.4 Distribution of Habitats, Flora and Fauna

Data Source: Literature sourced from the Ecology Lab reference library.

Distribution and diversity of macrofauna (invertebrates living on or within sediments) vary in space and time depending on a range of physical and biological factors. Physical factors include water depth and movement, salinity and type of sediment. Biological factors include food availability, competition and predation (McCaulry et al. 1977; Jones, 1986; Morrisey et al. 1992; Snelgrove and Butman, 1994; Newell et al. 1998). The nature of the sediment in particular, has a major influence on the animals living within it (Morrisey, 1998) and in general, subtidal sediments support a large variety of invertebrates and fish. The invertebrates may consist of 'infauna' which burrow to depths of about 50 cm into the sediments, and 'epifauna' which live on the surface of the sediments. Sub-tidal rocky reefs support very different communities to the sandy habitats. They also show some degree of 'zonation', with turfing macroalgae and kelp occurring in shallower waters, bare rock (which is actually covered by encrusting red algae) in intermediate areas and 'sponge gardens' in deeper water (Underwood *et al.* 1991).

A number of previous studies have focused on assemblages of marine invertebrates in the Port Kembla/Wollongong region in relation to impacts of nearshore spoil disposal. EPA (Environment Protection Authority, 1992) carried out surveys within the sub-tidal rocky reef habitats found at depths between 20 m- 22 m within the Five Islands area, outside of Port Kembla. Rocky reef habitat found at these depths was characterised by a diverse assemblage of encrusting flora and fauna including sponges, bryozoans, cnidarians ascidians and algae. A later study by The Ecology Lab (2001), investigated soft sediments, sub-tidal rocky reefs and weedy seadragons (*Phyllopteryx taeniolatus*) off Bellambi Point, Port Kembla and Shell Harbour. Particle grain size analysis of soft sediments showed that sediments (at depths between 10 m -20 m) consisted mainly of fine to medium sand and associated benthic infauna consisted of amphipod crustaceans, polychaetes and a high number of gastropod molluscs of the family Trochidae. Significant differences in community assemblages were also found to be related to depth. Sub-tidal rocky reef communities were variable amongst reference locations sampled although generally consisted of sponges, ascidians, encrusting and foliose algae. Weedy seadragon sampling took place at two reference locations, to the north of Wollongong Harbour and on the northern side of Big Island. Sites were selected on the interface of reef and sand (depth 15 m – 20 m) which appears to be favoured for weedy seadragons (The Ecology Lab, 1999). A total of 64 weedy seadragons were observed during the study with distribution appearing variable between locations.

4.5 Threatened Species Issues, Including Fish, Invertebrates, Marine Mammals and Marine Reptiles.

Data Source: Threatened species data was obtained from the NSW DPI threatened species database (web ref 1) and the NSW Government BioNet System (web ref 15). Literature was sourced from the Ecology Lab reference library.

Table 1 summarises marine species and populations listed under the *FM Act*, *TSC Act* and the *EPBC Act* which occur in the Wollongong study region (search criteria was for the Southern Rivers Catchment Management Authority). A total of 13 endangered, vulnerable or protected species are known to occur in the Wollongong study region including one species of reptile, seven species of marine mammal and six species of fish. Marine sea-birds (such as petrels, albatross and shearwaters) scheduled in the *TSC* and *EPBC Act* were excluded from the search as it is unlikely that their presence in a deployment area would be of significant relevance. Two species of whale, the Blue Whale (*Balaenoptera musculus*) and Southern Right Whale (*Eubalaena australis*) are listed under Commonwealth legislation as endangered migratory species and are known to occur in the Wollongong study region.

Southern Right Whales are increasingly being sighted off the NSW coast within inshore waters travelling between coastal locations (Allen & Bejeder, 2003). Distribution and migration maps produced by the Department of Environment and Heritage (web refs 16, 17 and 18) show that although Southern Rights are known to occur along the whole NSW coastline they are not known to aggregate in these waters, however calving females with young are known to remain close to the shore within a water depth of between 5 m – 10 m (Web Ref. 3) and it is recommended that placement of infrastructure in this zone is avoided. The Blue Whale is known to occur offshore in the Wollongong region although records of this species occurrence are sparse. The species primarily inhabits deep oceanic waters with occasional localised activity on the continental shelf which appears to be associated with temporary abundances of pelagic crustaceans, a major food source (Biosis Research, 1999).

The Grey Nurse Shark (*Carcharias taurus*) is listed as 'critically endangered' and is known to occur throughout this coast although is not know to aggregate in the region. Once more specific areas have been identified as potential zones for the deployment of OAR's then it would be possible to assess the likelihood of protected species occurring in the vicinity of the structures in greater detail.

4.6 Coastal and Oceanographic Processes

Data Source: Worley Parsons Pty Ltd

Refer to Appendix 1

4.7 Gaps in Information

- Commercial Fishing. Further information on localised fishing grounds from DPI would be beneficial at this stage.
- Nature of the Seabed. No published data are available at depth > 20 m offshore

5.0 CONCLUSIONS

Elimination of areas with major constraining features (within study regions) has led to identification of specific areas that may potentially suit OAR placement. Two sub-regions within each study region have been identified and are defined below:

- Newcastle (Figure 2)
    a) North, (Stockton Bight).
    b) South (south of Nobby's Head and spoil grounds).
- Sydney (Figure 3a/b)
    a) North (Broken Bay, off Barrenjoey Headland, south to Palm Beach).
    b) South (offshore, Bate Bay)
- Wollongong (Figure 4)
    a) North (Stanwell Tops to Bulli)
    b) South (south of Port Kembla off Perkins Beach)

Distribution/characteristics of substrata (mainly presence of unsuitable sub-tidal reef surfaces) and designated exclusion zones (such as port restrictions, cable exclusion zones and spoil grounds) were the main factors in isolating the sub-regions.

For each sub-region a summary table has been constructed to list key issues and their relevance in context with that sub region (Tables 4-6).

5.1 Newcastle

a) North, (Stockton Bight).

Offshore of Stockton Bight is a good potential region for siting of an OAR in terms of physical characteristics such as depth, seabed morphology, and few physical obstructions and/or exclusion zones (Figure 2) (Table 4). Wrecks of the Fitzroy, Osprey, Irresistible and Commodore are the only physical structures which need to be considered in the area. The remaining constraints at North Stockton are issues related to commercial fishing and shipping movements. The Stockton Bight is a well known trawling area and information on specific fishing areas is limited. More information on heavily trawled commercial fishing areas and consultation with the commercial fishing community is required. Shipping movements to and from the Port of Newcastle is exceptionally high, although anchoring is not permitted within port limits, within the 3 nm zone (state waters) or anywhere north of Little Red Head Point. Newcastle Port Authority consider Stockton Bight a relatively suitable location for placement of the OAR'S as it is not considered safe for vessels to anchor.

The area is also popular for recreational fishing and there are a number of boat ramps in the vicinity of Newcastle and Port Stephens.

b) South (south of Nobby's Head and spoil grounds).

There is potential for OAR's to be located within the southern Newcastle sub region, as physical characteristics are favourable in terms of suitable depth and substrata and anchorage is restricted to outside the 3 nm limit and within an anchorage zone (Figure 2). More information is required on commercial fishing activity in the sub region which is not in the public domain. The Belmont and Burwood deep ocean outfalls and two wrecks (The

Byron and Bonnie Dundee) present other potential constraints (Figure 2). Overall this sub region is considered the least viable of all the sub regions selected, mainly due to limited information.

5.2 Sydney

Table 5 summarises key constraining issues relevant to the two sub-regions identified within the Sydney study region. Extensive information and GIS data are available for the Sydney study region, thus potential OAR sites could be accurately defined. The main constraining features for the region are extensive rocky reef substrata, port limits for the two major ports and ACMA cable exclusion zones. These features combined however, leave relatively few options for OAR's, although it should be considered Sydney Ports harbour masters are open to consider the possibility of OAR' s within port limits provided they are not a risk to vessels and are located towards the extreme angles of the radial port limits.

a) North (Broken Bay, off Barrenjoey Headland, south to Palm Beach).

The north Sydney sub region was selected as one of few areas in the Sydney study region which was not constrained by the network of rocky reef extending for the majority of the coastline. A relatively small area (roughly 6 km^2) has been identified as a potential site (Figure 3a). The seabed at this location is predominantly medium to coarse orange sand with a small patch of reef at the southern end of the area (offshore from Little Head). There are few constraining features at this location apart from shipwrecks, namely the Valiant off Barrenjoey Head and the Birchgrove Park. Other wrecks are thought to occur in the sub region however, data on estimated positions are sparse. This sub region is otherwise considered to have good potential for OAR siting.

b) South (offshore of Bate Bay)

The south Sydney sub region is defined by the southern limit of Port Botany port limits to the southern limit of the study region (within the specified depth range), where an area approximately 10. 8 km^2 consists of medium to coarse grain orange sand substrata. Limiting features in the sub region are the already popular recreational fishing areas (such as off Port Hacking Point and Glaisher Point) and the presence of rocky reefs such as Osbourne Shoal and Jibbon Bombora amongst others. Exact positioning of OAR's in this sub region would be limited to a few particular locations to remain apart from existing reef habitats (Figure 3b).

Should Sydney Port Authorities agree to OAR's being positioned at the radial extremes of port limits then potential locations would be significantly broadened. This would also open up the possibility of a third suitable location between South Head and Ben Buckler (Figure 3b).

5.3 Wollongong

Table 6 summarises key constraining issues related to sub-regions within the Wollongong study region. The main constraints in the Wollongong study region are the Port Kembla port limits and associated anchor berths, shipping channels and boarding points. Other features such as spoil dumping grounds, the Wollongong deep ocean outfall and the Five Islands Nature Reserve are encompassed by the Port Limits (or outside the suitable depth range), so areas north and south of port limits have been identified as good locations for OAR's (Figure 4).

a) North (Stanwell Tops to Bulli)

The northern sub region is approximately 36 km^2 comprising predominantly sandy substrata apart from two reef shoals offshore from Stanwell Park and Brickyard Point (Figure 4). One wreck is thought to occur in the area (The Waratah) although this lies at < 25 m depth. Commercial and recreational fishing is mostly thought to take place further offshore than the OAR depth zone; however, recreational fishing does also take place off known reefs (such as the Five Islands Nature Reserve). More information on locations of popular commercial trawling sites is required for this region.

b) South (south of Port Kembla off Perkins Beach)

The southern sub region is defined by the southern line of Port Kembla port limits, south to the reef at the southern end of Perkins Beach (this area has been extended just south of the Wollongong study region originally specified by DPI). An area between roughly 7 km^2 and 8 km^2 has been identified where constraints are minimal (Figure 4). It should be noted that the Five Islands Nature Reserve is situated at the north of this area and a critical Grey nurse shark habitat is located approximately 5.5km to the south.

6.0 RECOMMENDATIONS

This study has identified a number of sub regions where constraining factors are demonstrated to be minimal, however, in order to validate the suitability of these locations, further information is required to avoid conflict of interest and to gain a detailed assessment of the seabed. It is therefore recommended that for one (or both) of the sub-regions identified for each study region, more site specific information is required in the following areas:

- Commercial fishing
- Nature of the seabed and shipwrecks
- Coastal and oceanographic processes

6.1 Commercial Fishing

Details of local commercial fishing activity is sensitive information, not readily available in the public domain. It would therefore be necessary for DPI to obtain log book data for selected areas and/or address this issue through consultation with the relevant cooperatives, fishers and the Seafood Industry Advisory Council. In particular, this applies to the North Stockton sub region. Further information of how Artificial Reef deployment will interact with share management fisheries and possible legal advice pertaining to this may also be required.

6.2 Nature of the Seabed and Shipwrecks

Data compiled in this study have enabled us to make general inferences about the distribution of seabed characteristics and associated habitat at a broad spatial scale, however, more information is required at a finer scale for accurate positioning. This information is of particular importance for the Newcastle and Wollongong sub regions where information on the distribution of sub tidal rocky reef habitat is sparse.

A significant amount of information has been compiled on the locations of shipwrecks, however, accuracy of the positions is limited (particularly for less well known wrecks) as wrecks may be fragmented and scattered over a large area of seabed.

It is therefore recommended that acoustic survey techniques and point ground truth sampling is employed, to provide full coverage information of the seabed within selected sub regions at the 1 km^2 – 3 km^2. Digital side scan sonar has been used successfully for many years to produce high resolution maps of the seabed (Boyd *et al*, 2006) and provides information on the nature (e.g. hardness, roughness, texture) of the sediments and the presence and deposition of seabed features (e.g. sand waves, rock reefs). Side scan sonar would also locate uncharted ship wrecks or anthropogenic debris on the seafloor. Data may then be georeferenced and interplolated (either manually or digitally) to produce continuous acoustic maps of the selected survey area. Ground truthing by analysis of benthic grab samples should be done within acoustically differentiated areas identified in the side scan survey (i.e. to match specific acoustic signatures with specific sediment types). Particle size and benthic assemblage data from the ground truth survey may then be interpolated with the acoustic survey to determine areas having distinct physical properties and associated habitats, ensuring reef units are positioned in the best possible location. In addition, sampling for demersal fish should be carried out (either by trawl or non-destructive remote

video technique) to give an indication of overall productivity. These data may then be combined to provide a baseline for future monitoring.

6.3 Coastal and Oceanographic Processes

At a later stage it is recommended that detailed numerical modelling be carried out once specific sites have been identified. However, at this stage, on consideration of the coastal and oceanographic processes occurring in the study area, it is recommended that the proposed artificial reefs are placed at deeper depths within the 25m to 40m depth limits. This is because, at deeper depths:

- the artificial reef would be less likely to affect wave refraction patterns and the like;
- wave-driven currents are smaller and therefore so are dynamic forces on the structure;
- navigation is less likely to be restricted;
- oceanographic currents are likely to be smaller and,
- sediment transport is likely to be negligible.

That stated, further analysis and modelling at specific locations may find that reefs placed at 25m depth are stable under extreme waves and currents, and do not significantly affect the nearshore wave climate.

7.0 ACKNOWLEDGEMENTS

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TABLES

Table 1. NSW marine species and populations listed under the Fisheries Management (FM) Act, Threatened Species Conservation (TSC) Act and the Environment Protection and Biodiversity Conservation (EPBC) Act where species may occur within the area of the proposal. CE = critically endangered, E = endangered, V = vulnerable. M = migratory, L = listed, Cet = cetacean and P = protected. Source: NSW DPI Threatened species database.

				Known or predicted to occur in the following CMA's (✓- known, P- predicted)		
Scheduled Species	Common Name	Status under *TSC/FM Act*	Status under *EPBC Act*	Hunter/Central Rivers	Sydney Metro	Southern Rivers
Marine Reptiles						
Caretta caretta	Loggerhead turtle	E	E, M	✓	✓	
Chelonia mydas	Green turtle	V	V, M	✓	✓	✓
Dermochelys coriacea	Leathery turtle	V	V, M	✓	✓	
Eretmochelys imbricata	Hawksbill turtle	V	V, M			
Marine Mammals						
Arctocephalus pusillus doriferus	Australian fur-seal	V	L		✓	✓
Arctocephalus forsteri	New Zealand fur-seal	V	L	✓	✓	✓
Balaenoptera musculus	Blue whale	E	E, M	P	P	✓
Balaenoptera bonaerensis	Antarctic minke whale	P	M			
Balaenoptera edeni	Bryde's whale	P	M			
Dugong dugon	Dugong	E	M	✓	✓	✓
Eubalaena australis	Southern right whale	V	E, M	✓	✓	✓
Megaptera novaeangliae	Humpback whale	V	V, M	✓	✓	✓
Orcinus orca	Killer whale					
Physeter macrocephalus	Sperm Whale	V		✓	✓	✓
Fish						
Anampses elegans	Elegant wrasse	P			✓	
Carcharodon carcharias	Great white shark	V	V, M	✓	✓	✓
Carcharias taurus (East Coast)	Grey nurse shark	E	CE	✓	✓	✓
Chaetodontoplus ballinae	Ballina angelfish	P				
Epinephelus coioides	Estuary cod	P				
Epinephelus daemelii	Black cod	V		✓	✓	✓
Epinephelus lanceolatus	Giant Queensland grope	P				
Girella Cyanea	Bluefish	P				
Odontaspis ferox	Herbsts nurse shark	P				
Paraplesiops bleekeri	Bleekers devil fish	P				
Pristis zijsron	Green sawfish	E		✓	✓	✓
Phyllopteryx taeniolatus	Weedy Seadragon	P	L	✓	✓	✓
Thunnus maccoyii	Southern bluefin tuna	E		✓	✓	✓
Invertebrates						
Branchinella buchananensis	Buchanans fairy shrimp	V				
Algae						
Van voorstia bennettiana	Bennets seaweed	presumed extinct				
Nereia lophocladia	Marine brown algae	V				
Marine Vegetation						
	All seagrass, seaweed and mangrove species	P				
Threatened Populations						
Eudyptula minor	Little penguin	Endangerd Population	L		✓	

Table 2. NSW Shipwreck GIS Data. Source: NSW Heritage Office. (*)Denotes wrecks and relics in coastal waters landward of the limit of the State. (**)Denotes wrecks and relics in inland waters. Highlighted wrecks are those considered an important constraining feature.

Vessel Name	Chart Datum	Latitude	Longitude	Easting	Northing	Depth	Comments	Date acquired
Sydney Region								
Dobroyd Head anchor *	WGS 84.	33 49.043	151 16.033			11m		25-Jun-05
ANNIE M MILLAR	AGD66	33 52.0816	151 17.8533			46m		
BALLS HEAD #2 -UNID*	AGD66	33 50.920	151 11.649			28m		
BARGE (Middle Hbr)*	AGD66	33 48.4793	151 14.072					
BELLUBERA	AGD66	33 42 48	151 21 00			48m		
BIRCHGROVE PARK	AGD66	33 38.306	151 22.702			51m		
CENTURION UTM*	WGS 84	33 49 03.4	151 16 51.8			19m	3 sets of	01-Aug-03
		33 49.0566	151 16.8633				coordinates	
				340912	6256738			
CENTURION UTM (Bow)*	WGS 84			340922	6256719			10-Nov-04
CENTURION UTM (Plinth)*	WGS 84			340922	6256740			10-Nov-04
CENTURION UTM (Stern*)	WGS 84			340912	6256764			10-Nov-04
CENTENNIAL	AGD66	33.84772	151.25008			18m	2 sets of	
		33.84944	151.24888				coordinates	
COOLOOLI	AGD66	33 43 11	151 20 53			48m		
CURRAJONG	AGD66	33 51.4	151 14.866			24m		
DEE WHY	AGD66	33 43 02	151 20 46			48m		
Debri (Long Rf ship's grave)		33 42.69	151 21.05			44m		
DUCKENFIELD	AGD66	33 43.1833	151 19.3833			24m	2 sets of	
	WGS84	33 43.096	151 19.426			24m	coordinates	31-Mar-05
DUNBAR	AGD66	33 51.0083	151 17.1467			8m		
EDWARD LOMBE* –	WGS84	33 49 44.69	151 16 11.43			12m	3 sets of	19-May-06
Anchor 1		33.82908	151.26983				coordinates	
				339895	6255449			
EDWARD LOMBE* –	WGS84	33 49 42.66	151 16 12.52			12m	3 sets of	19-May-06
Anchor 2		33.82853	151.27014				coordinates	
				339922	6255512			
EMU	WGS 84	31 50 02.78	152 44 09.72			0m	2 sets of	4-7 July
				475022	6477922		coordinates	1994
FAME*	AGD66	33 50.27	151 16.13			18.5m		
HILDA	AGD66	34 02.37	151 13.4783			25m		
HIMMA	AGD66	33 43 13	151 21 01			48m		
HMAS ENCOUNTER		33 55.8	151 36.0					
ITATA*	AGD66	33 49.03	151 13.43			0-5m		
KELLOE		33 59.1966	151 15.915			50m		
KOPUTAI		30 54.8	151 20.8 ??			76m		
MALABAR	AGD66	33 58 13	151 15 43			13-18m		2003-4
		33.97	151.2619					
MEGGOL	AGD66	33 43.6666	151 20.75			44m	2 sets of	
		3343.2	151.20.5				coordinates	
MYOLA	AGD66	33 45.789	151 21.774			48m		
PYRMONT		33 41.1	151.20.6			44m		
QUEEN OF NATIONS	AGD66	34 23.13	150 55.00			5m		2003-4
ROYAL SHEPHERD	WGS84	33 50 08.3	151 50 08.3			27-	2 sets of	2003-4
		33.8356388	151.8356388					
TUGGERAH	AGD66	34 08.3395	151 09.0367			48m		
UNDOLA	AGD66	34 10 52	151 05 34			45m		
Unidentified		33 42.89	151 20.99			44m		
VALIANT	AGD66	33 34 48	151 20 40			27m		
WONIORA	AGD66	34 01.395	151 15.5283			63m		
WOLLOMSTROM	AGD66	34 03 34	151 08 45			7m		

Continued

Table 2. Continued

Vessel Name	Chart Datum	Latitude	Longitude	Easting	Northing	Depth	Comments	Date acquired
Hunter Region								
BYRON		33 01.1	151 46.1					
COMMODORE		32 55.4	151 52.4					
DURISDEER	AGD66	32 54.4276	151 47.2975			3m		2003-4
FIFESHIRE		33 27.577	151 26.872			21m		
FIONA	AGD66	32 28 31.30	152 26 20.62			0-1m		
FITZROY		32 48.2	152 04.7					
FREAK*		32.71	152.15			15m		
GALAVA		33 22.645	151 30.741			51m		
HALL CAINE	AGD66	33 32 49	151 25 20			45m		
IRRESISTIBLE		32 53.5	151 49.8					
K-IX	AGD66	32 27 52.87	32 27 52.87			0m		22-Jun-05
KIAMA		33 22.329	151 32.844			47m		
MACLEAY	AGD66	32 42 20	152 14 43			43m		
OAKLAND	AGD 66	32 40 47	152 13 56			28m	2 sets of coordinates	2003-4
		32.67972	152.232222					
OIMARA						15m		
OSPREY		32 52.9	151 54					
PAPPINBARRA		152 26 20.62	152 11.5			6m		
Unidentified - Stockton		32 54.779	151 47.3158			3m		
WAUCHOPE		32.733333	152.193333			18m		
URALLA - 1928	WSG84	32.47565	151.59414			0-2m		2003-4
YAMBACOONA		33 38.35	151 36.75					26-Jun-05
YARRA YARRA	AGD66	32 54.303	151 48.009			15m		2004-5
Northern NSW								
AGNES IRVING	AGD66					15m		2004-5
ALBERTA		28 15.2267	153 35.5333			10-13m		
ALCIDES	WGS84	28 10.414	153 32.851					01-Oct-03
ANNE MOORE						10m		
BALLINA	AGD66	31.358333	152.916667			6m		
CATTERTHUN	AGD66	32 25.57	152 34.38			60m		2003-4
FIDO	WGS84	28 11.9533	153 35.4217			5-10m		2004-5
IDANT		31 38.4667	152 49.7267					
MANNING*	WGS84	31 54.717	152 27.927			0m		10-Jul-01
PRINCE OF WALES		31 38.545	152 50.4033					
SATARA	AGD66	32 28 50	152 31 11			43m		
TASMAN HAULER	AGD66	37 06 39	149 57 45			29m		
TELEGRAPH		31 38.5183	152 51.21					
TITAN		31 39.945	152 52.3367					

Continued

Table 2. Continued

Vessel Name	Chart Datum	Latitude	Longitude	Easting	Northing	Depth	Comments	Date acquired
Southern NSW								
BOMBO	AGD 66	34 26 43 34.4452777	150 55 25 150.9236111			32m	2 sets of coordinates	
BEGA	WGS84	36 39.235	150 05.203			76m		10-Feb-05
CORANGAMITE	AGD 66					15m		2004-5
CITY OF SYDNEY	AGD 66	37 15.46	150 00.70			22m		2004-5
CUMBERLAND	WGS84	37.3309	150.0942			94m		
EMPIRE GLADSTONE	AGD 66	36 57.14	149 56.79			11.3m		2004-5
HENRY BOLTE	AGD66	37 06 47	149 57 43			25m		
HIVE	AGD Zone 56			284645	6105670			
IRON KNIGHT	WGS84	36 27.268	150 14.765			125m		28-Jun-05
JOHN PENN	AGD 66	35 51.07.7	150 11 00.0			12m		2004-5
LADY DARLING	AGD 66	36 19.10 36 19 06.37	150 10.10 150 10 07.06			30m		23-Jun-05
LANERCOST	AGD 66	37 08.26	149 59.48			24m		2004-5
LY-EE-MOON	AGD 66	37 15.90	150 02.93			13m		2004-5
MERIMBULA	AGD 66	35 00 16 35.00444	150 49 42 150.828333			13m	2 sets of coordinates	2003-4
MIMOSA	AGD 66	36 34 58.6	150 03 27.2			21m		2004-5
NEW GUINEA	AGD 66	37 15.67	150 02.28			10m		2004-5
OLIVE CAM	AGD 66	37 09.15	150 00.36			12m		2004-5
PLUTUS	AGD 66	35.01	150.808333			4m		2004-5
QUEEN OF NATIONS	AGD 66	34.3855	150.916667			5m		2004-5
RODNEY	AGD66	33.21777	142.369444					2004-5
ROSE OFAUSTRALIA		35.17	150.691667			4m		
WALTER HOOD		35 13.4667	150 32.1333			4.4m		
WANDRA	AGD66	35 02.69	150 50.34			26m		
WARATAH		34 19.8	150 55.8					
FIREFLY*		35 00.772	150 43.897			13m		
WILLIAM DAWES	WGS 84	36 35 66	150 13 22			135m		
Western NSW								
RODNEY**	AGD66	33.218333	142.3691666					01-Jul-02
WAVE**	WGS84	30.08307	145.94306			riverbank		01-Aug-03
WANDERING JEW**	WGS84	29.95673	146.85756			1-1.5m		01-Aug-03
Port of Louth	WGS84	30.53446	145.11606			town		01-Aug-03

Table 3. Sediment composition data sampled by vibrocore and dredge at the the study regions. Source: Department of Geoscience, University of Sydney *DP= Dredge Core, VC = Vibro Core, BC = Box Core. All samples except for that taken off Red Head Point were collected at depths >60 m.

Location	Percentage composition (%) % Mud	% Sand	% Gravel	Distance from shore (km)	sampling method*
Newcastle					
North Stockton	45.7	54.3	0	4.18	DP
Red Head Point	0	94.4	5.6	0.27	DP
Sydney					
Bangalley Head (inner)	0.26	98.4	1.4	8.79	VC
Bangalley Head (mid)	0.13	99.5	0.33	15.25	VC
Bangalley Head (outer)	13.1	86.8	0.02	20.71	VC
North Head (inner)	1.37	98.6	0	10.52	VC
North Head (outer)	6.35	93.2	0.46	21.02	VC
South Head (inner)	3.2	96.6	0.23	6.87	VC
South Head (mid)	1.75	98.2	0	9.17	VC
South Head (outer)	0	97.4	2.6	22.28	BC
Cape Banks (inner)	10.18	89.6	0.2	3.67	VC
Cape Banks (mid)	12.7	86.1	1.2	22.3	VC
Cape Banks (outer)	4.3	95.5	0.2	29.01	VC
Sydney to Wollongong					
SE of Budeena (inner)	0.9	97.3	1.73	15.8	VC
SE of Budeena (mid)	4.9	95	0	24.98	VC
SE of Budeena (outer)	5.9	92.3	1.75	35.16	VC

Table 4. Summary of constraining features for sub-regions identified within the Newcastle study region. Depth is not listed as a constraining feature as other constraints are based on the assumption they are within the 25 m - 40 m depth range.

Location: Newcastle	Constraining feature	Comments
a.) North (Stockton Bight)	•**Exclusion Zones**	
	ACMA Cable exclusion zones	n/a
	Deepwater ocean outfalls	n/a
	Recognised recreational fishing areas	A number of popular reef fishing spots in this sub region
	Recognised commercial fishing areas	Major commercial trawling ground (ocean trap and line, ocean prawn trawl, ocean fish trawl). This area includes fishing zones 5 and 6
	Designated commercial shipping lanes and Port Authorities	Large volume of shipping traffic in the vicinity of Newcastle Harbour. There is a restricted zone for shipping at the entrance of Newcastle Harbour which defines the southern end of this potential area. Anchoring is excluded within the 3 nm limit and north of Little Red Head.
	Marine protected areas	The Port Stephens Great Lakes Marine Park starts at Anna Bay adjacent to the northern end of this study region. A buffer zone may apply.
	Mining exploration leases	Petroleum exploration licence (PEP 11) starts from Port Stephens South to Wollongong for 200 kms covering 2,000,000-acres. (the permit starts from 3 nm offhore).
	Historical ship wrecks	Wrecks of the Fitzroy, Osprey, Irresistable and Commodore are all located between 18 m and 36 m of water, a restricted zone applies to the Commodore. Other wrecks are likely to occur in the area
	Spoil grounds	n/a
	•**Other restricting zones**	
	FADS (Fish Attraction Devices)	n/a
	Buoys	n/a
	Desalination Plants	n/a
	•**Type of substrata**	Mostly sand some reef (e.g. pinnacle at boundary of restricted shipping zone, harbour entrance). Maybe areas of uncharted reef
	•**Habitat Distribution**	Typical benthic/epibenthic habitat associated with natural shelf sand
	•**Threatened species**	15 either endangered, vulnerable or protected species expected to occur in the area
	•**Oceanographic processes**	Coastal erosion is an issue at Stockton Beach

Continued

Table 4. Continued.

Location: Newcastle	Constraining feature	Comments
b.) South (South of Nobby's Head and Spoil Grounds)	**•Exclusion Zones**	
	ACMA Cable exclusion zones	n/a
	Deepwater ocean outfalls	Belmont and Burwood Ocean Outfalls
	Recognised recreational fishing areas	Popular for recreational fishing from beaches, off rocks and offshore. Off Merewether, Redhead and Swansea are popular locations
	Recognised commercial fishing areas	Major commercial trawling ground (ocean trap and line, ocean prawn trawl, ocean fish trawl). This area includes fishing zones 5 and 6
	Designated commercial shipping lanes and Port Authorities	Large volume of shipping traffic in the vicinity of Newcastle Harbour. There is a restricted zone for shipping at the entrance of Newcastle Harbour which is north of this potential area. Shipping volume is high outside of the 3nm no anchor zone
	Marine protected areas	n/a
	Mining exploration leases	Bounty Oil & Gas NL Biggus- 1 Exploration Well lies 25 kms south of Newcastle approximately 22 kms offshore at depth of 125 m. Unlikely to be a constraint although there is a 2 nm exclusion zone surrounding the rig. Petroleum exploration licence (PEP 11) starts from Port Stephens South to Wollongong for 200 kms covering 2,000,000-acres. (the permit starts from 3 nm offhore).
	Historical ship wrecks	Wreck of The Byron lies between 18 m and 36 m of water offshore from Red Head Point. Wreck of the Bonnie Dundee is in 18 m to 36 m of water off Moon Island. Other wrecks are likely to occur in the area.
	Spoil grounds	Spoil grounds are located at the north end of this potential area. A disposal site is also located offshore from Little Red Head.
	•Other restricting zones	
	FADS (Fish Attraction Devices)	n/a
	Buoys	n/a
	Desalination Plants	n/a
	•Type of substrata	Sand and reef
	•Habitat Distribution	Typical benthic/epibenthic habitat associated with natural shelf sand
	•Threatened species	15 either endangered, vulnerable or protected species expected to occur in the area
	•Oceanographic processes	Similar throughout study regions

Table 5. Summary of constraining features for sub-regions identified within the Sydney study region. Depth is not listed as a constraining feature as other constraints are based on the assumption they are within the 25 m - 40 m depth range.

Location: Sydney	Constraining feature	Comments
a.) North (Broken Bay, Off Barrenjoey Headland, south to Palm Beach)	**•Exclusion Zones**	
	ACMA Cable exclusion zones	Northern Sydney protection zone to the south of this area. The protection zone is from Warriewood south 4.3 km to South Narrabeen.
	Deepwater ocean outfalls	n/a
	Recognised recreational fishing areas	Some popular reef fishing spots outside the sub region and further offshore
	Recognised commercial fishing areas	Commercial fishery zone 6 (ocean trap and line, ocean prawn trawl, ocean fish trawl). Not a recognised commercial fishing area
	Designated commercial shipping lanes and Port Authorities	No commercial shipping lanes and not under the jurisdiction of any Port Authoritybut popular recreational boating area
	Marine protected areas	Barrenjoey Head and Narrabeen Head Aquatic Reserves are located in this area. Both extend out 100 m offshore.
	Mining exploration leases	Petroleum exploration licence (PEP 11) starts from Port Stephens South to Wollongong for 200 kms covering 2,000,000-acres. (the permit starts from 3 nm offshore).
	Historical ship wrecks	Wrecks of The Valiant and The Birchgrove Park are known to lie offshore of Barrenjoey Head and Bilgola Head respectively in the 18 m - 36 m depth range. A number of other wrecks are likely to occur in this area. A major dumping ground of a number of other wrecks is located between Turimetta Head and Long Reef.
	Spoil grounds	Designated disposal area between Turimetta Head and Long Reef
	•Other restricting zones	
	FADS (Fish Attraction Devices)	1 FAD located off Broken Bay at 110 m. Not a consideration
	Buoys	n/a
	Desalination Plants	n/a
	•Type of substrata	Mainly medium to coarse orange sand with patches of rocky reef and fine golden sand to the south.
	•Habitat Distribution	Habitat typical of rocky reef and natural shelf sands
	•Threatened species	16 either endangered, vulnerable or protected species expected to occur in the area
	•Oceanographic processes	Similar throughout study regions

Continued

Table 5. Continued

Location: Sydney	Constraining feature	Comments
b.) South, offshore from Bate Bay	**•Exclusion Zones**	
	ACMA Cable exclusion zones	Southern Sydney ACMA Protection zone is located north of this area. The zone extends from Ben Buckle Head South for 4.3 km to the southern headland of Coogee Beach but is not considered an issue for this sub region
	Deepwater ocean outfalls	n/a
	Recognised recreational fishing areas	A number of popular reefs within the sub region e.g. Osbourne Shoal, Jibbon Bombora, Glaisher Point
	Recognised commercial fishing areas	Not a recognised commercial fishing area, but some trawlers are known to operate here
	Designated commercial shipping lanes and Port Authorities	Port Jackson, Sydney Harbour Entrance (to the north of this potential area) is a major commercial shipping channel. Port Botany port limits set the northern limit of this sub region
	Marine protected areas	Boat Harbour Aquatic Reserve is located immediately to the north of the sub region
	Mining exploration leases	Petroleum exploration licence (PEP 11) starts from Port Stephens South to Wollongong for 200 kms covering 2,000,000-acres. (the permit starts from 3 nm offhore). Possible sand mining leases in the area
	Historical ship wrecks	One wreck located to the north of the sub region.
	Spoil grounds	n/a
	•Other restricting zones	
	FADS (Fish Attraction Devices)	FAD's occur in this area but outside the suitable OAR depth range
	Buoys	n/a
	Desalination Plants	n/a
	•Type of substrata	Other reef shoals are present in the area i.e. Osbourne Shoal and Jibbon Bombora.
	•Habitat Distribution	Typical benthic and epibenthic sand/reef community
	•Threatened species	16 either endangered, vulnerable or protected species expected to occur in the area
	•Oceanographic processes	Similar throughout study regions

Table 6. Summary of constraining features for sub-regions identified within the Wollongong study region. Depth is not listed as a constraining feature as other constraints are based on the assumption they are within the 25 m - 40 m depth range.

Location: Wollongong	Constraining feature	Comments
a.) North (Stanwell Tops to Bulli)	**•Exclusion Zones**	
	ACMA Cable exclusion zones	n/a
	Deepwater ocean outfalls	n/a
	Recognised recreational fishing areas	Recreational fishing popular around reefs and offshore. Reef off Austinmer popular for offshore fishing.
	Recognised commercial fishing areas	Commercial fishery zone 7 (ocean trap and line, ocean prawn trawl, ocean fish trawl). Few trawlers are known to operate in the sub-region. Trawlers operating in this area thought to operate in deeper water >40 m.
	Designated commercial shipping lanes	Port Kembla has a restricted zone around the Port Entrance, although the port area is not considered an option in this area.
	Marine protected areas	n/a
	Mining exploration leases	Petroleum exploration licence (PEP 11) starts from Port Stephens South to Wollongong for 200 kms covering 2,000,000-acres. (the permit starts from 3 nm offhore). Possible sand mining licences
	Historical ship wrecks	Wreck of the Waratah is located off Bulli Point but in water <25 m
	Spoil grounds	n/a
	•Other restricting zones	
	FADS (Fish Attraction Devices)	n/a
	Buoys	n/a
	Desalination Plants	n/a
	•Type of substrata	Mainly fine to medium sand with some isolated shallow reefs
	•Habitat Distribution	Typical benthic habitat associated with sandy soft sediments. Diverse assemblages associated wih reef habitats
	•Threatened species	14 either endangered, vulnerable or protected species expected to occur in the area
	•Oceanographic processes	Similar throughout study regions

Continued

Table 6. Continued.

Location: Wollongong	Constraining feature	Comments
b.) South (South of Port Kembla off Perkins Beach)	**•Exclusion Zones**	
	ACMA Cable exclusion zones	n/a
	Deepwater ocean outfalls	n/a
	Recognised recreational fishing areas	Recreational fishing popular around reefs and offshore. Areas off the Five Islands and Perkins Beach are popular
	Recognised commercial fishing areas	Commercial fishery zone 7 (ocean trap and line, ocean prawn trawl, ocean fish trawl). Few trawlers are known to operate in the sub-region. Trawlers operating in this area tend to work in deeper water >40 m.
	Designated commercial shipping lanes	Port Kembla has a restricted zone around the Port Entrance
	Marine protected areas	Five Island Nature Reserve to the north of this sub region and a Grey nurse shark critical habitat to the south
	Mining exploration leases	Petroleum exploration licence (PEP 11) starts from Port Stephens South to Wollongong for 200 kms covering 2,000,000-acres. (the permit starts from 3 nm offhore).
	Historical ship wrecks	Wreck of The Bombo located in approx. 18 m off Port Kembla Beach. Other wrecks are known to occur in the area
	Spoil grounds	None in this sub-region but two spoil grounds located directly to the east.
	•Other restricting zones	
	FADS (Fish Attraction Devices)	n/a
	Buoys	n/a
	Desalination Plants	n/a
	•Type of substrata	Mainly fine to medium sand with some isolated shallow reefs
	•Habitat Distribution	Typical benthic habitat associated with sandy soft sediments. Diverse assemblages associated wih reef habitats
	•Threatened species	14 either endangered, vulnerable or protected species expected to occur in the area
	•Oceanographic processes	Similar throughout study regions

Table 7. Names and GPS positions of popular recreational fishing locations in the Newcastle study region. Source: McEnally and McEnally (2004).

Location Name	Target Species	Latitude (S)	Longitude (E)
Merewether Reef	Bream, tailor kingfish, snapper	32.57.433	151.46.695
Ted's Hook Up	Snapper, tarwhine, trevally.	32.57.433	151.52.102
Bar Beach	Snapper, teraglin, mulloway	32.56.139	151.49.701
The Pines	mixed reef fish	32.55.262	151.50.121
Merre Mark	Morwong, trevally, flathead	32.58.811	151.50.312
Pogonski's Rise	Snapper, morwong	32.58.361	151.45.092
Cable Hook Up	mixed reef fish	32.58.329	151.51.216
Laverty's Rise	snapper morwong trevally	32.57.897	151.52.151
Yarra Yarra Wreck	mulloway, snapper	32.54.151	151.48.033
Short Shot	Snapper, teraglin, leatherjacket	32.55.291	152.02.503
Top Shot	morwong, teraglin snapper	32.54.152	152.06.512
North Reef	Snapper, bream, mulloway, trevally, kingfish	32.53.838	151.50.821
Mud Hole Reef	Snapper, flathead	32.52.663	151.50.581
Motor Mouth	Mixed reef fish	32.52.482	151.56.087
The Tank	Snapper, Kingfish	32.52.350	151.54.851
Sygna Wreck	Bream, tailor, small snapper	32.51.740	151.50.751
Bubbles	Snapper, other reef fish	32.51.004	152.04.311
The Stones	Mixed reef fish	32.51.002	152.04.812
Tilligary Shoals	Kingfish, snapper, trevally	32.50.731	151.58.862
Uralla Wide	Mulloway, tereglin, kingfish, snapper	32.50.622	152.00.431
Birubi Wide	Snapper, tereglin, flathead	32.50.508	152.04.571
Harvey's Reef	Mixed reef fish	32.50.167	152.00.152
Rommel's Reef	Snapper, mulloway, tereglin	32.50.091	152.03.644
Uralla Reef	Snapper, mixed reef fish, mulloway	32.49.231	152.03.546
Swansea Gravel	Local drft area for flathead	33.05.571	151.43.379
Swansea Wreck (Bonnie Dundee)	Snapper, mulloway, flathead	33.05.032	151.43.449
Jewells	Snapper, bream	33.01.924	151.43.022
Redhead Gravel	Snapper, flathead	33.01.497	151.44.194
Redhead Close	Snapper, mulloway, trevally, bream, flathead	33.00.713	151.44.043

Table 8. Names and GPS positions of popular recreational fishing locations in the Sydney study region. Source: Brown (2007).

Location Name	Target Species	Latitude (S)	Longitude (E)
North Head Bommie	Tailor kingfish, bonito, salmon	33.48.990	151.18.290
Bluefish Point	kingfish, bream, trevally, snapper and morwong	33.48.430	151.18.450
Murphy's	Snapper, trevally, morwong, leatherjacket	33.47.495	151.22.045
Manly/North Steyne Reef	Mixed reef fish	33.47.469	151.17.400
Wave Rider Buoys	Trevally, kingfish, salmon, bonito, marlin, dolphin fish	33.46.302	151.25.045
Freshwater Wide	Snapper, morwong, kingfish, trevally, leatherjackets, flathead	33.46.500	151.21.800
Dee Why Wide	Morwong, snapper, leatherjackets, mulloway, tereglin, bonito	33.45.710	151.22.280
Long Reef Wide	snapper, flathead, morwong, mixed reef fish	33.44.450	151.22.250
Good Property	mulloway, snapper, morwong, trevally, kingfish, leatherjacket	33.44.51	151.21.980
Long Reef Wall	Snapper, kingfish, bream, trevally	33.44.37	151.19.500
Narrabeen Wreck	snapper, sharks, morwong, kingfish, mulloway, tereglin, leatherjacket	33.43.00	151.19.000
Newport Reef	Snapper, morwong, trevally, leatherjackets and kingfish	33.43.598	151.20.234
Esmeralda Reef	Most reef species	33.99.520	151.25.640
Birchgrove Wreck	Mixed reef fish and bait fish	33.38.270	151.22.400
Avalon Gutter	Snapper, leatherjacket morwong, trevally	33.38.120	151.21.400
Reggies	snapper, mulloway	33.37.954	151.22.221
Boultons Reef	Snapper, other reef fish	33.36.000	151.22.260
Flathead Grounds	Flathead, other reef fish	33.35.100	151.26.000
Barrenjoey Wide	Mixed reef fish	33.34.990	151.31.650
Broken Bay Wide	Mixed reef fish	33.34.622	151.36.997
Hacking Wreck	snapper, mulloway, kingfish	34.08.330	151.09.050
Flathead Drift	Flathead, other reef fish	34.07.055	151.09.988
Jibbon Bombora	Mixed reef fish	34.04.900	151.10.450
Bate Bay Patches	Snapper, bream, trevally, kingfish, , tailor	34.03.600	151.11.100
Osbourne Shoal	Bream, kingfish, snapper, morwong, trevally, leatherjacket, flathead	34.03.150	151.11.350
Cronulla Flathead Grounds	Sand and tiger flathead	34.03.83	151.11.89
Boat Harbour	Snapper, morwong, trevally, leatherjackets and flathead	34.02.990	151.12.270
The Wave Buoy	kingfish, bonito, dolphin fish, tailor, salmon	34.02.570	151.15.160
Lighthouse	Snapper, morwong, leatherjacket	34.02.200	151.14.000
Kurnell Car Park	Snapper, kingfish, morwong, leatherjacket	34.01.320	151.14.300
Browns Mountain	Marlin, tuna, sharks, albacore, dolphin fish, wahoo, kingfish, blue eye cod	32.02.04	151.39.50
The Peak	Marlin, tuna, sharks, albacore, dolphin fish, wahoo, kingfish, mixed reef fish	33.58.760	151.21.760
Trag Grounds	Snapper, morwong, kingfish, trevally, leatherjackets, flathead	33.56.070	151.16.240
Wedding Cake Island	kingfish, snapper, bream	33.55.544	151.15.900
The Twelve Miler	Marlin, tuna, sharks, pelagics, snapper, pinkies, leatherjacket	33.55.660	151.28.510

FIGURES

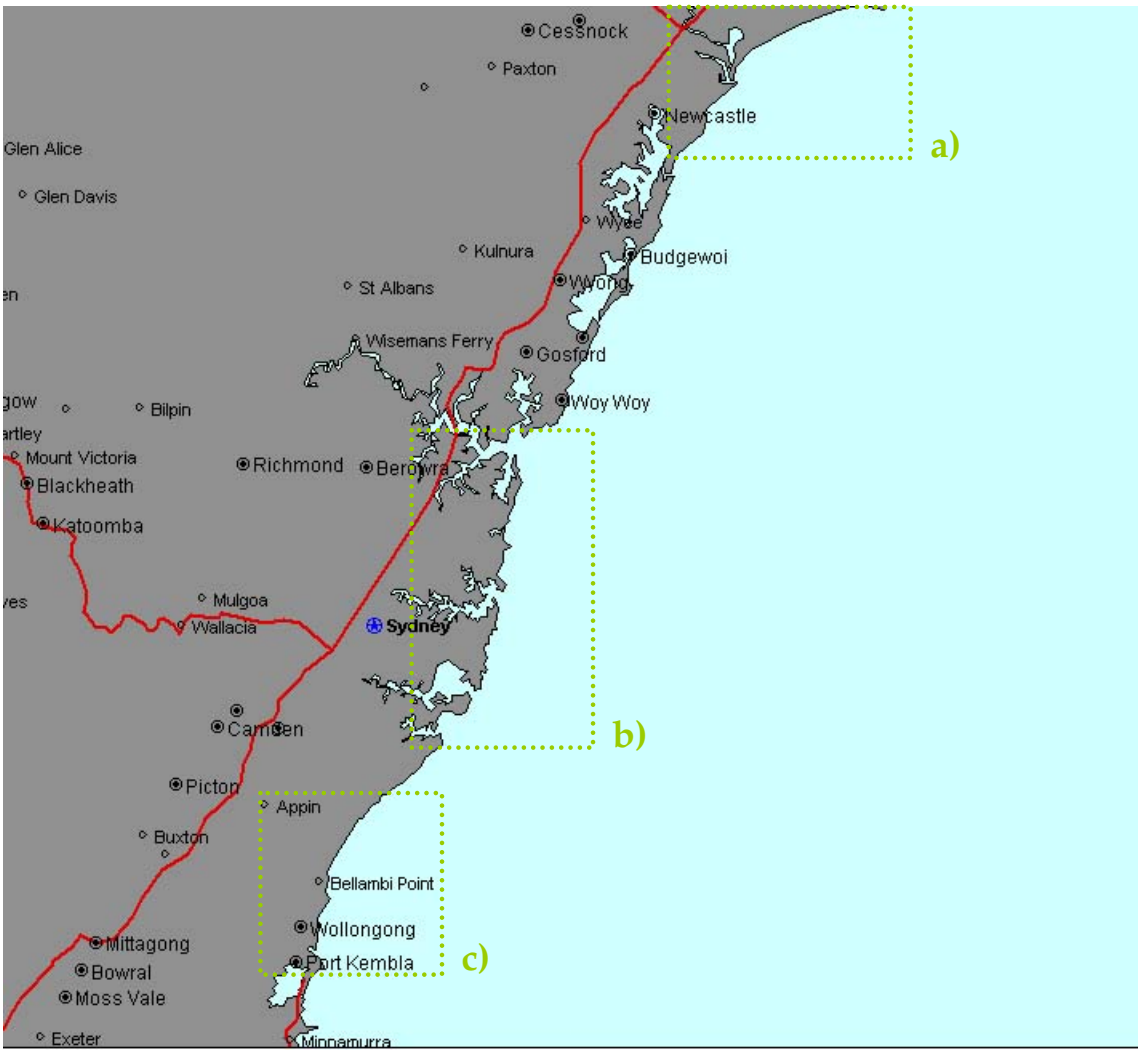

Figure 1. Map of study regions for offshore artificial reef constraint mapping. From north to south, a) Newcastle (Stockton Beach to Swansea), b) Sydney (Barrenjoey Head to Bundeena), c) Wollongong (Stanwell Tops to Port Hacking).

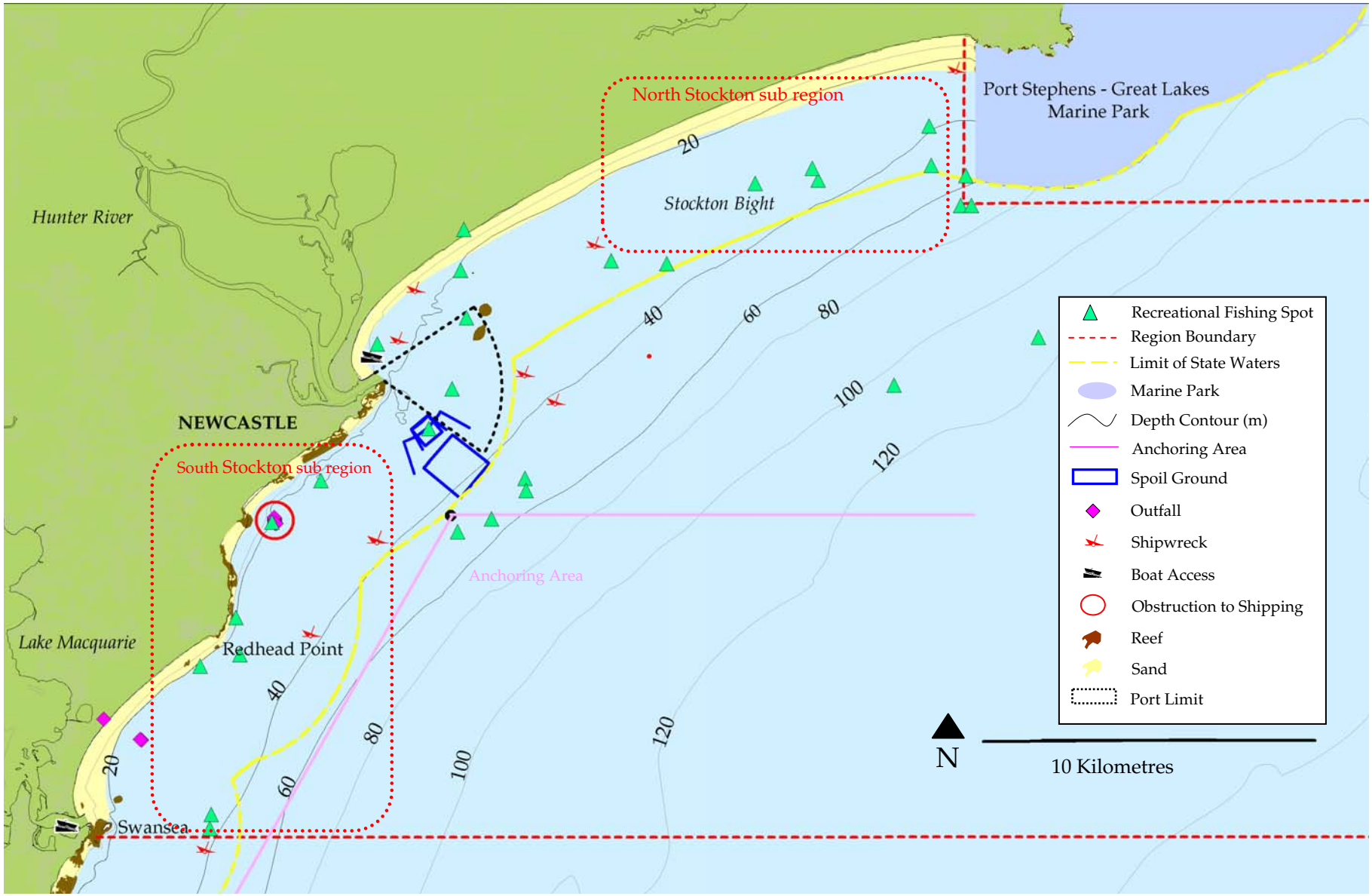

Figure 2. Map of major constraining features in the Newcastle (Stockton Beach to Swansea) study region. Sub regions are marked by red dotted boundaries.

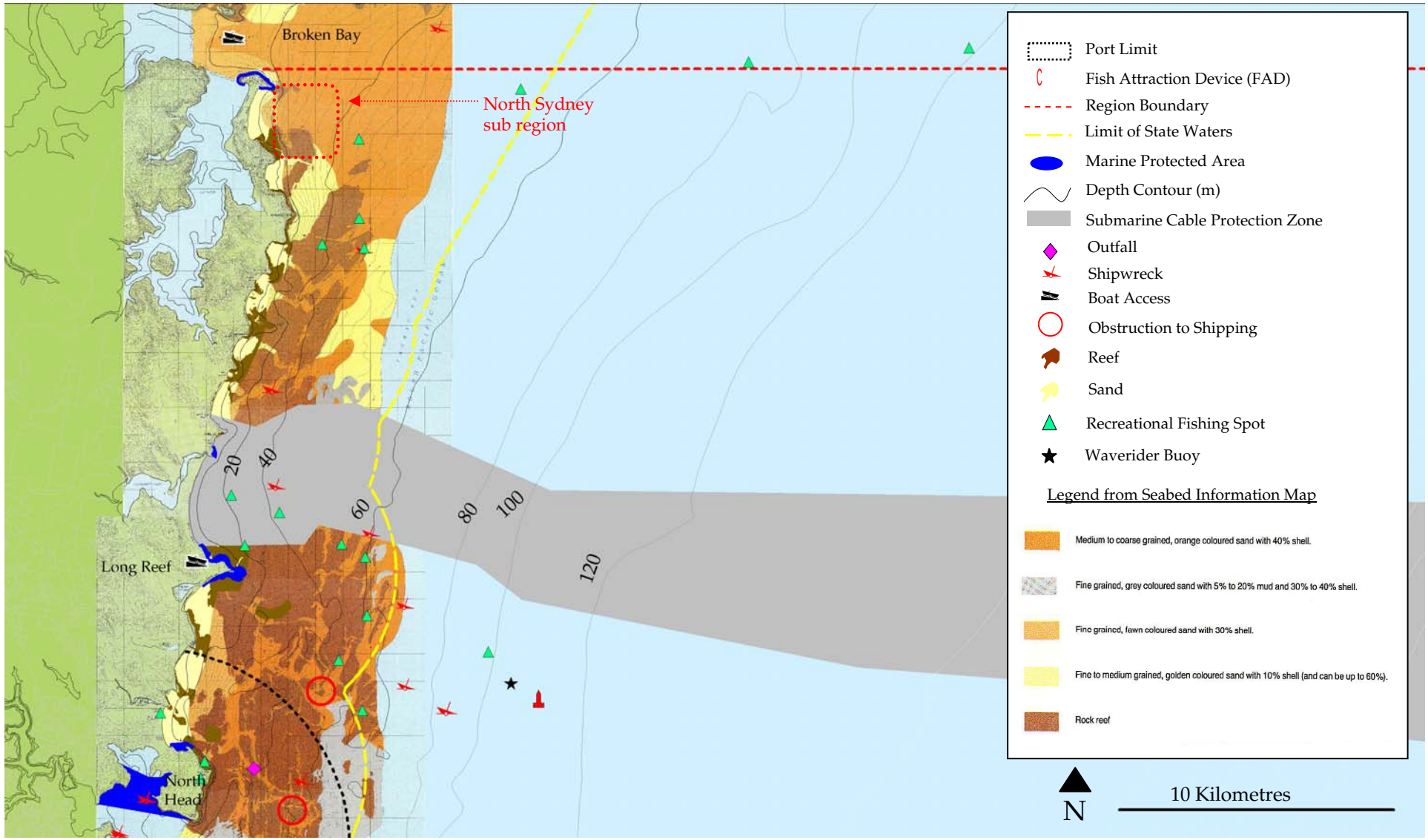

Figure 3a. Major constraining features in the northern section (Broken Bay to Port Jackson) of the Sydney study region. Sub regions are marked by red dotted boundaries.

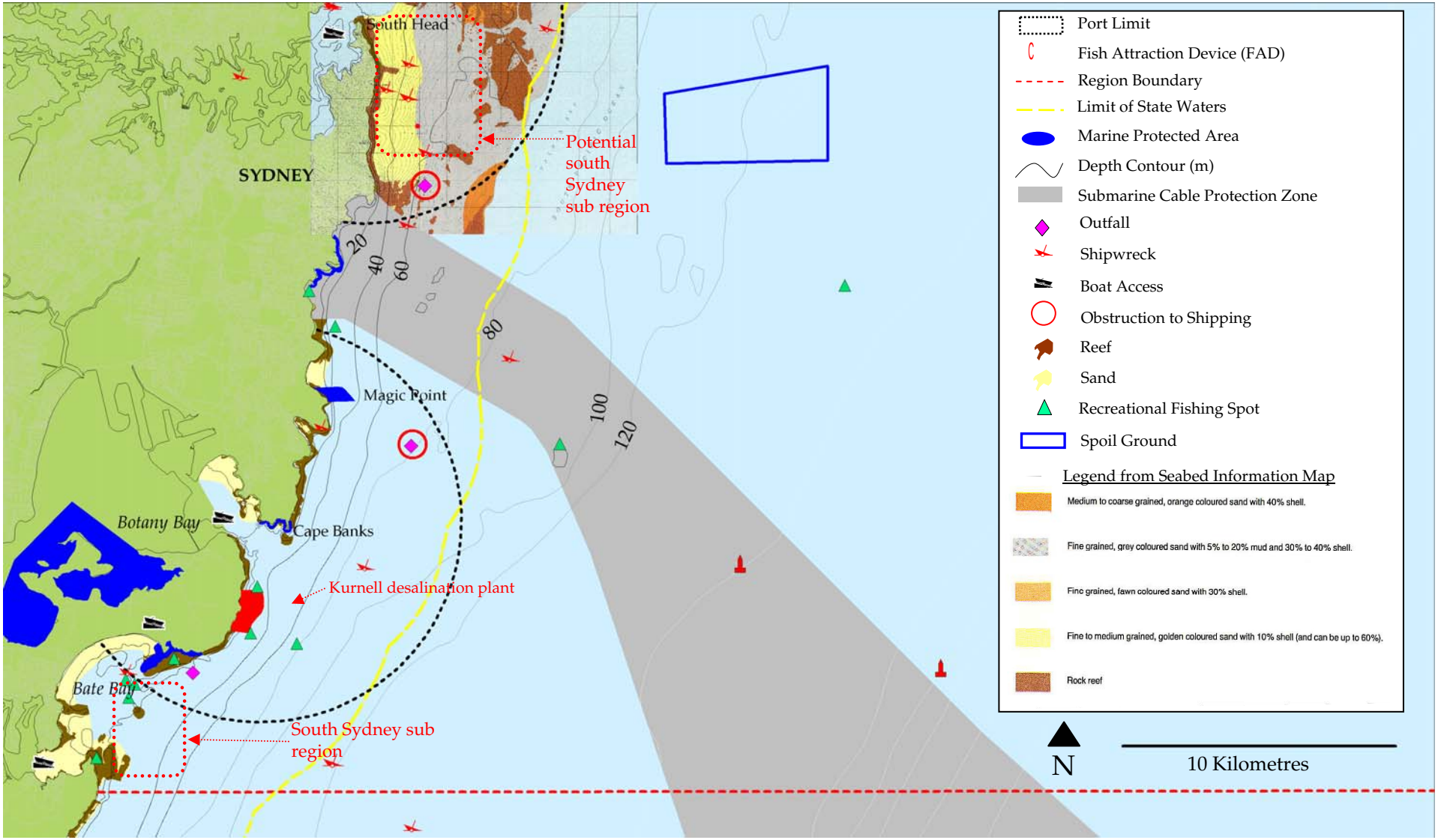

Figure 3b. Major constraining features in the southern section (Port Jackson to Bundeena) of the Sydney study region. Sub regions are marked by red dotted boundaries.

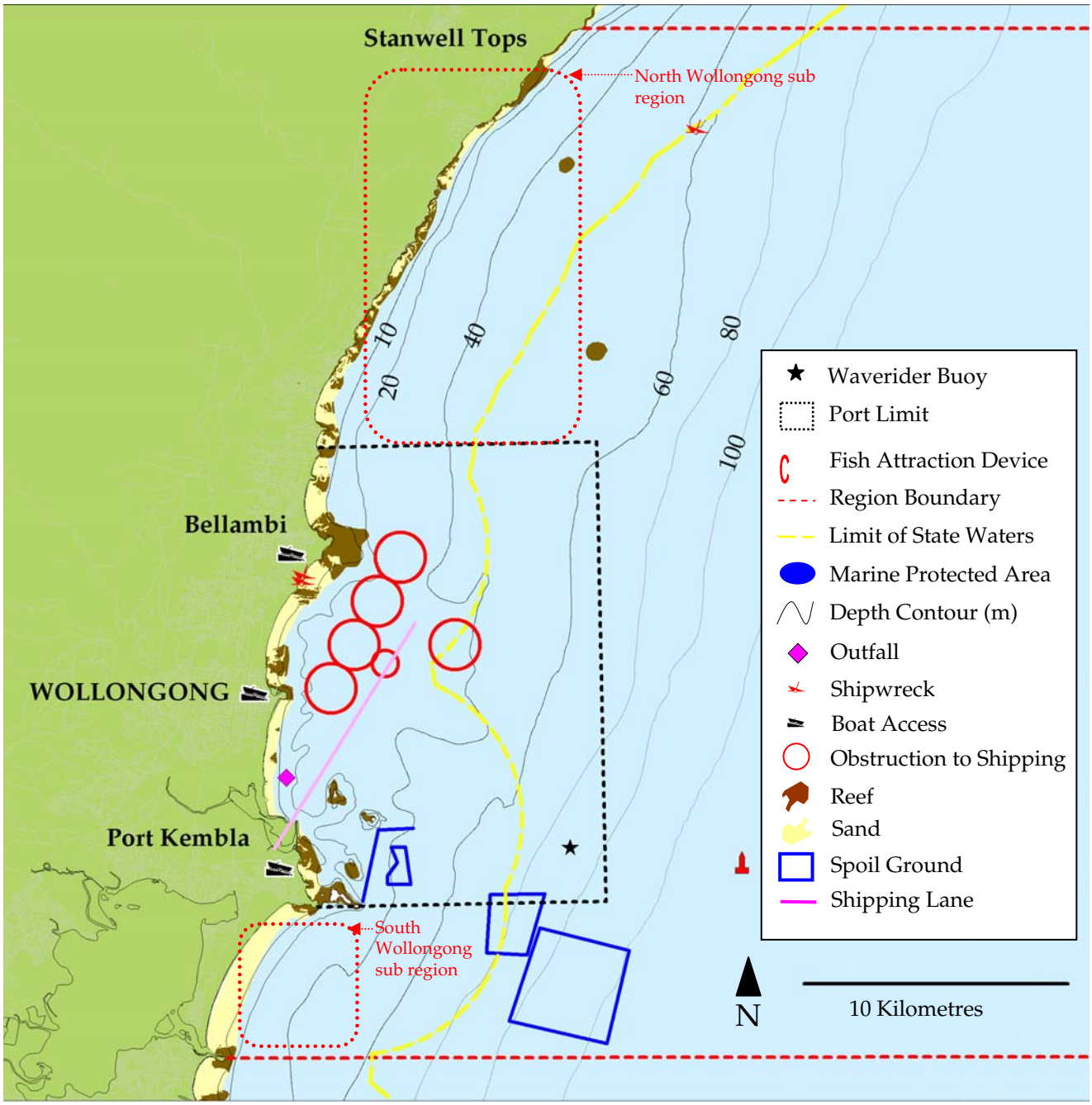

Figure 4. Major constraining features in the Wollongong study region. Sub regions are marked by red dotted boundaries.

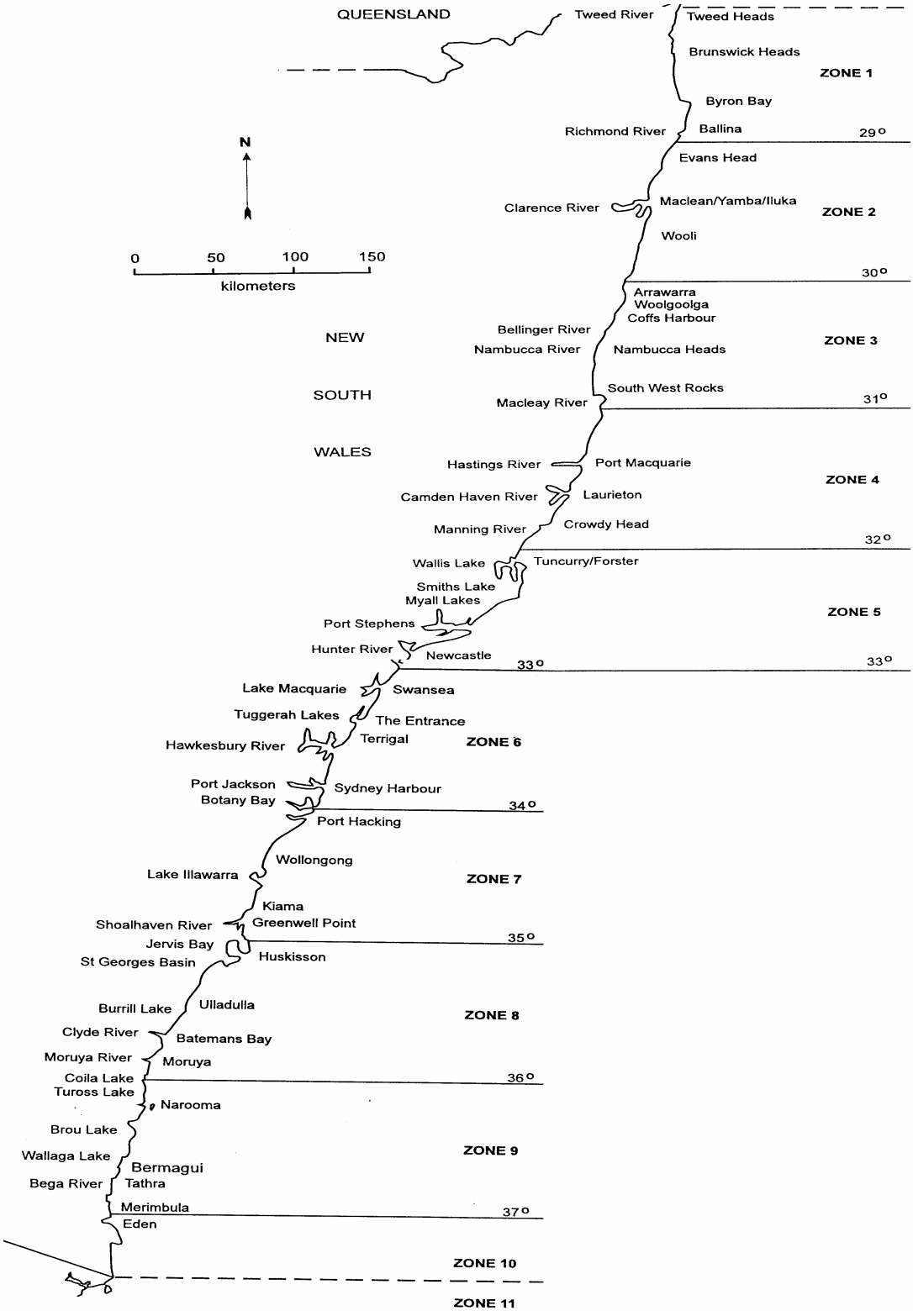

Figure 5. Catch reporting zones for Ocean Trap and Line, Ocean Prawn Trawl and Ocean Fish Trawl Fisheries.

APPENDICES

Appendix 1: Coastal and Oceanographic Processes. Report by Worley Parsons Pty Ltd

Appendix 2: General information on commercial fisheries operating in the Newcastle, Sydney and Wollongong study areas, including geographical extent of relevant fisheries, economic value and target species

Appendix 3a: Historical shipwreck data (NSW Heritage shipwreck database), Newcastle study region.

Appendix 3b: Historical shipwreck data (NSW Heritage shipwreck database), Sydney study region.

Appendix 3c:: Historical shipwreck data (NSW Heritage shipwreck database), Wollongong study region.

Appendix 4: Consultation between Worley Parsons Pty Ltd and Newcastle, Sydney and Port Kembla Port Authorities.

Appendix 1 Coastal and Oceanographic Processes. Report by Worley Parsons (formerly Patterson Britton & Partners) Pty Ltd

Coastal and Oceanographic Processes

1.1 Wave Climate

1.1.1 Measurements in Study Area

The wave climate of the study area can be considered to be similar throughout, and reasonably well defined.

Manly Hydraulics Laboratory (MHL), part of the NSW Department of Commerce, operates a network of Waverider buoys in deep water along the NSW coast. Waverider buoys are spherical floating accelerometers which determine sea level surface displacement based on the double integration of measured vertical accelerations. Analysis of the collected data allows (amongst other things) the significant wave height (H_s) and peak spectral wave period (T_p) to be determined[1]. For the NSW network, records are collected for 2048s bursts (about 34 minutes) every hour at 0.5s intervals (Lord and Kulmar, 2001).

Waverider buoys can be non-directional or directional. Directional buoys allow the predominant wave direction to be determined.

In the study area, Waverider buoys are located in about 80m depth of water offshore of Curl Curl in Sydney (directional), and offshore of Port Kembla (non-directional). These buoys have been operating since 1987 (directional since 1992) and 1974 respectively. Sydney Ports also operates a non-directional Waverider buoy offshore of Botany Bay, which has been collecting data since 1971.

Based on all data collected at the Sydney and Port Kembla buoys to the end of 2004, it is evident that the average H_s offshore of the study area is about1.6m. Storm conditions with H_s exceeding 4.5m have occurred for less than 1% of the time. Also, the average T_p is about 9.7s, with about 60% of T_p values between 8s and 12s, and about 90% of T_p values between 6s and 14s (Kulmar et al, 2005).

Kulmar *et al* (2005) predicted that the 100 year average recurrence interval (ARI) H_s exceeded for a duration of 1 hour and 6 hours offshore of Sydney was 9.5m and 8.5m respectively. These values are applicable to the entire study area.

The predominant wave direction offshore of the study area is from the SSE. Based on all data collected at the directional Sydney Waverider buoy to the end of 2004, Kulmar *et al* (2005) found that about 31% of waves were from the SSE, 19% from the S, and 16% from the SE. Furthermore, the SSE direction is dominant for larger waves.

[1] The significant wave height is the average height of the highest one-third of the waves in a particular record. The peak spectral wave period is determined by the inverse of the frequency at which the wave energy spectrum reaches its maximum.

1.1.2 Wave Transformation

As waves approach the shore from deep water, they may be transformed by the processes of refraction, shoaling, diffraction, attenuation, reflection and breaking. At the proposed water depths for placement of the artificial reefs of 25 to 40m, the dominant wave transformation processes would be refraction and shoaling (except where islands or other obstructions affect the wave climate and cause sheltering, diffraction and/or reflections).

For example, under shoaling only (assuming a wave period of 10s and linear wave theory), a 9.5m height wave in 80m water depth has a height of 9.0m and 8.7m in 40m and 25m water depth respectively. For a 15 second wave period, a 9.5m height wave in 80m water depth has a height of 9.4m and 9.9m in 40m and 25m water depth respectively. During design for the proposed artificial reef, it would be necessary to consider the wave conditions at the particular site of interest.

It would also be necessary to assess the potential for the artificial reefs themselves to alter wave patterns (in particular refraction) and therefore affect nearshore coastal processes. Any potential effects would be minimised by placement of the units in deeper water, and would only be significant in areas offshore of sandy beaches with development at threat due to coastline hazards.

It can be noted that Geomarine (1993), in assessing the effects of offshore dredging in Sydney on nearshore wave climates, developed depth limit criteria such that there would be no measurable impact on shorelines. They found that a 25m and 35m depth limit offshore of rocky and sandy areas respectively was acceptable, for a 5m extraction depth. Although the proposed artificial reef is a different concept (a skeletal steel structure approximately 10m high on the seabed, rather than a dredged hole), this gives some indication that at the shallower proposed depths around 25m there may be some influence on nearshore wave climate. Site specific detailed numerical modelling would be required to quantity any potential effects.

1.1.3 Wave Driven Currents and Forces

Waves also generate orbital velocities and accelerations in the water column below. At a particular location, the maximum horizontal velocity in the direction of wave propagation occurs at the wave crest, while the maximum horizontal velocity in the opposite direction to wave propagation occurs at the wave trough. In between, velocities vary through all directions between vertical and horizontal.

Knowledge of velocities and accelerations allows the calculation of hydrodynamic wave forces (drag and inertial forces), which would be determined as part of the detailed design of the proposed artificial reef[2]. This would be necessary to ensure that the proposed design would be stable under storm wave conditions. Completion of this assessment would require, among other things, knowledge of the member dimensions of the artificial reef. As part of this, all structural members and appurtenances[3] would have to be increased in cross-sectional area to account for the thickness of marine growth.

[2] Additional pressures caused by oceanographic currents (Section 0) would also need to be considered in the estimation of the wave forces as part of the structural analysis.

[3] Such appurtenances include sacrificial anodes to reduce the rate of corrosion of the steel members in the skeletal structure.

WorleyParsons has an Advanced Analysis Group that has experience in determining wave forces on underwater offshore structures. Knowledge of the wave climates and oceanographic conditions at the locations where the proposed artificial reef units have been previously deployed would also be useful in approximately predicting stability.

That stated, it can be generalised that for the 100 year ARI wave climate in the study area, maximum horizontal velocities at the structure would be in the order of about 1.8 to 2.6m/s (at the proposed depth ranges of 25 to 40m, assuming a 10m structure height and linear wave theory[4], the smaller velocities applying at larger depths). Given that the drag force on a member caused by waves is proportional to the velocity squared, it is evident that the maximum such force on the artificial reef would double moving from 40m to 25m depth. Therefore, generally speaking (for the same foundation conditions), larger depths would be favoured for stability as dynamic pressures under waves would be lower.

Note that although velocities would be smaller at larger depths, overall pressures generally increase with depth due to the effect of hydrostatic pressure. That stated, hydrostatic pressure is not an issue with regard to stability of the overall structure, as it is equal in all directions at a given depth. However, stresses in individual members would be affected by hydrostatic pressures (differential pressures) if the members were not filled with water of the same density as the ambient ocean[5].

1.2 Water Levels

The main factor that contributes to still water level movement offshore of NSW (offshore of the wave breaking zone, as per the study area) is astronomical tide. Barometric pressure changes also affect oceanic water levels amongst other oceanographic effects.

Astronomical tide is the regular rise and fall of sea level in response to the gravitational attraction of the sun, moon and planets, and the rotational effect due to the spin of the earth on its axis. Tides along the NSW coastline are semi-diurnal, with high and low water approximately equally spaced in time and occurring twice daily (that is, on average, there are two high tides and two low tides in any 24 hour period). There is also significant diurnal inequality in NSW coast tides, a difference in height of the two high waters or the two low waters of each tidal day.

Astronomical tide typically varies between about –1m AHD (Lowest Astronomical Tide) and 1m AHD (Highest Astronomical Tide) along the NSW coast, with 0m AHD close to mean sea level[6]. On the NSW coast, these and other tidal planes vary approximately as shown in **Table 1**[7].

[4] Consideration should be given to using higher order wave theories so as to define wave loading for detailed design.
[5] It would be expected that as part of the deployment, structural members would be filled with water as the structure is lowered to the seabed.
[6] AHD stands for Australian Height Datum.
[7] Spring tides occur twice per month (during new or full moons) and result in higher high tides and lower low tides (that is, a larger tidal range, compared to the average). Neap tides also occur twice per month (during quarter moons) and result in lower high tides and higher low tides (that is, a smaller tidal range, compared to the average). The height of the spring tide also varies throughout the year and due to the lunar Metonic cycle, the 18.6 period over which the moon returns to the same position relative to the earth (MHL, 1992).

Table 1: Approximate tidal planes in NSW

Tidal Plane	Water Level (m AHD)
Lowest Astronomical Tide	-1.0
Mean Low Water Springs	-0.6
Mean Low Water	-0.5
Mean Low Water Neaps	-0.4
Mean Sea Level	0.0
Mean High Water Neaps	0.4
Mean High Water	0.5
Mean High Water Springs	0.6
Highest Astronomical Tide	1.0

Barometric pressure changes cause localised vertical rises and falls in the still water level due to a reduction and increase respectively in atmospheric pressure. The variation in water level is approximately 0.1m for each 10 hectopascal difference to normal barometric pressure of 1013 hPa (MHL, 1992). Note that hectopascals are approximately equivalent to millibars.

The main significance of water level variation to the proposed artificial reef installation is to ensure adequate clearance above the structure for navigation. With some commercial vessels having drafts up to about 17.5m, a 10m height structure in 25m mean water depth may become an obstruction, particularly at low tides. Depending on the depth of embedment of the structure in the seabed, it would be necessary to ensure that the structure is placed at bed elevations below about -29m AHD (in recognised commercial shipping routes), to avoid navigation issues.

1.3 Coastal Storms

The NSW coastline is subject to intense tropical and non-tropical storms at irregular intervals. The Public Works Department [PWD] (1985, 1986) has categorised coastal storms in NSW on the basis of estimated offshore significant wave heights. Category X storms were defined as those with an estimated $H_s \geq$ 6m, and Category A storms were as defined as those with 5m $\leq H_s <$ 6m.

When combined with available Waverider buoy data, it is evident that over the 1880 to 2003 period there was 1 Category X event every 2.3 years (on average). However, the time period between storms has not been uniform. For example, there were no Category X storms from 1880-1891, 1900-1907, 1946-1951, 1960-1965, 1969-1973 and 1979-1985. Also, there were 3 Category X storms in both 1978 and 1990.

PWD (1985, 1986) recognised 6 different major storm types which impacted on the NSW coast, namely, tropical cyclones, easterly trough lows, inland trough lows, continental lows, southern secondary lows, and anticyclonic intensification. PWD (1985, 1986) found that, on average:

- the Central Coast (incorporating the study area) and South Coast had more storms than areas further north in NSW;
- southern secondary lows and easterly trough lows were the dominant storm types in the study area; and,

- most storms in the study area occurred in Autumn and Winter, in particular due to the prevalence of southern secondary lows and easterly trough lows during these seasons.

This seasonal variation can be confirmed by analysis of the Sydney directional Waverider buoy data collected from 1992 to 2003, derived from MHL (2004). The relative wave energy[8] for storms with an H_s exceeding 3m for each month is shown in **Figure 1**.

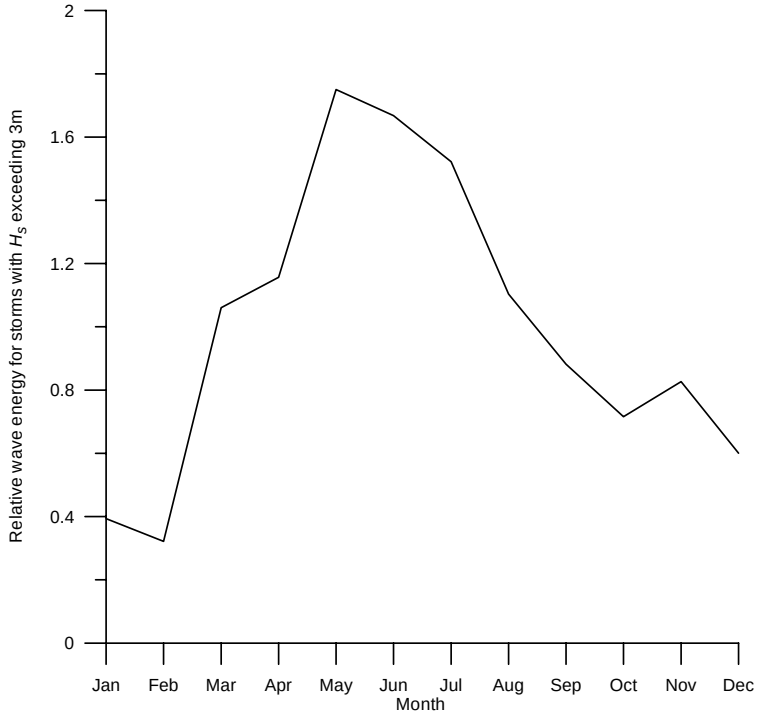

Figure 1: Relative monthly wave energy for storms offshore of Sydney, based on data collected from 1992 to 2003

It is evident that the Autumn and Winter seasons have been the most stormy, with May, June and July having been the most stormy months. The Winter period has been more than three times more stormy than Summer, with January and February being the least stormy months.

Knowledge of these seasonal variations may assist in planning the deployment of the artificial reef units. For example, it would be most likely that wave conditions would be calmer from October to February, which would be favourable for deployment. However, coastal storms can occur at any time, and whatever period is chosen for deployment it would be necessary to refer to Bureau of Meteorology coastal waters forecasts and the like to ensure that conditions would be acceptable.

Structural analysis of the deployment process would be essential to ensure that structural integrity would not be compromised during the installation of the proposed artificial reef.

[8] A relative wave energy was defined relative to a value of 1.0 for an average month. Therefore, values exceeding 1.0 indicate months with greater wave energy than the monthly average. Conversely, values less than 1.0 indicate months with less wave energy than the monthly average.

1.4 Oceanographic Effects

1.4.1 Preamble

The main processes causing coastal circulation in the Sydney region (generally applicable to the entire study area) include the East Australia Current, coastal trapped waves, winds, internal waves, and outflows from major estuaries. These processes are each dynamically distinct and occur on differing time and space scales, such that the net current velocity and direction at a particular location can vary depending on the dominant processes occurring at the time (Middleton et al, 1997).

As further described by Middleton et al (1997), longer period currents are generally directed parallel to the bottom contours, with speeds usually less than 1m/s (although sometimes exceeding 1.5m/s)[9]. These currents generally occur in a depth range of about 20m to 50m. In general, currents would be expected to reduce with depth in the water column, particularly due to the East Australian Current and wind-driven currents being much stronger at the water surface (Geomarine, 1993).

1.4.2 East Australia Current

The East Australia Current(EAC) transports warmer waters from the Coral Sea southwards into the Tasman Sea. Although the EAC is strong and persistent offshore of northern NSW, it sometimes separates from the continental shelf[10] north of the study area, around Seal Rocks (about 90km north of Newcastle)[11]. The EAC can also spawn large warm or cold core eddies that break off from the main EAC and move slowly southward. However, a typical EAC structure cannot be defined.

Roughan and Middleton (2004) noted that although currents upstream of the separation point are generally southward and strong, downstream currents are highly variable in both strength (generally lower speed than upstream) and direction. Encroachment of the EAC upon the coast was seen by Roughan and Middleton (2004) to have a profound effect on the coastal waters, accelerating the southward (alongshore) currents and decreasing the temperature in the bottom boundary layer by up to 5°C.

The EAC is generally strongest in summer, peaking in February, and weakest (by as much as half the flow) in winter (CSIRO Marine Research, 2000).

Australian Hydrographic Service charts (AUS Charts) available for the study area include notes on the EAC. For example, on AUS808 and AUS809 it is noted that the EAC is up to 2.1m/s (applicable to the entire study area).

1.4.3 Wind-Driven Currents

Wind-driven currents also occur. For winds from the NE, surface waters are driven offshore through Ekman transport, which can drive deeper (colder and more nutrient rich) waters upward towards the surface near the coast, with a current in the direction of the wind. Conversely, for winds from the SW, surface waters are driven onshore through Ekman

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[9] Cresswell (1998) noted that the EAC speed was up to 2m/s between 28°S and 33°S (that is all of NSW to just south of Newcastle).

[10] The continental shelf is the relatively gently sloping undersea area surrounding a continent at depths of up to 200m, at the edge of which the continental slope drops steeply to the ocean floor . The continental shelf of NSW is narrow, with an average width of about 25 km, and at midshelf it is 60 to 80 m deep (Cresswell, 1998).

[11] The separation point is variable. For example, Godfrey et al (1980) stated that the separation point was generally between 30°S and 34°S, which covers a distance of about 430km. However, most authors note that the usual separation point is around Seal Rocks to Port Stephens.

transport, which can drive warmer waters towards the coast and downward, again with a current in the direction of the wind (Middleton et al, 1997).

1.4.4 Coastal Trapped Waves

Coastal-trapped waves are current oscillations which move northward from Bass Strait over time scales of 7 to 20 days, affecting the study area about two days after being generated by strong winds in Bass Strait. They can cause either northward or southward flowing currents in the nearshore region (Middleton et al, 1997).

1.4.5 Internal Waves

Internal waves are disturbances which propagate along the interface between layers of water with different densities. In the study area, internal waves occur during most of the year when there is significant temperature stratification. They are manifested as periodic oscillations in currents and temperature, which are due to the orbital motions associated with waves.

Internal wave energy is concentrated in two bands, namely tidal frequencies and at a period of 10 to 30 minutes. The former, known as internal tides, cause currents of about 0.1m/s and displacements of the thermocline of up to 20 to 30m, with the latter generally having a smaller effect (Middleton et al, 1997).

1.4.6 Estuarine Influences

Major estuaries in the study area include Port Stephens (126km^2), Hunter River (30km^2), Lake Macquarie (115km^2), Tuggerah Lakes (70km^2), Broken Bay (145km^2), Port Jackson (50km^2), Botany Bay (62km^2) and Port Hacking (11km^2), refer to Roy et al (2001). Tidal outflows from these estuaries may have significant effects on current patterns, temperature and salinity extending several kilometres from the coastline.

1.4.7 Further Information

If required, details on currents at particular potential artificial reef deployment locations may be enhanced through discussions with fishermen and other marine operators in the area, installation of instrumentation, and reference to Australian Pilot publications and the like.

Also, numerous studies completed by Patterson Britton & Partners as part of investigations of the disposal of dredged spoil at Newcastle and Port Kembla provide some details on currents in these areas (as well as details on seabed conditions, sediment movement etc in these areas). For example, refer to Patterson Britton & Partners (1989, 1992, 2005).

1.5 Sediment Transport

The majority of sediment transport along the NSW coast occurs between where waves break and the shoreline, that is inshore from the depth limits under consideration in the investigation reported herein.

Onshore/offshore (also known as cross-shore) sand movement is caused by natural variations in wave climate and water level. The offshore movement of sand is usually referred to as storm erosion. This onshore/offshore movement of sand results in short term fluctuations in the width of the beach profile.

During storms with relatively large waves, beach sand moves offshore to form bars. This process typically occurs over a period of hours to days. When extended periods of calmer

waves occur, the material held in these bars migrates onshore to re-build the beach. Depending on the magnitude of the preceding storm, this beach building process can occur over a time scale of days to years.

Nielsen (1994a) found that, based on a synthesis of field and laboratory data and analytical studies (particularly offshore of SE Australia), there were consistent limits of subaqueous beach fluctuations, namely water depths (relative to AHD) of:

- 12m ± 4m being the limit of significant wave breaking and beach fluctuations (the position of the offshore face of surf zone bars);
- 22m ± 4m being the absolute limit of sand transport under extreme storm events; and,
- 30m ± 5m being the potential limit of reworking and onshore transport of beach sized sand under wave action alone (that is, the seaward limit of the foundation toe of the beach).

Nielsen (1994a) found that maximum seabed level variations were less than 0.2m at depths exceeding 15m.

Sedimentological data consistently shows distinct changes in the characteristics of sediments with water depth offshore of NSW. These changes include variations in grain size, sorting, carbonate content and colour. There are two distinctive sediment units immediately offshore of NSW, namely Nearshore Sand, and (further offshore and coarser) Inner Shelf Sand (also known as Shelf Plain Relict or Palimpsest Sand). Nearshore Sand is further subdivided into Inner and Outer Nearshore Sand units.

The boundary between Inner and Outer Nearshore Sand is typically found at about 11m to 15m depth (relative to AHD), while the boundary to Inner Shelf Sand is usually at 18m to 26m depth (consistent with the 22m ± 4m limit noted above). The boundary between Nearshore Sands and Inner Shelf Sands corresponds to those parts of the seabed considered to be active and relict. That is, there is no exchange of beach sediments with those of the Inner Shelf at depths exceeding at 22m ± 4m (Nielsen, 1994a).

Nielsen (1994b) has described the mechanism and depth limits for sediment transport in the study area under the action of waves and currents. Essentially, the back and forth motion of waves can place sediment into suspension, with net transport occurring in the presence of a superimposed steady current[12].

The sediment in and around the study area in depths between about 25m and 75m is generally quartzose marine sand, medium to fine grained, moderately sorted, with variable shell content and up to about 20% mud content (Nielsen, 1994b). Rock reefs are evident on the seabed between these sand bodies, for example offshore of north of Wamberal, Bouddi Point, Avalon Beach, Bungan Head, Turimetta Head, Long Reef, North Head, between Malabar and Botany Bay, and between Botany Bay and Bate Bay (as evident on Public Works Department Seabed Information Charts).

Sand waves evident in the study area between 25m and 75m depth are consistent with a general current structure flowing to the south. Wave-generated ripples are found on the seabed to depths of about 60m, causing reworking of the seabed surface to depths of about 0.2m on a daily basis at 25m depth, and for about 25% of the time at 60m depth (Nielsen, 1994b).

[12] At times, currents alone can be strong enough to transport sand.

However, Nielsen (1994b) found that there was negligible net sediment transport beyond 35m depth.

In summary, at the depth limits of 25m to 40m for the proposed artificial reefs, there is unlikely to be sediment movement such that there is significant burial or regional scour of the structures, or capture of sediment that would be worked on to beaches. To be conservative, some may argue that a minimum structure depth of 30m to 35m should be applied to ensure no possible interaction with nearshore sediment processes[13].

However, allowance for additional localised seabed scour due to currents and waves interacting with the artificial reef structure would need to be made as part of stability calculations in detailed design.

1.6 Synthesis

Based on a consideration of the coastal and oceanographic processes occurring in the study area, it is evident that a deeper installation of the proposed artificial reef within the 25m to 40m depth limits would generally be favoured. This is because, at deeper depths:

- the artificial reef would be less likely to affect wave refraction patterns and the like;
- wave-driven currents are smaller and therefore so are dynamic forces on the structure;
- navigation is less likely to be restricted;
- oceanographic currents are likely to be smaller; and,
- sediment transport is likely to be negligible.

That stated, detailed analysis and modelling may find that reefs placed at 25m depth are stable under extreme waves and currents, and do not significantly affect the nearshore wave climate.

[13] This issue would need to be addressed in a site specific and detailed manner when the possible locations for the artificial reefs are better defined.

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Appendix 2. General information on commercial fisheries operating in the Newcastle, Sydney and Wollongong study areas, including geographical extent of relevant fisheries, economic value and target species

Commercial fisheries potentially affected by the proposal are those that can operate in State waters. These include those under the jurisdiction of the State of NSW and those also under the jurisdiction of the Commonwealth of Australia that may operate within the 3 nm limit under a Section 37 permit of the *FM Act*.
Commercial fisheries under the jurisdiction of the State of NSW with potential to be affected by the project would be the Ocean Trap and Line Fishery, the Abalone Fishery, the Lobster Fishery, the Sea Urchin and Turban Shell Fishery, the Ocean Hauling Fishery and the Ocean Prawn Trawl Fishery.

The Ocean Trap and Line Fishery
The Ocean Trap and Line Fishery is a multi-method, multi-species fishery targeting demersal and pelagic fishes along the NSW coast. Snapper (*Pagrus auratus*), spanner crabs (*Ranina ranina*), yellowtail kingfish (*Seriola lalandii*), leatherjackets (Monacanthidae), bonito (*Sarda australis*) and silver trevally (*Pseudocaranx dentex*) form the bulk of the commercial catch. Other key species include rubberlip morwong (*Nemadactylus Douglasi*), blue-eye (*Hyperoglyphe antarctica*), gummy shark (*Mustelus antarcticus*), bar cod (*Epinephalus septemfasciatus*) and yellowfin bream (*Acanthopagrus australis*). In 2000/01 an estimated 1,742 t of fish were caught in the whole fishery with an estimated value of $10 million at first point of sale (Web Ref 7). The fishery uses a variety of methods, most commonly involving a line with hooks, or traps. Demersal fish trapping and line-fishing (for snapper, rubber-lipped morwong and leatherjackets) occurs in the Narrabeen area.

The Lobster, Abalone and Sea Urchin and Turban Shell Fisheries
The Lobster Fishery is a small but valuable fishery with a state-wide value of approximately $4.6 million (Web Ref 8). Eastern rock lobster (*Jasus verreauxi*) is the main species harvested with southern rock lobster (*Jasus novaehollandiae*) and tropical rock lobster (*Panulirus* spp.) forming a minor component. The fishery has an inshore sector that uses small beehive or square traps in waters up to 10 m deep. Offshore grounds are beyond the state limit.

The Abalone Fishery is one of the most valuable fisheries in NSW with a total catch of 130 tonnes of blacklip abalone (*Haliotis rubra*), worth more than $5 million at first point of sale, harvested annually (Internet Reference 23). In practice, most commercial abalone fishing takes place on the south coast of NSW, primarily from Jervis Bay to the Victorian border, with most abalone found close to the shore. The Sea Urchin and Turban Shell Fishery is a small fishery where divers collect two species of sea urchin and two species of turban shell.

The Ocean Hauling Fishery
The Ocean Hauling Fishery targets approximately 20 finfish species using commercial hauling and purse seine nets from sea beaches and in ocean waters within 3 nautical miles of the NSW coast. On average 3,500 t of fish is taken by the whole fishery each year; mainly sea mullet (*Mugil cephalus*), luderick (*Girella tricuspidate*), yellowtail scad (*Trachurus novaezelandiae*), blue mackerel (*Scomber australasicus*), pilchards (*Sardinops neopilchardus*) and sea garfish (*Hyporhamphus melanochir*). The total catch is worth around $6 million at first point of sale (Web ref 10). Purse seining for garfish, yellowtail scad and blue mackerel may occur occasionally within the vicinity of the proposed route.

Appendix 2 Continued.

The Ocean Prawn Trawl Fishery
The Ocean Prawn Trawl Fishery is the most valuable fishery in NSW and is worth around $32 million at first point of sale each year (Web ref 11). In 2000/01 the total catch for the fishery was 3,411 tonnes with 1,739 tonnes of that being prawn catch only.
Prawn trawlers use trawl nets to target prawns on soft sediments. Incidental catches of other species of fish may also be landed. A total of 312 fishing businesses hold endorsements to operate in one or more sectors of the Ocean Prawn Trawl Fishery in NSW. Of these, 267 are endorsed to trawl for prawns in the inshore sector of the fishery (from the coast to three nautical miles to sea), where the main species harvested are school prawns, school whiting and eastern king prawns.

The Ocean Fish Trawl Fishery
The Ocean Fish Trawl Fishery uses the demersal otter trawl to target a large number of species, such as silver trevally, tiger flathead (*Platycephalus richardsoni*), redfish (*Centroberyx gerrardi*), john dory (*Zeus faber*) and numerous species of sharks and rays. Total catches reported by fish trawl operators from NSW managed waters in 2000/01 were 1,171 tonnes, valued at $4 million at first point of sale (Web ref 12).
A total of 99 fishing businesses hold endorsements to operate in the Ocean Fish Trawl Fishery. Of these, 47 are endorsed to operate in the southern sector of the fishery, south of Barrenjoey Point, near Sydney in State waters.
Commercial fisheries under the jurisdiction of the Commonwealth of Australia with potential to be affected by the project would be the Eastern Tuna and Billfish Fishery, Southern and Eastern Scalefish and Shark Fishery, Jack Mackeral (Small Pelagics) Fishery, Southern Squid Jig Fishery, Eastern Skipjack Tuna Fishery and the Southern Bluefin Tuna Fishery.
Although these fisheries operate mostly outside of state waters, some operators in the Commonwealth tuna fisheries may catch bait (yellowtail, slimy mackerel and pilchards) within 3 nm of the coast under a permit issued in terms of Section 37 of the NSW *FM Act*. This occurs along the proposed route only very occasionally

Appendix 3a. Shipwreck search results for the Newcastle study region. Source: All data was sourced from the NSW Maritime Heritage Shipwrecks database apart from those records denoted by (**) indicating data was obtained from the Department of Urban Affairs and Planning Shipwreck Atlas of NSW.

Vessel name	Type	Date wrecked	Where wrecked	Comments	Lat max	Long max	Lat min	Long min
Admiral Gifford	Schooner	1834/10/08	Port Macquarie to Sydney		-33.833333	153.000000	-31.500000	151.333333
Australia	Brig	1826/04/13	Newcastle 12 mls north		-32.834333	152.083333	-32.783833	151.868167
Blue Gum	Unknown		Swansea channel		-33.100000	151.666667	-33.067000	151.633333
Boyd	Schooner	1812/07/16	Newcastle, Stockton Beach		-32.917000	152.201000	-32.750000	151.780000
Byron**								
Charlotte	Sloop	1827/09/19?	Newcastle, ashore.		-32.916667	151.883333	-32.834333	151.783333
Comet	Sloop	1823/09/6+	Unknown		-33.833667	151.800333	-32.916667	151.283333
Contest	Sloop	1807/02/28	Port Stephens, sth end of north beach		-32.784833	152.250167	-32.650000	151.967667
Davenport	Steamer screw	4/10/1943	Newcastle, Oyster Bank 300ft off 'Adolphe'		32.906667	151.796667	x	x
Dundee	Ship	1808/08/15	Newcastle, Oyster Bank		-32.917667	151.800000	-32.883333	151.766667
Eliza		1811/06/?	Port Stephens		-33.550000	152.250167	-32.650000	151.334333
Elizabeth	Brig	1829-1830	Sydney to Newcastle, between		-33.833333	151.800000	-32.916667	151.266667

Continued

Appendix 3a. Continued

Vessel name	Type	Date wrecked	Where wrecked	Comments	Max Lat	Max long	Min lat	Min Long
Ena	Schooner		Newcastle, North Stockton		-32.916667	152.85	-32.783667	151.783333
Estramina	Schooner	1816/01/19	Newcastle, Oyster Bank		-32.916667	151.833333	-32.900833	151.833333
Fitzroy **				18 m of water				
Francis	Schooner	1805/03/21+	Newcastle, nth of 1805 entrance		-32.917667	151.8	-32.883333	151.766667
Governor Arthur	Cutter	1829/04/24?	Newcastle, Nobbys reef		-32.933333	151.800667	-32.916667	151.784
Governor King	Schooner	1806/04/22	Newcastle near wreck of Francis, 1805		-32.917667	151.8	-32.883333	151.766667
Kate Tatham	Schooner	4/11/1907	Newcastle, North Stockton, on River Bank		-32.90666	151.78166	x	x
Kuring Gai	Steamer screw	1930	Hunter River, Hexham		-32.83	151.69	x	x
Mars	Sloop	1826/04/12	Newcastle, 5mls north of harbour		-32.85	152.067667	-32.783333	151.85
Nautilus	Brig	1816/11/24	Newcastle, Oyster Bank, (Point Ross, off)		-33.017	151.868167	-32.800333	151.701
Nereid	Cutter	1825/06/19	Newcastle, 100mls north		-32.85	152.067667	-32.783333	151.833333
Newcastle	Schooner	1826/08/?	Sydney Heads to Hunter River, between		-33.833333	151.866667	-32.917	151.266667

Continued

Appendix 3a Continued.

Vessel name	Type	Date wrecked	Where wrecked	Comments	Lat max	Long max	Lat min	Long min
Norfolk	Sloop	1800/10/?	Newcastle, Pirate Point		-32.917	151.784	x	x
Osprey** Paterson	Steamer screw	11/06/1951	Norah Head, nth of Cabbage Tree Bay		-32.91	151.795	x	x
Recovery	Sloop	1816/06/?	Port Stephens		-32.784667	152.283667	-32.584667	152
Resource	Schooner	1814/09/?	Newcastle		-33.8335	151.866667	-32.917	151.266667
Sophia	Schooner	1826/07/26	Newcastle, high on shore near Oyster Bank		-32.916667	152.067667	-32.783667	151.783333
Surprise	Sloop	1805/04/?	Newcastle, 2mls north of harbour entrance		-32.917667	151.883333	-32.8	151.766667
Sygna	Motor Vessel	27/05/1974	Newcastle, Stockton Beach		-32.86	151.843333		
Trimmer	Sloop	1805/07/?	Newcastle		-33.017	151.883333	-32.8	151.701
Tua Wha (See Yua Wha)	Motor Vessel	5/01/1947	Newcastle, Stockton Bight, 8km east		-32.883333	151.898333	x	x
Unidentified	Unknown	1801	Port Stephens, north		-32.784833	151.933333	x	x
Yarra Yarra	Steamer paddle	1877/07/15	Newcastle off Stockton Bight		-32.905	151.8	x	x

Appendix 3b. Shipwreck search results for the Sydney study region. Source: All data was sourced from the NSW Maritime Heritage Shipwrecks database apart from those records denoted by (**) indicating data was obtained from the Department of Urban Affairs and Planning Shipwreck Atlas of NSW.

Vessel name	Type	Date Wrecked	Where wrecked	Comments	Max lat	Max long	Min lat	Min long
Aenid	Cutter	1865/11/12	Sydney, Long Reef	Crew included Lt Mead, Lt Hunt, Mr	33.7575	151.333333	33.724167	151.308333
Altair	Ketch	1942	Sydney, Long Reef		33.7575	151.333	33.724167	151.308333
Annie M. Miller**								
Anzac Ex-H.M.A.S.	Steamer screw	1936/05/07	Sydney, Disposal Area	Destroyer.	34.016667	151.6195	33.983333	151.586167
Arawatta	Hulk	1936/09/14	Sydney, Disposal Area		34.016667	151.6195	33.983333	151.586167
Archer	Hulk	1946/01/10	Sydney, Disposal Area	Hulked 1935 and engines believed to have been removed.	33.883333	151.666667	33.85	151.633333
Bantam	Steamer screw	1946/09/24	Sydney, Disposal Area	Badly damaged from bomb attack at Oro Bay, New Guinea in 1943 and then towed to Sydney.	34.133333	151.268333	34.1	151.235
Belbowrie	Steamer screw	1939/01/16	Sydney, Maroubra, Mistral Point	This vessel was a twin screw steamer (tss).	33.7575	151.33333	33.724167	151.308333
Bellubera	Other	1980/08/01	Sydney, Long Reef	Double ended ferry.	33.959667	151.268	33.957	151.263833
Birchgrove Park	Steamer screw	1956/08/02	Broken Bay, 7km sth, off Avalon		33.638433	151.378367	x	x
caisson		1980	Sydney, Long Reef		33.723333	151.3555	33.706333	151.338833
Camro	Ketch	1939/03/22	Sydney, Disposal Area	Had been owned by Cam & Sons, ex Trawler.	34.025	151.575	33.991667	151.541667
Captain Phillip	Steamer screw	1947/10/03	Sydney, Disposal Area	Originally the pilot vessel 'Captain Cook'.	34.016667	151.6195	33.983333	151.586167
Cavan	Barquentine	1932	Sydney, disposal area	ex 4 Mast Schooner.	34.333333	151.666667	33.833333	151.333333
Centurion	Barque	1887/01/16	Sydney Harbour, North Head, Cannae Point	The site lies in 18-19 metres of water.	33.8176	151.2811	x	x

Continued

Appendix 3b. Continued

Christina Gollan	Steamer screw	1920	Sydney, Long Reef, 4 miles off shore		33.790833	151.420833	33.690833	151.320833
Coolooli	Dredge	1980/08/29	Sydney, off Collaroy near the Dee Why		33.723333	151.3475	33.715	151.339167
Currajong	Steamer screw	1910/03/08	Sydney Harbour, Bradley's Head	Launched as the 'Clarence'; renamed June 1883.	33.856667	151.248333	x	x
Currajong	Hulk	1946/07/24	Sydney, Disposal Area	Originally named 'Argo'.	33.85	151.006833	x	x
Dee Why	Steamer screw	1976/05/25	Sydney, dumping ground off Collaroy Beach	Double ended ferry.	33.716667	151.343333	33.700833	151.334167
Duckenfield	Steamer screw	1889/05/24	Sydney, north of Long Reef	The site lies in about 23 metres of water.	33.71827	151.32377	x	x
Dunbar	Ship	1857/08/20	Sydney, South Head, north of Signal Station	Dunbar Head gained its name from this wreck event.	33.850133	151.285783	x	x
Edward Lombe	Barquentine	1834/08/25	Sydney Harbour, Middle Head	Bateson -Australian Shipwrecks.	33.82908	151.26983	x	x
Egeria	Steamer screw	1945/11/26	Sydney, Disposal Area	Tug boat.	33.525	151.383333	33.491667	151.35
Emmanuel	Ketch	1890/08/07	Sydney, Botany Bay		34.083333	151.3	33.983333	151.2
Encounter Ex-H.M.A.S.	Steamer screw	1932/09/14	Sydney, Disposal Area	Light cruiser.	33.934167	151.604167	33.925833	151.595833
Fame	Barquentine	1857/08/02	Sydney Harbour, Sow & Pigs Shoal	A gale forced Fame into Port Jackson.	33.837833	151.268833	33.837833	151.268833
Ferry Pontoon		1980	Sydney, Long Reef	No information located to date.	33.725	151.3555	33.708333	151.338833
Flora Bella	Brigantine	1857/01/20	Sydney, Bondi, near Ben Buckley		33.898667	151.290333	33.8875	151.2805
Gabo	Hulk	1933/11/30	Sydney, Disposal Area	1917-1921 owned by China Australia Mail SS Line.	34.333333	151.666667	33.83333	151.333333

Continued

Appendix 3b. Continued

Gannet	Steamer paddle	1946/01/24	Sydney, Disposal Area	Hulked in 1941.	34.333333	151.666667	33.833333	151.333333
Geebung	Steamer screw	1947/08/06	Sydney, Disposal Area		34.016667	151.6195	33.983333	33.983333
Geranium ex-H.M.A.S.	Sloop	1935/04/16	Sydney, Disposal Area	Some naval documentation - 'The Mid War Period - Sloops'.	34.333333	151.666667	33.833333	151.333333
Goolgwai	Steamer screw	1955/05/29	Sydney, Long Bay, Malabar, north side	Formerly 'Almeria'.	33.972167	151.2695	33.966667	151.261167
Governor Blackall	Hulk	1931/07/01	Sydney, Disposal Area	Hulked 1910.	34.333333	151.666667	33.833333	151.333333
Greyhound	Steamer screw	1894/05/04	Sydney, Long Reef		33.790833	151.420833	33.690833	151.320833
Hereward	Ship	1898/05/06	Sydney, Maroubra Beach, Lurline Bay	Lost in the 'Maitland Gale'.	33.95	151.259667	33.947167	151.2625
Hilda	Steamer screw	1893/06/20	Port Hacking, north head, near shore	Register says lost 20 July but Marine Enquiry says June.	34.0395	151.224633	x	x
Himma	Steamer screw	1977/08/30	Sydney. Fish Reef, Dee Why	Tug boat.	33.719167	151.3475	33.7175	151.345833
Hope	Sloop	1803/10/31	Sydney Harbour, North Head		33.866667	151.351	33.8	151.266667
Hopper barge		1980	Sydney, Long Reef		33.725	151.3555	33.708333	151.338833
Hopper barge 400 Tons	Barge	1934/04	Sydney, Disposal Area		34.333333	151.666667	33.833333	151.333333
Hopper barge 50 Tons	Barge	1934/04	Sydney, Disposal Area		34.333333	151.666667	33.833333	151.333333
Hopper barge 500 Tons	Barge	1934/04	Sydney, Disposal Area		34.333333	151.666667	33.833333	151.333333
Hopper barge No. 15	Barge	1948/04	Sydney, Disposal Area	Side delivery hopper barge.	34.016667	151.583333	33.983333	151.55
Hopper barge No. 16	Barge	1948/04	Sydney, Disposal Area	Side delivery hopper barge.	34.016667	151.583333	33.983333	151.55
Hopper barge no. 969	Barge	1947/08	Sydney, Disposal Area		34.333333	151.666667	33.833333	151.333333

Continued

Appendix 3b. Continued

Hopper Barge 656	Barge	1980/06/10	Sydney, Long Reef	Hopper Barge.	33.722833	151.351667	33.7145	151.343333
Horn	Launch	1948/11/16	Sydney, Long Reef		33.790833	151.420833	33.690833	151.320833
Hornet	Steamer screw	1915/03	Sydney, 4mls south of Sydney Heads		33.908333	151.308333	33.891667	151.291667
Huon H.M.A.S.	Other	1931/04/10	Sydney	Torpedo boat/destroyer.	33.916667	151.616667	33.883333	151.583333
Itata	Barquentine	1906/01/12	Sydney Harbour, Middle Hbr, Salt Pan Ck	Burnt and damaged during a cargo fire at Newcastle.	33.817167	151.223833	x	x
Kelloe	Steamer screw	1902/05/13	Sydney, Botany Bay (Off Little Bay)	Departed from South Bulli Jetty.	33.986617	151.26525	33.985833	151.2645
Kembla	Steamer paddle	1936/01/7	Sydney, Disposal Area	.	34.333333	151.666667	33.833333	151.333333
Kianga	Steamer screw	1948/07/07	Sydney, Disposal Area	First Register 8/1922 - annotated wrecked total loss in June 1931 - register closed.	34.016667	151.6195	33.983333	151.586167
Koputai	Steamer paddle	1920/03/05	Sydney, 5 mls SE South Head	Described as a powerful tugboat that had previously operated in New Zealand until 1917.	30.914167	151.3475	33.9125	151.345833
Kurnell	Steamer screw	1946/06	Sydney, Disposal Area	Double ended ferry.	34.333333	151.666667	33.833333	151.333333
Magnet	Ketch	1874	Sydney, Botany Bay, off		34.083333	151.3	33.983333	151.2
Malabar	Motor Vessel	1931/04/02	Sydney, Malabar, Long Bay, Miranda Point	The suburb Malabar gained its name from this wreck event.	33.9695	151.259667	33.966667	151.257
Malachite	Hulk	1946/05/28	Sydney, Disposal Area		33.883333	151.666667	33.85	151.633333
Mallow Ex-H.M.A.S.	Steamer	1935/08/3	Sydney, Disposal Area	'Flower' class sloop.	34.038333	151.611667	34.005	151.578333
Marrawah	Hulk	1951/05/10	Sydney	Ex screw steamer.	33.961666	151.579166	x	x
Matagalpa	Motor Vessel	1947/09	Sydney, Disposal Area	Caught fire in Kerosene Bay 13/9/47.	34.333333	151.666667	33.833333	151.333333

Continued

Appendix 3b. Continued

Medusa	Hulk	1948/01/20	Sydney, Disposal Area	Became a RN auxilliary minesweeper in 1939.	34.016667	151.6195	33.983333	151.586167
Meggol	Steamer screw	1976/12/09	Sydney, Fish Reef, Dee Why	Ex 'HMS Wexford', ex 'HMAS Doomba', ex 'Doomba'.	33.727767	151.345833	x	x
Myee	Hulk	1933/08/03	Sydney, Disposal Area	Owned by North Coast Steam Navigation Company prior to sale for demolition.	33.875	151.358333	x	x
Myola	Steamer screw	1919/04/01	Sydney, Long Reef		33.763167	151.362833	x	x
Namoi	Steamer paddle	1933/06/16	Sydney, Disposal Area	Sold to Swadling and sons by Newcastle & Hunter River Steamship Co for dismantling.	34.333333	151.666667	33.833333	151.333333
Our Elsie	Lighter	1932	Sydney, Disposal Area	Damaged by fire Register closed April 1928 - 'permanantly out of commission'.	34.333333	151.666667	33.833333	151.333333
Phyllis	Lighter	1936/09/16	Sydney, Disposal Area		34.016667	151.6195	33.983333	151.586167
Pioneer Ex-H.M.A.S.	Steamer screw	1931/02/18	Sydney, Disposal Area		34.333333	151.666667	33.833333	151.333333
Poseidon	Dredge	1947/05/09	Sydney, Disposal Area	Suction dredge.	34.025	151.616667	33.991667	151.583333
Prima Donna	Schooner	1882/03/29	Sydney, Bondi, 4-5 mls off		33.973667	151.3805	33.891667	151.283333
Prince of Wales	Steamer screw	1886/07/16	Sydney, Botany Bay, 12 mls off		34.116667	151.466667	34.016667	151.366667
Pyrmont II	Barge	1976/07/05	Sydney, Long Reef	Built to dump ash from Pyrmont Power House.	33.685	151.345	33.683333	151.341667
Royal Shepherd	Steamer screw	1890/07/14	Sydney Heads	The site lies in about 27 metres of water.	33.837283	151.286867	x	x
Sally*	Unknown	1826/8?	Hawkesbury and Sydney	No primary source data located.	33.833667	151.400667	33.518	151.283333
Sea Spray	Brig	1878/04	Sydney, ~25 mls sth and ~15 mls off land		34.266667	151.416667	34.1	151.25

Continued

Appendix 3b. Continued

Sir William Broughton	Sloop	1820/07/08	Botany Bay Heads, south	Note: this vessel is referred to as simply 'WIlliam Broughton' in the Sydney Gazette but was registered as 'Sir William Broughton'.	34.117	151.25	34	151.134
Skerryvore	Brig	1860/03/11	Sydney Heads, NE 15-18 mls		33.783333	151.666667	33.616667	151.5
Sophia Maria	Unknown	1803/06/14	Sydney, Collaroy/Dee Why		33.783333	151.317167	33.7	151.284667
St Albans	Steamer screw	1882/05/17	Sydney, Malabar, Long Bay, on North Head		33.973667	151.2695	33.977667	151.263833
Stalwart H.M.A.S.	Steamer screw	1939/07/21	Sydney, Disposal Area	Destroyer.	34.016667	151.6195	33.983333	151.586167
Standard	Launch	1931/03/24	Sydney, Long Reef		33.75	151.335833	151.335833	151.324167
Success H.M.A.S.	Steamer screw	1941/12/20	Sydney, Disposal Area	tss destroyer.	34.333333	151.666667	33.833333	151.333333
Susannah Cuthbert	Steamer screw	1875/07/07	Sydney, Long Reef, near, ashore in 7' off Jenkins Point		33.741667	151.308333	33.7445	151.3
Sydney	Barge	1935/03/21	Sydney, Disposal Area	Formerly 'ps City of Brisbane'.	34.333333	151.666667	33.833333	151.333333
Tasmania H.M.A.S.	Steamer screw	1939/03/16	Sydney, Disposal Area	tss destroyer.	34.145833	151.433333	34.1125	151.416667
Taviuni	Hulk	1931/05/12	Sydney, Disposal Area	Previously owned by Union SS Co of NZ during operational life.	34.333333	151.666667	33.833333	151.333333
Tekapo	Steamer screw	1899/05/16	Sydney, Maroubra Bay, Magic Pt, 1.5m to Herw'd		33.957	151.265333	33.954167	151.2625
Three Sisters	Cutter	1836	Sydney and Hawkesbury River		33.833333	151.416667	33.516667	151.25
Try One	Launch	1947/07/31	Sydney, Malabar Point		33.975	151.275	33.958333	151.258333
Tuggerah**								

Continued

Appendix 3b. Continued

Undola**								
Valiant	Motor Vessel	1981	Broken Bay, Barranjoey	Tug boat.	33.58	151.345	x	x
Vendetta H.M.A.S.	Steamer screw	1948/07/01	Sydney, Disposal Area	V & W class destroyer.	34.016667	151.6195	33.983333	151.586167
Wallsend	Steamer screw	1935/02/15	Sydney, Disposal Area	A '60 miler' - collier on the Newcastle/Sydney run.	34.016667	151.6195	33.983333	151.586167
Whale	Sloop	1816/07/?	Sydney to Hawkesbury River	Both Winney and Cooper were on board.	33.833333	151.417	x	x
Wicklow	Barge	1933/12/14	Sydney, Disposal Area		34.333333	151.666667	33.833333	151.333333
William Cossar	Unknown	1825/02/14?	Sydney Harbour, Sow and Pigs Shoal	Sometimes referred to in the press as 'The Cossar'.	33.834333	151.267333	33.833333	151.251333
Windsor	Sloop	1816/06/?	Sydney, Long Reef	This vessel had picked up survivors of the 'Recovery', wrecked near Port Stephens.	33.734667	151.317333	33.734	151.301
Wodonga	Steamer screw	1931/04/30	Sydney, 9500 yds E of the Sth Hd Signal Stn	Newspaper says sunk 9500 yards east of the South Head Signal Station.	34.333333	151.666667	33.833333	151.333333
Woniora	Steamer screw	1882/10/28	Sydney, Botany Bay, south east of heads		34.02325	151.2588	x	x
Yamba	Steamer screw	1942/04/16	Sydney, Disposal Area	Tug boat.	34.333333	151.666667	33.833333	151.333333
Yarra Ex-H.M.A.S.	Steamer screw	1932/08/22	Sydney, Disposal Area	Torpoedo boat/destroyer.	34.333333	151.666667	33.833333	151.333333
Yuloo	Steamer screw	1932/11/14	Sydney, Disposal Area	Original name - 'Teeswood'.	34.333333	151.666667	33.833333	151.333333

Appendix 3c. Shipwreck search results for the Wollongong study region. Source: All data was sourced from the NSW Maritime Heritage Shipwrecks database apart from those records denoted by (**) indicating data was obtained from the Department of Urban Affairs and Planning Shipwreck Atlas of NSW.

Vessel name	Type	Date wrecked	Where wrecked	Comments	Max lat	Max long	Min lat	Min long
Bombo	Steamer screw	21/02/1945	Wollongong	The site lies in about 32 metres of water.	34.4452777	150.9236111	x	x
Charlotte	Sloop	1808/08/27	Sydney Heads		34.5	150.95	34.434333	150.901333
Franz	Schooner	1879/09/09	Windang, Shellharbour, nth of Lake Illawarra, sth of Five Islands	Involved in carrying road metal from Kiama to Sydney.	34.53334	150.8736	x	x
Munmorah	Steamer screw	17/05/1945	Bellambi Point, Inner Reef	Wreck located 133 degrees and 548m from Bellambi Jetty.	34.373333	150.933333	x	x
Queen of Nations	Barquentine	1881/05/31	Wollongong, at Corrimal Beach, ashore	The site lies in about 5 metres of water.	34.3855	150.916667	x	x

Appendix 4. Results of consultations between Patterson Britton Pty Ltd and Port Authorities in relation to shipping movements and port exclusion zones.

Newcastle Port Corporation
The study area relating to Newcastle Port extends from the northern end of Stockton Bight down to Swansea in the south. Within this area there are two published restrictions, as shown on AUS Chart 207, namely:

1. A 'Restricted Area' seaward of the harbour entry channel representing a fairway for commercial shipping. This area covers almost a quadrant between the north-east bearing of the northern breakwater and a south-east approach to the southern breakwater; and,
2. A circular zone prohibiting anchoring immediately east of Little Redhead Point.

In addition to these restrictions, there are designated spoil grounds immediately adjacent to the southern boundary of the fairway for commercial shipping.

During consultation with Newcastle Port Corporation (Mr Tim Turner - Harbour Master), it was advised that:

- the Port Limit (which does not appear on AUS Chart 207) is a circular line of 3 nautical mile radius from Nobbys Head lighthouse;
- the 'recommended' anchorage for commercial shipping is south of 32°58' latitude (Little Redhead Point) and not closer than 3 nautical miles (ie 5556 metres) to the coastline (which is at a depth of about 40m relative to Chart Datum);
- the Harbour Master has no jurisdiction outside of the Port Limit, therefore it is possible that a vessel could anchor outside of the recommended anchorage.

The Harbour Master advised that no consideration would be given to the placement of artificial reefs within the Port Limit and that any proposed location should be well clear of the 'massive anchorage' for Newcastle Port's heavy shipping.

Notwithstanding the above, the Harbour Master considers Stockton Bight to be a relatively suitable area for the placement of artificial reefs, particularly as it is not considered a safe area for the anchorage of vessels. In addition, an artificial reef would be marked on the chart and therefore provide a suitable warning to any shipping.

The Harbour Master also noted that the circular zone prohibiting anchoring immediately east of Little Redhead Point was understood to be related to a historical wreck

Sydney Ports Corporation
The study area relating to Sydney Ports extends from Barrenjoey Head in the north down to Bundeena in the south. Within this area there are three main published anchorage exclusion zones, as shown on AUS Chart 808, namely:

Appendix 4. Continued

1. The radial Port Limit for Port Jackson, which encompasses the coastline between Dee Why and Bondi;
2. The Southern Sydney Protection Zone between Bondi and Coogee which fans out as it moves seaward to encompass a number of submarine cables;
3. The radial Port Limit for Botany Bay, which encompasses the coastline just north of Maroubra south to midway along Bate Bay.

During consultation with Sydney Ports Corporation (Mr Robin Heath – Harbour Master), it was advised that the Port Limits are intended for traffic separation purposes. Therefore, the radial nature of the Port Limit lines are not necessarily a representation of the vessel approach paths to the harbour (eg vessels do not approach at an acute angle to the harbour entrances from 1 nautical mile offshore). On this basis the Harbour Master may give consideration to the placement of artificial reefs within the Port Limits, provided they were not considered by the Ports Corporation to be a risk to vessel traffic.

It was also advised that offshore anchorage zones are not part of Sydney Ports Corporation's management policy, as vessels are anchored inside the harbours. In the unlikely event that a vessel is queuing for berth space, vessels generally drift well offshore.

Port Kembla Port Corporation

The study area relating to Port Kembla Port extends from Stanwell Beach in the north down to Port Kembla in the south. Within this area there is one main published restriction, being the Port Kembla Port Limit, as shown on AUS Chart 808. The Port Limit extends from Red Point, just south of the port entrance, up to Bulli Point in the north.

The approach and departure direction for larger vessels entering/leaving Port Kembla is on a bearing of 213 degrees. Either side of this approach direction are a number of designated anchorage areas.

During consultation with Port Kembla Port Corporation (Mr Don Buckthought – Acting General Manager Marine and Port Operations), it was advised that in addition to the approach direction of 213 degrees used by larger vessels, smaller commercial vessels also traffic the area immediately south of Tom Thumb Islands (this is also within the Port Limit). In addition, the Port Corporation advised that any proposed artificial reef structure to the north of the Port Limit should be located clear of the projected approach path of vessels. However, referring to AUS Chart 808, this projected approach path would generally be seaward of the seabed contour of 40m below Chart Datum.

In summary, the Port Corporation would not be supportive of any proposed artificial reef locations within the Port Limit.

Appendix 2 Summary of risk scores for 50 receptors evaluated during the risk assessment workshop. Three numbers within a cell signify the number of receptors at the small, intermediate and large spatial scales, respectively. A zero signifies that no receptors were assessed within that cell at any spatial scale. See Appendix 3 for detailed results.

Risk Analysis Matrix

		Probability (Likelihood)				
		A	B	C	D	E
Consequence	1	0	0	0	0	0
	2	0	0	4; 0; 0	0	0; 1; 0
	3	1; 0; 0	0	2; 1; 0	0	0
	4	11; 0; 0	2; 1; 0	7; 0; 0	0; 2; 2	0
	5	6; 1; 0	2; 0; 0	11; 12; 0	1; 4; 2	3; 29; 40

= Low significance = Medium significance = High significance

Appendix 3. Results of Risk Assessment Workshop (17/1/08) on Offshore Artificial Reefs. For risk values, L = likelihood and C = consequence (see Tables 1 and 2 of main report for explanations).

Potentially constraining feature (receptor)	Hazard/Negative Impact	Risk Values						Safety?
		Small (< 1 km^2)		Interm. (1 - 10 km^2)		Large (>10 km^2)		
		L	C	L	C	L	C	
Coastal Processes & Oceanography:								
Waves & Currents	Increased wave height, breaking waves (Mit: design; location)	C	2	E	5	E	5	*
	Changed wave direction	C	5	C	5	C	5	
	Changed current direction and magnitude	C	5	E	5	E	5	
	Impact on structure: stability of Units	C	2	E	5	E	5	
Coastal erosion/sedimentation	Increased beach erosion	E	5	D	4	D	4	
	Increased deposition (beach or channel)	E	5	D	4	D	4	
Scouring/deposition	Scouring around reefs	C	5	E	5	E	5	
	Deposition on reefs	C	5	E	5	E	5	
	Scouring/deposition around Units	A	4	E	5	E	5	
Contamination:								
Contamination/pollution issues	Mobilisation of existing contaminants (e.g. from outfalls/ spoil grounds)	D	5	E	5	E	5	*
	Creation of contaminants (steel structures; aluminium anodes)	A	4	E	5	E	5	*
	Contamination from local boats - increased or concentrated boating	A	5	E	5	E	5	
	Gross pollution (lost gear, nylon lines, lead weights, etc)	A	4	E	5	E	5	
Ecosystem Processes:								
Substratum type	Change to sedimentary characteristics (e.g. grain size, biota from structures)	A	4	C	5	E	5	
Habitat distribution	Effects of flow on scouring/erosion and emplacement of Units	B	5	E	5	E	5	
	Loss of sediments	A	5	E	5	E	5	
Threatened species	Loss of habitat for saw sharks	A	5	E	5	E	5	
	Interruption ot movement corridors (e.g. GNS, marine mammals)	C	3	C	3	C	3	
	Increased capture/interactions of threatened species that use reef habitat	C	2	E	2	E	2	
Benthic diversity & productivity	Changes to diversity and productivity of soft sediments	A	4	C	5	E	5	
	Increased predation by fishes from the OAR on benthos	A	4	A	5	E	5	
	Provision of structure for a different assemblage of (attached) benthic organisms	A	5	E	5	E	5	
Demersal fishes/invertebrates	Removal of habitat for demersal biota	A	5	E	5	E	5	
	Increased predation by fishes from the OAR on demersal fishes	A	4	C	5	D	5	
Pelagic fish and invertebrates	Increased predation on pelagic fishes attracted to Units	A	4	C	5	D	5	
Introduced species	New habitat for potential utilisation by alien species (e.g. *Sabella*)	C	3	E	5	E	5	
Success of OAR re biodiversity and abundance	Failure to increase/enhance biodiversity and abundance	E	5	E	5	E	5	

continued…

Appendix 3, continued

Potentially constraining feature (receptor)	Hazard/Negative Impact	Risk Values						Safety?
		Small (< 1		Interm. (1 -		Large (>10		
		L	C	L	C	L	C	
Climate change:								
Climate change	Effects of climate change on Units affecting stability, etc	C	4	E	5	E	5	
	Effects of climate change on amenity of the Units	C	4	E	5	E	5	
	Effects of climate change on the above contraints	C	4	C	5	C	5	
Fisheries:								
Commercial fishing	Loss of fishing grounds	A	4	C	5	E	5	
	Loss of gear	A	4	C	5	E	5	
	Increased conflict with other users	C	5	D	5	E	5	*
	Safety issues (e.g. gear hookups)	C	4	E	5	E	5	*
Recreational fishing	Reduced availablity of demersal fishes (e.g. flathead)	C	5	D	5	E	5	
	Increased catch of fishes	A	4	B	4	C	5	
	Increased capture of under-sized fish	B	4	C	5	C	5	
	Increased conflict with other users	C	5	D	5	E	5	*
	Safety issues (e.g. anchor hookups)	B	5	E	5	E	5	*
Scuba Diving	Increased conflict with other users	A	5	E	5	E	5	*
	Safety issues (e.g. boatstrike; decompression illness; entanglement)	C	5	E	5	E	5	*
Spearfishing	Increased catch of fishes	C	4	E	5	E	5	
	Increased capture of under-sized fish	B	4	C	5	C	5	
	Increased encounters with dangerous marine animals	C	5	E	5	E	5	*
	Increased conflict with other users	C	5	E	5	E	5	*
	Safety issues (e.g. boatstrike; entanglement)	C	5	E	5	E	5	*
Coastal Infrastructure:								
OAR structure	Stability of units; corrosion	A	3	C	5	E	5	
AMCA cables	n/a (see constraints mapping)	-	-	-	-	-	-	
Deepwater outfalls	n/a (see constraints mapping)	-	-	-	-	-	-	
Shipping lanes & anchorages	n/a (see constraints mapping)	-	-	-	-	-	-	
Marine protected areas	n/a (see constraints mapping)	-	-	-	-	-	-	
Mining exploration leases	n/a (see constraints mapping)	-	-	-	-	-	-	
Spoil disposal grounds	n/a (see constraints mapping)	-	-	-	-	-	-	
Historical ship wrecks	Damage to wrecks from unit emplacement	C	2	E	5	E	5	
	Indirect damage due to changes in water & sediment movements	C	4	D	5	E	5	
	Anchor damage from vessels close to Units	C	4	E	5	E	5	