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Appendix T

Marine ecology

January 2020

Roads and Maritime Services

Western Harbour Tunnel and Warringah Freeway Upgrade

Technical working paper: Marine ecology

January 2020

Prepared for

Roads and Maritime

Prepared by

Cardno (NSW/ACT) Pty Ltd

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Glossary

Acronym	Definition
AEPs	Auditory evoked potentials
AOBV	Area of outstanding biodiversity value
ANC	Acid neutralising capacity
AASS	Actual ASS
ASS	Acid sulfate soils/sediments
BAM	Biodiversity Assessment Method
BOD	Biological oxygen demand
BoM	Bureau of Meteorology
Cardno	Cardno (NSW/ACT) Pty Ltd
CBD	Central Business District
CCA	Crustose coralline algae
CEMP	Construction environmental management plan
cm	Centimetres
CM Act	NSW *Coastal Management Act 2016*
CZMP	Coastal zone management plan
dB	Decibel
DDT	Dichlorodiphenyltrichloroethane
DECC	Formerly Department of Environment and Climate Change
DoE	Department of the Environment
DoEE	Department of the Environment and Energy
DPI Fisheries	NSW Department of Primary Industries (Fisheries)
EAC	East Australian Current
EEC	Endangered ecological community
EIA	Environmental impact assessment
Elasmobranchs	Sharks and rays
EMP	Environmental management plan
EP	Endangered population
EPA Act	NSW *Environmental Planning and Assessment Act 1979*
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
Epibiota	Organisms living on the surface of the bed of the harbour
EPIs	Environmental planning instruments
ESD	Ecologically sustainable development
The estuary	Parramatta River estuary (Sydney Harbour)
FM Act	NSW *Fisheries Management Act 1994*
H	Hour
ha	Hectares
HAT	Highest astronomical tide
The harbour	Sydney Harbour
Infauna	Organisms living within marine sediment

Acronym	Definition
JASCO	JASCO Applied Sciences
kHz	Kilohertz
km	Kilometres
KTPs	Key threatening processes
LFC	Low frequency cetacean
LHC	Life-history characteristic
L/s	Litres per second
m	Metres
MARS	Maritime Arrivals and Reporting System
MFC	Mid-frequency cetacean
mg/L	Milligrams per litre
Minister	Federal Minister for the Environment
mm	Millimetres
MNES	Matters of National Environmental Significance
NAS	Noise attenuation system
NAGD	National Assessment Guidelines for Dredging
NPWS	National Parks and Wildlife Service
NSW	New South Wales
NTU	Nephelometric Turbidity Unit
OCP	Organochlorine pesticides
OEH	NSW Office of Environment and Heritage
PAH	Polycyclic aromatic hydrocarbon
PASS	Potential ASS
PCA	Principal components analysis
PCDD/Fs	Polycyclic dibenzo bioxins and furans (PCDD/Fs)
PCO	Principal coordinate analysis
PEI	Preliminary environmental investigation
PMST	Protected Matters Search Tool
The policy	*Policy and Guidelines for Fish Habitat Conservation and Management* (NSW DPI, 2013a)
POP	Persistent organic pollutant
POMs	Pacific oyster mortality syndrome
PTS	Permanent threshold shift (permanent hearing loss)
Ramsar wetland	Wetland of international importance defined by the Ramsar Convention
Roads and Maritime	Roads and Maritime Services
RTA	Formerly Roads and Traffic Authority
SEARs	Secretary's environmental assessment requirements
SEPP	State Environmental Planning Policy
SSI	State significance infrastructure
TBT	Tributyltin

Acronym	Definition
TEC	Threatened ecological community
TPH	Total petroleum hydrocarbon
TRH	Total recoverable hydrocarbon
TTS	Temporary threshold shift (temporary hearing loss)
µPa	Micropascals
UVCs	Underwater visual counts
WHT	Western Harbour Tunnel and Warringah Freeway Upgrade (the project)
WMS	Work method statement
ZoHI	Zone of High Impact
ZoI	Zone of Influence
ZoMI	Zone of Moderate Impact

Executive Summary

Introduction

The Western Harbour Tunnel and Beaches Link program of works is a NSW Government initiative to provide additional road network capacity across Sydney Harbour and to improve connectivity with Sydney's northern beaches. The Western Harbour Tunnel and Warringah Freeway Upgrade project (the project) comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project.

Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2 of the *Environmental Planning and Assessment Act 1979* (EPA Act) to construct and operate the project, which would comprise two main components:

> A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)

> Upgrade and integration works along the existing Warringah Freeway, including infrastructure required for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

The majority of the construction footprint would be located underground within the mainline tunnels but a major part of the works would be a crossing of Sydney Harbour between Yurulbin Point (Birchgrove) and Balls Head that would involve placing immersed tube tunnels on a dredged trench on the sea floor. Surface areas, including in Sydney Harbour, would be required to support tunnelling activities and to construct the tunnel connections, tunnel portals and operational ancillary facilities.

This report has been prepared to support the environmental impact statement for the project and has been completed by Cardno (NSW/ACT) Pty Ltd (Cardno) to assess the potential impacts of the project on receiving marine habitats and biota. The environmental impact statement will accompany the application for approval of the project, and address the environmental assessment requirements of the Secretary of the Department of Planning and Environment ('the Secretary's environmental assessment requirements').

This report assesses impacts on biodiversity values that cannot be assessed using the Biodiversity Assessment Method (BAM). This includes Matters of National Environmental Significance (MNES) listed under the *Environment Protected and Biodiversity Conservation Act 1999* (EPBC Act) and impacts on all marine biodiversity values related to the project in accordance with the NSW Department of Primary Industries (Fisheries) (DPI Fisheries) *Policy and Guidelines for Fish Habitat Conservation and Management* (NSW DPI, 2013a) under the *Fisheries Management Act 1994* (FM Act). Impacts on other marine ecology issues (such as seabirds, marine mammals or endangered marine ecological communities as listed under the *Biodiversity Conservation Act 2016*) have been assessed separately and excluded from this report. Impacts on the disposal of dredged material are also addressed separately and have not been considered in this report.

The marine ecological investigations included a combination of desktop and field studies based on an initial screening of existing information about key habitats and biota relevant to the project. The potential for direct and indirect impacts of the project on marine habitats and biota within the study area (defined as the Sydney Harbour estuary between Gladesville Bridge and just to the east of Garden Island and Robertsons Point) was assessed by determining the tolerances of habitats and biota to potential impacts during construction and operational phases of the project. A risk assessment assisted with this process.

Existing environment

Sydney Harbour possesses a wide range of marine habitats which has been categorised into five broad habitat types:

> Intertidal rocky shores

> Shallow soft sediments including seagrass, saltmarsh, mangroves and intertidal sand and mudflats

> Subtidal rocky reefs

> Deep soft sediments

> Open water.

The habitats in the study area have been classified according to the *Policy and Guidelines for Fish Habitat Conservation and Management*. This requires consideration of the waterway 'sensitivity' (Type), which refers to the importance of the habitat to the survival of fish and its robustness (ability to withstand disturbance). This ranking is used within the policy and guidelines to differentiate between permissible and prohibited activities or developments and for determining value in the event offsetting is required. The waterway 'class' is also considered. Waterway 'class' is based on the functionality of the water as fish habitat and can be used to assess the impacts of certain activities on fish habitats in conjunction with the habitat sensitivity. All biodiversity values occur within a Class 1 waterway (the estuary).

The review of existing information and project-specific field investigations identified 12 biodiversity values relevant to the project. Of these values, seven were related to marine habitat and vegetation while five were related to threatened and/or migratory species listed under the FM Act and/or the EPBC Act. For marine habitat and vegetation, sensitivity Type, as given in the *Policy and Guidelines for Fish Habitat Conservation and Management,* was identified.

The characteristics of each value, and justifications for their identification and Type, are given in Table ES1 below.

Table ES1 Identified biodiversity values within the study area

Biodiversity value	Justification as biodiversity value
Marine habitat and vegetation	
Intertidal rocky shore habitats	▪ Type 2 - Moderately sensitive key fish habitat ▪ Contains marine vegetation protected under the FM Act ▪ Important habitat for many commercially and recreational important fish.
Seagrass habitats	▪ Type 1 - Highly sensitive key fish habitat, or Type 2 (if area <5 m^2) ▪ Contains marine vegetation protected under the FM Act ▪ Potentially sensitive to disturbances ▪ Important habitat for many commercially and recreational important fish.
Mangrove habitats	▪ Type 2 - Moderately sensitive key fish habitat ▪ Contains marine vegetation protected under the FM Act ▪ Provides important ecosystem services and habitats for threat- and migratory-listed fauna.
Intertidal sand and mudflat habitats	▪ Type 2 - Moderately sensitive key fish habitat ▪ Provides foraging habitats for threat- and migratory listed fauna and commercially and recreationally important fish.
Subtidal rocky reef habitats	▪ Type 1 - Highly sensitive key fish habitat (medium and high relief reef is known habitat of threatened black rockcod and all subtidal reef is known habitat of the nominated-for-listing White's seahorse) ▪ Contains marine vegetation protected under the FM Act ▪ Important habitat for many commercially and recreationally important fish ▪ Potential habitat for threat-listed fish.
Deepwater soft sediment habitats	▪ Type 3 - Minimally sensitive key fish habitat ▪ Occupies the largest area within the study area ▪ Provides connectivity between habitats ▪ Periodically used by important, transient marine fauna.
Open water habitats	▪ Type 3 - Minimally sensitive key fish habitat ▪ Occupies the largest area within the study area ▪ Provides connectivity between habitats ▪ Periodically used by important, transient marine fauna.
Threatened and/or migratory species listed under the FM Act and/or EPBC Act	
Black rockcod (*Epinephelus daemeli*)	▪ Listed as vulnerable under the FM Act and EPBC Act ▪ The study area lies within its known distribution and anecdotally recorded within the greater estuary

Biodiversity value	Justification as biodiversity value
	▪ Usually occurs in Type 1 and Type 2 key fish habitat.
White's seahorse^	▪ Nominated to be listed as threatened under the FM Act ▪ The study area lies within its known distribution and anecdotally recorded within the greater estuary ▪ Usually occurs in Type 1 and Type 2 key fish habitat.
Marine mammals (whales, dolphins and seals)	▪ Threat-, migratory- and/or marine- listed under the EPBC Act ▪ Iconic marine fauna of the greater Sydney region ▪ Usually occurs in Type 3 key fish habitat.
Marine reptiles (turtles)	▪ Threat-, migratory- and/or marine- listed under the EPBC Act ▪ Iconic marine fauna of the greater Sydney region ▪ Usually occurs in Type 3 key fish habitat.
Elasmobranchs (sharks and rays)	▪ Threat-, migratory- and/or marine- listed under the FM Act and/or EPBC Act ▪ Recreationally and commercially important species ▪ Iconic marine fauna of the greater Sydney region ▪ Can occur in Type 1, 2 or 3 key fish habitat.

^ = *nominated listing*

Potential project hazards

The construction and operational phases of the project would pose various hazards to biodiversity values within the study area. Nine hazards (refer Table ES2) were identified from seven main project activities (Table ES3). These hazards can have effects at various spatial and temporal scales if they are above natural background levels and if not managed appropriately. The hazards would be generally confined to the construction phase of the project given that the crossing, once operational, would be below the bed of the harbour and the temporary construction support sites would be decommissioned following project completion. The only exception would be a permanent wastewater treatment plant located at Rozelle Rail Yards.

Construction phase activities to which the hazards apply are given in Table ES3.

Table ES2 Identified hazards to marine ecology within the study area

Hazard identifier	Hazard
ME1	Removal of habitat/benthic habitat
ME2	Turbidity
ME3	Sedimentation
ME4	Mobilisation of contaminants
ME5	Introduction/spread of marine pests
ME6	Altered hydrodynamics
ME7	Underwater noise
ME8	Boat strike to marine mammals and/or reptiles
ME9	Spill of contaminants

Table ES3 Project phase activities and the hazards they cause to marine ecology

Construction phase	Operation phase	Activity	Hazard	Relevant construction support sites
✓	✓	Construction support site establishment (including permanent commissioning of project elements)	ME1, ME2, ME3, ME4, ME5	Rozelle Rail Yards (WHT1), White Bay (WHT3), Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7)
✓		Cofferdam construction	ME1, ME2, ME3, ME4, ME5, ME6	Sydney Harbour south (WHT5) and Sydney Harbout north (WHT6) cofferdams
✓		Temporary wharf constructions (including floating structures)	ME1, ME2, ME3, ME4, ME5, ME7	White Bay (WHT3), Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7)
✓		Dredging	ME1, ME2, ME3, ME4, ME7	Dredging footprint between Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6) cofferdams
✓		Piling	ME1, ME2, ME3, ME4, ME5, ME7	White Bay (WHT3), Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7)
✓		Vessel movements	ME5, ME7, ME8, ME9	Snails Bay mooring facility, Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6), Berrys Bay (WHT7) and surrounding areas
✓		Installation of instream structures	ME6	Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7)

Assessment of impacts

Risk analysis and preliminary assessment

The assessment of potential impacts on biodiversity values as a result of project construction and operational activities required:

- Predictions of the extent, intensities, frequencies and durations of hazards from project construction and operational activities relative to ambient levels
- A description of the locality, quality and sensitivities of habitats and biota within the spatial extent of predicted dredge plumes
- The tolerances of habitats and biota to the hazards
- A qualitative risk analysis was used to investigate the above information and identify key issues associated with the project.

Key inputs to the risk analysis were:

- Determination of the Zones of High Impact (irreversible impacts within the direct footprint of the project), Moderate Impact (abuts on and lies immediately outside the Zone of High Impact and where areas would be impacted but would recover after completion of dredging) and Influence (areas which at some time during the dredging may experience [detectable] changes in water quality or sedimentation outside the natural ranges that are the norm)
- Identification of contaminants in the dredging footprint (Douglas Partners and Golder Associates, 2017)

- Modelling of changes to hydrodynamics, flushing times and sedimentation due to project construction and operational activities carried out by Royal Haskoning DHV
- An acoustic modelling study of underwater noise generated during the in-water construction activities of dredging and pile installation done by JASCO Applied Sciences (JASCO).

Risk levels identified are summarised in Table ES4.

Table ES4 Summary of risk analysis (✓ indicates key issues)

Hazard	Biodiversity values											
	Marine habitat and vegetation								Threatened and/or migratory species (FM Act and EPBC Act)			
	Intertidal rocky shore habitats	Seagrass habitats	Mangrove habitats	Intertidal sand and mudflat habitats	Subtidal rocky reef habitats	Deepwater soft sediment habitats	Open water habitats	Black rockcod	White's seahorse	Marine mammals	Marine reptiles	Elasmobranchs
ME1: Removal of habitat/benthic habitat		✓			✓	✓						
ME2: Turbidity		✓			✓							
ME3: Sedimentation		✓			✓		N/A			N/A		
ME4: Mobilisation of contaminants		✓			✓							
ME5: Introduction/spread of marine pests		✓			✓					N/A		
ME6: Altered hydrodynamics		✓			✓							
ME7: Underwater noise	N/A	✓			✓	✓	✓	✓	✓	✓	✓	✓
ME8: Boat strike to marine mammals and/or reptiles	N/A	✓	N/A	N/A	✓	✓	✓	N/A	N/A	✓	✓	N/A
ME9: Spill of contaminants		✓			✓							

Key	
Extreme risk	Risk is unmanageable and cannot be justified under any circumstances. Measures to reduce risk to a lower level are required.
High risk	Risk is significant and requires significant cost-effective measures for risk reduction and/or management.
Moderate risk	Routine and cost-effective measures required to reduce and/or manage risk. Risk may be acceptable.
Low risk	Risk can be managed by routine procedures and/or no further measures to manage the risk are required.

As shown in Table ES4, the risk analysis did not identify any extreme or high risks. All potential risks were identified as moderate or low.

Key issues were determined by consideration of the:

> Level of risk

> Sensitivity of habitats (ie key fish habitat type), or threatened species, to hazards

> Spatial scale of potential impact relative to the overall extent of unaffected habitat in the harbour.

The risk analysis identified 24 key issues relating to Type 1 or Type 3 key fish habitats as well as six key issues associated with threatened, migratory and/or marine species listed under the EPBC Act (MNES). There were no key issues relating to Type 2 key fish habitat.

For simplicity, the 24 key issues were grouped into 11 over-arching key issues, according to the hazard, whether it affects Type 1 or 3 key fish habitats, and MNES (see Table ES5).

Table ES5 Key issues identified from the risk analysis

Key issue	Over-arching key issues for impact assessment
Type 1 highly sensitive key fish habitat	
Removal of habitat/benthic habitat to seagrass habitats	Potential for direct removal of seagrass or low/medium/high relief rocky reef
Removal of habitat/benthic habitat to subtidal rocky reef habitat	
Turbidity to seagrass habitats	Excessive turbidity and sedimentation (from dredging) in seagrass or low/medium/high relief rocky reef habitat
Sedimentation to seagrass habitats	
Turbidity to subtidal rocky reef habitats	
Sedimentation to subtidal rocky reef habitats	
Mobilisation of contaminants to seagrass habitats	Mobilisation of contaminants to seagrass or low/medium/high relief rocky reef
Mobilisation of contaminants to subtidal rocky reef habitats	
Introduction/spread of marine pests to seagrass habitats	Introduction/spread of marine pests to seagrass or low/medium/high relief rocky reef
Introduction/spread of marine pests to subtidal rocky reef habitats	
Altered hydrodynamics to seagrass habitats	Altered hydrodynamics in seagrass or low/medium/high relief rocky reef
Altered hydrodynamics to subtidal rocky reef habitats	
Underwater noise to seagrass habitats	Underwater noise impacts to fish and elasmobranchs in seagrass or low/medium/high relief rocky reef
Underwater noise to subtidal rocky reef habitats	
Boat strike to marine mammals and/or reptiles to seagrass habitats	Boat strike to marine mammals and marine reptiles (in MNES)
Boast strike to marine mammals and/or reptiles to subtidal rocky reef habitats	
Spill of contaminants to seagrass habitats	Spill of contaminants in seagrass or low/medium/high relief rocky reef
Spill of contaminants to subtidal rocky reef habitats	
Type 3 minimally sensitive key fish habitat	
Removal of habitat/benthic habitat to deepwater soft sediment habitats	Direct removal of deepwater soft sediment habitat
Underwater noise to deepwater soft sediment habitats	Underwater noise impact to fish and elasmobranchs in deepwater soft sediment habitat (including open water)
Underwater noise to open water habitats	
Boat strike to marine mammals and/or reptiles to deepwater soft sediment habitats	Boat strike to marine mammals and marine reptiles (in MNES)
Boat strike to marine mammals and/or marine reptiles to open water habitats	
MNES	
Removal of habitat/benthic habitat of the black rockcod	Potential for direct removal of seagrass or medium/high relief subtidal rocky reef (same key issue as per Type 1 above)
Underwater noise on black rockcod	Underwater noise impacts to fish and elasmobranchs in seagrass or medium/high relief subtidal rocky reef (same key issue as per Type 1 above)
Underwater noise on marine mammals	
Underwater noise on marine reptiles	

Key issue	Over-arching key issues for impact assessment
Type 1 highly sensitive key fish habitat	
Underwater noise on elasmobranchs	Underwater noise impact to marine reptiles, marine mammals and elasmobranchs (same key issue as per Type 1 or 3 above)
Boat strike on marine mammals	Boat strike to marine mammals and marine reptiles (same key issue as per Type 1 or 3 above)
Boat strike on marine reptiles	

Assessment of impacts

The impact assessment was based on the over-arching key issues (identified in Table ES5).

Potential for direct removal of seagrass or medium/high relief subtidal rocky reef habitat

Removal of seagrass for the purposes of project construction is not predicted however, scour from vessel movement in project areas during construction and groundwater treatment plant discharge could unintentionally remove small areas of these habitats.

As a precautionary approach, protection will involve implementation of exclusion zones, velocity dampeners at discharge points and routine and event-based monitoring. A small amount (less than 0.01 hectares) of rocky reef requires removal but this would be reinstated following construction.

Excessive turbidity and sedimentation (from dredging) in seagrass or subtidal rocky reef habitat

Only a very small area of high relief reef occurs within the Zone of Moderate Impact (less than 0.01 hectares) representing less than one per cent of the extent of similar habitat in the study area. Given that biota would recover quickly after construction through natural recruitment and immigration, the removal of biota in this small area of high relief rocky reef would not compromise populations of fish or assemblages of benthic communities in this habitat (including the threatened black rockcod or nominated-for-listing White's seahorse).

A small area (about 0.03 hectares) of the Zostera (*Zostera muelleri* subsp. *capricorni*) seagrass occurred in the Zone of Influence and areas where five to 10 millimetres of sedimentation from dredging is predicted. However, loss of patches in these areas are not expected due to existing adaptations to ambient conditions and the implementation of controls outlined in Section 1.7 and 6. Other areas of Zostera and medium/high relief rocky reef were close to project activities at Yurulbin Point (WHT4), Berrys Bay (WHT7), Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) construction support sites, albeit outside of the modelled sedimentation and Zone of Moderate Impact.

During dredging, to safeguard against small changes (ie on the scale of metres) to the predicted extents of the Zone of Moderate Impact or areas of excessive sedimentation, a precautionary approach would be to implement exclusion zones and routine and event-based monitoring.

Mobilisation of contaminants to seagrass or subtidal rocky reef habitat

Contaminants would occur in the top layer of soft sediment to be dredged. However, these are unlikely to dissociate and be released into the water column as dissolved phases. The pathway for spread of contaminants would be restricted to the component of dredged contaminated sediment that would disperse during excavation or from barge overflow and settle back onto the bed of the harbour. Given most of the potential dredge-induced accumulations of sediment would most likely be sediment that had dispersed during the dredging of deeper uncontaminated sediment, there would be little potential for spread of contaminants.

The management of sediments with elevated levels of contaminants would be a priority that would require appropriate controls. This would include using an environmental clamshell bucket on a backhoe dredge during excavation of the top metre of sediment and silt curtains to minimise dispersion of overflow material from the dredge barge.

Introduction/spread of marine pests to seagrass or subtidal rocky reef habitat

The number of additional vessels in the harbour is likely to be small relative to the overall number of commercial vessels currently operating in the harbour. However, the risk of marine pest introductions would need to be managed given it would pose a risk to seagrass and rocky reef habitats.

One identified marine pest, *Caulerpa taxifolia*, currently occurs in the study area at Neutral Bay and a number of other locations east and efforts would need to be made to avoid its spread to the project area. Controls would include the implementation of vessel and equipment wash-downs and inspection protocols as well as ballast water management.

Altered hydrodynamics in seagrass or subtidal rocky reef habitat

Cofferdams would alter tidal currents in nearshore areas adjacent to these structures. During ebb and flood tide, differences would be most pronounced in the surface layer of the water column when compared to bottom layers. There would also be an increase in current speeds at a location downstream of the Greenwich Baths during spring flood tides. Any reductions to currents are not likely to cause an adverse impact to biota given the alterations to currents are temporary and not likely to be outside of the range in speeds in other parts of the study area where seagrass or rocky reef habitat can also be found.

Underwater noise impacts on fish and elasmobranchs in seagrass or subtidal rocky reef habitat

Modelling indicates that dredging operations or pile drilling would not cause harm to fish beyond the confinements of the dredging or piling operations. However, impulsive underwater noise from impact piling could cause mortality or potential mortal injury to the most sensitive fish group (and potentially elasmobranchs) within 0.43 kilometres of the source of underwater noise (JASCO, 2019). Some fish and elasmobranchs (including some threat listed black rockcod or nominated-for-listing White’s seahorse) have potential to be exposed but the affected areas are very small (ie less than one per cent) relative to the extent of these habitats in Sydney Harbour.

The hazard of underwater noise would be staged and it is expected that any impacted assemblages would recover within one or two years through natural processes of recruitment and immigration. This impact would be acceptable in terms of the broader ecological functioning of fish and elasmobranch communities, or the long-term viability of a local population of black rockcod or nominated-for-listing White’s seahorse.

Spill of contaminants in seagrass or subtidal rocky reef habitat

Spills are not predicted but strict management measures would be implemented to ensure either no spills occur as a result of the project and/or that accidental spills are management quickly and effectively. These would be detailed in the construction environmental management plan (CEMP) and apply to all project vessels.

Direct removal of deepwater soft sediment habitat

The removal, by dredging, of about 10.51 hectares of deepwater soft sediment habitat in the dredging footprint for placement of the immersed tube tunnel units for the crossing would result in a temporary loss of epifauna and infauna. Impact piling at the Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) would also result in this very small loss. Given field surveys in the footprint detected as many differences in the composition of infauna among areas in the project areas as outside of it, it is considered that these areas would not have any unique characteristics that would render its removal a major loss to biodiversity. Further, as fill would be placed over the tunnel to restore the existing profile of the bed of the harbour, soft sediment would be expected to quickly accumulate on top of the fill, facilitating re-establishment of the assemblage within two years. This process would also re-establish direct connectivity between deepwater soft sediment habitat on either side of the tunnel. Given these results, it is considered that the temporary impact would be acceptable in terms of the concern to the broader ecological functioning of soft sediment communities.

Underwater noise impacts on fish and elasmobranchs in deepwater soft sediment habitat (including open water)

Direct impacts from underwater noise to fish and elasmobranchs have been discussed above. Fish and elasmobranchs would be affected in up to 121.25 hectares of soft sediment habitat during impact piling at the Sydney Harbour south cofferdam (WHT5) and 75.42 hectares during impact piling at Sydney Harbour north cofferdam (WHT6). Some fish or sharks may succumb to mortality or mortal injury in smaller areas (11.64 hectares and 17.59 hectares during impact piling at the Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) respectively), but these areas would be very small (ie less than one per cent) relative to the extent of these habitats in Sydney Harbour. Further, the hazard of underwater noise is temporarily associated with impact piling activity, which would be staged between the Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6), and it is expected that assemblages or populations would recover within one to two years through natural processes of recruitment and immigration. This impact would be acceptable in terms of the broader ecological functioning of fish communities or sharks.

Underwater noise impacts on marine reptiles, marine mammals and elasmobranchs

Underwater noise from impact piling can potentially harm marine reptiles, marine mammals and elasmobranchs as potentially affected areas would span the width of the estuary around the impact piling sites at Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6). The majority of marine mammals or marine turtles are migratory and have rarely been observed this far upstream of the estuary.

As marine mammals and marine turtles can be observed from above the water, impacts on marine mammals can potentially be easily mitigated using observers and stop-work protocols when a species is seen in the vicinity of impact piling activities.

Some threatened sharks (ie grey nurse shark [*Carcharias taurus*] or white shark [*Carcharodon carcharius*]) may occur in the potentially affected areas, although given the study area would provide suboptimal foraging habitat for these species, very few individuals are likely to occur there during the construction phase.

Boat strike to marine mammals and reptiles

Marine mammals and marine turtles would be susceptible to potential harm from vessel strike during construction in all of the subtidal habitats within the project area. However, the majority of these fauna are migratory and rarely observed this far upstream of the estuary. The proportional increase in vessel traffic during construction is considered to be very small relative to overall vessel traffic in the study area.

As marine mammals and marine turtles can be observed on the surface of the water, impacts on marine mammals and marine reptiles would be easily mitigated using observers and stop-work protocols when a species is seen in the vicinity, such that mortality or mortal injury would be prevented or greatly minimised. Potential for vessel strike would also be further reduced by reducing boat speeds which would minimise frequency and severity of collisions.

Conclusion

Biodiversity values occur throughout the entire study area. The most sensitive of these occur within nearshore areas (ie where Type 1 [highly sensitive] key fish habitats of seagrass and subtidal rocky reef occur). Impacts on these key fish habitats would be confined to the construction phase of the project. Most of the risk is associated closely with construction activities occurring at the proposed crossing of Sydney Harbour. However, there are other risks to Type 1 habitats in different locations in the study area where other temporary construction facilities would be located. Some threatened species are also expected to occur in these habitats and in the main channel of the study area.

The design of the crossing and its method of construction have considered the means by which the hazards to biodiversity values would best be avoided or minimised. Safeguards have been proposed to reduce the extent of impacts during construction where it is unavoidable to Type 1 (highly sensitive) key fish habitat or to minimise risk to threatened species. This avoidance and control of impacts would restrict impacts on a few small areas around the shorelines of the crossing. These impacts would be associated with the removal of some rocky reef habitat, turbidity and sedimentation from dredging and underwater noise from impact piling. Some biota in these areas were unable to be salvaged before construction and are likely to perish, however the impacts are considered small and acceptable (including from cumulative impacts from multiple hazards) considering the relative extent of the habitats and/or biota to that available in Sydney Harbour. The impacts would not compromise the functionality, connectivity or viability of habitats, or ecological processes within assemblages of biota beyond the small affected areas.

Given the bed of the harbour at the tunnel crossing would be restored to the existing profile, there would be no operational impacts from the project other than the permanent wastewater treatment plant discharges at Rozelle Bay where no residual operational impacts on biodiversity values are expected.

The project would not have a significant impact on any threatened species, population, endangered ecological community (including those which are MNES) or trigger any key threatening process. A referral under the EPBC Act is not considered to be required.

Given these findings, consideration to the proposed safeguards and the potential option for offsets in the event of inadvertent, irreparable damage to marine habitats, the project has acceptable outcomes to biodiversity values in Sydney Harbour.

1 Introduction

This section provides an overview of the Western Harbour Tunnel and Warringah Freeway Upgrade (the project), including its key features and location. It also outlines the Secretary's environmental assessment requirements addressed in this technical working paper.

1.1 Overview

The Greater Sydney Commission's *Greater Sydney Region Plan – A Metropolis of Three Cities* (Greater Sydney Commission, 2018) proposes a vision of three cities where most residents have convenient and easy access to jobs, education and health facilities and services. In addition to this plan, and to accommodate for Sydney's future growth the NSW Government is implementing the Future Transport Strategy 2056 (Transport for NSW, 2018), a plan that sets the 40 year vision, directions and outcomes framework for customer mobility in NSW. The Western Harbour Tunnel and Beaches Link program of works is proposed to provide additional road network capacity across Sydney Harbour and to improve transport connectivity with Sydney's northern beaches. The Western Harbour Tunnel and Beaches Link program of works include:

> The Western Harbour Tunnel and Warringah Freeway Upgrade project comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project

> The Beaches Link and Gore Hill Freeway Connection project which comprises a new tolled motorway tunnel connection across Middle Harbour from the Warringah Freeway and Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of Wakehurst Parkway from Seaforth to Frenchs Forest and upgrade and integration works to connect to the Gore Hill Freeway at Artarmon.

A combined delivery of the Western Harbour Tunnel and Beaches Link program of works would unlock a range of benefits for freight, public transport and private vehicle users. It would support faster travel times for journeys between the Northern Beaches and south, west and north-west of Sydney Harbour. Delivering the program of works would also improve the resilience of the motorway network, given that each project provides an alternative to heavily congested harbour crossings.

1.2 The project

Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade, which would comprise two main components:

> A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)

> Upgrade and integration works along the existing Warringah Freeway, including infrastructure required for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

Key features of the Western Harbour Tunnel component of the project are shown in Figure 1-1. The key components which are relevant to this report includes:

> Twin mainline tunnels about 6.5 kilometres long and each accommodating three lanes of traffic in each direction, connecting the stub tunnels from the M4-M5 Link at Rozelle to the Warringah Freeway and to the Beaches Link mainline tunnels at Cammeray. The crossing of Sydney Harbour between Birchgrove and Waverton would involve a dual, three lane, immersed tube tunnel

> Connections to the stub tunnels at the M4-M5 Link project in Rozelle and the mainline tunnels at Cammeray for (future connection to the Beaches Link and Gore Hill Freeway Connection project)

> Surface connections at Rozelle, North Sydney and Cammeray, including direct connections to and from the Warringah Freeway (including integration with the Warringah Freeway Upgrade), an off ramp to Falcon Street and an on ramp from Berry Street at North Sydney

> Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, signage, tolling infrastructure, fire and life safety systems, lighting, emergency evacuation and emergency smoke extraction infrastructure, CCTV and other traffic management systems.

Key features of the Warringah Freeway Upgrade component of the project are shown in Figure 1-2. The key components which are relevant to this report include:

- Upgrade and reconfiguration of the Warringah Freeway from immediately north of the Sydney Harbour Bridge through to Willoughby Road at Naremburn
- Upgrades to interchanges at Falcon Street in Cammeray and High Street in North Sydney
- New and upgraded pedestrian and cyclist infrastructure
- New, modified and relocated road and shared user bridges across the Warringah Freeway
- Connection of the Warringah Freeway to the portals for the Western Harbour Tunnel mainline tunnels and the Beaches Link tunnels via on and off ramps, which would consist of a combination of trough and cut and cover structures
- Upgrades to existing roads around the Warringah Freeway to integrate the project with the surrounding road network
- Upgrades and modifications to bus infrastructure, including relocation of the existing bus layover along the Warringah Freeway
- New and upgraded public and shared user infrastructure
- Other operational infrastructure, including surface drainage and utility infrastructure, signage, tolling, lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) and construction of the project is described in Chapter 6 (Construction work) of the environmental impact statement. The project alignment at the Rozelle Interchange shown in Figure 1-1 and Figure 1-2 reflects the arrangement presented in the environmental impact statement for the M4-M5 Link, and as amended by the proposed modifications. The project would be constructed in accordance with the finalised M4-M5 Link detailed design (refer to Section 2.1.1 of Chapter 2 (Assessment process) of the environmental impact statement for further details).

The project does not include ongoing motorway maintenance activities during operation or future use of residual land occupied or affected by project construction activities, but not required for operational infrastructure. These would be subject to separate planning and processes at the relevant times.

Subject to the project obtaining planning approval, construction is anticipated to commence in 2020 and is expected to take around six years to complete.

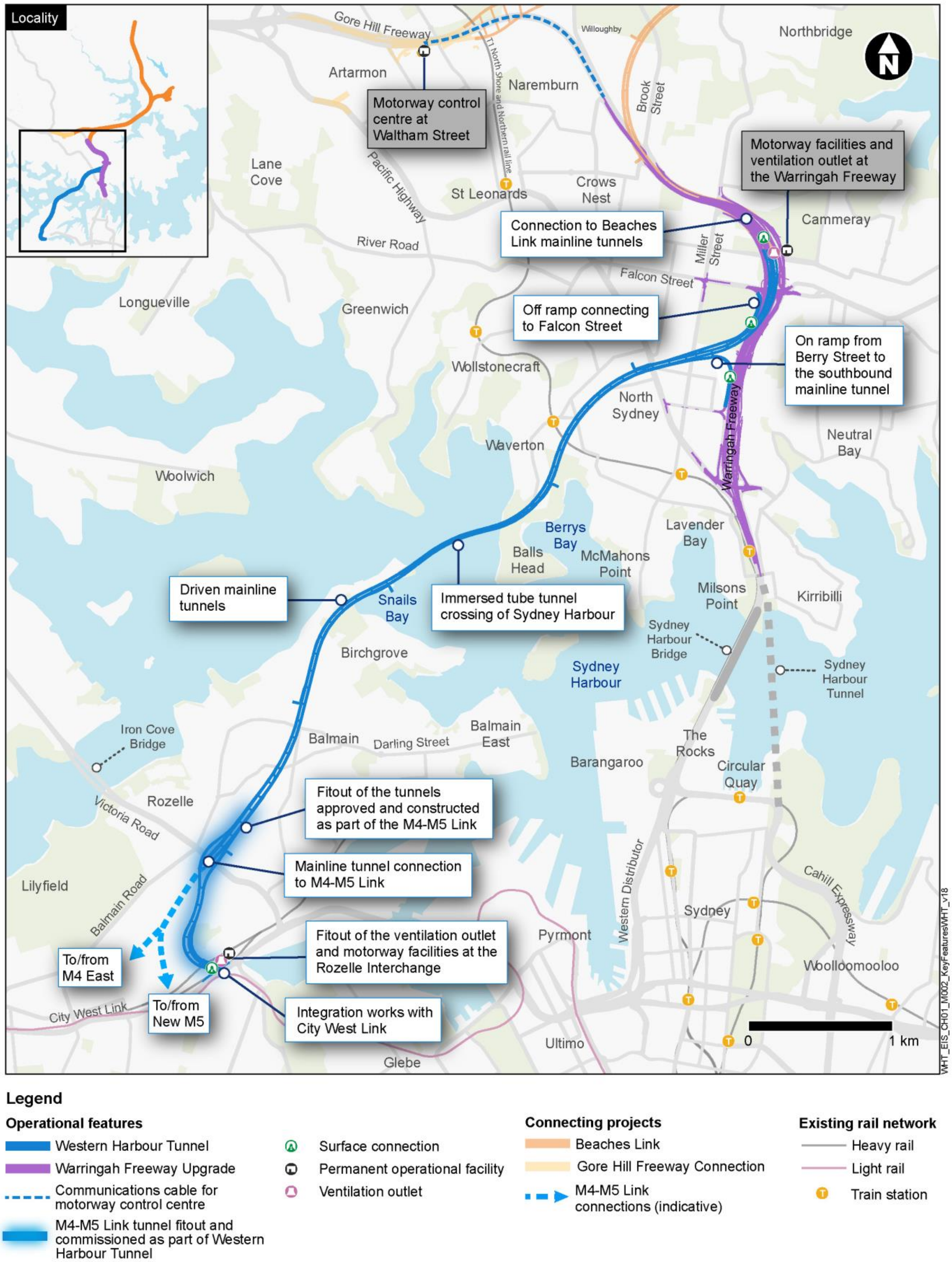

Figure 1-1 Key features of the Western Harbour Tunnel component of the project

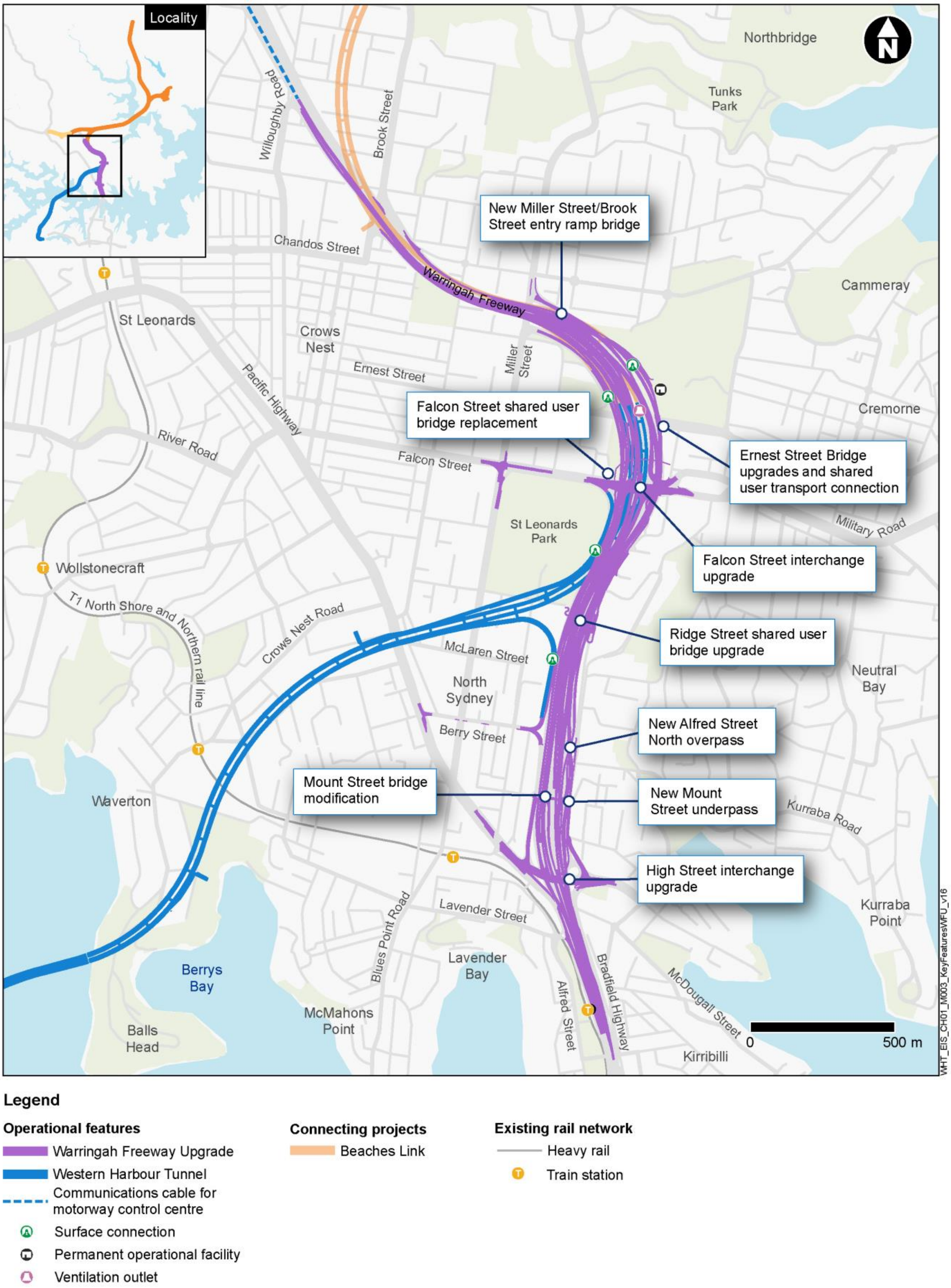

Figure 1-2 Key features of Warringah Freeway Upgrade component of the project

1.2.2 Immersed tube elements

The immersed tube tunnels would connect to the driven mainline tunnels in Sydney Harbour offshore from Yurulbin Point at Birchgrove and from Balls Head at Waverton.

The immersed tube tunnels would be installed as a series of pre-cast units in a trench excavated in the bed of Sydney Harbour. Fill and armour materials would be placed around the immersed tube tunnels for stability and protection. The top of the immersed tube tunnels, including rock armour, would not reduce the navigation depth of existing shipping channels. Each immersed tube tunnel would accommodate three traffic lanes.

An indicative cross section of the immersed tube tunnel crossing of Middle Harbour is shown in Figure 1-3. An indicative long section of the immersed tube tunnels are shown in Figure 1-4.

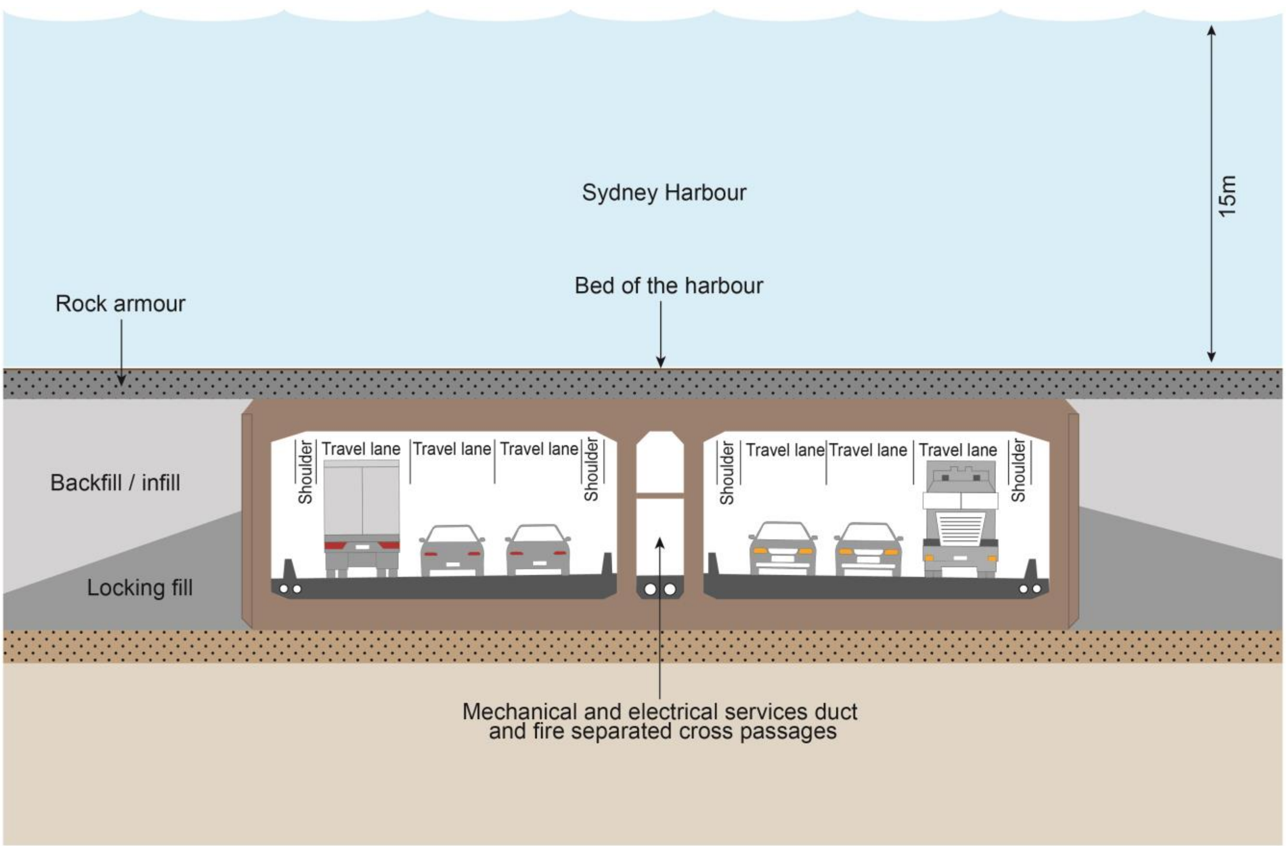

Figure 1-3 Indicative cross section of the immersed tube tunnels (Sydney Harbour)

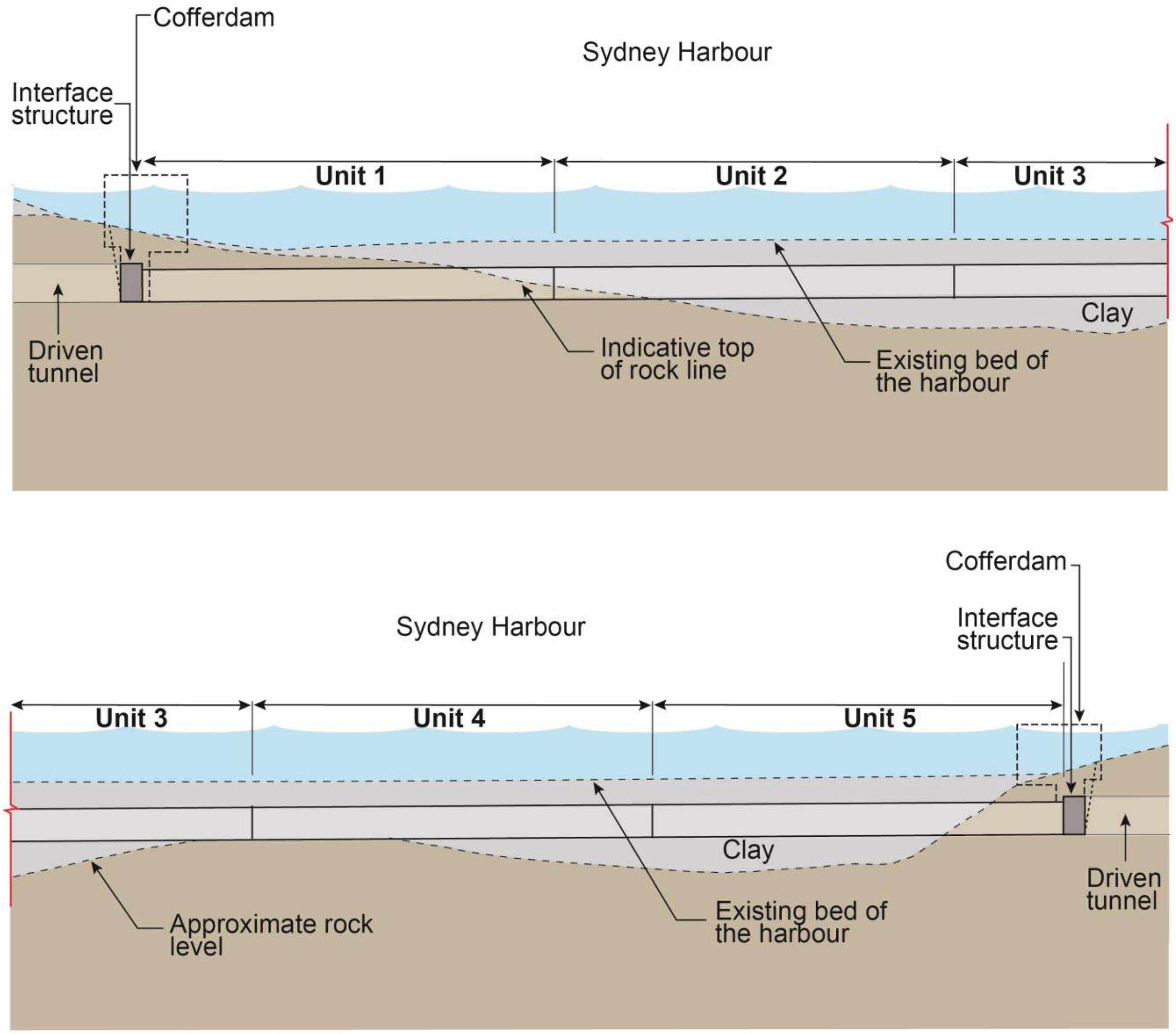

Figure 1-4 **Indicative long section of the immersed tube tunnels (Sydney Harbour)**

1.3 Key construction activities

The area required to construct the project is referred to as the construction footprint. The majority of the construction footprint would be located underground within the mainline tunnels. However, surface areas would be required to support tunnelling activities and to construct the tunnel connections, tunnel portals and operational ancillary facilities.

Key construction activities relecant to this report would include:

- Early works and site establishment, with typical activities being property acquisition, utilities protection, adjustments and relocations, installation of site fencing, environmental controls (including noise attenuation) and traffic management controls, vegetation clearing, earthworks and demolition of structures, establishment of construction support sites including acoustic sheds and associated access decline acoustic enclosures (where required), temporary relocation of swing moorings within Berrys Bay and relocation of the historic vessels.
- Construction of Western Harbour Tunnel, with typical activities being excavation of tunnel construction accesses, construction of driven tunnels, cut and cover and trough structures and construction of cofferdams, dredging activities in preparation for the installation of immersed tube tunnels, casting and installation of immersed tube tunnels and civil finishing and tunnel fitout
- Construction of operational facilities comprising of a motorway control centre at Waltham Street at Artarmon, motorway and tunnel support facilities and, ventilation outlets at the Warringah Freeway in

Cammeray, construction and fitout of the project operational facilities that form part of the M4-M5 Link Rozelle East Motorway Operations Complex, a wastewater treatment plant at Rozelle and the installation of motorway tolling infrastructure

> Construction of the Warringah Freeway Upgrade, with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of road furniture, lighting, signage and noise barriers
> Testing of plant and equipment, and commissioning of the project, backfill of access declines, removal of construction support sites, landscaping and rehabilitation of disturbed areas and removal of environmental and traffic controls.

Temporary construction support sites would be required as part of the project (refer to Figure 1-5), and would include tunnelling and tunnel support sites, civil surface sites, cofferdams, mooring sites, wharf and berthing facilities, laydown areas, parking and workforce amenities. Only six construction support sites are relevant to this report. These are:

> Rozelle Rail Yards (WHT1)
> White Bay (WHT3)
> Yurulbin Point (WHT4)
> Sydney Harbour south cofferdam (WHT5)
> Sydney Harbour north cofferdam (WHT6)
> Berrys Bay (WHT7).

A detailed description of construction works for the project is provided in Chapter 6 (Construction work) of the environmental impact statement.

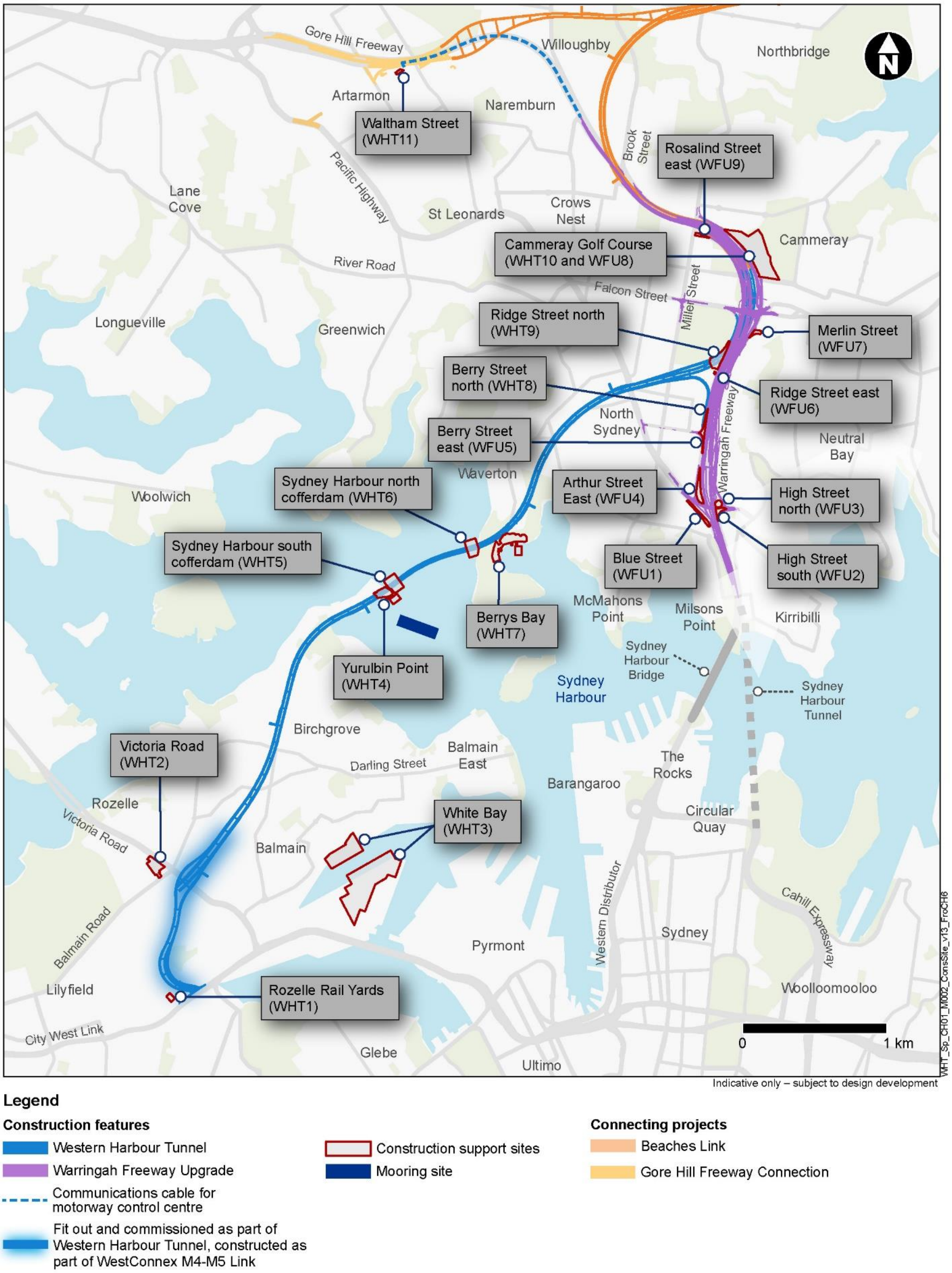

Figure 1-5 Overview of construction support sites

1.4 Project location

The project would be located within the Inner West, North Sydney and Willoughby local government areas, connecting Rozelle in the south with Naremburn in the north.

Commencing at the Rozelle Interchange, the mainline tunnels would pass under Balmain and Birchgrove, then cross Sydney Harbour between Birchgrove and Balls Head. The tunnels would then continue under Waverton and North Sydney, linking directly to the Warringah Freeway to the south of the existing Ernest Street bridge.

The motorway control centre would be located at Waltham Street, Artarmon, with a trenched communications cable connecting the motorway control centre to the Western Harbour tunnel along the Gore Hill Freeway and Warringah Freeway road reserves.

The Warringah Freeway Upgrade would be carried out on the Warringah Freeway from around Fitzroy Street at Milsons Point to around Willoughby Road at Naremburn. Upgrade works would include improvements to bridges across the Warringah Freeway, and upgrades to surrounding roads.

1.5 Purpose of this report

This report has been prepared to support the environmental impact statement for the project and to address the environmental assessment requirements of the Secretary of the Department of Planning, Industry and Environment (formerly Department of Planning and Environment) (‘the Secretary’s environmental assessment requirements’).

This report has been completed by the Applied Ecology team at Cardno (NSW/ACT) Pty Ltd (Cardno) to assess the potential impacts of the project on receiving marine habitats and biota.

1.6 Secretary’s environmental assessment requirements

The Secretary’s environmental assessment requirements relating to marine ecology, and where these requirements are addressed in this report are outlined in Table 1-1.

Table 1-1 Secretary’s environmental assessment requirements – marine ecology

Secretary’s environmental assessment requirements	Where addressed
6.6 Impacts on biodiversity values that cannot be assessed using the Biodiversity Assessment Method (BAM) must also be otherwise assessed. The values include: ▪ Marine mammals ▪ Wandering seabirds ▪ Matters of national significance listed under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.	This report assesses marine mammals and marine Matters of National Environmental Significance (MNES) listed under the *Environment Protected and Biodiversity Conservation Act 1999* (EPBC Act). Wandering seabirds are assessed in the *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Biodiversity development assessment report* (Arcadis, 2020) and excluded from this report. In addition, this report also assesses impacts to all marine biodiversity values related to the project in accordance with the NSW Department of Primary Industries (Fisheries) (DPI Fisheries) *Policy and Guidelines for Fish Habitat Conservation and Management* (NSW DPI, 2013a) under the *Fisheries Management Act 1994* (FM Act) with guidance from the *Aquatic Ecology in Environmental Impact Assessment – EIA Guideline* (Lincoln Smith, 2003).

1.7 Avoid and minimise

Under the Roads and Maritime Services (Roads and Maritime) *Biodiversity Guidelines: Protecting and managing biodiversity on RTA projects* (Roads and Traffic Authority (RTA), 2011) the management of biodiversity should aim to:

1. Avoid and minimise impacts first
2. Mitigate impacts where avoidance is not possible
3. Offset where residual impacts cannot be avoided (Section 6).

NSW Department of Planning, Industry and Environment (DPIE) (Regions, Industry, Agriculture & Resources) requires that proponents should, as a first priority, aim to avoid impacts upon key fish as a general principle. Where avoidance is impossible or impractical, proponents should then aim to minimise impacts. Any remaining impacts should then be offset with compensatory works (Section 6). NSW DPI assesses activity and development proposals in relation to general policies and with consideration for the 'sensitivity' of the affected fish habitat.

The Secretary's environmental assessment requirements issued for the project specifically identified the following as a key issue and desired performance outcome:

"The project design considers all feasible measures to avoid and minimise impacts on terrestrial and aquatic biodiversity."

The project has been designed to avoid and minimise potential impacts on marine ecology. The existing project footprint has been reduced as far as practicable to avoid areas of marine vegetation and habitat. Standard management measures would be implemented throughout the project area to minimise potential impacts on marine ecology. These include:

> Treatment of tunnel wastewater via a treatment plant prior to discharge from work areas to avoid adverse impacts on water quality in the harbour

> Installation of silt curtains during dredging

> Use of a closed environmental bucket (clamshell)

> Construction staging

> Management of contaminated sediments and acid sulfate soils.

Further detailed information in relation to the description of the project along with the parameters of associated construction activities (and how they are to be managed) are presented in Chapter 5 (Project description) and Chapter 6 (Construction work) of the environmental impact statement and would be further refined during the detailed design process to reduce the area of impact to marine vegetation and habitat.

Residual impacts on marine ecology as a result of the project are predicted (Section 5.2) and measures are recommended to mitigate these impacts to achieve a 'no net loss' of marine habitats (Section 6), in particular key fish habitat.

1.8 Legislative context

Legislation and planning policies relevant to the protection of marine biodiversity or their habitats outlined in this report are provided below. These statutory instruments provide conditions, matters for consideration and requirements to seek authorisation (licences and approvals) to carry out various actions and activities. The list of NSW and Australian Government legislation with relevance to this assessment are:

> NSW *Environmental Planning and Assessment Act 1979* (EP&A Act)

> NSW *Fisheries Management Act 1994* (FM Act)

> NSW *Coastal Management Act 2016* (CM Act)

> Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

1.8.1 Environmental Planning and Assessment Act 1979

All projects assessed as state significant infrastructure under Part 5, Division 5.2 of the EP&A Act requires an environmental impact statement to address the Secretary's environmental assessment requirements (see Section 1.6).

According to the Secretary's environmental assessment requirements, the environmental impact statement must assess marine mammals and Matters of National Environmental Significance (MNES) in addition to the assessment of biodiversity impacts in accordance with the BAM (addressed in the *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Biodiversity development assessment report* (Arcadis, 2020)).

1.8.2 Fisheries Management Act 1994

The FM Act contains provisions for the conservation of fish stocks, key fish habitat, biodiversity, threatened species, populations and ecological communities. The FM Act regulates the conservation of fish, marine vegetation and some aquatic macroinvertebrates and the development and sharing of fishery resources of

NSW for present and future generations. Part 7 of the FM Act identifies requirements for the protection of aquatic habitats while Part 7A of the FM Act lists threatened species, populations and ecological communities and key threatening processes (KTPs) for species, populations and ecological communities in NSW waters. Section 220ZZ of the FM Act outlines significant impact considerations to threatened species, populations and ecological communities listed under the FM Act.

1.8.3 Biodiversity Conservation Act 2016

The BC Act contains provisions for the conservation of some NSW marine threatened species, populations and communities not covered under the FM Act. Potential impacts on threat-listed marine mammals listed under the BC Act are addressed in this report. Listed seabirds would be addressed in the Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Biodiversity development assessment report (Arcadis, 2020).

1.8.4 Coastal Management Act 2016

The previous *Coastal Protection Act 1979* was implemented through a series of coastal zone management plans (CZMPs). However, CZMPs will now be superseded by the development of coastal management programs in four areas across NSW as part of the coastal management legislation reform gazetted in the new CM Act. The four areas are defined in the new CM Act as part of the new *State Environmental Planning Policy (Coastal Management) 2018* (Coastal Management SEPP). The Coastal Management SEPP will integrate and improve current coastal-related SEPPs and ensure that future coastal development is appropriate and sensitive to our coastal environment, and that public access to beaches and foreshore areas are maintained. The Coastal Management SEPP is the single land use planning policy for coastal development, bringing together and modernising provisions from SEPP 14 – Coastal Wetlands, SEPP 26 – Littoral Rainforest and SEPP 71 – Coastal Protection.

1.8.5 Environment Protection and Biodiversity Conservation Act 1999

The EPBC Act protects nationally and internationally important flora, fauna, ecological communities and heritage places, which are defined in the EPBC Act as Matters of National Environmental Significance (MNES). MNES relevant to marine biodiversity are:

- Wetlands of international importance
- Nationally listed threatened species and ecological communities
- Migratory species
- Commonwealth marine areas.

The significance of impacts on MNES is determined in accordance with the *Significant Impact Guidelines 1.1 – Matters of National Environmental Significance* (Department of the Environment (DoE), 2013).

Where an action is likely to have a significant impact on a MNES, the action is referred to the Federal Environment Minister. The referral process involves a decision on whether or not the action is a ‘controlled action’. When an action is declared a controlled action, approval from the Minister is required.

1.9 Previous investigations for the project

A number of marine ecological investigations were done during the early planning stages for the project.

A preliminary environmental investigation (PEI) identified the key issues to marine ecology potentially associated with the project with respect to marine habitat, threatened species and other biota and to wildlife connectivity corridors (Cardno, 2016). The PEI supported a State Significant Infrastructure application for the project.

This report builds on and incorporates the relevant details from these previous investigations where appropriate.

1.10 Other project investigations

The marine ecology assessment has been informed by predictions of changes to marine water quality, sedimentation, hydrodynamics, underwater noise and mobilisation of contaminants during construction. These predictions were detailed in various specialist reports including:

- *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Marine water quality* (Cardno, 2020)

- Summaries from the *Western Harbour Tunnel and Beaches Link Geotechnical Investigation: Contamination Factual Report – Marine Investigations* (Douglas Partners and Golder Associates, 2017)
- *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Contamination* (Jacobs, 2020)
- *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Hydrodynamic and dredge plume modelling* (Royal Haskoning DHV, 2020).

1.11 Definitions

The following definitions are used in this report:

- This report: this marine ecology technical paper
- The project: refers to that described in Sections 1.2 and 1.2.2
- Project area: refers to the area to be directly impacted by the project
- Study area: refers to the estuarine areas from the highest astronomical tide (HAT) encompassing the project area, and areas adjacent from Gladesville Bridge and the open water area just to the east of Garden Island and Robertsons Point (about 1197.84 hectares) (Figure 1-6)
- Study locality: refers to an area within 10 kilometres of the project area (for the purpose of the desktop review) (Figure 1-6).

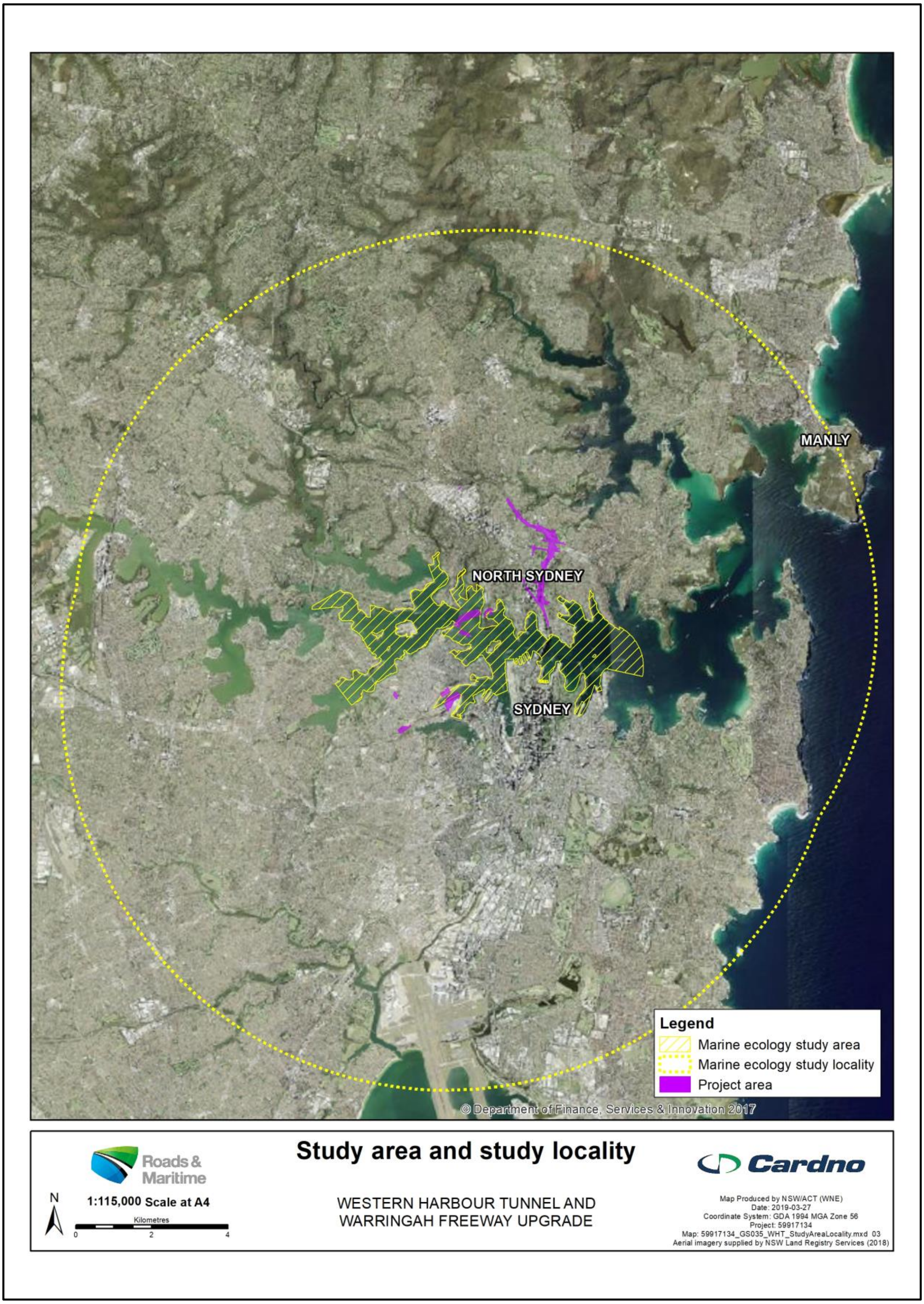

Figure 1-6 Study area and study locality

2 Methods

2.1 Overview

This chapter provides details of the marine ecology assessment approach to background research, field surveys, data analyses, risk assessment and impact assessment for the biodiversity values of the study area.

This report presents the results of these studies and the assessment of potential impacts as a result of the project. To address the Secretary's environmental assessment requirements, this report has been developed in accordance with the following policy and guidelines:

- *Policy and Guidelines for Fish Habitat Conservation and Management* (NSW DPI, 2013a)
- *Why Do Fish Need to Cross the Road? Fish Passage Requirements for Waterway Crossings* (Fairfull & Witheridge, 2003)
- *Aquatic Ecology in Environmental Impact Assessment – EIA Guideline* (Lincoln Smith, 2003).

The *Policy and Guidelines for Fish Habitat Conservation and Management* (the Policy) (NSW DPI, 2013a) outlines the information requirements for proposed developments for DPI (Fisheries) to confidently assess the potential for impacts. In addition to subject matter about the nature of the development, the requirements include:

- A clear description of the aquatic environment (within the project area as well as a regional context)
- The condition of potentially affected habitats
- An aquatic fauna assessment.

In compiling this information, a proponent can consider whether adequate existing information is available (ie previous studies) for a robust assessment of impacts. However, if the existing information is inadequate, then the policy and the associated document entitled *Aquatic Ecology in Environmental Impact Assessment – EIA Guideline* (Lincoln Smith, 2003) recommends that detailed field studies are carried out to fill gaps in information.

To minimise any duplication of works already commissioned, this report builds on previous investigations already done. It includes a combination of desktop and field studies based on the results of initial screening of existing information about key habitats and biota relevant to the project (ie from the previous studies). The habitats with potential to be affected by the project include the following nearshore habitats:

- Seagrass
- Subtidal rocky reef
- Intertidal rocky shore
- Soft sediment
- Deepwater habitats:
  - Soft sediment
  - Open water (for fish and marine mammals and reptiles).

Fish passage within (or that relies upon) these habitats also required investigation.

Investigations involved an initial screening of desktop information to determine the availability and adequacy of existing information for describing existing conditions and assessing the potential impacts of the project. It was considered that desktop studies would be sufficient for the assessment of the project on 'fish passage', 'deeper water fish communities' and 'marine mammals and marine reptiles'. However, field-based data collection (of habitat condition and biota) was required in some habitats in potential impact areas of the project and nearby areas for context (the study area) due to the lack of suitable, existing site-specific information for many key habitats.

The potential for direct and indirect impacts of the project on the locality and quality of habitats and biota within the study area (as determined from the combination of desktop and field data) was assessed by determining tolerances of habitats and biota to potential impacts from the project during its construction and operational phases. A risk assessment assisted with this process.

2.1.1 The marine ecology assessment methodology

The *Policy and Guidelines for Fish Habitat Conservation and Management* (NSW DPI, 2013a) and the associated document *Aquatic Ecology in Environmental Impact Assessment – EIA Guideline* (Lincoln Smith, 2003) require an aquatic ecology assessment to be done as part of an environmental impact statement. A description of the approach used here (and the relevant sections of this report) is given below.

1. **Establish the context.** Context included information about the aquatic environment and activities and stages of the project
   a. **Identify biodiversity values**. Sufficient detail of the extent and quality of aquatic habitats and biota within the project area and surrounding areas along with an understanding of the sensitivity of each of constituents (Section 3) is required for an assessment of potential impacts
   b. **Identify hazards associated with the project**. The effects of a project on the environment are unique, due to its construction, operation and location. These can be categorised in terms of their potential physical, chemical and biological effects, which help to focus on the nature of impacts and their likely magnitude (Section 4)
2. **Determine the risk of hazards to biodiversity values*.*** The risk of hazards vary depending on the sensitivity and resilience of receivers to disturbance but also with respect to the type of disturbance (ie pulse, or acute and short-term disturbances; press, sustained or chronic disturbance which may cause a long-term response; or catastrophic, major destruction with limited ability for a recovery). These factors can be considered for each biodiversity value in a risk analysis framework that incorporates both the likelihood of a hazard occurring and its consequence (Section 5.1)
3. **Identify key issues*.*** The *Aquatic Ecology in Environmental Impact Assessment – EIA Guideline* (Lincoln Smith, 2003) indicates that predictions regarding the effects of a proposed project should be evaluated in terms of their relative importance, and with particular regard to the value of the ecosystem. Key issues were identified for impact assessment (Section 5.1.3)
4. **Evaluate potential impacts on key issues.** Potential impacts on key issues were evaluated according to an understanding of the project, predictions of changes that would result from the project and knowledge of the habitats and biota in the study area. (Section 5.2)
5. **Mitigate residual impacts and apply offsetting.** There is scope for mitigating the effects of a project in the way it is designed, constructional activities, long-term operational aspects and timing of activities associated with construction and operation. Aquatic ecology has been considered early in the design phase (Section 1.7) but also to minimise the potential for impacts during construction (Section 6).

2.2 Personnel

The Marine Ecology Technical Paper was prepared by the following personnel:

> Dr Craig Blount (BSc (Hons), PhD, Grad Dip) – technical lead

> Dr Marcus Lincoln Smith (BA, BSc (Hons), MSc, PhD) – technical advisor

> Dilys Zhang (BSc (Hons)) – aquatic ecologist.

Cardno also employed a number of field and laboratory technicians for the duration of the field survey including:

> Kate Reeds (BSc (Hons), MSc) – aquatic ecologist

> Chris Roberts (BSc (Hons)) – aquatic ecologist

> Yesmin Chikhani (BSc Hons) – aquatic ecologist

> Ivon Jolan Sebastian (BSc Hons) – aquatic ecologist

> Matt Smith (BSc (Hons)) – environmental scientist

> Chloe Vandervord (BSc, MSc) – environmental scientist

> Jamie Maclean (BSc Hons) – environmental scientist.

2.3 Background research

The following databases were searched for records of listed threatened marine and coastal species, populations and communities, migratory species, protected species and marine pests in the study locality:

> BioNet the website for the Atlas of NSW Wildlife: www.bionet.nsw.gov.au

> NSW Office and Environment and Heritage (OEH) Threatened Species Profile Database: www.environment.nsw.gov.au/threatenedspecies NSW DPI Fish Communities and Threatened Species Distribution of NSW (NSW DPI, 2016a)

> NSW DPI Listed Threatened Species, Populations and Ecological Communities website: www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current#key

> NSW DPI Listed Protected Fish Species website: www.dpi.nsw.gov.au/fishing/species-protection/conservation/identifying

> NSW DPI *Mapping The Habitats of NSW Estuaries* (Creese, et al., 2009)

> Department of the Environment and Energy (DoEE) (formerly DoE) Protected Matters Search Tool (PMST): www.environment.gov.au/epbc/protected-matters-search-tool

> Atlas of Living Australia: www.ala.org.au/

> The National System for the Prevention and Management of Marine Pest Incursions website: www.marinepests.gov.au/Pages/default.aspx

> Aerial imagery from PhotoMaps by Nearmap (http://maps.au.nearmap.com/)was used to identify potential marine vegetation and habitat for the creation of presumptive maps

Any sensitive ecological sites (eg Commonwealth Marine Reserve, National Parks/Reserves, conservation areas, wetlands and other reserves) and areas protected by State and local environmental planning instruments (EPIs) due to their ecological significance were also identified using:

> Regional Conservation Plans prepared by NSW OEH: www.environment.nsw.gov.au/biodiversity/regconsplans.htm

> NSW DPI Critical Habitat register: www.dpi.nsw.gov.au/fisheries/species-protection/conservation/what/register

> NSW DPI key fish habitat maps: www.dpi.nsw.gov.au/fishing/habitat/publications/pubs/key-fish-habitat-maps

> Australian Government DoEE Register of Critical Habitat: www.environment.gov.au/cgi-bin/sprat/public/publicregisterofcriticalhabitat.pl

> Locations of NSW marine parks and Commonwealth marine reserves available from NSW DPI Marine Parks website: www.dpi.nsw.gov.au/fishing/marine-protected-areas/marine-parks and DoEE Australian marine parks website for the temperate east network: www.environment.gov.au/topics/marine/marine-reserves/temperate-east

> Location of Commonwealth Marine Reserves: www.environment.gov.au/topics/marine/marine-reserves

> Marine Bioregional Plans for the temperate east prepared by DoEE: www.environment.gov.au/marine/marine-bioregional-plans.

2.4 Field survey

Field surveys of the marine habitat within the study area were conducted between Gladesville Bridge and the open water area just to the east of Garden Island and Robertsons Point (Figure 1-6). The surveys were to determine the characteristics and condition of marine communities and potential flora and fauna habitat, with particular consideration given to species of conservation concern identified during background research (Section 2.3), such as threatened, protected and/or migratory species. Methodology for the marine field survey is described below.

The first task was to produce presumptive habitat maps for focused investigations of biota and habitat quality. Mapping work was carried out to inform the preliminary assessment. Gaps were identified and this information was verified with additional field mapping to identify key habitats with potential to be impacted.

The next task was to conduct field surveys of biota and habitat where existing information (ie previous studies) was inadequate for a robust assessment of impacts (see Section 2.1). These included investigations of the following habitats:

> Seagrass
> Subtidal rocky reef
> Intertidal rocky shore
> Subtidal soft sediment.

Investigations were one-off snap-shot surveys. Information about temporal variability within these habitats was inferred from desktop information.

2.4.1 Weather and sea conditions

The weather and sea conditions during the field survey campaign in association with the field activity is summarised in Table 2-1 (Bureau of Meteorology (BoM), 2018; WillyWeather, 2018).

Table 2-1 Weather and sea conditions during the field survey campaign

Date	Activity	Temperature range (°C)	Rainfall (mm)	Wind direction	Wind speed (km/h)	High tide (time, m)	Low tide (time, m)
20/11/2017	Deepwater soft sediment surveys	17.2-21.3	2.8	SE	11-33	10.04, 1.73 m	16.38, 0.38 m
21/11/2017		17.0-21.5	1.6	E	9-30	10.39, 1.71 m	17.15, 0.40 m
22/11/2017		17.1-21.9	7.8	ENE	7-30	11.15, 1.68 m	17.56, 0.43 m
23/11/2017		17.8-21.5	0.0	NNE	9-41	11.53, 1.63 m	18.38, 0.47 m
24/11/2017		18.1-22.3	0.0	NNE	7-44	12.35, 1.57 m	19.26, 0.51 m
28/11/2017		19.1-23.5	0.0	SE	7-31	04.28, 1.32 m	10.13, 0.71 m
29/11/2017		20.1-23.9	0.8	E	11-22	05.21, 1.42 m	11.19, 0.64 m
6/12/2017	Intertidal rocky shore surveys	17.8-24.9	4.4	SSW	20-48	11.01, 2.01 m	17.43, 0.14 m
7/12/2017		17.9-28.4	5.6	NNE	17-46	11.54, 1.95 m	18.39, 0.20 m
11/12/2017	Seagrass surveys	18.3-22.2	0.0	NE	17-44	15.52, 1.48 m	09.44, 0.66 m
12/12/2017		20.4-22.5	0.0	NE	11-46	16.56, 1.40 m	10.55, 0.65 m
20/12/2017	Subtidal rocky reef surveys	22.2 -31	0.0	SSW	7-81	10.17, 1.75 m	16.55, 0.38 m
20/12/2017		22.4-31.0	0.0	SSW	7-81	10.17, 1.75 m	16.55, 0.38 m
21/12/2017		21.1-23.0	3.0	SE	22-39	10.53, 1.73 m	17.32, 0.40 m
22/12/2017		20.8-23.2	0.2	ENE	13-31	11.30, 1.69 m	18.11, 0.42 m
29/01/2018		23.0-24.9	0.0	NE	13-35	10.03, 1.82 m	16.35, 0.28 m
30/01/2018		21.6-24.9	0.0	NE	7-50	10.43, 1.82 m	17.14, 0.27 m

Date	Activity	Temperature range (°C)	Rainfall (mm)	Wind direction	Wind speed (km/h)	High tide (time, m)	Low tide (time, m)
07/02/2018		20.6-25.1	0.0	NE	9-41	05.53, 1.70 m	12.37, 0.42 m

2.4.2 General survey locations and site selection

Potential impacts during construction for the project could occur within parts of Sydney Harbour. As such, sampling effort (in habitats) needed to be distributed in such a way so that the data collected was representative of the entire area of potential impact (Figure 2-1). For the purposes of allocating sampling effort, this area was defined by preliminary investigations. Sampling was done at an appropriate number of sites and with a suitable number of sampling units to provide for both adequate representation (of the variability among sites for particular habitats) and precision.

Site selection also considered the collection of contextual data across the study area. The wide extent of data collection was aimed at providing the necessary context for the assessment of potential impacts from the project (ie whether a particular habitat, and the biota within it, was regionally extensive or unique).

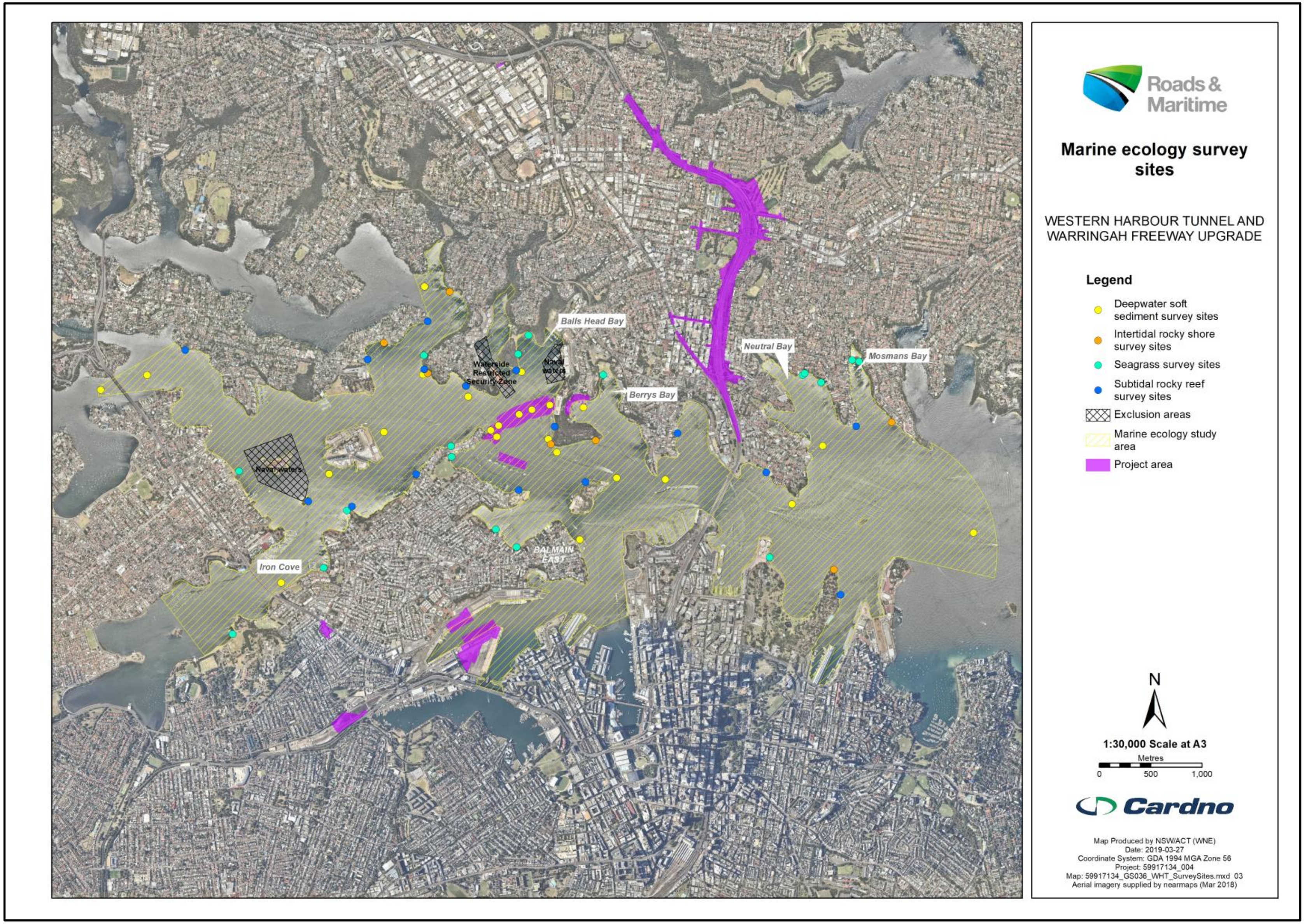

Figure 2-1 Marine ecology survey sites

2.4.3 Habitat mapping

Presumptive habitat maps were created for the study area using ArcGIS 10.4.1 from an orthorectified aerial photograph captured on 6 May 2017 (NearMap, 2017). Potential seagrass and macroalgae beds were then outlined on a preliminary map layer via on-screen digitising at a scale of 1:600 to demarcate likely seagrass and macroalgae bed boundaries as polygons determined from dark areas on the photos and from marine vegetation maps of the harbour previously prepared by Creese et al (2009). Survey points were then overlayed onto polygons to provide a reference for field validation.

Fieldwork was carried out from a five metre Cardno survey vessel using a combination of underwater towed video camera and/or bathyscope. Weather conditions at the time of sampling were good with reasonable underwater visibility (about three to four metres). The vessel navigated to the pre-determined survey points within all identified beds of seagrass (and/or reef/macroalgae) using an iPad and hand held GPS accurate to two metres. At each location, the habitat was verified and/or reclassified according to the categories below. For larger beds, the video was towed through the bed to help assign habitat types.

Seagrasses were classified as follows:

> Species: Zostera (*Zostera muelleri* subsp. *capricorni* [previously *Zostera capricorni*])/Posidonia (*Posidonia australis*)/Halophila (*Halophila* spp.)

> Density: high (greater than 50 per cent cover), medium (between 15 and 50 per cent cover) and low (less than 15 per cent cover).

Reef habitat was classified into two major groups:

> Reef with monospecific macroalgal communities

> Reef with mixed macroalgal communities.

The complexity of reef habitat was also classified, given complexity was considered to be a reasonable indicator of the potential for an area of reef to be habitat for black rockcod (*Epinephelus daemelii*). Habitat complexity was categorised as either:

> High = greater than one metre high relief complex habitat associated with natural, unmodified shoreline, includes consolidated or boulder reef with/without macroalgae (Plate E1 in Appendix E)

> Medium = 0.5 to one metre medium relief complex habitat associated with natural or modified shoreline, includes consolidated or boulder reef with/without macroalgae (Plate E2 in Appendix E)

> Low = less than 0.5 metres low relief reef with/without macroalgae (Plate E3 in Appendix E).

Following completion of the field survey, polygons drawn in the presumptive maps were reclassified as per the results of the field validation exercise. Any areas which appeared as seagrass or macroalgae in the aerial imagery but were not marine vegetation (eg dead wrack, submerged rocks or detritus) were removed from the final maps. There were some areas where the habitat was mixed (eg Zostera with an understorey of Halophila). Where a mixed habitat occurred within an area, these were differentiated by the most abundant seagrass species.

2.4.4 Seagrass

Habitat mapping (see Section 2.4.3) indicated that Zostera and Halophila seagrass occurred within the study area while Posidonia was only present outside of the study area. Eight (n=8) seagrass survey sites were selected for Zostera and Halophila within the study area (Figure 2-1).

At each site, divers counted seagrass shoot density in five randomly placed (50 x 50 centimetres) quadrats, measured the length of 10 leaves from seagrass plants and recorded their epiphyte load as either low (up to 25 per cent cover), moderate (from 30 to 50 per cent cover) or high (greater than 50 per cent cover).

2.4.5 Subtidal rocky reef

Habitat mapping (see Section 2.4.3) indicated that high, medium and low relief reef occurred within the study area. Sampling was prioritised in the high and medium relief reef habitats given these were considered potential habitat of the threatened black rockcod which is known to occur in Sydney Harbour.

Eight (n=8) subtidal rocky reef survey sites were selected for medium and high relief rocky reef within the study area (Figure 2-1).

At each site, divers measured percentage cover of macroalgae and sessile invertebrates in four randomly placed (1 x 1 metre) quadrats. At each site, divers also carried out three, four minute timed underwater visual counts (UVCs) to count fish and collect opportunistic information about the suitability of habitat for black rockcod, or occurrence of individuals.

2.4.6 Intertidal rocky shore

Intertidal rocky shores were known to occur within the study area (see Section 2.4.2). Eight (n=8) intertidal rocky shore sites were selected within the study area of potential impact (Figure 2-1).

At each site at low tide staff measured percentage cover of macroalgae and sessile invertebrates and counted mobile invertebrates in four randomly placed (50 x 50 centimetres) quadrats at two shore heights. The shore heights were low shore (defined at the lowest height by the low tide mark and at the high point by the general extent of macroalgae) and high shore (defined at the lowest height by the general extent of macroalgae and at the high point by the general extent of mobile invertebrates).

2.4.7 Deepwater soft sediment

Habitat mapping indicated that deeper areas within the study area consisted mostly of soft sediment habitat. Given the dredge footprint and potentially affected areas have a large range in depth and that diversity of intertidal biota varies with depth, sampling was done in the following strata: shallow (five to15 metres depth) and deep (greater than 15 metres depth) deepwater soft sediment areas. Sampling was done at 12 (n=12) randomly selected sites in each of depth strata throughout the study area (Figure 2-1).

A five metre survey vessel navigated to each predetermined sampling site using an iPad and hand held GPS. Once on site, a Van Veen grab (an instrument used to sample sediment in the water) was deployed to collect three samples of sediment containing infauna (animals living within the sediment). Two, 50 metre towed video transects were also conducted. Towed video transects within the site were about 10 metres apart. After sediment samples were collected they were sieved at Cardno's laboratory through a one millimetre mesh sieve and the retained sediment and infauna transferred to a labelled bag, fixed with formalin and stained with rose-bengal solution. Samples collected for analysis of macroinvertebrates were processed at Cardno's in-house laboratory. Prior to sorting, samples were drained of the excess formalin over a one millimetre sieve, rinsed under water and transferred to an alcohol solution for preservation and identification and counts. Infauna from each sample were removed from the sediment under a binocular microscope into major taxonomic groups. All infauna from each sample were then counted and identified to family level or higher, whichever was practical for that group.

Video from transects was downloaded and viewed to identify epibiota (organisms living on the surface of the bed of the harbour) visible on the surface. Percentage cover of epibiota in proportion to the two, 50 metres transects was recorded.

2.5 Data analyses

The sampling design and data collected lends itself to statistical analyses. These were necessary to support conclusions about similarity (or differences) among assemblages in the study area for potential impacts from the project as determined for particular areas. The analyses proposed fell into the following categories:

> General findings including graphs and tables describing abundances or per cent covers of biota or other attributes within intertidal, seagrass, subtidal rocky reef and subtidal soft sediment habitats

> Multivariate statistical analyses of entire assemblages in each of the habitats using PERMANOVA (permutational multivariate analysis of variance) and principle coordinate analyses (PCO) to examine spatial differences among sites within the study area.

For seagrass, the analytical design for analysis of samples consisted of one factor ('site'), a random factor with various levels (ie levels of the factor 'site' depended on the number of sites sampled for each habitat):

> 'Site' had eight levels. Separate analyses were done for Halophila and Zostera.

For intertidal habitats, separate analyses were done for per cent cover of macroalgae and counts of mobile invertebrates. The analytical design for analysis of samples consisted of two factors:

> Height, which included the levels of 'low' and 'high' shores

> 'Site', a random factor nested within height with eight sites nested within each height strata.

For subtidal rocky reef habitats, separate analyses were done for macroalgae and fish. The analytical design for analysis of samples consisted of two factors:

> 'Relief', which included the levels of 'high and 'medium'

> 'Site', a random factor nested within 'relief' with eight sites nested within each relief strata.

For subtidal soft sediment habitat, statistical analyses were done for samples of infauna but given the limited data collected for epifauna in video, only general findings of these data were presented in tables. The analytical design for analysis of samples consisted of two factors:

> 'Depth'

> 'Site', a random factor nested within depth with twelve sites nested within each depth strata.

2.5.1 Multivariate

A matrix of differences in the types and relative abundance of the taxa between all possible pairs of benthic infauna samples was compiled by calculating their respective Bray-Curtis dissimilarity coefficients[1]. Data transformations, which reduce the influence of highly abundant animals and thereby ensure that dissimilarities reflect groups of animals with large and moderate abundances, were not considered necessary.

Permutational analysis of variance (PERMANOVA+ in Primer v6) was used to examine spatial differences in assemblages. Differences among sites were examined by *post-hoc* permutational t-tests, where appropriate. Only statistical differences with a significance level of $P \leq 0.05$ were considered. Significant differences between sites, if present, may arise due to differences between site means, differences in dispersion (equivalent to variance) among sites or a combination of both.

Multivariate patterns in the data were examined using the PCO routine in PERMANOVA+. This is a generalised form of principal components analysis (PCA) in which samples are projected onto linear axes based on their dissimilarities in a way that best describes the patterns among them while using as few dimensions as possible (Clarke and Gorley, 2006). The amount of variation explained by each principal axis is indicated and the dissimilarity between data points can be determined from their distances apart on the axes (Anderson et al., 2008).

2.6 Limitations

Survey efficacy is influenced by a range of factors. Fieldwork for this study was completed during summer. For this type of survey, limitations are generally due to a single, short duration survey that does not account for seasonal or other temporal variation. The detection of certain species may be affected by:

> Seasonal migration (particularly migratory and transient species)

> Seasonal availability of food for fauna

> Weather conditions during the survey period (some species may go through cycles of activity related to specific weather conditions)

> Species lifecycle (cycles of activity related to breeding).

These potential limitations have been addressed by applying the precautionary principle in cases where the survey methodology may have given a false negative result (eg a species that could reasonably be expected to occur, based on previous records and available habitat, was not observed). All species (including threatened species) have been assessed on the basis of the presence of their habitat and the likely significance of that habitat to a viable local population.

The study area had a number of exclusion areas where access was restricted (Figure 2-1). Information from these areas required to complete the impact assessment (where required) was derived from existing information (where available) and noted.

[1] **Bray–Curtis dissimilarity** is a statistic used to quantify the compositional dissimilarity between two different sites, based on counts at each site

2.7 Impact assessment (including risk analysis)

The assessment of potential impacts on receiving habitats and biota as a result of project construction and operational activities required:

> Predictions of the extents, intensities, frequencies and durations of hazards from project construction and operational activities relative to ambient levels

> A description of the locality, quality and sensitivities of habitats and biota within the spatial extent of predicted dredge plumes

> The tolerances of habitats and biota to the hazards.

A risk analysis was used to investigate the above information and to identify key issues associated with the project and ultimately focus the impact assessment. For example, if the risk analysis had shown there to be a moderate risk to the growth of a particular species of seagrass from dredge plumes, the impact assessment would interpret the implications of this to the species survival at a local and broader level.

Key inputs to the risk analysis were:

> Determination of the Zones of High Impact (ZoHI), Moderate Impact (ZoMI) and Influence (ZoI) - refer below for further description of these zones

> Identification of contaminants in the dredging footprint (Douglas Partners and Golder Associates, 2017)

> Modelling of changes to hydrodynamics, e-folding times and sedimentation due to project construction and operational activities carried out by Royal Haskoning DHV (Royal Haskoning DHV, 2020)

> An acoustic modelling study of underwater noise generated during the in-water construction activities of dredging and pile installation done by JASCO (2019).

The Western Australian Environmental Protection Authority Technical Guidance Document *Environmental Impact Assessment of Marine Dredging Proposals* (EPA, 2016) provides a useful approach for presenting predictions of the likely range of environmental impacts of dredging, which in turn, provides the basis for facilitating the transfer of these predictions into recommended conditions and environmental monitoring and management strategies. This approach has been used to assist with the assessment of impacts from the project. The effects of dredging are mapped in terms of zones of Impact and Influence. These zones are defined as:

> Zone of High Impact (ZoHI): This zone constitutes the direct footprint of the project and includes the dredged area and any nearshore footprints (project areas). Impacts in these areas are predicted to be severe and often irreversible

> Zone of Moderate Impact (ZoMI): This zone abuts on and lies immediately outside the ZoHI. Within the ZoMI, damage/mortality of benthic communities may occur primarily as a result of the indirect impacts from increased turbidity and sedimentation that may occur at times over areas within the zone. Impacts within this zone are predicted, but the disturbed areas may recover after completion of the dredging and disposal operations. It is expected that there would be no long-term modification of the benthic habitats

> Zone of Influence (ZoI): This zone includes the areas which at some time during the dredging activities may experience (detectable) changes in water quality or sedimentation outside the natural ranges that are the norm.

To delineate these zones, the potential impact of dredging related excess turbidity and excess sedimentation (considered to be greater than five millimetres) on a particular type of habitat or biota, an assessment of estimated ecological tolerance limits for each habitat type or biota is required. Tolerance limits for habitats are generally derived in two different ways:

> Tolerance limits for turbidity are derived from water quality monitoring data, with the argument that resident flora and fauna are adapted to local conditions but would be stressed if exposed to conditions that regularly exceed normally prevailing background concentrations

> Tolerance limits for sediment deposition are derived from habitat-specific dose-response experiments and field observations reported in the scientific literature.

Given dose-responses were unavailable for most species in the study area, tolerance limits for habitats were derived from marine water quality monitoring data (Cardno, 2020).

2.7.1 Risk analysis

A qualitative risk analysis was carried out to identify potential risks associated with the project, to determine and evaluate the level of risk associated with activities. The risk assessment process was based on the Australian and New Zealand Standard guidelines for risk management (AS/NZS 4360:2004) and the Handbook for Environmental Risk Management – Principles and Process (HB 203:2006) (Standards Australia, 2006) which are considered international benchmarks in standard risk management. Risk is defined as the chance of something happening that will have an impact on objectives. It is measured in terms of consequences and their likelihood. Risk in the environmental context should be thought of as the environmental consequences of a given severity and the likelihood of that particular consequence occurring (AS/NZS 4360: 2004).

Risk analysis is a tool to help identify the appropriate level of management required and also to assist with an assessment of impacts by identifying key issues to biodiversity values within the study area (see below).

The risk analysis involved the following steps:

1. Identification of biodiversity values
2. Hazard identification
3. Identification of risk levels.

Biodiversity values within the study were determined from a combination of a review of existing information and the project-specific field investigations. These are detailed in Section 5.1.1.

Potential hazards (project activities that have a potential impact pathway associated) in relation to the biodiversity values of the study area were identified through a combination of specialist advice, literature review, stakeholder consultation and from issues identified in the Secretary's environmental assessment requirements. The risk analysis was used to identify the relative significance of hazards both before and after the treatment of risks (ie after consideration of proposed mitigation).

Potential hazards that may be associated with construction as well as operational activities of the crossing are given in Section 4.

The risk analysis comprises an assessment of the level of consequence of individual potential impacts and the likelihood of the impact occurring, and a score was assigned to each consequence and likelihood. The rationale for scoring likelihood and consequence of a potential impact occurring is given in Table 2-2 and Table 2-3. Scores of likelihood and consequence are then combined into a matrix to provide a qualitative assessment of risk for individual natural values as shown in Table 2-4. Based on this, each risk is identified as low, moderate, high or extreme. This does not mean that the project should not proceed (ie if the level of risk is high) or that an issue should be ignored if the level of risk is considered low, but rather that the issue may need greater or less effort in management and mitigation or that further research on the receiving environment is required. Consequence criteria were formulated based on the Significant Impact Guidelines for EPBC Act MNES and considered the potential for direct impacts (for example, loss of habitat in the crossing footprint) and indirect impacts (for example, altered community structure in response to altered water quality), and irreversible or temporary impacts.

Table 2-2 Qualitative measures of likelihood

Likelihood	Description
Almost certain	Is expected to occur as a result of the project under most circumstances.
Likely	Will probably occur as a result of the project in most circumstances.
Possible	Could occur and has occurred in similar circumstances.
Unlikely	Could occur as a result of the project but is not expected.
Rare	Could occur only in exceptional circumstances.

Table 2-3 Qualitative measures of consequence adjusted to the spatial scale of the project marine area

Consequence	Description
Catastrophic	Widespread impact to habitat/species throughout the study area and potentially outside of this area – recovery longer than 10 years or unlikely.
Major	Localised or widespread impact to habitat/species within the study area – limited prospect of recovery.

Consequence	Description
Moderate	Localised or potentially widespread impact to habitat/species within the study area - recovery greater than two years.
Minor	Localised impact to habitat/species within the study area - recovery measurable within one to two years.
Insignificant	No impact on baseline environment (habitat/species) within the study area - no additional mitigation required.

Table 2-4 Risk matrix (after AS/NZ 4360:2004)

Likelihood \ Consequence	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Moderate	Moderate	High	Extreme	Extreme
Likely	Moderate	Moderate	High	High	Extreme
Possible	Low	Moderate	Moderate	High	Extreme
Unlikely	Low	Low	Moderate	Moderate	High
Rare	Low	Low	Moderate	Moderate	Moderate

E	Extreme risk	Risk is unmanageable and cannot be justified under any circumstances. Measures to reduce risk to a lower level are required.
H	High risk	Risk is significant and requires significant cost-effective measures for risk reduction and/or management.
M	Moderate risk	Routine and cost-effective measures required to reduce and/or manage risk. Risk may be acceptable.
L	Low risk	Risk can be managed by routine procedures and/or no further measures to manage the risk are required.

Key points about the general risk analysis:

> Potential impacts were identified through a combination of specialist advice, modelling, literature review and stakeholder consultation

> The categories for environmental consequence are based on duration and spatial scale of potential impacts. Those that are localised but reversible in one to two years were considered minor, whereas those that would last longer and more widespread have a greater consequence

> The risk analysis identifies the relative significance of risks with proposed mitigation (eg implementation of construction and operational environmental management plans for the project)

> Although some risks are considered to be low, further action may be recommended (through routine procedures) as appropriate.

Detailed discussion of the potential impacts of the project and the rationale for the levels of risk are discussed in the following sections.

3 Existing environment overview

3.1 Geology and socio-economics

The project resides along the foreshores and within the waters of Sydney Harbour (the harbour), the estuarine reaches of the Parramatta River estuary (the estuary) as defined by Birch (2006). Sydney Harbour is a drowned valley, tidal estuary (Roy, et al., 2001; Sydney Institute of Marine Science, 2014) about 30 kilometres long and occupies about 5000 hectares (Birch, 2006). The Parramatta River was deeply incised in Hawkesbury sandstone between 15 and 29 million years ago. Subsequent sea level rise, about 17,000 years ago, resulted in the flooding of the river valley, deposition of sediments and the formation of the tidal estuary.

The study area (defined in Section 1.11 and Figure 1-6) lies within the waters of Sydney Harbour in the Pittwater subregion of the Sydney Basin Bioregion (NSW National Parks and Wildlife Service, 2003). This subregion is characterised by small beach, dune and lagoon barrier systems and steep coastal cliffs and rock platforms. The bathymetry of the study area is a composite of the natural geology and anthropogenic alterations. A wide depth range is a result of dredged shipping channels and deep holes (28 to 45 metres) separated by shoals of three to five metre depths (Sydney Institute of Marine Science, 2018). A number of shallow bays fringe the main channel on the northern and southern sides. Eighteen of these bays occur within the study area of which eleven are south of the main channel and seven are north of the main channel Along the south they are: Iron Cove; Snails Bay; Mort Bay; White Bay; Rozelle Bay; Blackwattle Bay; Darling Harbour; Walsh Bay; Circular Quay; Royal Botanic Gardens; Woolloomooloo; and along the north: Gore Cove; Balls Head Bay; Berrys Bay; Blues Bay; Lavender Bay; Milson Park; Neutral Bay; Mosman Bay.

Sydney Harbour is of high aesthetic, ecological and socio-economic importance to the most populated city in Australia. The foreshores of the estuary are highly urbanised and the harbour itself conducts a large volume of commercial and private boating activities. The estuary is the final destination for runoff from about 50,000 hectares of the catchment of which at least 86 per cent is urbanised and/or industrialised through a long history since the 1800s (Birch, 2006). The total natural area of the estuary has been reduced by 23 per cent over 220 years through extensive reclamation in areas such as Homebush Bay, Rhodes Peninsula, Blackwattle Bay, Darling Harbour and Woolloomooloo. Bays were enclosed by sandstone seawalls and the intertidal areas were reclaimed by infilling with garbage, industrial wastes and sediments removed from the floor of the adjacent estuary. These changes within the estuary have resulted in major alterations to ecological function, hydrology and physio-chemical attributes (Birch, 2006). Despite these changes the estuary has exhibited signs of recovery (Johnston, et al., 2015).

3.2 Coastal processes and hydrology

The poleward flowing East Australian Current (EAC) brings nutrient-depleted waters to the entrance of the harbour. Hence, the water at the entrance of the harbour is continually being renewed (Sydney Institute of Marine Science, 2014).

Water circulation in drowned valley estuaries is dominated by tidal currents as opposed to wind stress (Roy, et al., 2001; Sydney Institute of Marine Science, 2014). Tides are predominately semi-diurnal and reverse every six hours but can vary considerably spatially and temporally. Tidal velocities can reach up to 0.25 metres per second with the most distal branches of the estuary usually experiencing slower velocities, sometimes up to an order of magnitude less (Sydney Institute of Marine Science, 2014). In some areas of the estuary, tide-induced residual circulation forms a number of gyres at regions of complex geometry which may force the retention of biota or pollutants (Das, et al., 2000).

Three common wind patterns are known on Sydney Harbour. The strongest of the three originate from the south (southerlies) and occur about 17 per cent of the time. The most frequent of the three (about 22 per cent of the time) are north-easterlies while the least common of the three patterns are westerlies which usually occur during the winter months (Sydney Institute of Marine Science, 2014).

The Hawkesbury Sandstone is a recognised aquifer and elsewhere across Sydney provides a source of potable groundwater, though it often has elevated levels of iron (up to 300 ppm) and manganese (up to 15 ppm).

3.3 Sediment properties

The estuary lies on the southern edge of the Hornsby Plateau, an upland area of massive, vertically jointed Hawkesbury sandstone capped with Wianamatta Group shales (McLoughlin, 2000). Northern tributaries have cut deep steep-side valleys with little capacity for shorelines sediment accumulation without substantial filling of the valley. The Wianamatta Group shales weather rapidly to fine-grained and easily transported clays. Sediment deposits over bedrock range between 25 and 50 metres vertical depth downstream of the Harbour Bridge and 20 to 35 metres in channels and bays upstream of the Harbour Bridge. The acceleration of sedimentation within the estuary was triggered by the advent of vegetation clearing and soil disturbance from 1788 across the catchment (McLoughlin, 2000). The level of sedimentation was sufficient to completely fill some embayment areas on the southern side of the estuary upstream of the Balmain peninsula, creating alluvial flood plains and wetlands inundated only by spring tides. In 1986, sedimentation in channels and berthing basins was estimated at 15,000 to 20,000 cubic metres per year (Maritime Services Board Planning Branch, 1986). The process of removing accumulating silt, reshaping foreshores and bed of the harbour for shipping and amenities was virtually continuous for 140 years from 1842. Reclamation aimed to eliminate and replace mudflats and marshes with flat waterside for industry and recreation. As mentioned in Section 3.1, foreshore reclamation areas also became the final destination for dredged material which otherwise would be taken out to sea.

The present-day estuary comprises five environmental/sedimentological units including:

- Harbour entrance (marine flood-tide delta sands)
- Lower estuary (sands)
- Central estuary (muddy sands)
- Upper estuary (muds)
- Off-channel bays (muds) (Birch, 2006).

Generally, sediments west of Sow and Pigs Reef (west of units 1 and 2) are dominated by terrestrial mud (OzCoasts, 2015).

3.3.1 Acid sulfate sediments

Acid sulfate soils/sediments (ASS) is the common name given to naturally occurring soils and sediments that contain iron sulfate (pyrite). Acid sulfate soils/sediments are defined as either:

- Actual ASS (AASS) - highly acidic soils or sediments with pH <4, or
- Potential ASS (PASS) - soils or sediments containing sulphuric material that have not been oxidised but have potential for oxidation to generate high acidity.

The unconsolidated materials in the study area are either high risk ASS (mostly sediments that have been eroded from the land and deposited in the deeply cut bays) or disturbed terrain likely from reclamation activities.

3.3.2 Sediment quality

Further to dredged material, demolition and construction rubble and domestic, commercial and industrial waste were also used as reclamation fill at various locations across the estuary (Birch, 2006). Landfill along foreshore areas were also constructed of similar materials with the Homebush Bay area being one of the best documented cases. Soils and sediments of the estuary contained heavy metals, asbestos, hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and organochlorine pesticides (OCPs). Although Homebush Bay sediments were cleaned up prior to the Sydney 2000 Olympic Games and industrial activities on the foreshores have greatly reduced, leachates have been documented to enter the estuary from rainwater filtration and tidal action. Thus, high sediment contaminant concentrations at Homebush Bay and other bays in the estuary are likely to be the result of historical reclamation. Stormwater discharge locations also coincide with these bays and identifying the sources of sediment contamination is complex. Stormwater has been identified as the main, contemporary source of heavy metal contamination in the estuary (Montoya, 2015).

Some concentrations of heavy metals in sediments in Sydney Harbour have been documented to be the highest in Australia and internationally (Montoya, 2015). About 20 per cent of all copper, lead and zinc could be found in four bays in the estuary in the early 2000s: (1) Iron Cove; (2) Rozelle and Blackwattle Bays; (3) Homebush Bay; and (4) Hen and Chicken Bay. Iron Cove, Rozelle and Blackwattle bays are located within the study area while the latter two bays are located further upstream. Other areas where heavy metals have been detected in sediments are located in small, highly concentrated areas of upper parts of tributaries and bays but are usually low in concentrations.

Burning of waste, chemical manufacturing and certain industrial processes have introduced dioxins into estuary sediments (Montoya, 2015). Once in an aquatic environment, dioxins can be absorbed quickly by particulate organic matter before settling in bottom sediments. This group of chemicals is mostly resistant to biological and chemical breakdown in the aquatic or terrestrial environment and persists in estuary sediments. Following detection of this substance in the late 1980s, total fin-fish bans were implemented in Homebush Bay in 1989 extending to a commercial fishing ban upstream of the Gladesville Bridge in 1990.

Microplastics are tiny plastic fragments, fibres and granules generally smaller than five millimetres in diameter (Montoya, 2015). These can either be manufactured as microplastics or as a result of breakdown of larger plastic debris. Microplastics in the water column can settle in the sediment following accumulation of microbial films, algae and invertebrates and/or the adherence to other particles. A large number of compounds in plastics can interfere with biologically important processes resulting in endocrine disruption and carcinogenesis. Furthermore, marine plastic debris has been found to accumulate waterborne pollutants up to 100 times greater than sediments (Browne, et al., 2013). The highest concentrations of microplastics in sediments have been recorded in Sydney Harbour and Middle Harbour with some areas containing an order of magnitude greater than other estuaries internationally (Montoya, 2015). Berrys Bay and Balls Head Bay are two bays with the highest concentration of microplastics in Sydney Harbour (21 to 40 fragments per 100 millilitres of sediment). Although many manufacturers are phasing out or have phased out the use of microplastics and microbeads in their products, the persistence of microplastics in the marine environment continues to present a problem to biota.

Sediment sampling carried out for the project (for Sydney Harbour, White Bay and Berrys Bay) found that selected contaminants were generally above guideline criteria (where available) in samples collected (Douglas Partners and Golder Associates, 2017; Jacobs, 2020). These contaminants were within the top one metre of sediments with minor detections of contaminants above guideline criteria from deeper sections. Minor detections of selected contaminants were detected in samples collected from depths of greater than one metre. Contaminants above guideline criteria included:

- Polycyclic aromatic hydrocarbons (PAHs)
- Total recoverable hydrocarbons (TRHs)
- Organochlorine pesticides (OCPs)
- Tributyltin (TBT)
- Arsenic
- Copper
- Mercury
- Lead
- Silver
- Zinc.

Dioxins were detected above laboratory levels of reporting in sediment samples taken from Sydney Harbour and White Bay (Technical working paper: Contamination, Jacobs, 2020). Testing for dioxins at Berrys Bay was not carried out.

3.4 Water quality

The quality of the waters within the estuary reflect the balance between the upstream catchment loads of varying quality (depending on the land use and practices within the catchment), the downstream ocean inputs and the tidal flushing that mixes the different water masses (Cardno, 2020). Tidal flushing intensity diminishes from the ocean entrance at the heads to the upstream extremities near the river and creek inputs. During the frequent rainfall events the creek and river flows carry suspended particles and dissolved substances into the estuary causing the estuarine waters to become turbid. Following the runoff event these particles are dispersed into the estuary by tidal and wind-induced currents and settle to the bed where they can be resuspended by subsequent events. The dispersion process effectively dilutes the introduced constituents and over time their concentrations diminish toward the pre-event concentration. In general, the turbidity varies along the estuary from clearer low turbidity oceanic waters near the mouth to higher values near the river/creek inputs. In addition, the temporal variability is characterised by higher turbidity following significant inflow events and relatively low values during dry periods.

The turbidity at a particular location depends on a range of complex interaction of the physical processes including: intermittent suspended sediment inflows, settling to the bed, local resuspension and transport processes and proximity to sources of material affecting the optical transmission properties of the water. The variability in total suspended solid concentrations near the project area at Sydney Harbour is presented in Table 3-1 below. This data set combined the available historic measurements that were typically biased towards to fair weather samples with SHERM (Sydney Harbour Ecological Response Model) outputs that capture the peak total suspended solid concentrations occurring for short periods (a few hours) in the high flow events (see *Western Harbour Tunnel and Warringah Freeway Upgrade Technical working paper: Marine water quality* (Cardno, 2020) for details).

Table 3-1 Variability of ambient total suspended solid concentrations near the project area

Statistical parameter	Ambient turbidity (mg/L)
95%	18.5
90%	11.9
50% (median)	2.9
10%	1.3
5%	1.0

Suspended sediments attenuate light penetration through the water column and thereby limit pelagic and benthic primary production (the process of converting light energy into biomass). As the suspended matter settles to the bed of the harbour it may smother benthic organisms and affect the type of organisms and plants that can exist in this environment. Fluctuations in light and rates of sedimentation occur naturally in Sydney Harbour due to regular resuspension of particulate matter by the tidal currents, wind-driven mixing and runoff events. Any activities which involve bed of the harbour disturbance have the potential to increase sedimentation and turbidity beyond the natural range.

3.5 Marine habitat types and communities

The Sydney Harbour estuary has a wide range of marine habitats which support one of the most biodiverse estuarine ecosystems in Australia, and potentially the world (Johnston, et al., 2015). For example, 2473 species of polychaetes, crustaceans, echinoderms and molluscs have been recorded in the harbour as opposed to 1636 in Botany Bay and 981 in Port Hacking (Hutchings, et al., 2013). Sydney Harbour also has a high diversity of marine fish with 574 recorded species some of which are iconic species including syngnathids (family Syngnathidae), tropical vagrants and elasmobranchs (sharks and rays). The harbour's location is unique as it acts as an ecotone, providing refuge for a number of tropical fish species at the limit of their southern distribution (Booth, 2010). Species richness appears to follow the salinity gradient along drowned valley estuaries (Roy, et al., 2001). The open, deep and saline mouths of drowned valley estuaries attract a higher abundance and diversity of marine fauna due to its suitability for transient and migratory species (Roy, et al., 2001).

The estuary has five broad marine habitat areas (Sydney Institute of Marine Science, 2014; Johnston, et al., 2015):

> Intertidal rocky shores
> Shallow soft sediments that include seagrass, saltmarsh, mangroves and intertidal sand and mudflats
> Subtidal rocky reefs
> Deep soft sediments
> Open water.

These five habitats span the supralittoral, intertidal, subtidal and deep water areas throughout the estuary and are described in the sections below and in relation to their sensitivity 'Type' and waterway 'Class' as given in the *Policy and Guidelines for Fish Habitat Conservation and Management, 2013 update* (NSW DPI, 2013).

3.5.1 Key fish habitat classification

The habitats in the study area can be classified according to the *Policy and Guidelines for Fish Habitat Conservation and Management* (NSW DPI, 2013a). This requires consideration of the waterway 'sensitivity' (Type), which refers to the importance of the habitat to the survival of fish and its robustness (ability to withstand disturbance). This ranking is used within the policy and guidelines to differentiate between permissible and prohibited activities or developments and for determining value in the event offsetting is required. The waterway 'Class' is also considered which is based on the functionality of the water as fish habitat and can be used to assess the impacts of certain activities on fish habitats in conjunction with the habitat sensitivity. The waterway 'Class' can also be used to make management recommendations to minimise impacts on different fish habitats (eg waterway crossings, if applicable). Sensitivity 'Types' relevant to the study area and waterway 'Class' classifications are given in Table 3-2 to Table 3-4 below. Only the Class 1 waterway category is relevant to the study area.

Table 3-2 Key fish habitat classification

Sensitivity 'Type'		Waterway 'Class'	
Type 1	Highly sensitive key fish habitat	**Class 1**	Major fish habitat
Type 2	Moderately sensitive key fish habitat	**Class 2**	Moderate fish habitat
Type 3	Minimally sensitive key fish habitat	**Class 3**	Minimal fish habitat

Table 3-3 Key fish habitat sensitivity

Type	Characteristics of waterway 'Type'
Type 1 - Highly sensitive key fish habitat	▪ *Posidonia australia* ▪ *Zostera*, *Heterozostera*, *Halophila* and *Ruppia* species of seagrass beds >5 m^2 in area ▪ Coastal saltmarsh >5 m^2 in area ▪ Any known or expected protected or threatened species habitat or area of declared 'critical habitat' under the FM Act.
Type 2 – Moderately sensitive key fish habitat	▪ *Zostera* and *Halophila* species of seagrass beds <5 m^2 in area ▪ Mangroves ▪ Coastal saltmarsh <5 m^2 in area ▪ Marine macroalgae such as *Ecklonia* and *Sargassum* species ▪ Estuarine and marine rocky reefs ▪ Stable intertidal sand/mud flats, coastal and estuarine sandy beaches with large populations of in-fauna.
Type 3 – Minimally sensitive key fish habitat	▪ Coastal and freshwater habitats not included in Types 1 or 2. ▪ Ephemeral marine habitat not supporting native marine or wetland vegetation.

Table 3-4 Waterway classifications

Classification	Characteristics of waterway 'Class'	Minimum recommended crossing type	Additional design information
Class 1 – Major fish habitat [1]	Marine or estuarine waterway or permanently flowing or flooded freshwater waterway (eg river or major creek), habitat of a threatened or protected fish species or 'critical habitat'.	Bridge, arch structure or tunnel	Bridges are preferred to arch structures
Class 2 – Moderate fish habitat	Non-permanently flowing (intermittent) stream, creek or waterway (generally named) with clearly defined bed and banks with semi-permanent to permanent waters in pools or in connected wetland areas. Freshwater marine vegetation is present. Type 1 and 2 habitats present.	Bridge, arch structure, culvert or ford	Bridges are preferred to arch structures, box culverts and fords (in that order)

Classification	Characteristics of waterway 'Class'	Minimum recommended crossing type	Additional design information
Class 3 – Minimal fish habitat	Named or unnamed waterway with intermittent flow and sporadic refuge, breeding or feeding areas for marine fauna (eg fish, yabbies). Semi-permanent pools form within the waterway or adjacent wetlands after a rain event. Otherwise, any minor waterway that interconnects with wetlands or other Class 1 - 3 fish habitats.	Culvert or ford	Box culverts are preferred to fords and pipe culverts (in that order)
Class 4 – Unlikely fish habitat	Waterway (generally unnamed) with intermittent flow following rain events only, little or no defined drainage channel, little or no flow or free standing water or pools post-rain events (eg dry gullies or shallow floodplain depressions with no marine flora present).	Culvert, causeway or ford	Culverts and fords are preferred to causeways (in that order)

[1] The waterway that comprises the study area is considered to be 'Class 1'

3.5.2 Intertidal rocky shores

Rocky intertidal shores lie between the low- and high-water tidemarks and fringe coastlines worldwide (Menge & Branch, 2000). Rocky intertidal habitat in the study area consists of artificial seawalls and natural, sandstone rocky shores (Cardno, 2017) and are generally Type 2 or Type 3 key fish habitat. Sydney rock oysters (*Saccostrea glomerata*) covered the majority of exposed intertidal hard surfaces throughout the study area.

This habitat is unique in that it alternates between exposure to air and inundation and is exposed to a range of physical conditions. Some of these conditions are severe and can drive community composition, distribution and species interaction along rocky intertidal shores. These include wave forces, degree of immersion, thermal conditions, nutrient concentrations and climate. These forces vary in severity across two main gradients on rocky intertidal shores:

> Wave exposure gradients: occurring horizontally across the shoreline, generally declining in severity from rocky headlands to sheltered bays

> Tidal excursion gradients: occurring vertically up and down the shore where high intertidal areas experience longer periods of emersion.

Species interaction (eg grazing, competition, predation) can also determine species distribution along rocky intertidal shores.

Intertidal rocky shores in Sydney Harbour are usually horizontal and/or gentle sloping sandstone platforms similar to most shores in NSW (Bulleri, et al., 2005). Natural boulderfields are less common in the harbour (Chapman, 2003). Sydney Harbour foreshores have been subject to extensive foreshore works with 50 per cent of the foreshores being retaining walls (Chapman, 2003). These vertical rocky intertidal shores exhibit some assemblage differences to horizontal or gentle sloping platforms with some taxa unique to each habitat. These variations were detected at different heights of the shore and locations within the harbour. The same 2003 study recorded 127 taxa across three sites east of the Harbour Bridge (Chapman, 2003). Low intertidal areas can be characterised by foliose algae, tubiculous polychaetes (eg *Galeolaria gemineoa*) and/or the ascidian cunjevoi. Midshore assemblages comprise Sydney rock oysters, limpets, barnacles and encrusting algae. Many of these species are considered habitat-forming species which generate habitat complexity to support a diverse range of other biota.

3.5.2.1 *Field survey findings*

3.5.2.1.1 Algae and sessile invertebrates

General findings

Intertidal rocky shores occupy up to 60.14 kilometres of the study area shoreline. Twenty taxa were identified from the intertidal samples. The average number of taxa at sites ranged from 2.8 to 7.5 in low shore and from 3.0 to 3.5 in high shore (Figure 3-1). On average, the cover of algae and sessile invertebrates at sites was greater in low shore than high shore, ranging between 65 to 100 per cent and 11 to 51 per cent respectively (Figure 3-2 and Figure 3-3). Hard surfaces in low or high shore zones were covered by various red (Phylum: Rhodophyta), green (Phylum: Chlorophyta) or brown algae (Phylum: Ochrophyta), sessile invertebrates (mussels (*Mytilus edulis*) or oysters (Sydney rock oysters (*Saccostrea glomerata*) and Pacific oysters (*Crassostrea gigas*)). On average, sessile invertebrates had the greatest cover at sites in high shore whereas red algae had the greatest cover at sites in the low shore (Figure 3-1 and Figure 3-2).

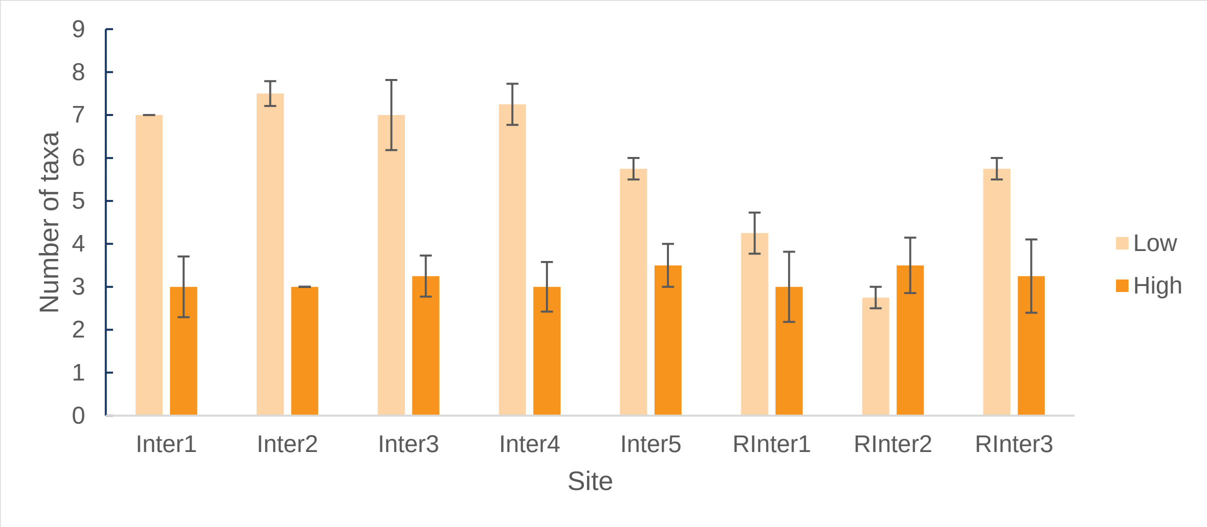

Figure 3-1 **Mean number of sessile taxa at intertidal sites**

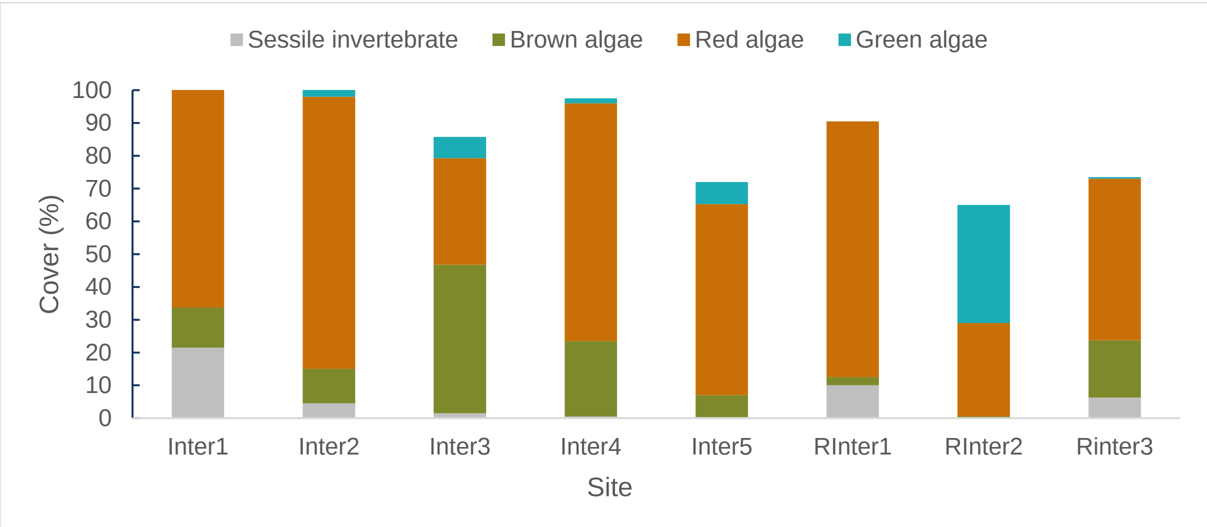

Figure 3-2 **Mean cover of sessile groups at low shore sites**

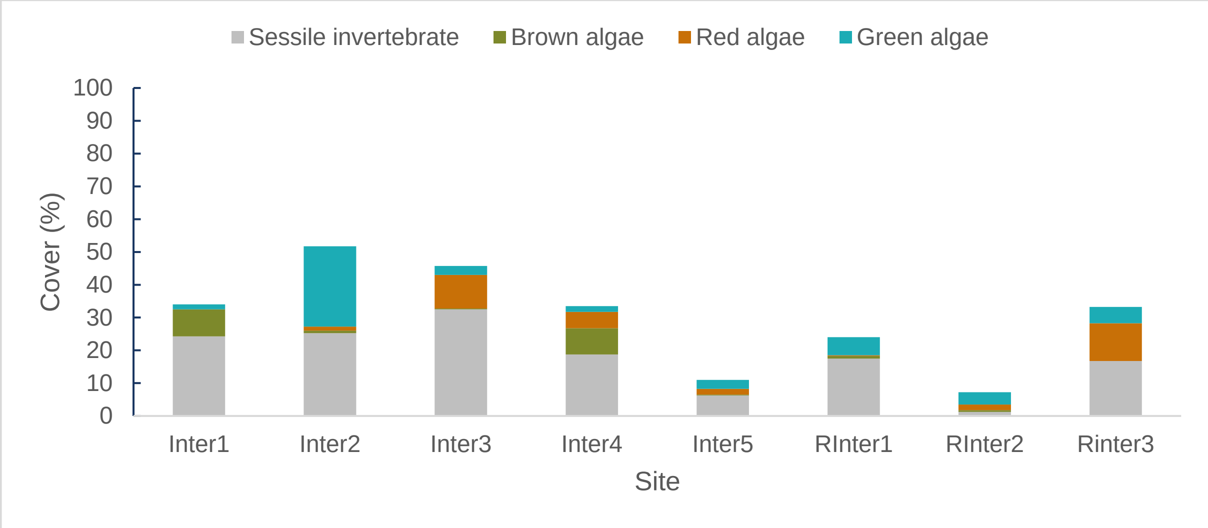

Figure 3-3 Mean cover of sessile groups at high shore sites

Statistical analysis

PERMANOVA detected a significant difference among sites within each of the shore heights, and vice-versa, for the composition of algae, mussels and oysters (Appendix FiA). Pairwise tests indicated this was due to a difference between the high and low zones at five of the eight sites but also differences among many of the sites in the low zone and between the sites Inter1 and RInter2 in the high zone (Figure 3-8 and Appendix FiB). These differences are also seen in the PCO which shows a general separation between high shore and low shore assemblages and a spreading of the sites (Figure 3-4). SIMPER[2] analysis suggested the cover of oysters, articulated coralline algae, filamentous green and brown algae and *Ulva lactuca* contributed most to differences in assemblage structure between high and low zones. These species, apart from *Ulva lactuca*, were also among the main contributors to differences among sites within zones where these differences occurred.

[2] SIMPER analysis calculates the contribution of each species (per cent) to the dissimilarity between each two groups

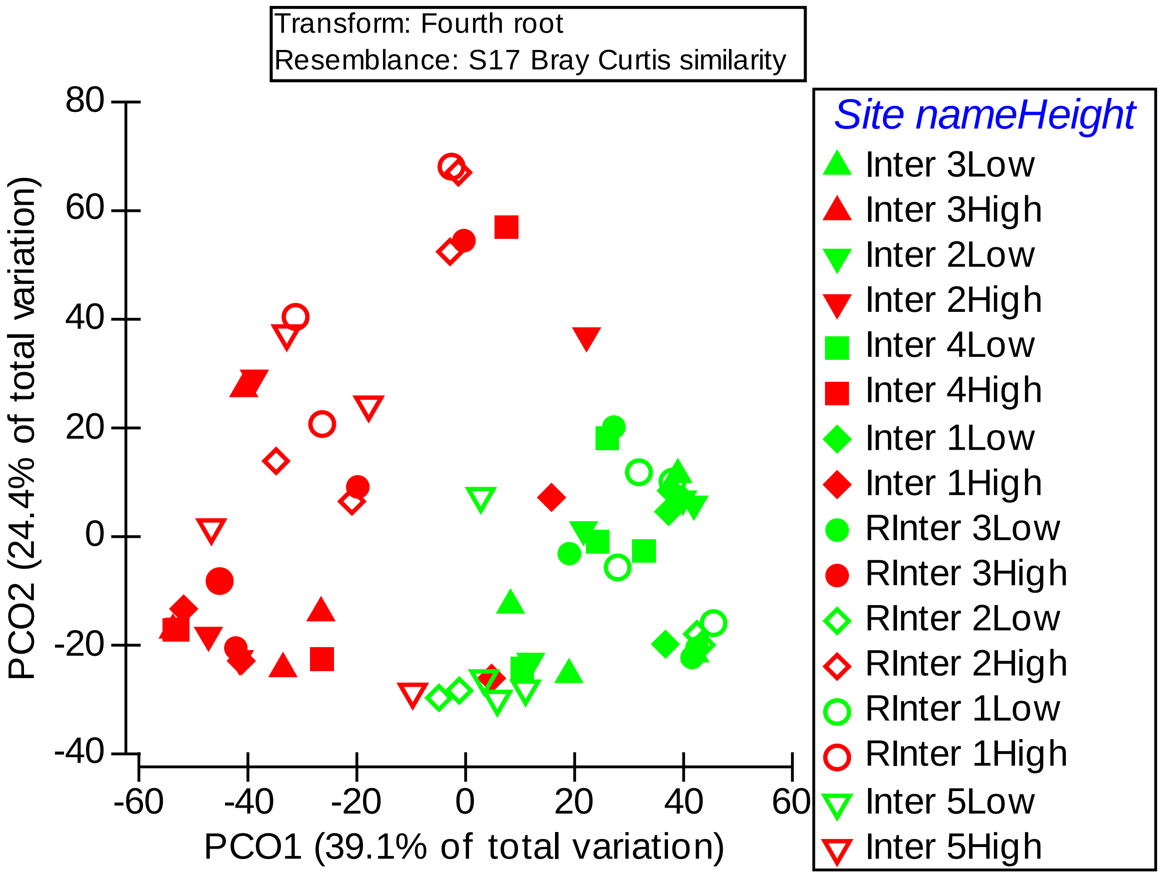

Figure 3-4 Principal coordinate analysis results for assemblage of algae and sessile invertebrates in intertidal habitat

3.5.2.1.2 Mobile invertebrates

General findings

A total of 27 taxa were sampled. On average, the number of taxa and abundance of mobile invertebrates was generally greater in high shore zones than in low shore zones apart from sites RInter1 and RInter3 (Figure 3-5, Figure 3-6 and Figure 3-8). The gastropod *Bembicium auratum* and the limpets *Patelloida muffria* and *Siphonaria denticulata* were the most abundant mobile invertebrates.

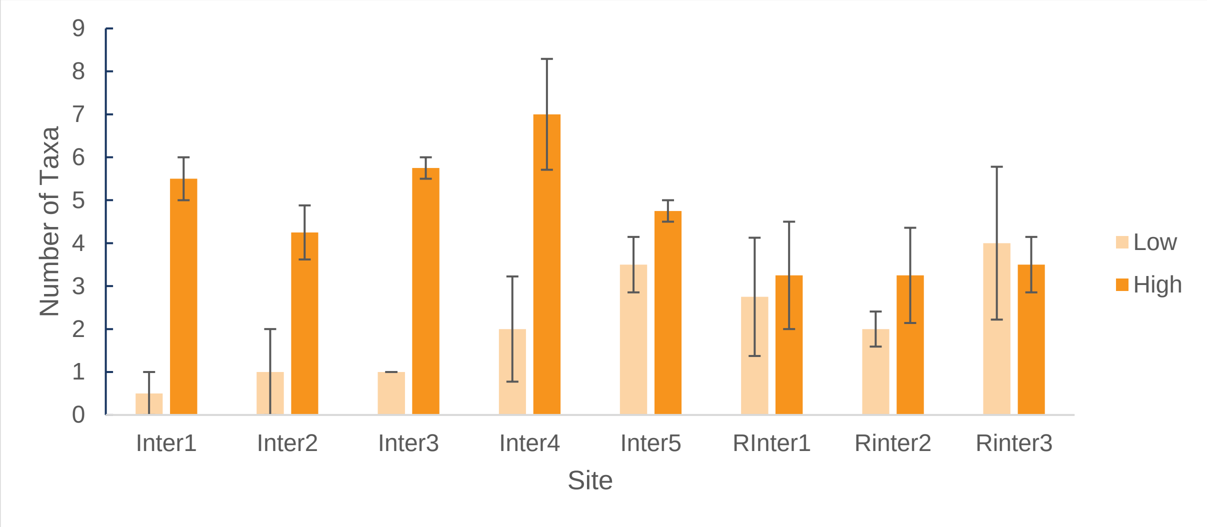

Figure 3-5 **Average number of mobile invertebrate taxa at intertidal sites**

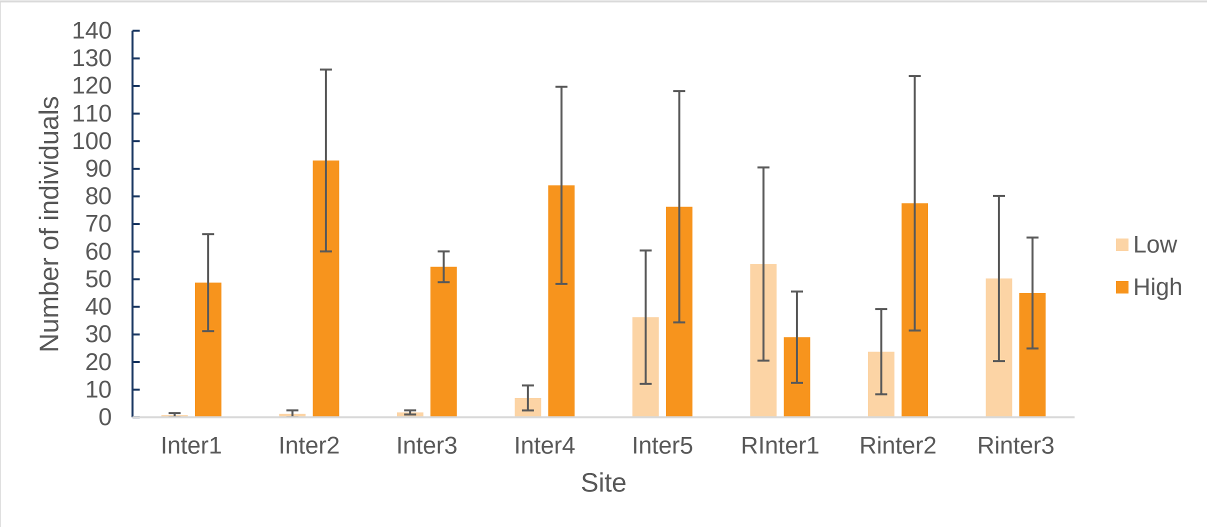

Figure 3-6 **Average number of mobile invertebrates at intertidal sites**

Statistical analysis

PERMANOVA detected significant differences in the structure of mobile invertebrate assemblages among sites between heights and vice versa (Appendix FiC). Pairwise tests indicated this was due to a difference between the high and low zones at four of the eight sites and differences between many of the pairwise comparison of sites in both the low and high zones (Appendix F).

These findings are supported by the PCO (Figure 3-7), which indicated a general separation of low and high zone samples for each site, with assemblages on the low and high zones tending to group on the right and left of the PCO, respectively.

SIMPER suggested these differences among high and low zone assemblages were due mainly to *Bembicium auratum, Patelloida muffria* and *Bembicium nanum*, *Austrocochlea porcata* and *Siphonaria denticulata.* These species were also among the main contributors to differences among sites within zones where these differences occurred.

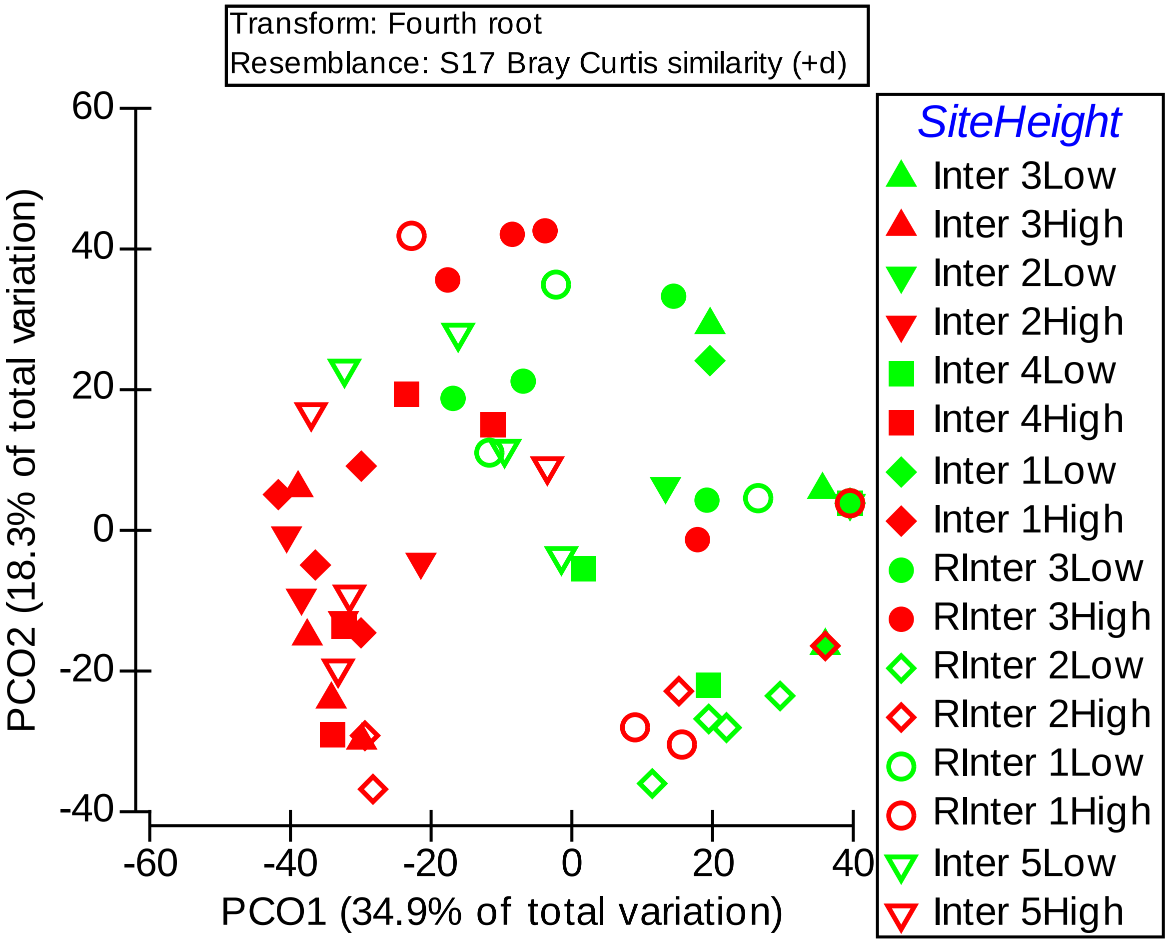

Figure 3-7 Principal coordinate analysis results for assemblages of mobile invertebrates in intertidal habitat

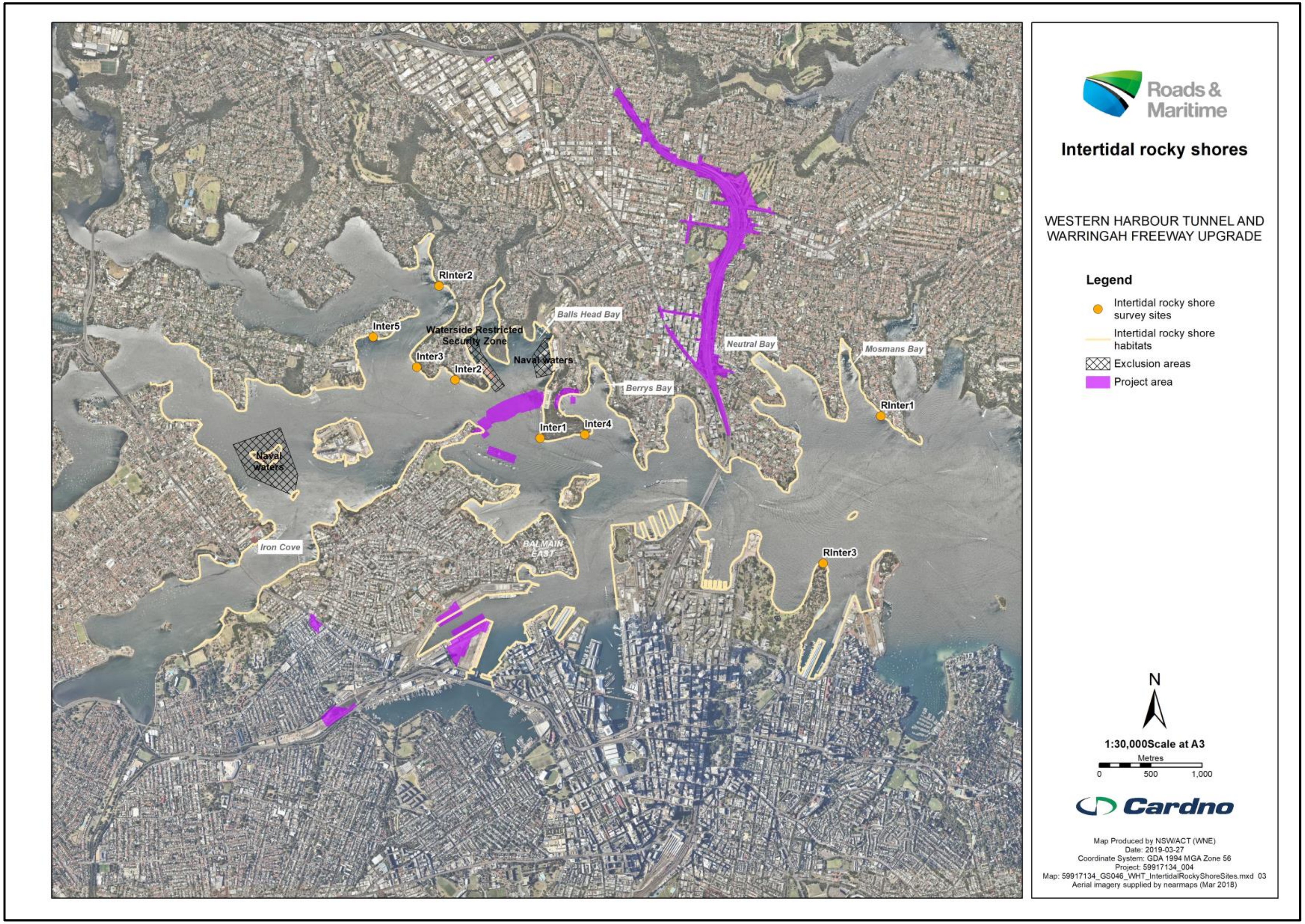

Figure 3-8 Intertidal rocky shores and associated survey sites within the study area

3.5.3 Seagrass

Some shallow soft sediment habitats in the study area contain marine angiosperms including seagrass meadows (Cardno, 2017). Seagrass meadows generally extend from the lower intertidal to subtidal areas. Mangroves can occupy the entire intertidal areas, while saltmarsh are usually confined to supralittoral areas landward of mangroves. Areas of seagrass are all considered Type 1 or Type 2 key fish habitat.

Seagrass meadows are usually less prevalent in drowned valley estuaries due to steeper slopes, stronger currents and higher turbidity levels (Roy, et al., 2001). Nonetheless, seagrass meadows in Sydney Harbour persist in some bays. These meadows predominantly occur in waters less than two metres but may range between maximum depths of four to eight metres (Roy, et al., 2001; West & Williams, 2008). The species of seagrass recorded from Sydney Harbour include Halophila (*Halophila ovalis*, *H. minor*, *H. major*, *H. decipiens*), Zostera (*Zostera muelleri* subsp. *capricorni*), Posidonia (*Posidonia australis*) and *Heterozostera nigricaulis*.

Seagrasses in the estuary are usually found in narrow patchy bands and persistence in certain areas is variable (West & Williams, 2008; Creese, et al., 2009). They are usually found in the lower reaches of the estuary (Sydney Institute of Marine Science, 2014). Long term mapping studies indicate 25 per cent of all mapped seagrass meadows have been consistently present in Port Jackson but the other 75 per cent of seagrass meadows are considered to be ephemeral (West & Williams, 2008; Creese, et al., 2009). During Cardno's habitat mapping exercise in 2017, only Zostera and Halophila (*Halophila* spp.) were recorded in the study area. Posidonia was not recorded within the study area but is known to occur in bays east of Point Piper and Bradleys Head (Creese, et al., 2009; Cardno, 2017). Posidonia appears to prefer areas where salinity is high and nutrient levels are low. As a consequence, this species is mostly confined to the entrance of drowned valley estuaries (Roy, et al., 2001).

Seagrasses are widely recognised as important fish habitats, particularly as a nursery for juvenile fish. They help reduce erosion and improve water quality and are a source of food for many marine fauna (NSW DPI, 2007). Their ecosystem value has been estimated to be similar to macroalgae beds ($19,004 per hectare per year) (Costanza, et al., 1998). Along with these ecosystem services, seagrass meadows are one of the most productive (primary productivity) ecosystems in the world (Westlake, 1963). They also sequester atmospheric carbon and store substantial volumes of organic carbon per square kilometre (Fourqurean, et al., 2012). The extent of seagrass in the estuary has declined overall and is estimated to occupy less than half the area (about 51.7 hectares) than it did in 1943 (Sydney Institute of Marine Science, 2014). All seagrass, saltmarsh and mangroves are protected as marine vegetation under the FM Act (see Section 3.9) and the occurrence of Posidonia in Sydney Harbour is listed as an endangered population under the FM Act and an endangered ecological community (EEC) under the EPBC Act (see Sections 3.6 and 3.8).

3.5.3.1 Field survey findings

3.5.3.1.1 General findings

Zostera and Halophila were the only two species recorded within the study area. Seagrass can be found in monospecific meadows or mixed meadows with Zostera and Halophila. Varying densities of Halophila were recorded in Zostera meadows at Zos3, RZos1 and RZos2 while varying densities of Zostera were recorded in Halophila meadows at Hal2, Hal4, RHal1, RHal2 and RHal3 (Figure 3-12). Although Posidonia meadows were not recorded within the study area, it is noted that they occur east of the study area in lower parts of Sydney Harbour.

Zostera meadows in the study area ranged in sizes from as small as less than 0.01 hectares up to 0.53 hectares. These include medium to high density patches at Birchgrove Park and Mort Bay near the Balmain Docks (Cardno, 2017). The largest meadow within the study area was located in Iron Cove and extends along about 0.47 kilometres of the shoreline. Halophila meadows were generally smaller than Zostera meadows and ranged in sizes from less than 0.01 hectares up to 0.09 hectares within the study area. The largest meadow within the study area was also located in Iron Cove and extends along about 0.18 kilometres of the shoreline.

3.5.3.1.2 Statistical analysis

Shoot densities (number of shoots) within meadows of Zostera were significantly different between sites within the study area (Appendix FiiA) with mean shoot densities ranging between 42 and 432 per 0.25 square metres (Figure 3-9). The highest mean shoot densities were recorded at Zos1, Zos5 and RZos3, located at Greenwich, Balmain East and Rozelle respectively while lowest mean shoot densities were recorded at Zos2 and Zos4, located at Berrys Bay and White Horse Point respectively (Figure 3-9 and Figure 3-12). Pairwise comparisons indicate densities at some of these sites were significantly different from those at others (Appendix FiiB). Leaf length was also significantly different among sites (Appendix FiiC). Zos5 not only had one of the highest mean shoot densities but also had the longest mean leaf length across all sites within the study area (Figure 3-10) and was significantly greater than many other sites (Appendix FiiD). Epiphyte loads ranged between low to high across all sites with sites towards Iron Cove recording the highest average epiphyte loads (Zos4 and RZos3). Lowest average epiphyte loads were recorded at Berrys Bay and Neutral Bay (Zos2 and RZos1) (Figure 3-12).

Figure 3-9 **Mean number of shoots across Zostera and Halophila sites within the study area**

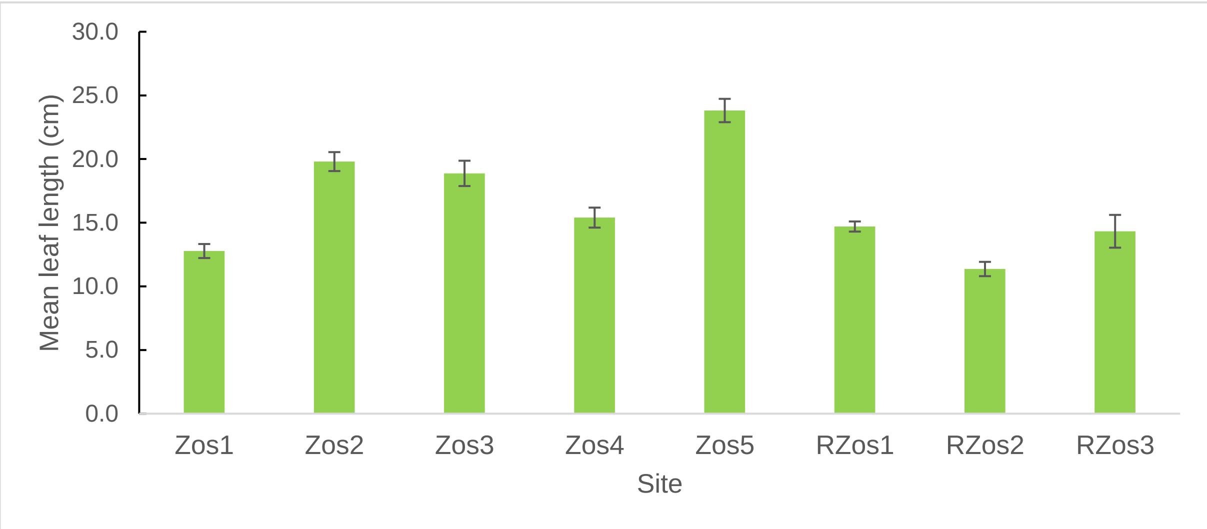

Figure 3-10 **Mean leaf length of Zostera across all sites within the study area**

Shoot densities within Halophila meadows were significantly different among sites within the study area (Appendix F) and ranged between 19 and 816 per 0.25 square metres (Figure 3-9). The highest mean shoot density was recorded at Hal1 on the northern side of Birchgrove while the lowest mean shoot density was recorded at Hal2 on the southern side of Birchgrove and pairwise comparisons in leaf length between many of the sites were significantly different (Figure 3-9, Figure 3-12 and Appendix F). Leaf lengths also varied significantly across the study area (Appendix F) with mean leaf lengths ranging between 1.7 and 4.9 centimetres (Figure 3-11). Leaf lengths recorded at Hal1 were significantly smaller than all other sites (Appendix F). This may be function of its relatively higher density compared to other sites (Figure 3-9). Hal5, RHal1 and RHal3, located at Balmain East, Neutral Bay and Mosman respectively, exhibited the longest mean leaf lengths within the study area (Figure 3-10 and Figure 3-12). Average epiphyte loads were generally categorically moderate across all sites with the exception of sites at Birchgrove and Mosman (Hal1 and RHal3) where average epiphyte loads were low. Low epiphyte loads at Hal1 corresponded to significantly smaller leaves recorded at the site (Figure 3-11). This may be attributed to new growth relative to other sites across the study area.

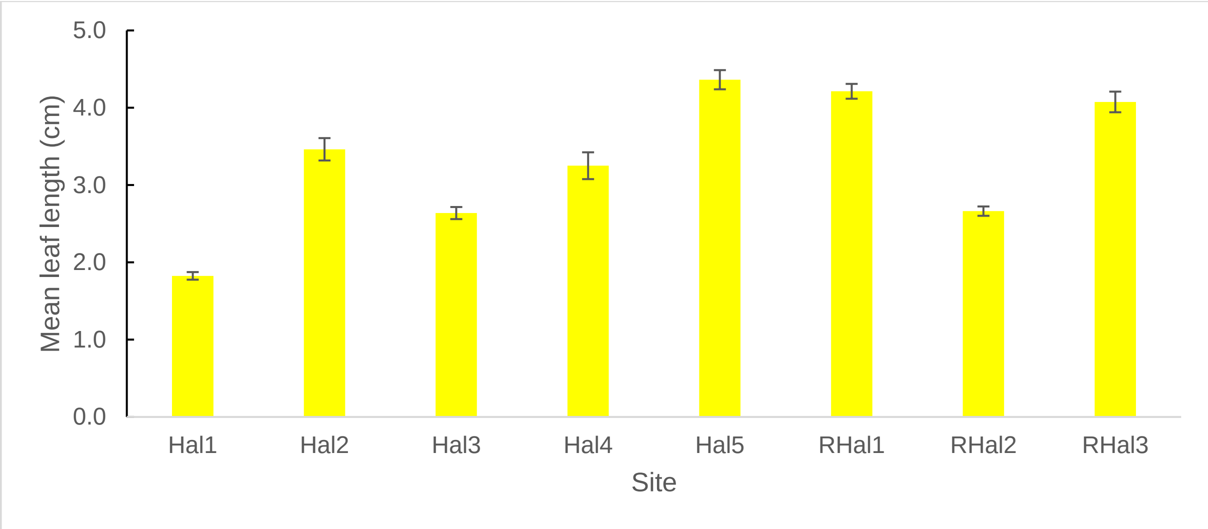

Figure 3-11 Mean leaf length of Halophila across all sites within the study area

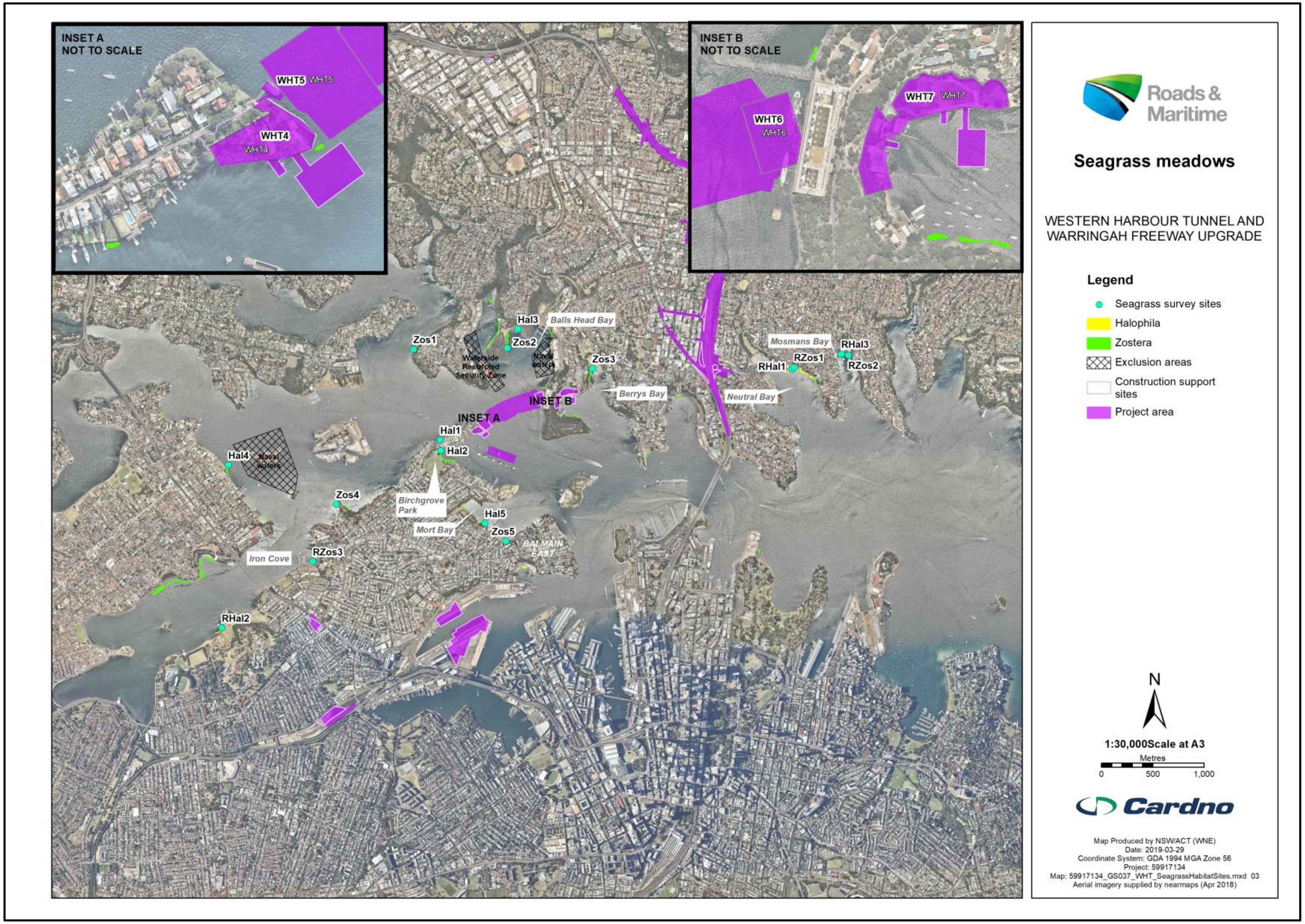

Figure 3-12 Seagrass meadows and associated survey sites within the study area

3.5.4 Saltmarsh

Saltmarsh is a community of shrubs, grasses and herbaceous plants that colonise supralittoral areas (Sydney Institute of Marine Science, 2014) and are generally considered Type 1 or Type 2 key fish habitat. The distribution of saltmarsh is influenced by a combination of elevation, salinity and frequency of inundation (NSW DPI, 2013b). Similar to mangroves, saltmarsh have historically been undervalued, however they provide habitat for aquatic and terrestrial biota, are a food source and a carbon sink as well as facilitate sediment and nutrient buffering to maintain water quality. Saltmarsh communities have declined significantly in the estuary since colonisation (McLoughlin, 2000; West & Williams, 2008) with an estimated 37 hectares remaining in 2005 (Sydney Institute of Marine Science, 2014). The occurrence of saltmarsh in some areas of the estuary are likely to be too small for detection from aerial photography hence, underestimates of the extent area predicted (Kelleway, et al., 2007).

Saltmarsh is listed as *Coastal Saltmarsh in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions* under the BC Act and *Subtropical and Temperate Coastal Saltmarsh* under the EPBC Act. The threat-listed occurrence of saltmarsh would be addressed in the Technical working paper: Biodiversity development assessment report (Arcadis, 2020). Based on Creese et al. (2009) mapping and the Technical working paper: Biodiversity development assessment report (Arcadis, 2020), no saltmarsh was recorded within the project or study areas. Thus, saltmarsh will not be considered further in this report.

3.5.5 Mangroves

Mangroves are trees and shrubs that colonise intertidal soft sediment habitat in areas where water temperatures do not usually fall below 20 degrees Celsius (NSW DPI, 2008a; Sydney Institute of Marine Science, 2014). The grey mangrove (*Avicennia marina*) and the river mangrove (*Aegiceras corniculatum*) are the two commonly occurring mangrove species in NSW. Mangrove forests, or mangals, are generally restricted to the intertidal margins of sheltered bays and inlets of the estuary and are considered Type 2 key fish habitat. Mangrove litter provides nourishment for the detrital-based food web in the estuary, which supports species from most trophic levels. Mangrove forests also provide habitat for a number of species, including juvenile and adult fish of commercial and recreational importance as well as reduce erosion and maintain water quality. Mangroves were considered ‘wastelands’ and experienced extensive clearing, dredging and reclamation prior to the 1870s. However, with increased knowledge of the value of this habitat (estimated to be $9990 per hectare per year (Costanza, et al., 1998)), mangroves are now protected as key fish habitat. In contrast to seagrass meadows and saltmarsh, mangroves have increased their extent since the 1870s with the current mapped extent estimated to be 184 hectares. Their expansion has replaced saltmarsh in many areas of the estuary (Kelleway, et al., 2007). Of the 184 hectares, about 0.15 hectares of mangrove forest resides within the study area based on Creese et al. (2009) mapping (Figure 3-13). Mangroves are also protected as marine vegetation under the FM Act (see Section 3.9).

3.5.6 Intertidal sand and mudflats

Habitats with no vegetation along the intertidal shorelines with unconsolidated substratum are considered as intertidal sand and mudflats. These habitats are usually in protected areas and occur as an accumulation of alluvial and marine sediment depositions within the estuary. Although these areas are generally considered Type 3 habitats, they are some of the most productive of all marine habitats as they are nutrient traps attributed to hydrodynamics. As such, sand and mudflats support a diversity of infauna which subsequently support fish and shore/wading bird populations. Taxonomic richness of intertidal sand and mudflats in Australia is largely attributed to echinoderms, polychaetes, gastropods and crustaceans (*Phylum: Echinodermata, Class: Polychaeta,* Class*: Gastropoda* and *Subphylum: Crustacea* respectively) in order of biomass contribution (Piersma, et al., 1993). Up to 4.71 kilometres of the shoreline is considered sand and mudflat habitat within the study area with the majority concentrated along the northern shoreline and along the banks of Iron Cove (Figure 3-13). True to the hydrodynamics which build sand and mudflats, the majority of these are located in bays rather than in the main channel of the estuary (Figure 3-13).

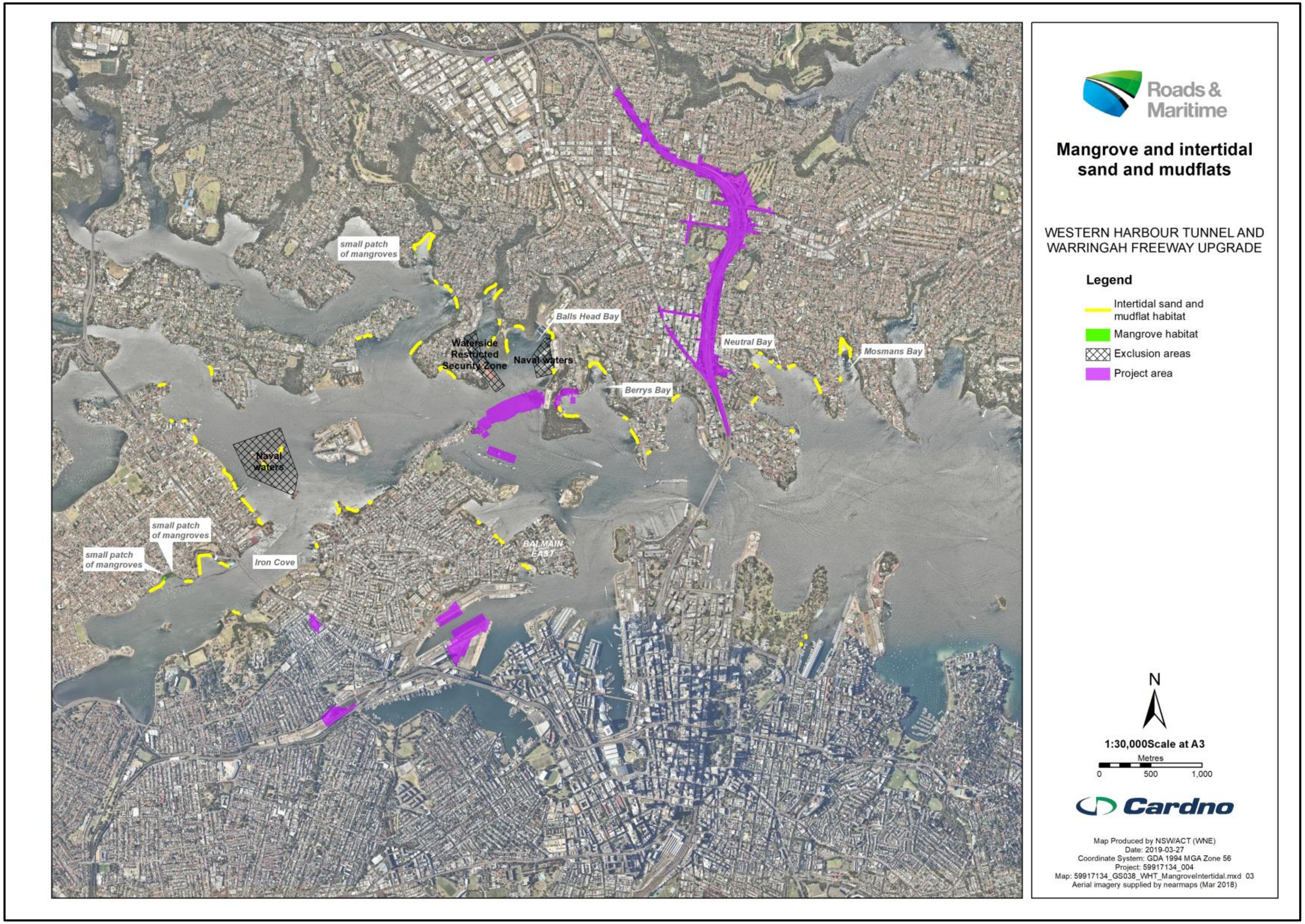

Figure 3-13 Mangrove and intertidal sand and mudflats within the study area (source: Creese et al., 2009)

3.5.7 Subtidal rocky reefs

Witman and Dayton (2000) define subtidal rocky reefs as “any benthic habitat composed of hard substrate from intertidal/subtidal fringe down to the upper limit of the deep sea”. These areas are generally Type 1 and Type 2 habitats. In Sydney Harbour, this includes artificial and natural rock walls and cobble and boulder fields, and are similar to those found on the open coast of NSW (Underwood, et al., 1991; Sydney Institute of Marine Science, 2014). About 35.52 kilometres of the shoreline within the study area comprise subtidal rocky reefs (about 17.63 hectares) of varying reliefs comprising natural and artificial structures (Figure 3-14) (Cardno, 2017). The shallowest of these areas are commonly colonised by a range of macroalgae. However the composition is not as rich as southern Australia and the Sydney region does not have a high level of endemism (Farrant & King, 1982; Witman & Dayton, 2000). Urchin barrens are the second most common type of subtidal rocky reef habitat, although little is known of these areas (Sydney Institute of Marine Science, 2014) however these do not occur in the study area. The deeper fringe of subtidal rocky reefs (greater than 20 metres in depth) are primarily colonised by sponges, ascidians, bryozoans and cnidarians (Roberts, et al., 2006) but again these do not occur in the study area.

3.5.7.1 Macroalgae and sessile invertebrates

There have been at least 50 genera of macroalgae recorded on subtidal rocky reefs throughout the estuary. These are from three different phylum: *Chlorophyta* (green algae), *Ochrophyta* (brown algae) and *Rhodophyta* (red algae) and composition varied spatially and temporally (Farrant & King, 1982; Sydney Institute of Marine Science, 2014). The commonly occurring kelp (*Ecklonia radiata*) forests usually comprise fucoids (eg *Sargassum* spp.), dictyotalean algae (eg *Dictyota dichotoma* and *Zonaria* sp.) and corallines (eg *Amphiroa anceps* and *Corallina* spp.) (Underwood, et al., 1991). Mixed kelp beds described by Underwood et al. (1991) were common within the study area (Cardno, 2017). These fringing reefs appeared to occur on all heads of bays protruding into the main channel of the estuary but were less common within the bays of the study area. In most cases, these fringing reef habitats did not extend more than 10 to 20 metres from the shoreline.

In addition to beds of macroalgae, cunjevoi (*Pyura stolonifera*) can be the most abundant habitat-forming species in intertidal/subtidal fringing habitats (Sydney Institute of Marine Science, 2014).

The slope of the subtidal rocky reef can strongly influence community composition (Witman & Dayton, 2000). Kelp forests usually occur along horizontal gradients while vertical walls are commonly colonised by sessile invertebrates. These habitat variabilities are very distinct and are not exclusive to the estuary. Other drivers of composition include natural disturbances (eg storms) and grazing pressure (Dayton, 1985).

Many of these algal species support a diverse community of mobile and sessile epibiota from primary producers to grazers to predators, providing sources of food and/or shelter (NSW Industry and Investment, 2011). These beds are commonly known as nurseries for juvenile fish and are key to nutrient cycling in the marine environment. The ecosystem services that macroalgae beds provide have been valued at $19,004 per hectare per year (Costanza, et al., 1998). Due to their importance in supporting marine ecosystems and their role in providing ecosystem services, macroalgae (and all marine vegetation) are protected under the FM Act.

3.5.7.2 Fish

Subtidal rocky reefs harbour fish that depend on this habitat for food, shelter and/or spawning sites at some stage during their lives. Many species are affected by the topography of the reef and are more abundant in areas of greater physical complexity. Some reef fish may be very active and can traverse large areas of reef. There are also many less mobile, reef associated species, which spend most of their time on or near the bottom and cryptic species that remain within caves, overhangs and crevices. Bottom dwelling fish include species from the *Gobiidae* and *Bleniidae* families while species which inhabit caves and crevices include the threatened black rockcod, among others. Reefs also support a range of highly mobile fish which visit these reefs but range over a much greater area. Examples include *Carangidae* and *Carcharhinidae*, many of which are commercially or recreationally important.

Subtidal rocky reefs provide foraging, breeding and/or sheltering grounds for about 60 per cent of fish species in Sydney Harbour (Booth, 2010). Six hundred species of fish have been recorded in the harbour including residential, migratory and visitor species (Booth, 2010; McGrouther, 2013). Several species are endemic to the waters of Sydney including the Sydney scorpionfish (*Scorpaenopsis insperatus*), known from Chowder Bay, and Sydney pygmy pipehorse (*Idiotropiscis lumnitzeri*) (Booth, 2010).

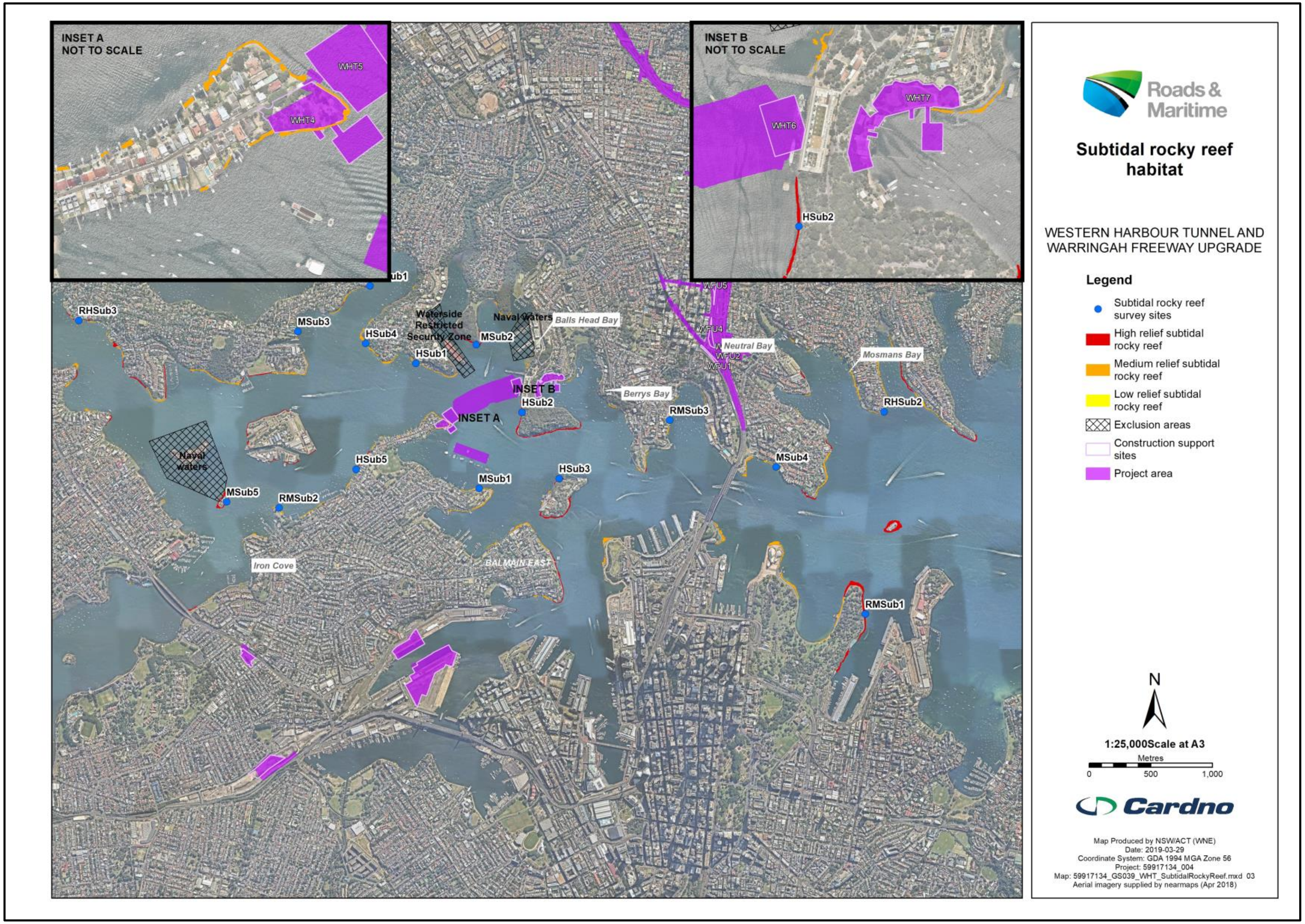

Figure 3-14 **Subtidal rocky reef and associated survey sites within the study area**

3.5.7.3 *Field survey findings*

3.5.7.3.1 Macroalgae and sessile invertebrates

General findings

On average, the groups with most benthic cover were the brown alga followed by the red alga (Figure 3-15 and Figure 3-16). The taxa with the most cover were the brown algae *Ecklonia radiata*, *Sargassum vestitum* or brown filamentous, or the red alga *Halyptilon roseum* and *Gracilaria edulis*. At a small number of sites, the cover of mussels (*Mytilus edulis*), cunjevoi (*Pyura stolonifera*) or red filamentous algae could also be great in some quadrats. Brown and red algae generally had more taxonomic richness than green algae. Although most algae grew close to the substratum, some species formed canopy cover (*Ecklonia radiata*, *Sargassum* spp. and *Dilophus marginatus).*

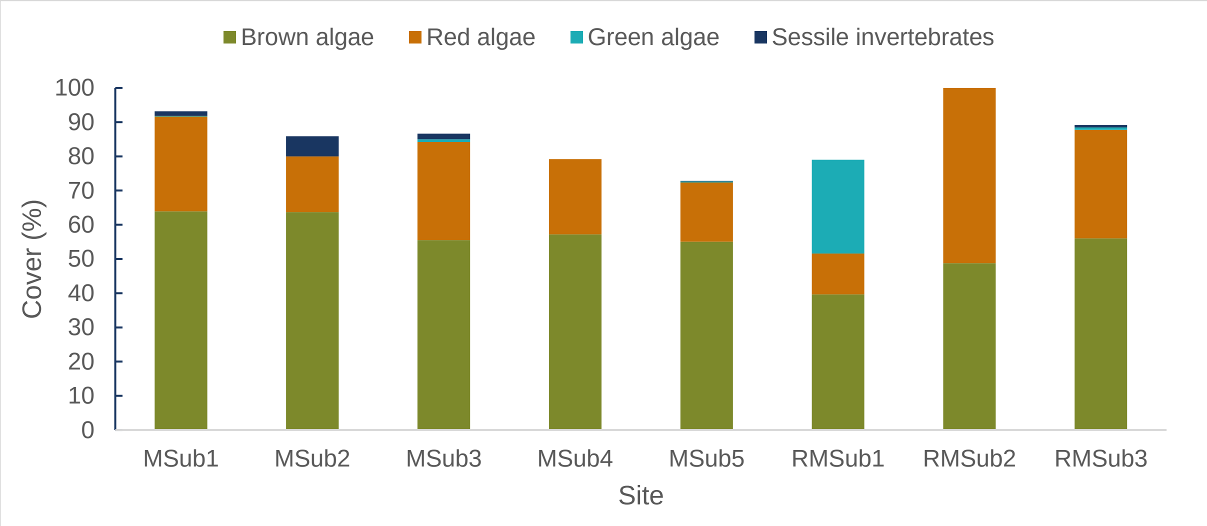

Figure 3-15 Mean cover of biota at sites in medium relief rocky reef habitat

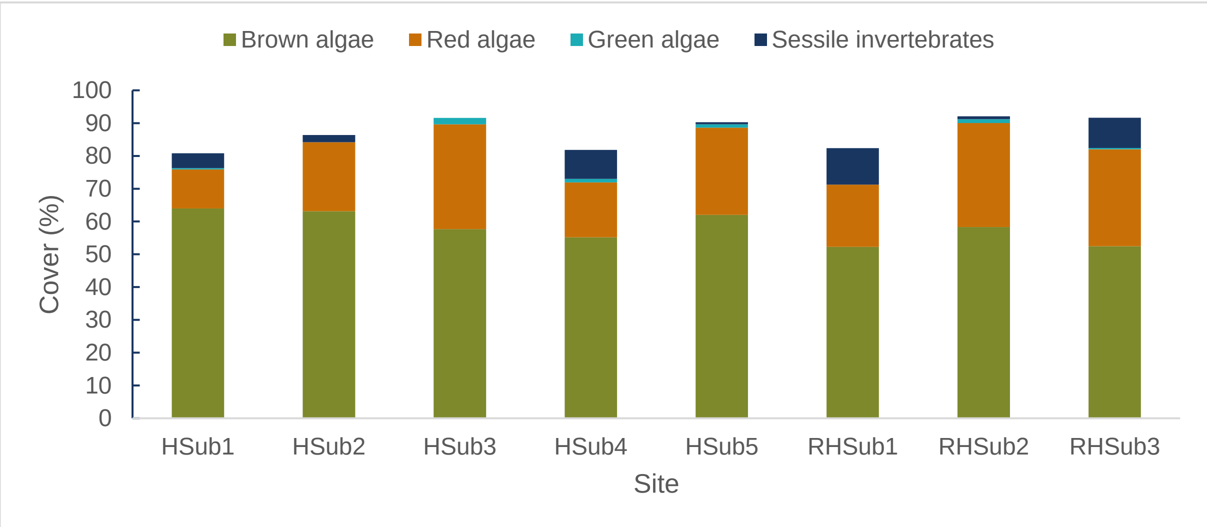

Figure 3-16 Mean cover of biota at sites in high relief rocky reef habitat

Statistical analysis

PERMANOVA detected no differences among relief for the composition of algae and sessile invertebrates but there were significant differences among sites within the two levels of relief (Appendix FiiiA). In the high relief strata, pairwise tests indicated this was due to a difference between site RHSub2 and six other sites. In the medium relief strata, there were differences among many of the sites (Figure 3-14 and Appendix FiiiB). These differences are also seen in the PCO which shows intermingling among the high relief (red) and low relief (green) sites and a separation of some of the RHSub2 samples from the rest of the high relief samples (Figure 3-14 and Figure 3-17). SIMPER analysis suggested RHSub2 differed from the other sites due to its high cover of the brown algae, *Dilophus marginatus* and low covers of the red algae *Rhodymenia australis* and brown filamentous algae. SIMPER indicated the differences among the medium relief sites were due to a variety of species.

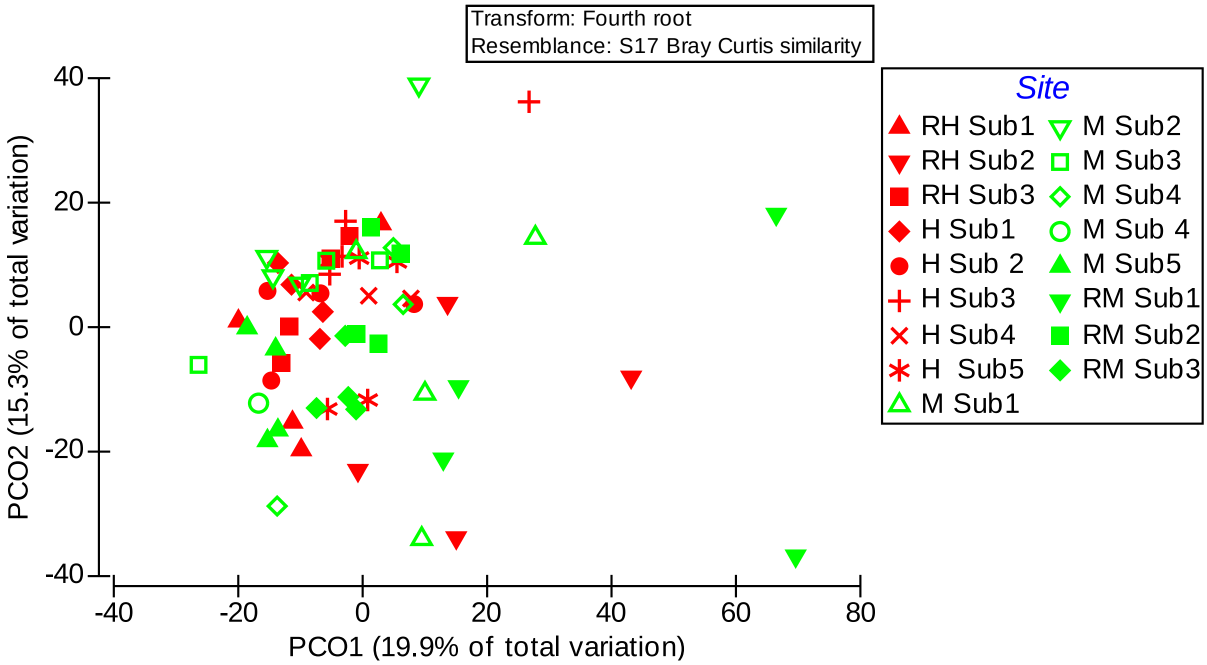

Figure 3-17 Principal coordinate analysis results for assemblages of algae and sessile invertebrates in subtidal rocky reef habitat

3.5.7.3.2 Fish

General findings

In total, 40 species of fish were observed from 20 families. The mean number of taxa at sites ranged from 4.0 to 6.0 taxa in medium relief sites and from 3.7 to 12.0 taxa in high relief sites (Figure 3-18 and Figure 3-19). These included a variety of cryptic, demersal and pelagic species. Mean total abundance at sites ranged from 8.7 to 74.7 individuals in medium relief sites and from 7.0 to 161.7 individuals in high relief sites (Figure 3-20 and Figure 3-21). Small schooling fish such as the eastern hulafish (*Trachinops taeniatus*), Wood's siphonfish (*Siphamia cephalotes*) and glassy perchlet (*Ambassis agassizii*) were the most abundant, but these did not occur in all sites. By far, the most common recreational and/or commercial species was the yellowfin bream (*Acanthopagrus australis*), although many other recreational and/or commercial species were observed, including luderick (*Girella tricuspidata*), tarwhine (*Rhabdosargus sarba*), various species of leatherjacket (Monacanthidae), silver biddy (*Gerres subfasciatus*), longfin pike (*Dinolestes lewini*) and Australian sawtail (*Prionurus microlepidotus*).

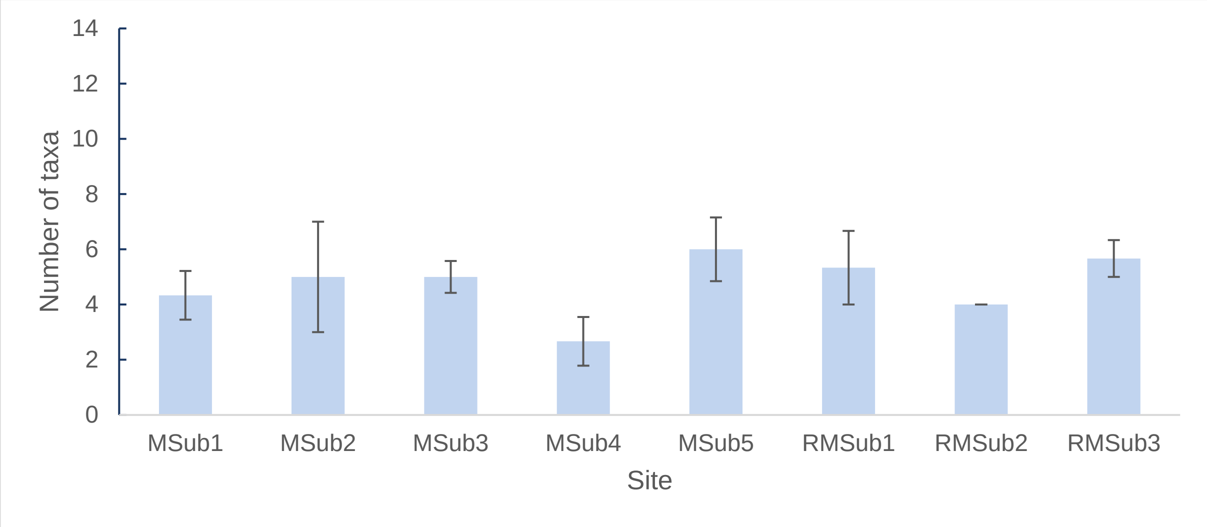

Figure 3-18 **Mean number of fish taxa at sites in medium relief rocky reef habitat**

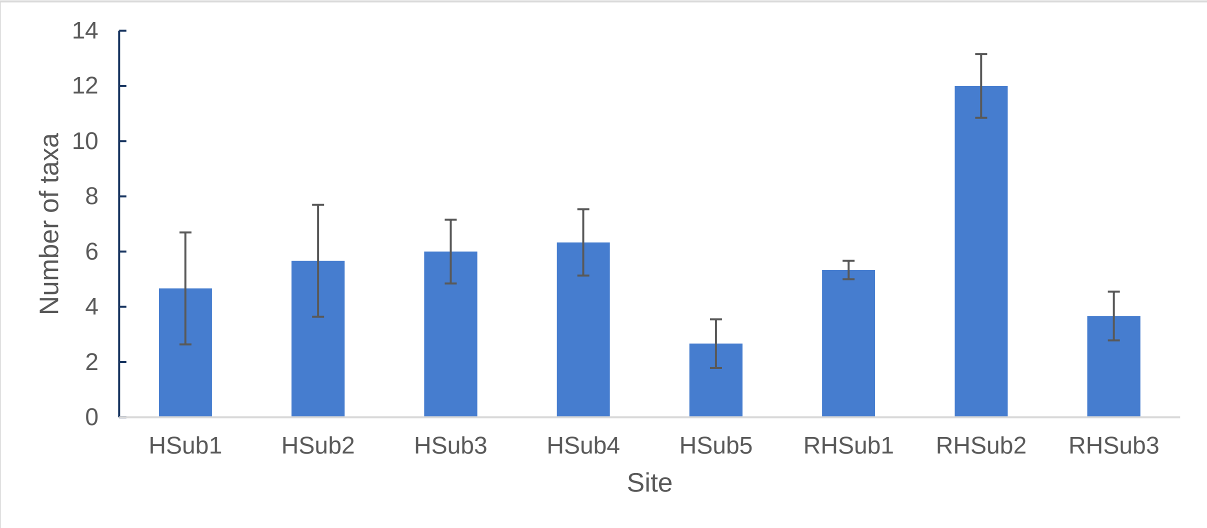

Figure 3-19 **Mean number of fish taxa at sites in high relief rocky reef habitat**

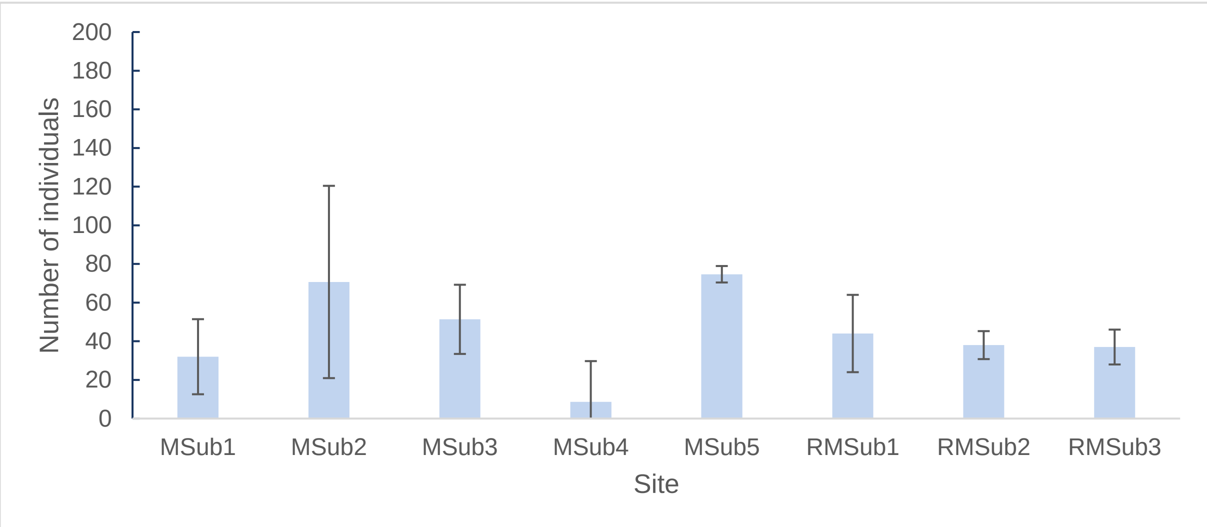

Figure 3-20 **Mean number of fish at sites in medium relief rocky reef habitat**

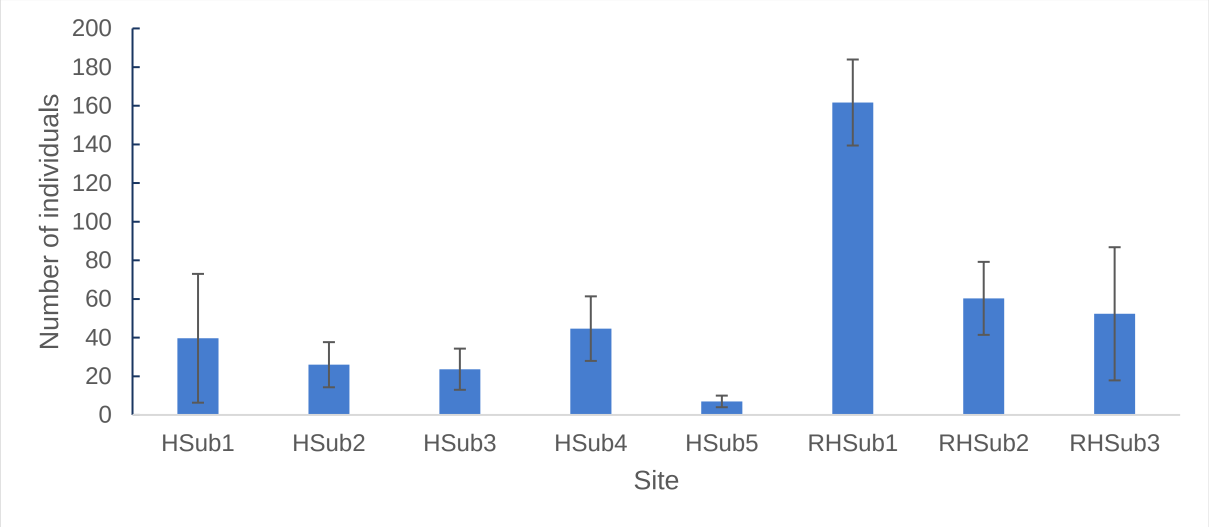

Figure 3-21 Mean number of fish at sites in high relief rocky reef habitat

Statistical analysis

PERMANOVA detected no differences among relief for the composition of fish but there were significant differences among sites within the two levels of relief (Appendix FiiiC). These differences (among sites) were confined to the high relief strata, with pairwise tests showing differences among the three RHSub sites and between RHSub2 and HSub4 (Figure 3-14 and Appendix FiiiD). The similarity between the high and medium relief generally is also seen in the PCO, which shows intermingling among the high (red) and medium (green). This is due mostly to variable abundance of glassy perchlet, eastern hulafish, smallscale hardyhead (*Atherinason hepsetoides*), little weed whiting (*Neoodax balteatus*) and luderick (Figure 3-22).

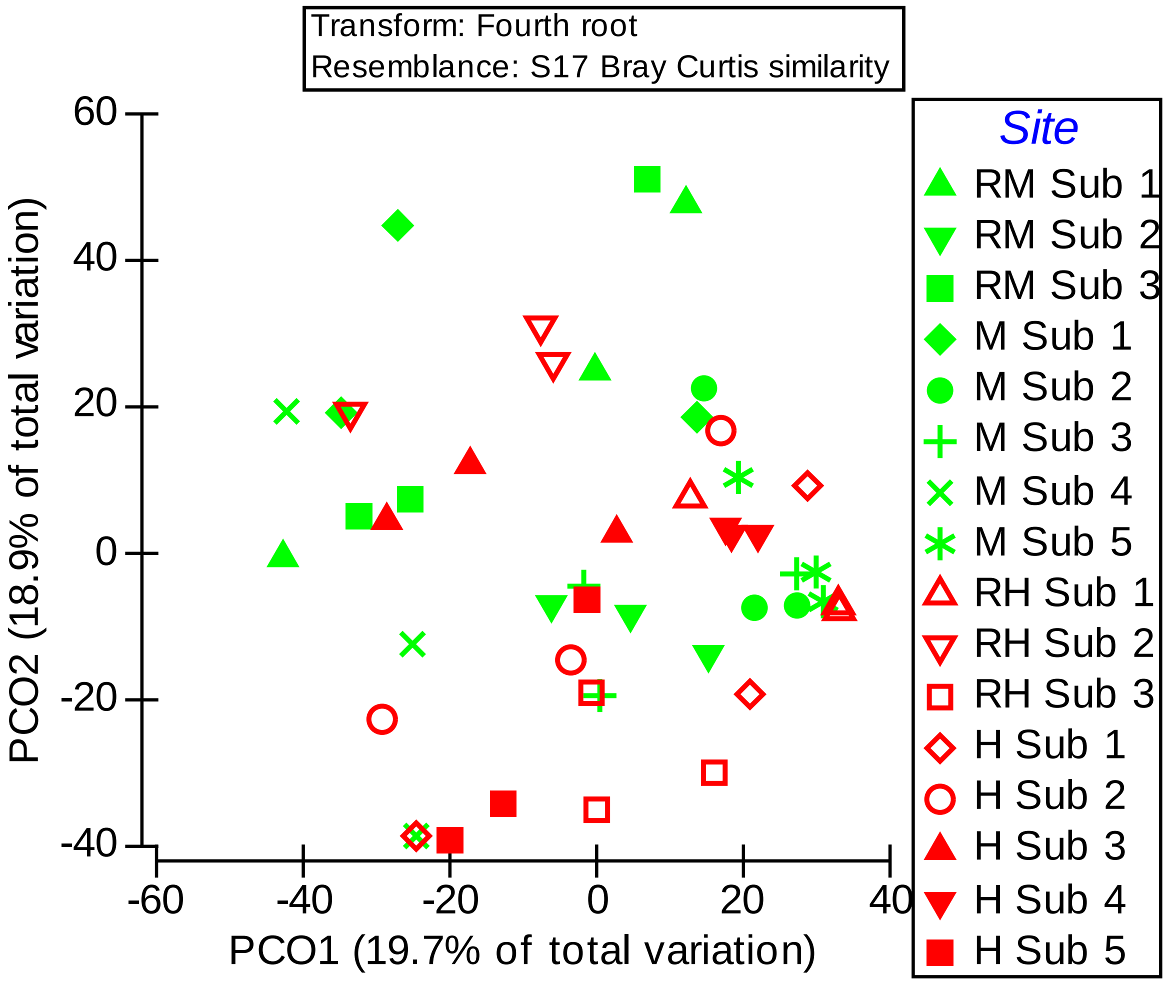

Figure 3-22 **Principal coordinate analysis results for assemblages of fish in subtidal rocky reef habitat**

3.5.8 Deepwater soft sediments

Marine soft sediments cover more than 80 per cent of the ocean floor, forming the largest habitat type in the world (Lenihan & Michelli, 2000) but are considered as Type 3 habitats. Soft sediment habitat covered the majority of the study area and includes deeper channel areas as well as shallow subtidal areas where subtidal rocky reef do not occur. Biota occupying soft sediment habitats range in size from bacteria to sharks and whales. However, the macrofaunal invertebrates (greater than 0.05 centimetres) constitute the majority of the benthic biomass. These include polychaete worms, crustaceans, echinoderms and molluscs and can vary greatly in time and location. These animals are generally found within the upper 30 centimetres of the sediment and are influenced by a range of bio-physical factors including sediment composition and grain size (Coleman, et al., 1978; Brown & McLachlan, 2006; Post, et al., 2006), hydrographic processes, bed of the harbour exposure/sediment mobility (Post et al. 2006), salinity, turbidity, dissolved oxygen, water depth (Currie & Small, 2006) and disturbance (Lenihan & Michelli, 2000). Biotic factors such as invertebrate burrowing behaviours and density dependent interactions, such as competition and predation, may also influence distribution and diversity (Connell & Gillanders, 2007).

3.5.8.1 Infauna

Deep soft sediment areas are mostly centred around the main channel of the estuary and receive little to no light. The majority of these areas appear bare but are rich in invertebrate macrofaunal richness. Of the more than 3000 aquatic species in Sydney Harbour there are two to three times the number of polychaete worms, crustaceans and mollusc species (2355) compared with neighbouring estuaries of Botany Bay (1636), Hawkesbury River (1335) and Port Hacking (981) (McGrouther, 2013). Recorded diversity of soft sediment fauna are likely to be considerably underestimated as many parts of the estuary have been poorly sampled (Sydney Institute of Marine Science, 2014). The majority of these species persist, at least for some stage of their life, under the sediment surface with pits and mounds on the bed of the harbour as the only evidence of activity (Plate E4 in Appendix E) (Sydney Institute of Marine Science, 2014).

Due to the high likelihood of contaminated sediments (see Section 3.3.2), the benthic assemblage of some sections of Sydney Harbour are likely to comprise less sensitive invertebrates such as capitellids (Family Capitellidae), spionids (Family Spionidae), nereids (Family Nereididae) and bivalves (Class Bivalvia) (Stark, 1998).

Biota utilising soft sediment habitats usually have profound influences on the physical, chemical and biological structure of their surroundings. The activity of benthic assemblages in nearshore sediments has been linked to pelagic processes and thus, affects exchange processes between coastal and offshore systems (Eyre & Ferguson, 2005; Connell & Gillanders, 2007).

3.5.8.2 Epifauna

Epifauna can generally be classed as either sessile (ie attached to the bed of the harbour) or mobile. Sessile organisms are often attached to hard structure such as reef or gravel. However some sponges, hydroids, ascidians, burrowing anemones and tube building polychaetes can also establish within soft sediments, although epifaunal biota found in association with soft sediments is comparatively sparse compared to that of hard bottom or coral reef substrata. There are a diverse range of epifaunal taxa including numerous types of crustaceans (amphipods, isopods, tanaids, cumaceans, penaeids, squat lobsters, copepods, ostracods, shrimp, hermit crabs and brachyuran crabs), polychaete worms (from a variety of families and feeding guilds), molluscs (bivalves, opisthobranchs, nudibranchs and microgastropods), echinoderms (ophiuroids, echinoids, holothurians and crinoids) and other worm-like taxa such as nematodes, nemerteans, oligochaetes, phoronids, platyhelminthes and sipunculids. Other taxa in broader groups included anemones, bryozoans, hydrozoans, sponges, pycnogonids (sea spiders), branchiostomes (small eel-like invertebrates) and juvenile fish.

3.5.8.3 Fish

The biota in soft sediments also play a central role in the functioning of ecosystems by forming the basal elements of many food chains (Gadd & Griffiths, 1977). Benthic and demersal fish live or feed on the infauna and epifauna of deepwater soft sediment and many of these species are important to recreational fishing in the harbour. Compared to reef habitats, sandy soft sediment habitats have less physical structure. The variation observed in fish assemblages among sandy areas, however, suggests that fish do discriminate among them (Lincoln Smith and Jones 1995 in Underwood and Chapman 1995). Commercial prawn trawling no longer occurs in Sydney Harbour but a previous study by Liggins et al. (1996) of the fish and large invertebrates caught in prawn nets is a good indicator of the assemblage of fish and large invertebrates that occur in this habitat. Another independent survey of trawlable fauna in Port Jackson was conducted in 1984 (Henry 1984). The Liggins et al study (1996) took place over two years in the months of November to March (1991-92 and 1992-93) west of the harbour bridge. Overall, 96 taxa were observed including 75 finfish from various families, 11 crustaceans (including three species of prawns and various crabs) and 10 molluscs (including squid, cuttlefish and octopus, among others). Forty-two of these taxa were considered to be commercially or recreationally important. The ratio of volumes of these taxa to prawns was about 5:1. The majority of finfish by-catches were less than 20 centimetres in length, although several species were commonly caught at greater sizes. Liggins et al (1996) concluded that there was a great difference in the composition of species between the two years and Henry (1984) concluded that species diversity was inversely related to distance from the estuary mouth. Henry (1984) observed that snapper (*Pagrus auratus*) was strongly distributed toward the seaward end of the estuary in line with other studies of fish and invertebrates in estuaries that suggested correlations of species diversity and abundances with distances upstream and salinity and temperature gradients.

3.5.8.4 Field survey findings

3.5.8.4.1 Epibiota

Epibiota in deep soft sediment habitats were observed at all sites except three shallow sites: (1) Shallow4 at Berrys Bay; (2) RShallow1 up the Lane Cove River; and (3) RShallow1 towards the entrance to Iron Cove (Figure 3-23, Figure 3-24 and Figure 3-27). The diversity of epibiota diversity was greatest at one shallow site (Shallow6 at Balmain East) and two deep sites (Deep4 and Deep5 in the main channel of the harbour, west of the Sydney Harbour Bridge) (Figure 3-23, Figure 3-24 and Figure 3-27). Macroalgae (attached to gravel or dead shells) contributed to the highest proportion of cover at the majority of the shallow sites while sea pens and soft corals (sea whips) were the most prevalent at majority of the deep sites (Figure 3-24). Sea pens were also recorded at some shallow sites (Shallow8 and Shallow9 near the confluence of the Lance Cove River and Parramatta River).

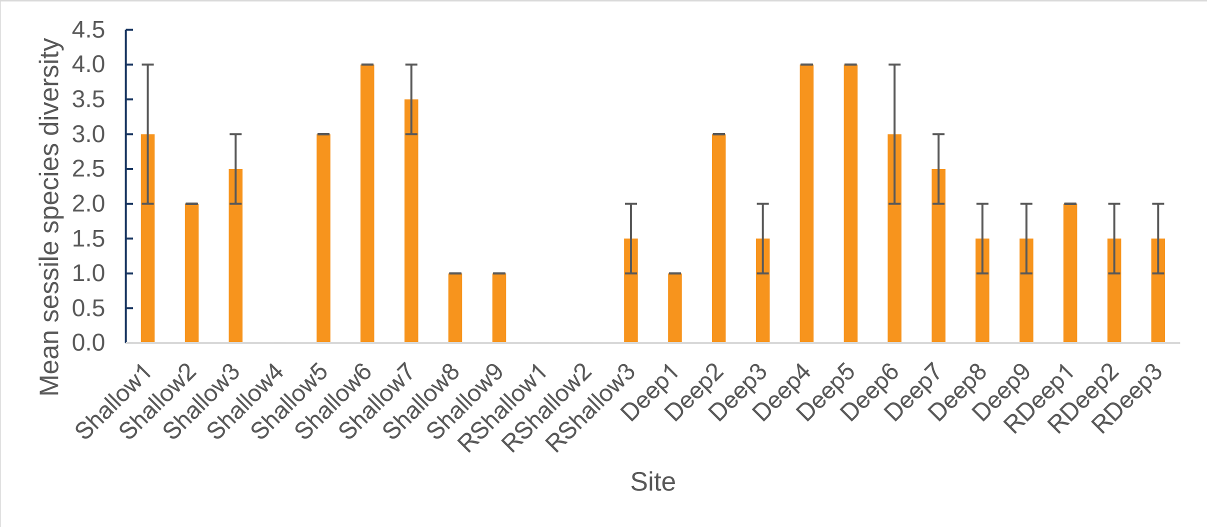

Figure 3-23 **Mean epibiota diversity observed across sites**

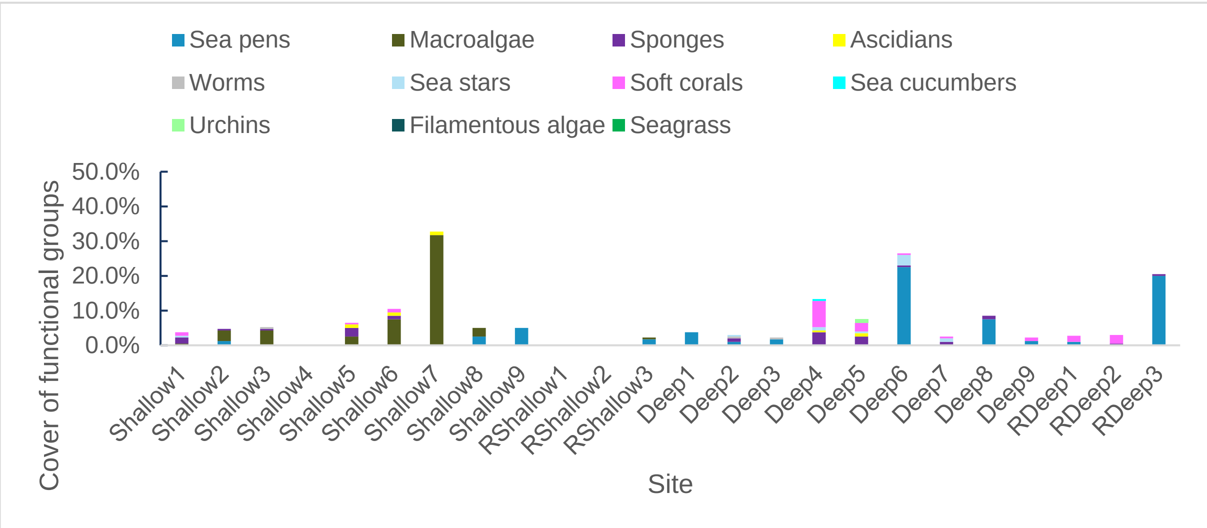

Figure 3-24 **Standardised percentage cover of functional epibiotic groups**

3.5.8.4.2 Infauna

General findings

Sixty two taxa and a total of 3865 individuals were identified from the benthic infauna samples. The average number of taxa at sites ranged from between two and 17 (Figure 3-25) and the average number of individuals ranged between four and 173 (Figure 3-26). More than half of the individuals were crustaceans and in order of abundance, the remainder consisted of polychaetes, molluscs, echinoderms, other worm phyla and other minor other taxa. The proportions of each of these groups at sites varied and crustaceans and polychaetes were the most abundant biota across the sites.

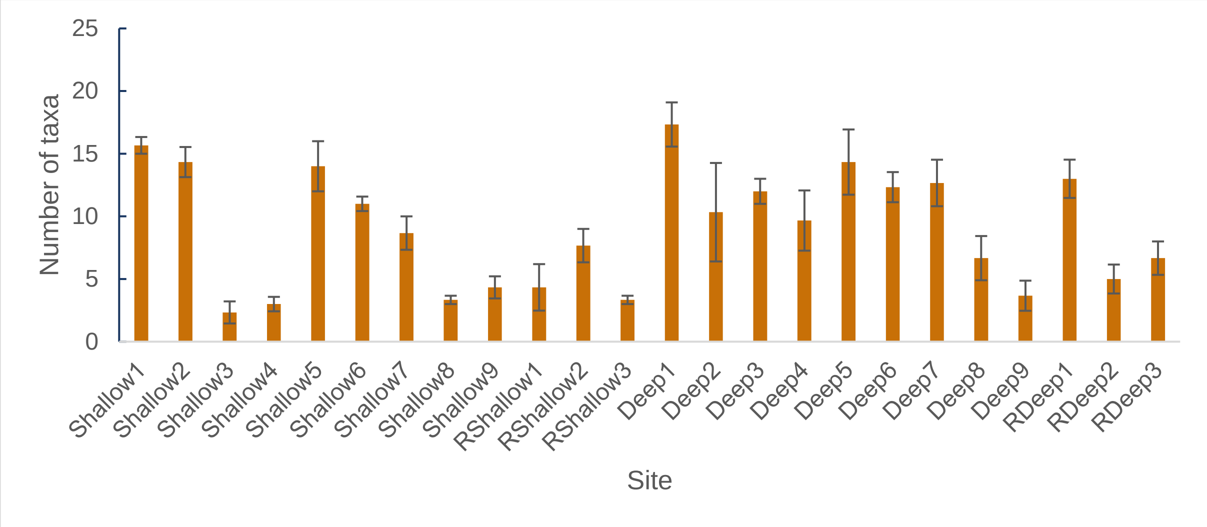

Figure 3-25 **Total number of taxa across sites**

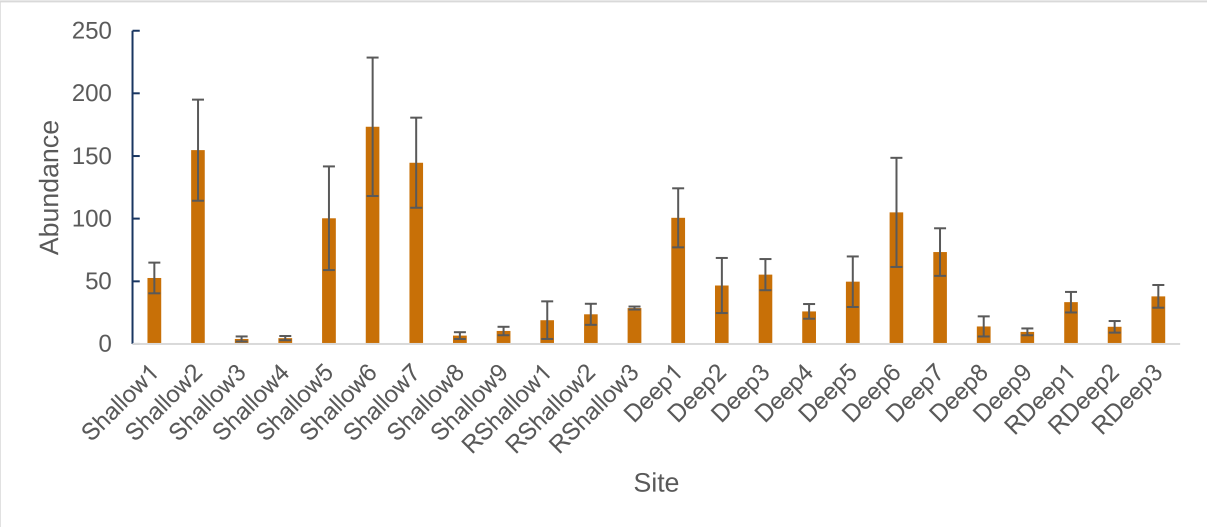

Figure 3-26 **Total abundance of individuals across sites**

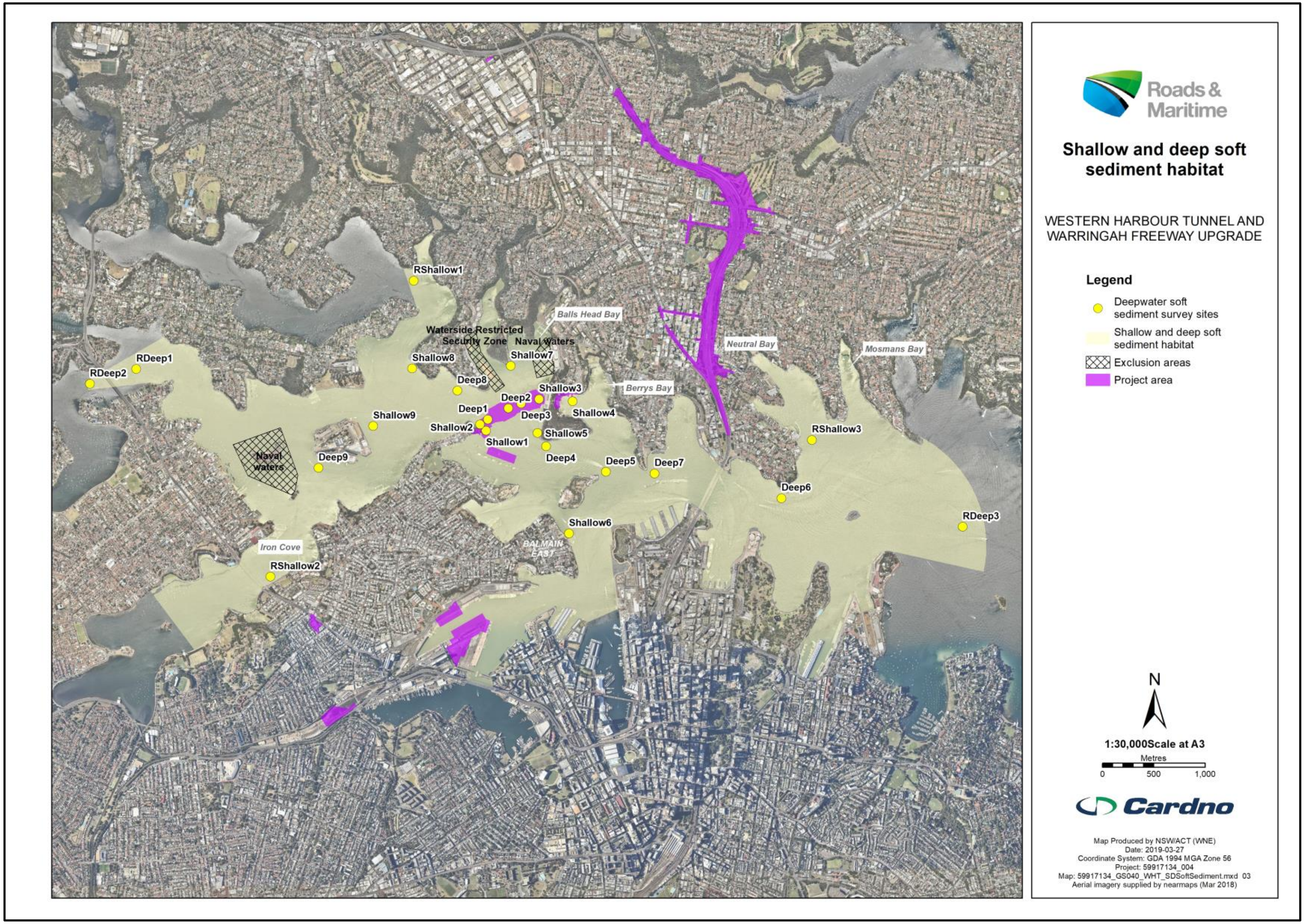

Figure 3-27 Deepwater soft sediment habitat and associated survey sites within the study area

Statistical analysis

PERMANOVA detected no differences among depth for the composition of infauna but there were significant differences among sites within each of the depth strata (Appendix FivA). Roughly half of the pairwise tests (between sites) in the shallow and deep strata indicated significant differences between assemblages whereas the other half of the tests indicated similarity between the rest of the sites (Appendix FivB). Pairwise test results for shallow and deep sites within the dredging footprint conformed to this pattern and assemblages at some of the sites within the footprint were similar to sites situated outside of the footprint. The general similarity between the shallow and deep is also seen in the PCO which shows intermingling among the shallow and deep strata (Figure 3-28). Where there were significant differences between sites, SIMPER analyses indicated that the presence and/or abundance of many taxa contributed to these differences and that a different suite of taxa were responsible in each case.

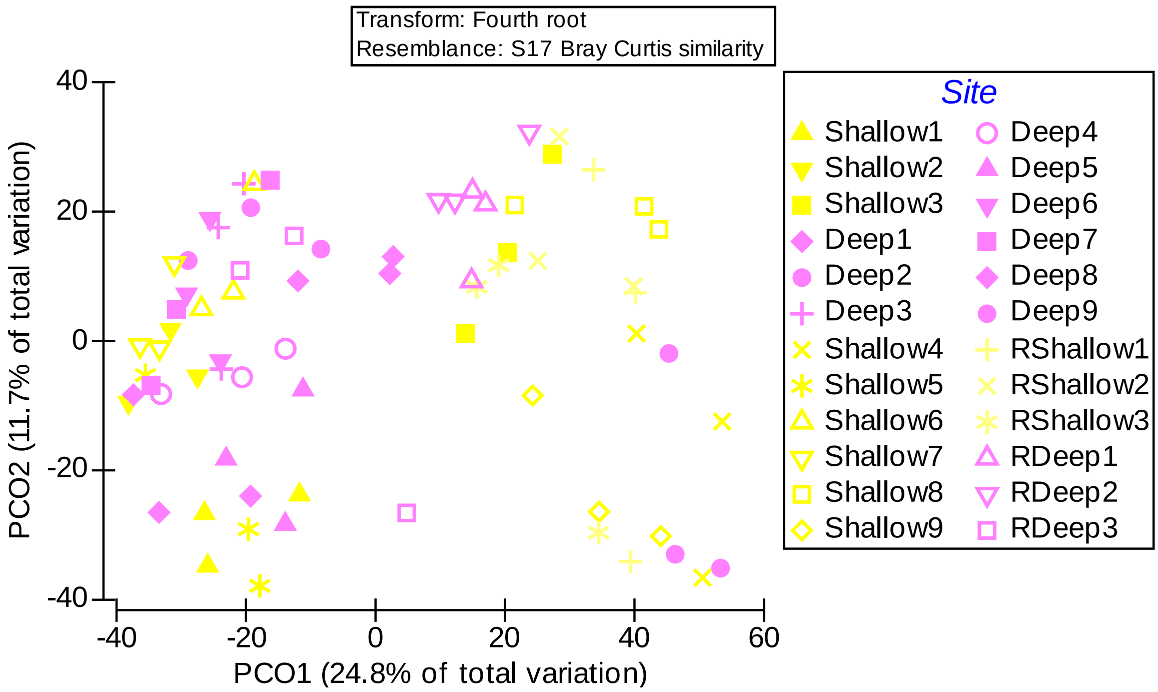

Figure 3-28 Principal coordinate analysis results for infauna in deep soft sediment habitat

3.5.9 Open water

Little is known of the open water habitat of the estuary in proportion to the area it occupies in comparison to other habitats (Sydney Institute of Marine Science, 2014). These areas are generally considered Type 3 habitats. The biota of this large expanse ranges in size from single-celled (algae and dinoflagellates) to the large marine mammals (whales). The assemblages in this habitat vary greatly with time and space and it is occupied by resident species as well as transient species.

3.5.9.1 Plankton

Plankton is made up of two general groups: meroplankton, which spends part of its life in the plankton, usually as larvae; and holoplankton, which spends its entire life in the plankton. A number of biotic and abiotic factors are important in determining the taxonomic composition and relative abundances of individual planktonic taxa present in the water column (Gray and Miskiewicz, 2000), such as seasonal differences and spawning times.

Although plankton assemblages in the estuary have not been well documented, rare toxic algal and dinoflagellate blooms in the harbour have been recorded since colonisation (Sydney Institute of Marine Science, 2014). These blooms have been identified as being of concern to human health and marine biota. For example, *Chattonella gibosa* (associated with red tides) has been linked to high mortality of yellowtail (*Trachurus declivis*) and yellowfin Bream (*Acanthopagrus* spp.).

3.5.9.2 Fish and sharks

Henry's (1984) study of recreational fishing in Sydney Harbour indicates the type of pelagic fish that occur in the open water habitats of Sydney Harbour. About 15 per cent of the 46 species landed included pelagic, open water species such as yellowtail kingfish (*Seriola lalandi*), slimy mackerel (*Scomber australasicus*), striped tuna (*Katuwo pelamis*), pilchards (*Sardinops neopilchardus*), and jack mackerel (*Trachurus declivis*). Many other pelagic species have also been observed in more recent studies, including Australian bonito (*Sarda australis*), frigate mackerel (*Auxis thazard*) and mackerel tuna (*Euthynnus affinis*) (Smoothey et al., 2016).

Sharks also occur in the open water areas of Sydney Harbour. During two years of sampling, Smoothey et al. (2016) caught four species of sharks (Port Jackson (*Heterodontus portusjacksoni*), wobbegong (*Orectolobus maculatus*), dusky whaler (*Carcharhinus obscurus*) and bull shark (*Carcharhinus leucas*)). Although most of these were caught at the mouth of the harbour, some bull sharks were also caught far up the Parramatta River and at various depths. This indicates a broader distribution within the harbour than the other species. Although the sharks were caught on bottom set lines, the charcharinids are likely to use the entire water column and may also occur in other nearshore habitats of the harbour. Other species of shark may also occur in Sydney Harbour including the threatened grey nurse shark (*Carcharias taurus*), but Smoothey et al. (2016) speculates that the lack of capture of other species in their study most likely reflects the rare occurrence of these species (Section 3.8).

3.5.9.3 Marine mammals and marine turtles

Occasionally, some marine mammals and marine turtles (including some threatened species, see also Section 3.8) may enter Sydney Harbour although their visits are generally confined to the lower parts of the harbour. Marine mammals entering the harbour include whales, dolphins and seals. Southern right whales (*Eubalaena australis*) migrate between summer feeding grounds in Antarctica and winter breeding grounds around the coasts of southern Australia, New Zealand, South Africa and South America. They are thought to feed in the open ocean in summer and are known to move inshore in winter for calving and mating. Calving females and females with young usually remain very close to the coast, often where the depth of water is only five to 10 metres. Southern right whales are known to be present along the east coast of Australia between May and November where they occasionally enter estuaries such as Port Jackson, Botany Bay, Jervis Bay and Twofold Bay. Females travel to temperate waters to give birth and anecdotal evidence shows that mother and calf sightings are becoming more common in the Sydney region as the species' population increases (DEH, 2005a).

The east coast population of humpback whales (*Megaptera novaeangliae*) migrates along the Victorian, NSW and Queensland coasts to the Coral Sea from late autumn to early winter and back along the coast in late spring and early summer. Often on the return trip, adults swim close to the shore and are accompanied by newborn calves. At this time, humpback whales may rest in some of the larger estuarine bays such as Sydney Harbour (DEH, 2005b).

Long-beaked bottlenose dolphin (*Tursiops aduncus*), bottlenose dolphin (*Tursiops truncatus*) and common dolphin (*Delphinus delphis*) are found right around the coast of Australia, in temperate and tropical waters. They occupy a diverse range of habitats, including open coasts, sheltered bays and waterways, lagoons, large estuaries and occasionally occur in the lower parts of Sydney Harbour and potentially in the study area.

Australian fur seals (*Arctocephalus pusillus doriferus*) are coastal mammals that range over the continental slope and shelf waters of south-eastern Australia (Shaughnessy, 1999). They may also move into estuaries occasionally. Australian fur seals eat pelagic and mid-water fish and cephalopods and can dive to depths of about 200 metres while chasing food. They breed on 10 islands in the Bass Strait. Pregnant females feed intensively at sea in early spring before returning to colonies in late October/early November to give birth to a single pup (Menkhorst and Knight, 2001). In the past, Australian fur seals were reported to have bred in NSW (prior to commercial sealing) at Seal Rocks and Montague Island but they no longer do so. There are other nonbreeding (haul-out) colonies between Kangaroo Island in South Australia and Jervis Bay in NSW. These are Green Cape, Montague Island and Steamers Beach near Jervis Bay. In addition, other various locations along the NSW coast are used irregularly as haul-out sites. Although the species no longer breeds in NSW, habitat and resources within the State remain important to non-breeding individuals.

New Zealand fur seals (*Arctocephalus forsteri*) occur in coastal waters of Australia and New Zealand. In Australian waters, New Zealand fur seals have been recorded in all of the southern States as well as in Queensland (south of Fraser Island). They eat fish and cephalopods and to a lesser extent birds such as penguins, both in shallow waters and around the margins of the continental shelf. Breeding colonies in Australia are known from islands off Western Australia, South Australia and Tasmania, including Macquarie Island. Although the species does not breed in NSW, habitat and resources within the State remain important to non-breeding individuals. Montague Island is a regular haul-out site in NSW (Shaughnessy, 1999). Both Australian and New Zealand fur seals may occasionally forage in estuaries although this is not generally considered core habitat.

There are three marine turtles that could potentially occur in Sydney Harbour: loggerhead turtle (*Caretta caretta*); green turtle (*Chelonia mydas*); and leatherback turtle (*Dermochelys coriacea*). They tend to prefer warmer waters, ranging from tropical to warm temperate seas (Marquez 1990). For a large part of their life cycle, marine turtles are pelagic, particularly leatherbacks, although green turtles tend to stay in coastal waters. The green turtle is generally found in the more northern latitudes of Australia although resident groups of green turtles have been found in NSW, with some as far south as Jervis Bay. Loggerhead turtles occur in coral reefs, bays and estuaries in tropical and warm temperate waters off the coast of Queensland, Northern Territory, Western Australia and NSW. Like green turtles, there are also resident groups of loggerhead turtles in the waters of northern NSW. Loggerheads are carnivorous. The leatherback turtle has a wide distribution and may be observed all around the coast of southern Queensland and NSW. Leatherbacks are carnivorous and feed on jellyfish and soft-bodied invertebrates mainly in the open ocean. They are a highly pelagic species and as such would rarely occur in estuaries apart from some of the coastal bays. Marine turtles are probably most vulnerable when they come ashore to nest, but they do not do this in the southern areas of their distribution such as Sydney Harbour.

3.6 Threatened ecological communities

A review of the NSW DPI Threatened Species, Populations, Ecological and Key Threatening Processes website and the DoEE PMST revealed two marine threatened ecological communities (TECs) within the study locality. Table 3-5 presents the list of TECs, their listing status and their approximate extents within the study locality. Both TECs are also listed under the EPBC Act. In addition, the occurrence of *Posidonia australis* in Sydney Harbour is also listed as an Endangered Population under the FM Act (see Section 3.8). Although TECs occur within the study locality, none occur within the study area and would not be considered further in this report.

Table 3-5 Marine TECs potentially occurring within the study locality

FM Act	EPBC Act	Total area within the study locality (ha)	Total area within the study area (ha)
Saltmarsh (protected)	*Subtropical and Temperate Coastal Saltmarsh* listed as vulnerable	3.1	0.0
Posidonia australis seagrass – Port Hacking, Botany Bay, Sydney Harbour, Pittwater, Brisbane Waters and Lake Macquarie populations (endangered population)	Posidonia australis *seagrass meadows of the Manning-Hawkesbury ecoregion* listed as endangered	10.4	0.0

3.7 Critical habitat

Critical habitat is listed under the FM Act and the EPBC Act. Critical habitat declared under Division 3 of the FM Act refers to the whole, or part of, the habitat of an endangered population or threatened species or ecological community that is critical to the survival of the population, species or ecological community.

A review of the NSW DPI and the Australian Government's Register of Critical Habitat revealed no declared critical habitat to occur within the study locality.

3.8 Threatened marine species and endangered populations

A review of the OEH BioNet database, NSW DPI Listed Threatened Species, Populations, Ecological and Key Threatening Processes website and DoEE PMST revealed 19 threatened species and two endangered populations with potential to occur within the study locality. One of the two endangered populations is also listed as a TEC under the EPBC Act (Section 3.6). The other endangered population is a bird species listed under the NSW *Biodiversity Conservation Act 2016* (BC Act) and impacts on this species are addressed in the Technical working paper: Biodiversity development assessment report (Arcadis, 2020). Of these 21 threatened species, three were fish, five were elasmobranchs, eight were marine mammals and five were marine reptiles. An assessment of the likelihood of occurrence of all threatened species and endangered populations were carried out to determine the potential for these species to occur within the study area. Table 3-6 provides the likelihood of occurrence criteria used in the assessment and Table 3-7 a summary of the assessment.

In addition to these 21 species, White's seahorse (*Hippocampus whitei*), which is currently listed as protected under the FM Act and EPBC Act, has been nominated for threat-listing under the FM Act. Public exhibition of the proposed determination closed on 26 November 2018 and the NSW Fisheries Scientific Committee are currently preparing a final determination. This species has been included as a protected species in Section 3.9. However, a preliminary assessment under the FM Act threatened species protection has been carried out for completeness.

Table 3-6 Likelihood of occurrence criteria

Likelihood of occurrence	Criteria
Unlikely	▪ Species highly restricted to certain geographical areas not within the proposal footprint ▪ Species that have specific habitat requirements are not present in the Study Area.
Low	Species that fit into one or more of the following criteria: ▪ Have not been recorded previously in the study area/surrounds and for which the study area is beyond the current distribution range ▪ Use specific habitats or resources not present in the study area ▪ Are a non-cryptic perennial flora species that were specifically targeted by surveys and not recorded.
Moderate	Species that fit one or more of the following criteria: ▪ Have infrequently been recorded previously in the study area/surrounds ▪ Use specific habitats or resources present in the study area but in a poor or modified condition ▪ Are unlikely to maintain sedentary populations, however may seasonally use resources within the study area opportunistically or during migration ▪ Are cryptic flowering flora species that were not seasonally targeted by surveys and that have not been recorded.
High	Species that fit one or more of the following criteria: ▪ Have frequently been recorded previously in the study area/surrounds ▪ Use habitat types or resources that are present in the study area that are abundance and/or in good condition within the study area ▪ Are known or likely to maintain resident populations surrounding the study area ▪ Are known or likely to visit the site during regular seasonal movements or migration.

Table 3-7 Summary of likelihood of occurrence of threatened species (see Appendix C for the rationale behind the assessment)

Scientific name	Common name	EPBC Act*	FM Act*	BC Act	Likelihood of occurrence			
					Unlikely	Low	Moderate	High
Marine flora								
Posidonia australis	*Posidonia australis* seagrass – Port Hacking, Botany Bay, Sydney Harbour, Pittwater, Brisbane Waters and Lake	E (ecological community)	EP	-				✓

Scientific name	Common name	EPBC Act*	FM Act*	BC Act	Likelihood of occurrence			
					Unlikely	Low	Moderate	High
	Macquarie populations							
Fish								
Epinephelus daemelii	Black rockcod	V	V	-				✓
Prototroctes maraena	Australian grayling	V	E	-	✓			
Thunnus maccoyii	Southern bluefin tuna	-	E	-	✓			
Elasmobranchs								
Carcharias taurus	Grey nurse shark	CE	CE	-			✓	
Carcharodon carcharias	White shark	V, M	V	-			✓	
Rhincodon typus	Whale shark	V, M	-	-	✓			
Sphyrna lewini	Scalloped hammerhead shark	-	E	-	✓			
Sphyrna mokarran	Great hammerhead shark	-	V	-	✓			
Marine mammals								
Arctocephalus forsteri	New Zealand fur seal			V				✓
Arctocephalus pusillus doriferus	Australian fur seal			V			✓	
Balaenoptera borealis	Sei whale	V, M	-	-	✓			
Balaenoptera musculus	Blue whale	E, M	-	E	✓			
Balaenoptera physalus	Fin whale	V, M	-	-	✓			
Dugong dugon	Dugong	M, Ma	-	E	✓			
Eubalaena australis	Southern right whale	E, M	-	E			✓	
Megaptera novaeangliae	Humpback whale	V, M	-	V			✓	
Marine reptiles								
Caretta caretta	Loggerhead turtle	E, M, Ma	-	E			✓	
Chelonia mydas	Green turtle	V, M, Ma	-	V			✓	
Dermochelys coriacea	Leatherback turtle	E, M, Ma	-	E			✓	
Eretmochelys imbricata	Hawksbill turtle	V, M, Ma	-	-			✓	
Natator depressus	Flatback turtle	V, M, Ma	-	-			✓	
Marine birds								
Eudyptula minor	Little penguin in the Manly Point area (being the area on and near the shoreline from Cannae	Ma	-	EP			✓	

Scientific name	Common name	EPBC Act*	FM Act*	BC Act	Likelihood of occurrence			
					Unlikely	Low	Moderate	High
	Point generally northward to the point near the intersection of Stuart Street and Oyama Cove Avenue, and extending 100 metres offshore from that shoreline)							

** EP = endangered population, CE = critically endangered, E = endangered, V = vulnerable, M = migratory (EPBC Act), Ma = marine (EPBC Act)*

Of the 21 species and two endangered populations with potential to occur within the study locality, nine species and one endangered population were considered unlikely to occur or have a low likelihood of occurring in the study area. The black rockcod (*Epinephelus daemelii*), two elasmobranchs, four marine mammals, all five marine turtles and the endangered population of little penguins (*Eudyptula minor*) were considered to have a moderate to high likelihood of occurrence in the study area.

The black rockcod is listed as vulnerable under the FM Act and the EPBC Act. This species is known to occur in warm temperate to subtropical waters of the south-western Pacific Ocean (Aquaculture, Conservation and Marine Parks Unit, Port Stephens Fisheries Institute, 2012). The species has been recorded along the east coast of Australia from southern Queensland to Kangaroo Island off South Australia and around Lord Howe and Norfolk Islands. The black rockcod distribution is centred around the NSW coast and adults are usually found in caves, gutters and beneath bommies on rocky reefs up to more than 50 metres in depth. Juveniles of this species prefer coastal rock pools while larger juveniles prefer rocky reefs in estuaries. This species has high site fidelity and is territorial. Significant habitat for the species have been identified and the intertidal rocky shore within the coastal depth zone between zero and 20 metres of the Hawkesbury Shelf is considered as significant. Although the study area does not extend to the coastal areas of the Hawkesbury Shelf, the estuary has potential to provide habitat for juvenile black rockcod due to the presence of suitable habitat. Suitable habitat for the black rockcod within the study area include subtidal, medium to high relief, rocky reef areas (about 14.02 hectares) which lines sections of the shorelines of the study area (Cardno, 2017). Due to the presence of suitable habitat within the study area, of which less than 0.01 hectares occurs within the project area, and the species' characteristic high site fidelity, assessments of significance (AoS) have been completed for the species (Appendix D).

The white shark (*Carcharadon carcharias*) is found throughout the world in temperate and subtropical oceans with a preference for cooler waters (NSW DPI, 2015). This species occurs throughout NSW waters and typically is found from inshore habitats to the outer continental shelf and slopes. White sharks may travel long distances or remain in an area for weeks or months. Stockton Beach and Hawks Nest in NSW have been identified as primary residency areas for juveniles. Juveniles mainly feed on fish and other sharks and rays while adults will increase their diet to include marine mammals, squid, crustaceans and birds. Due to the presence of foraging habitat for the species, an AoS has been completed for the species (Appendix D).

Grey nurse sharks were once abundant but have experienced reduced populations restricted to Australia, the east coasts of North and South America, and South Africa (NSW DPI, 2013c). This species is mostly found in inshore coastal waters and spend the majority of their time in depths of less than 40 metres. Grey nurse sharks congregate at a number of sites along the coast of NSW and southern Queensland. These sites are usually characterised by rocky reef with gravel or sand filled gutters, overhangs or caves. These aggregate sites in NSW are important to the survival of the species and individuals can migrate between sites depending on gender, sexual maturity and reproductive stage. This species is known to reproduce very slowly (biennial) with a late onset of sexual maturity making grey nurse shark populations particularly vulnerable. Due to the presence of foraging habitat for the species, an AoS has been completed for the species (Appendix D).

The Australian fur seal (*Arctocephalus pusillus doriferus*) and New Zealand fur seal (*Arctocephalus forsteri*) are both wide-ranging species with potential to use the study area. Both species are not known to breed in NSW however but still use the resources throughout the state (NSW Scientific Committee, 2011a; NSW Scientific Committee, 2011b). Both species mainly feed on fish and cephalopods (eg squid and octopus) with the New Zealand fur seal sometimes preying on birds such as penguins. A number of important haul-out sites have been identified including Steamers Beach and Green Cape for Australian fur seals and Montague Island for both species. These sites are at least 200 kilometres south of the study area. As such, the study area is likely to constitute a foraging habitat for these species while the shorelines of the estuary may also be used for the species to bask and rest during foraging trips although records indicate the latter activity is rare. One New Zealand fur seal individual has been returning annually to the Sydney Opera House steps since 2014 to bask and is likely to forage in the greater Sydney region. Due to the presence of foraging habitat for the species, an AoS has been completed for the species (Appendix D).

Southern right whales and humpback whales are two of the most common whale species sighted in the estuary which lends to their likelihood determinations. The habitat and ecology of these species are discussed in Section 3.5.9.3. As they have potential to enter the study area during their annual migration, an AoS has been completed for the species (Appendix D).

All marine turtles have been anecdotally recorded within the study area, despite the area not providing preferred, high quality habitat for these species. All these species also transit or migrate north and south along the coastline with currents for optimal environmental and foraging conditions. For example, leatherback turtles are most commonly reported feeding in coastal waters and come ashore to breed during December and January. Loggerhead turtles occur in coral reefs, bays and estuaries with a similar breeding schedule to leatherback turtles. All threatened marine turtles have designated breeding grounds outside of the study area and would only transit through, or forage in, the study area. Impacts on these species as a result of the project, including an assessment of significance have been completed in Appendix D.

The little penguin population in the Manly Point area (being the area on and near the shoreline from Cannae Point generally northward to the point near the intersection of Stuart Street and Oyama Cove Avenue, and extending 100 metres offshore from that shoreline) is listed as an endangered population under the BC Act. This endangered population was considered to have a moderate likelihood of occurring within the study area as the associated Area of Outstanding Biodiversity Value (AOBV) listed under the BC Act occurs about seven kilometres from the study area in the adjoining waters of Middle Harbour hence, the study area resides within the species foraging range. The little penguin population at Manly is the only know breeding population on the mainland of NSW (NSW National Parks and Wildlife Service (NPWS), 2003). Breeding occurs between July and February however, the species is known to use burrows during other times of the year to rest and moult. Adult penguins usually forage in nearby areas (10 to 30 kilometres) with the adults' foraging range known to greatly reduce once young have hatched. Young birds (less than three years of age) exhibit philopatry, moulting in their natal colonies. Little penguins breed from three to four years of age. The main threats to the Manly population of little penguins include loss of suitable habitat, predation by foxes, dogs and cats and disturbance of nesting habitat (NSW NPWS, 2002). Stormwater runoff, rubbish dumping and other pollutants have also been known to impact little penguins. Contaminants such as elevated concentration of dieldrin, Dichlorodiphenyltrichloroethane (DDT) and chlordane can be associated with thinner egg shells (Gibbs, 1995). Impacts on this species are considered in Section 4, and the significance of impacts on this endangered population is considered in the Technical working paper: Biodiversity development assessment report (Arcadis, 2020).

3.8.2 Nominated threatened species

White's seahorse has been nominated for threat-listing under the FM Act (NSW Fisheries Scientific Committee, 2018). It has limited geographical distribution in Australia and appears to be endemic to just nine estuaries, coastal lakes and embayments from Wallis Lake in the north to Lake Illawarra in the south, along approximately 300 kilometres of the NSW coast (Harasti, et al., 2014). White's seahorse is known to occur at depths of between one and 15 metres and can be found utilising a wide range of habitat types (both natural and artificial). Natural habitat for White's seahorse in estuaries is marine vegetation (ie seagrass, macroalgae on rocky reef and mangroves) as well as sponges and corals (Australian Museum, 2018; Kuiter, 2009; Harasti, et al, 2014). In Sydney, they are often found associated with artificial structure, particularly protective swimming net enclosures and jetty pylons. Their use of artificial habitats appears to be most common in areas where natural habitat such as seagrass, sponges and soft corals has been lost within Sydney Harbour (NSW Fisheries Scientific Committee, 2018). The species is found to prefer habitats with dense epibiotic growth and avoids areas devoid of growth, possibly in relation to the greater availability of shelter and prey in these areas (Harasti, et al., 2014). Densities in artificial habitats such as swimming nets can be as much as one square metre, but estimates in natural habitat have been around an order of magnitude less (Harasti, et al, 2012). The estuary study area provides suitable habitat for White's seahorse. Suitable habitat for White's seahorse within the study area include subtidal, low, medium and high relief, rocky reef areas (about 17.63 hectares) and the seagrasses Halophila (0.32 hectares) and Zostera (2.50 hectares). Due to the presence of suitable habitat within the study area, of which less than 0.01 hectares occurs within the project area, and the species' characteristic high site fidelity, assessments of significance (AoS) have been completed for the species (Appendix D).

3.9 Protected marine species

Some species of fish have been formally protected because they are naturally scarce or their numbers have substantially reduced over recent decades. These species are protected to help prevent them becoming threatened in the future. Twenty-nine marine fauna are protected under the FM Act. Fishing and collecting of these species without a permit incurs a penalty in accordance with Section 19 of the FM Act. An assessment of the likelihood of occurrence of all FM Act protected species, in accordance with the criteria set out in Table 3-6, was carried out to determine the potential for these species to occur within the study area (Appendix B). A summary of the likelihood of occurrence assessment is provided in Table 3-8.

The EPBC Act also provides for the protection of marine species, referred to as Marine listed species. Their listing under the EPBC Act highlights the need for their conservation and management as protecting them from being killed, injured, taken, traded, kept or moved. All 23 syngnathids (Family: Syngnathidae) protected under the FM Act are also listed as Marine under the EPBC Act. The Protected Matters Search Tool also identified/predicted the occurrence of two marine mammals and one marine reptile within the study locality. The two marine mammals are also threat-listed under the BC Act and and their potential for occurrence within the study is discussed above.

Of the 23 syngnathids, 16 were considered to have a moderate or high likelihood of occurrence within the study area due to their habitat requirements and distribution. This includes White's seahorse which has been nominated for threat-listing under the FM Act (see Section 3.8.2). The majority of the 16 species have an affinity to marine vegetation and habitat in estuaries (ie seagrass, macroalgae, mangroves and rocky reef). These 16 species have a wide distribution and are not unique to the estuary (endemic).

A further three fish species were also considered to have a moderate or high likelihood of occurrence within the study area, including:

- Estuary cod (*Epinephelus coioides*)
- Eastern blue devil (*Paraplesiops bleekeri*)
- Species from the Family Pegasidae.

The estuary provides potential habitat for juvenile estuary cod as adults are generally coast-dwellers. The eastern blue devil is usually solitary and associated with rocky reefs from shallow estuaries to deeper offshore reefs. Both species have potential to occur due to the presence of suitable habitat but are not endemic to the estuary and occupy a wide range of habitats across w large distribution.

The only two species which occur in NSW waters from the Family Pegasidae are the dragon fish (*Eurypegasus draconis*) and the slender seamoth (*Pegasus volitans*). If in the estuary, these species would most likely be found on sandy, rubble substratum among seagrass meadows. In other parts of Australia and the world, these species are widespread and can also be found on coral reefs.

The yellow-bellied seasnake (*Pelamis platurus*) is the most widely distributed of all sea snake species. A population living near the central coast of NSW was thought to be permanent and breeding, though no new studies have confirmed this. Given the seasnake is usually found within a few kilometres of the coast and prefers shallow inshore waters between 11.7–36 °C, its occurrence in the estuary is considered unlikely.

All marine vegetation, including seagrass, saltmarsh, mangroves and macroalgae, are protected under the FM Act.

Table 3-8 Summary of likelihood of occurrence for protected species (see Appendix B for the rationale behind the assessment)

Scientific name	Common name	EPBC Act	FM Act	BC Act	Likelihood of occurrence			
					Unlikely	Low	Moderate	High
Fish								
Acentronura tentaculata	Shortpouch pygmy pipehorse	Ma	P	-		✓		
Anampses elegans	Elegant wrasse	-	P	-	✓			
Epinephelus coioides	Estuary cod	-	P	-			✓	

Scientific name	Common name	EPBC Act	FM Act	BC Act	Likelihood of occurrence			
					Unlikely	Low	Moderate	High
Festucalex cinctus	Girdled pipefish	Ma	P	-				✓
Filicampus tigris	Tiger pipefish	Ma	P	-				✓
Girella cyanea	Blue drummer	-	P	-	✓			
Heraldia nocturna	Upside-down pipefish	Ma	P	-				✓
Hippichthys penicillus	Beady pipefish	Ma	P	-				✓
Hippocampus abdominalis	Big-belly seahorse	Ma	P	-				✓
Hippocampus whitei	White's seahorse^	Ma	P	-				✓
Histiogamphelus briggsii	Crested pipefish	Ma	P	-		✓		
Lissocampus runa	Javelin pipefish	Ma	P	-				✓
Maroubra perserrata	Sawtooth pipefish	Ma	P	-		✓		
Notiocampus ruber	Red pipefish	Ma	P	-				✓
Odontaspis ferox	Herbst nurse shark	-	P	-	✓			
Paraplesiops bleekeri	Eastern blue devil	-	P	-				✓
Family *Pegasidae*	Seamoths	-	P	-				✓
Phyllopteryx taeniolatus	Common seadragon	Ma	P	-				✓
Solegnathus spinosissimus	Spiny pipefish	Ma	P	-				✓
Solenostomus cyanopterus	Robust ghost pipefish	Ma	P	-			✓	
Solenostomus paegnius	Rough-snout ghost pipefish	Ma	P	-		✓		
Solenostomus paradoxus	Ornate ghost pipefish	Ma	P	-	✓			
Stigmatopora argus	Spotted pipefish	Ma	P	-				✓
Stigmatopora nigra	Widebody pipefish	Ma	P	-				✓
Stigmatopora olivacea	Gulf pipefish	Ma	P	-				✓
Syngnathoides biaculeatus	Double-end pipefish	Ma	P	-				✓
Trachyrhamphus bicoarctatus	Bentstick pipefish	Ma	P	-		✓		
Urocampus carinirostris	Hairy pipefish	Ma	P	-				✓
Vanacampus margaritifer	Mother-of-pearl pipefish	Ma	P	-				✓
Marine mammals								
Arctocephalus forsteri	New Zealand fur seal	Ma	-	V		✓		
Arctocephalus pusillus doriferus	Australian fur seal	Ma	-	V	✓			
Marine reptiles								
Pelamis platurus	Yellow-bellied seasnake	Ma	-	-	✓			

* P = protected, Ma = marine (EPBC Act); ^ = nominated for threat-listing

3.10 Matters of National Environmental Significance (MNES)

There are nine types of MNES listed under the EPBC Act of which actions that have, or are likely to have, a significant impact would require approval from the Federal Minister for the Environment. Of the nine types of MNES, four are potentially relevant to the project:

> Listed threatened species and ecological communities
> Wetlands of international importance
> Migratory species
> Commonwealth marine areas.

Threatened species and ecological communities listed under the EPBC Act are considered as MNES and are discussed in Sections 3.6 and 3.8. The location and/or relevance of migratory species, the Great Barrier Reef Marine Park, Commonwealth marine areas and wetlands of international importance are discussed in the following sections.

3.10.1 Migratory marine species

Migratory species are those that migrate to Australia and its external territories, or pass though or over Australian waters during their annual migrations. Listed migratory species may include any native species identified in an international agreement approved by the Minister. All listed migratory species are MNES under the EPBC Act. An action will require approval if the action has, will have, or is likely to have, a significant impact on a listed migratory species.

The PMST indicated eight species have either been previously recorded or are predicted to occur within the Study Area (Appendix C). This included three elasmobranchs (sharks) and five cetaceans (whales and dolphins). A summary of the likelihood of occurrence assessment is provided in Table 3-9. No listed migratory species were considered to have a moderate or high likelihood of occurrence in the study area.

Table 3-9 Summary of likelihood of occurrence for migratory species (see Appendix C for the rationale behind the assessment)

Scientific name	Common name	EPBC Act	FM Act	BC Act	Likelihood of occurrence			
					Unlikely	Low	Moderate	High
Elasmobranchs								
Lamna nasus	Mackerel shark	M	-	-	✓			
Manta alfredi	Reef manta ray	M	-	-	✓			
Manta birostris	Giant manta ray	M	-	-	✓			
Marine mammals								
Balaenoptera edeni	Bryde's whale	M	-	-	✓			
Caperea marginata	Pygmy right whale	M	-	-	✓			
Lagenorhynchus obscurus	Dusky dolphin	M	-	-		✓		
Orcinus orca	Orca	M	-	-	✓			
Sousa chinensis	Indo-Pacific humpback dolphin	M	-	-		✓		

3.10.2 Commonwealth marine areas

Commonwealth marine areas extend from three to two hundred nautical miles from the coast of Australia. Therefore, the study locality and the study area lie outside of any Commonwealth marine areas. However, the coastal waters to the east of the study area are within the Temperate East Marine Region which covers 383,352 square kilometres and includes eight marine reserves. The study area does not include any Commonwealth marine reserves. The closest marine reserves are the Hunter Commonwealth Marine Reserve, about 170 kilometres north of the study area, and the Jervis Commonwealth Marine Reserve, about 127 kilometres south of the study area (Figure 3-29).

3.10.3 Wetlands of international importance

Wetlands of international importance are defined by the Ramsar Convention which recognises these areas as being of significant value for their respective countries as well as for humanity as a whole. The study area does not encompass or lie adjacent to any wetlands of international importance (Ramsar wetlands). The closest Ramsar wetland is the Towra Point Nature Reserve, about 14 kilometres south of the study area in Botany Bay (Figure 3-29).

3.11 Wetlands and conservation areas

There are no marine parks within the study locality. However, there are three aquatic reserves within the study locality:

> North Harbour Aquatic Reserve

> Cabbage Tree Bay Aquatic Reserve

> Bronte-Coogee Aquatic Reserve.

All three aquatic reserves occur outside of the study area. North Harbour Aquatic Reserve is at North Harbour towards the heads of the estuary, about eight kilometres from the study area while Cabbage Tree Bay and Bronte-Coogee aquatic reserves are both along the coast, outside of the estuary (Figure 3-30).

Six Coastal Wetlands listed under the Coastal Management SEPP occur within or next to the study area where their proximity areas occur within the study area (Figure 3-30). The proximity area under the Coastal Management SEPP is a buffer around the coastal wetland for developers to consider indirect impacts as well as direct impacts.

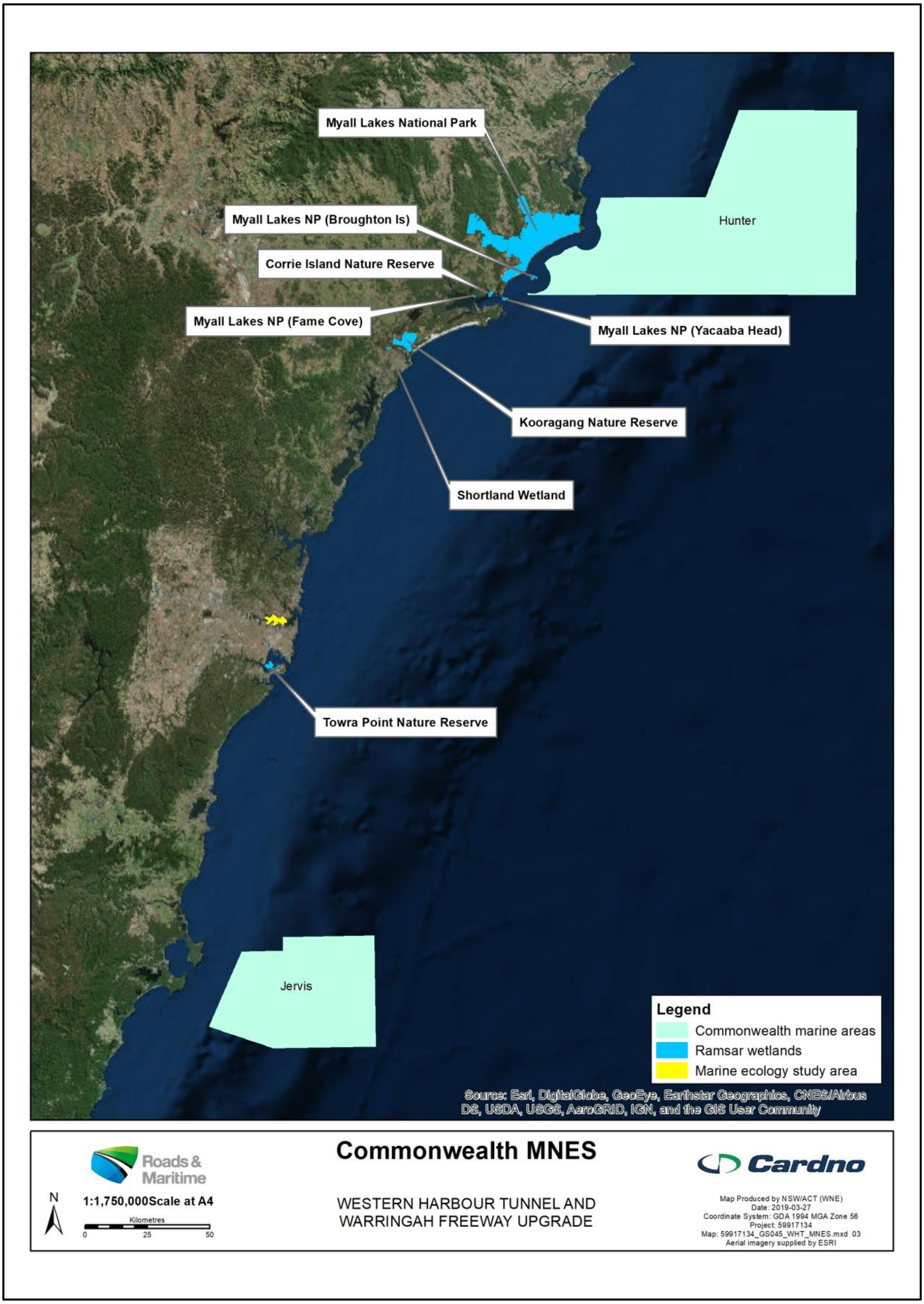

Figure 3-29 Commonwealth MNES in relation to the study area

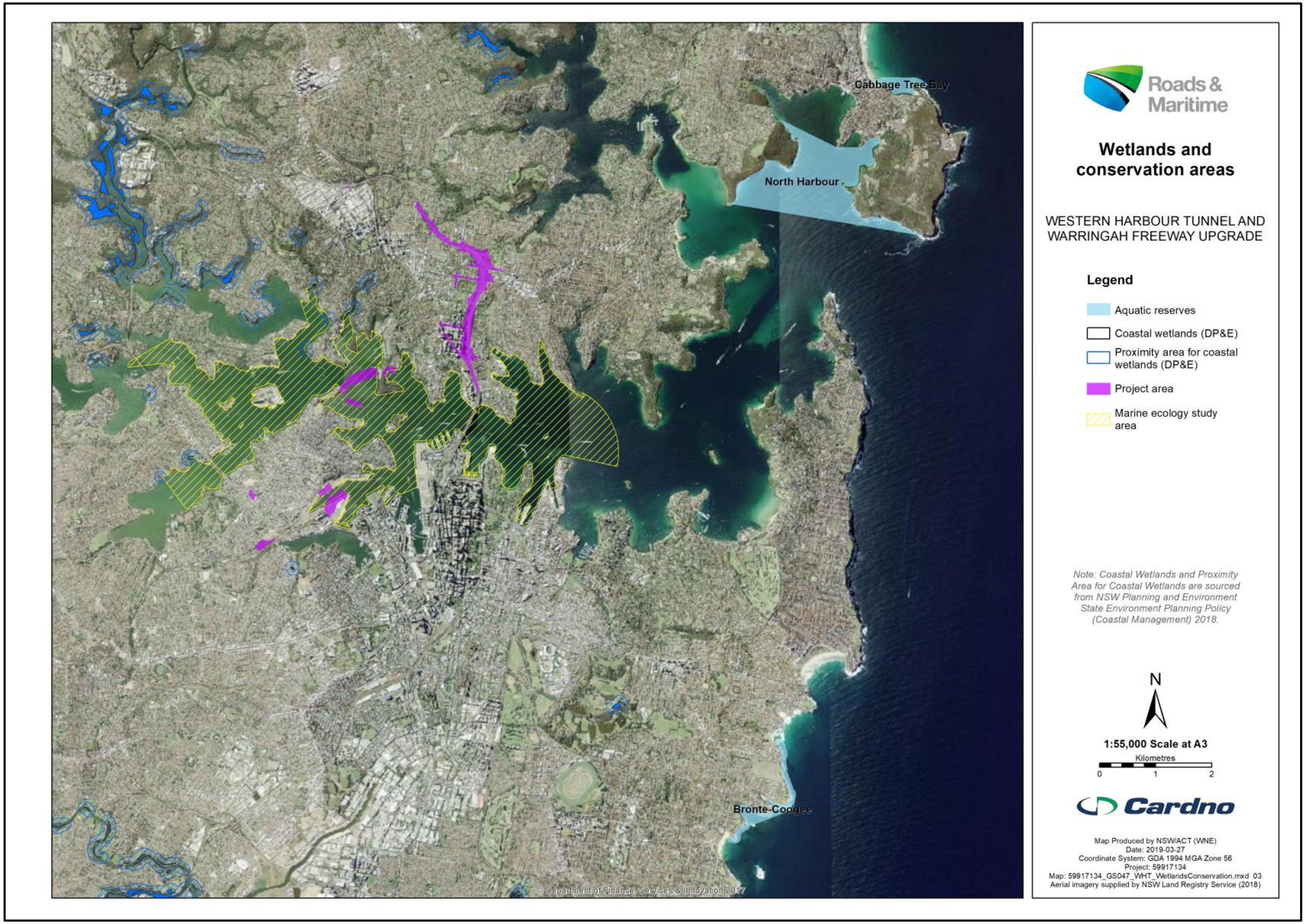

Figure 3-30 Wetlands and conservation areas within the study area

3.12 Key threatening processes (KTPs)

A KTP is a process that threatens, or may have the capability to threaten, the survival or evolutionary development of species, populations or ecological communities. KTPs are listed under the FM Act, BC Act and EPBC Act. At present, there are eight listed KTPs under the FM Act and 21 listed under the EPBC Act. Broadly, the KTPs include threats to threatened species, population and ecological communities as well as cause species, population or ecological communities to become threatened. Of these KTPs, five have potential to be triggered by the project. These are:

> Human-caused climate change (FM Act)

> Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams (FM Act)

> Introduction of non-indigenous fish and marine vegetation to the coastal waters of New South Wales (FM Act)

> Noval biota and their impact on biodiversity (EPBC Act)

> Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris (EPBC Act).

The assessment of these KTPs in relation to the project are detailed in Section 5.3.

3.13 Pests and diseases

Labyrinthula spp. is a Stramenopile protist that causes seagrass wasting disease (Trevathan-Tackett, et al., 2018). This genus of protists are ubiquitous to coastal and marine ecosystems and are important to nutrient cycling as they excrete enzymes to break down plant or algal detritus (Raghukumar, 2002). However, *Labyrinthula* spp. has been known to infect living seagrass leaf cells leading to the necrosis of chloroplast leaving distinct black lesions. The potential manifestation of seagrass wasting disease is linked to genetic clades varying in virulence and the production of constitutive or induced defence metabolites by the host (Martin, et al., 2016). *Labyrinthula* spp. are also less tolerant to low salinities. Therefore, seagrass meadows occurring in areas such as estuaries have the opportunity to clear their load of *Labyrinthula* spp. during freshwater influx events (McKone & Tanner, 2009). Seagrass wasting disease has not been described in the southern hemisphere since the 1960s and little is understood of its ecology. Trevathan-Tackett et al (2018) highlights the importance of monitoring the disease in Australian seagrass populations.

Like a great number of other estuaries and waterways, Sydney Harbour is at risk of infestation from the marine pest *Caulerpa taxifolia* (Aquarium Caulerpa) (NSW DPI 2013). *Caulerpa taxifolia* is a fast-growing marine alga native to tropical Australia and the South Pacific (NSW DPI, 2016b). This species is known to alter physical and chemical habitat affecting biodiversity. Populations have been recorded in Port Jackson at Neutral Bay, Mosman, Clifton Gardens, Rushcutters Bay, Double Bay, Rose Bay and many locations in North Harbour and Middle Harbour. The mapped occurrence of this species at Neutral Bay is the only instance where this species is known to occur within the study area. Small occurrence of this species was also observed in seagrass meadows at Mosman Bay, directly adjacent to Neutral Bay. *Caulerpa taxifolia* is known to spread via fishing and boating activities as well as natural hydrology and has potential to occur in other areas within the study area.

A large number of viral, bacterial and parasitic diseases affecting finfish, molluscs, crustacean and amphibians are known within NSW waterways. The most renowned include Red Spot Disease, QX oyster disease and Pacific Oyster Mortality Syndrome (POMs) (NSW DPI, 2018a). Red Spot Disease (or Epizootic ulcerative syndrome) is a fungal disease endemic in a number of waterways in NSW. This disease can affect many species of finfish and shows as red lesions or deep ulcers which can then be susceptible to secondary bacterial infections. Although the freshwater and estuarine waterways of the Sydney region have not reported Red Spot Disease outbreaks, it is known to occur in all NSW waterways. QX oyster disease and POMs are high risk to the oyster aquacultures of which none currently reside within the study area.

3.14 Commercial and recreational fishing

Drowned valley estuaries are the most productive of all estuary types in terms of commercial and recreational fishing (Roy, et al., 2001). In 1980-81, commercial fish catch was about 108 tonne, while the corresponding recreational fish catch was estimated as 165 tonne. Since then, prawn trawling has been phased out.

Henry (1984) found recreational fishing in Sydney Harbour to be generally greater in summer and autumn and on weekends. It is estimated that more than one million fish were caught in 1981. Recreational fishers took 46 fish species from the estuary during the one-year survey period, with species occurring in a range of benthic, demersal and pelagic habitat. At that time, the top ten species by abundance were yellowtail (*Trachurus novaezelandiae*), tailor (*Pomatomus saltatrix*), yellowfin bream (*Acanthopagrus australis*), snapper, (*Pagrus auratus*), silver trevally (*Caranx georgianus*), dusky flathead (*Platycephalus fuscus*), sweep (*Scorpis lineolatus*), fanbelly leatherjacket (*Monacanthus chinensis*), yellowfin leatherjacket (*Meuschenia trachylepis*) and sand whiting (*Sillago ciliata*). More recent anecdotal information indicates yellowtail kingfish (*Seriola lalandi*) are now among the top ten common fish caught. Rod fishing and hand lining were the main recreational fishing methods observed during Henry's (1984) survey. Few fishers used traps (crab, lobster, fish), nets (prawn, scissors, dip) or spearfished in the harbour. Fishing from the shoreline was more popular than from boats. Fishing techniques may be attributed to the geography of the estuary. An extensive, convoluted shoreline provides many protected access points to the water's edge. Deep water can be reached by an easy cast of a lightly weighted line and given Sydney Harbour is a major shipping waterway, the heavy water traffic is a hazard to small boats.

Due to elevated levels of dioxins in fish and crustaceans across Sydney Harbour, including Parramatta River and other connected tidal waterways, a ban was placed on commercial fishing in 2006. Recreational fishing in the harbour has not been banned, but fishers are urged to follow dietary advice on the levels of consumption of seafood from Sydney Harbour, Parramatta River and other connected tidal waterways. Fishers can also continue to practise catch and release.

4 Potential project hazards

Without mitigation, the construction and operational phases of the project pose various hazards with potential to cause direct or indirect impacts on marine ecology within the study area. Nine hazards (Table 4-1) have been identified from eight main project activities (Table 4-2). The hazards can have effects at various spatial and temporal scales if they are above natural background levels and durations and if not mitigated or managed appropriately.

Table 4-1 Identified hazards to marine ecology within the study area

Hazard identifier	Hazard	Direct/indirect impacts
ME1	Removal of habitat/benthic habitat	Direct
ME2	Turbidity	Indirect
ME3	Sedimentation	Indirect
ME4	Mobilisation of contaminants	Indirect
ME5	Introduction/spread of marine pests	Indirect
ME6	Altered hydrodynamics	Indirect
ME7	Underwater noise	Indirect
ME8	Boat strike to marine mammals and/or reptiles	Direct
ME9	Spill of contaminants	Indirect

Table 4-2 Project phase activities and the hazards they cause to marine ecology

Construction phase	Operation phase	Activity	Hazard	Relevant construction support sites
✓	✓	Construction support site establishment (including permanent commissioning of project elements)	ME1, ME2, ME3, ME4, ME5, ME6	Rozelle Rail Yards (WHT1), White Bay (WHT3), Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7)
✓		Cofferdam construction	ME1, ME2, ME3, ME4, ME5, ME6	Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6) cofferdams
✓		Temporary wharf constructions (including floating structures	ME1, ME2, ME3, ME4, ME5, ME7	White Bay (WHT3), Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7)
✓		Dredging	ME1, ME2, ME3, ME4, ME7	Dredging footprint between Sydney Harbour south (WHT5) and Sydney Harbour south (WHT6) cofferdams
✓		Impact piling	ME1, ME2, ME3, ME4, ME5, ME7	White Bay (WHT3), Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7)
✓		Vessel movements	ME5, ME7,	Snails Bay mooring facility, Yurulbin Point (WHT4), Sydney Harbour south cofferdam

Construction phase	Operation phase	Activity	Hazard	Relevant construction support sites
			ME8, ME9	(WHT5), Sydney Harbour north cofferdam (WHT6), Berrys Bay (WHT7) and the surrounding areas
✓		Installation of instream structures	ME6	Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7)

To understand the potential effects of these hazards it is important to understand the sensitivities of particular habitats and biota and their life history stages as well as their capacity to recover. A general description of the potential effects of the hazards to known habitats and biota within or having potential to occur in the study area, is given in the following sections.

4.1 Removal of habitat/benthic habitat (ME1)

Based on the project activities, removal of habitat/benthic habitat can occur from direct removal from dredging and/or piling, scour from high velocity/volume discharges and indirectly by shading from over-water structures. The impact of direct removal of habitat would depend on the importance (to biota) of the area to be removed, relative to the amount of habitat remaining and its recovery potential. This can depend on how unique the area of habitat is and/or the scale of removal. There could also be instances where an area of habitat to be removed would fragment an existing area of habitat or create edge-effects so that it either reduces/removes connectivity between areas or reduces the functionality of the remaining areas of habitat. These factors also need to be considered when assessing the potential impact.

4.2 Turbidity and sedimentation from dredging (ME2 and ME3)

Elevated turbidity as a result of the project can arise from any activity which would disturb the bed of the harbour and/or terrestrial runoff/discharge. The primary source of turbidity and sedimentation would likely be from dredging in relation to the project. Other construction activities also have potential to contribute to turbidity and sedimentation although not at the scale of dredging.

Recently in Australia, there has been a focus on improving an understanding of the ecological impacts of dredging for better management of potential impacts. Key recent reviews by Fraser et al (2017), McMahon et al (2017) and Wenger et al (2016) focus on benthic biota and fish. One of the key outcomes of these reviews was that there were knowledge gaps for many species. Nevertheless, the reviewers were able to be make generalisations about the vulnerability of particular groups of biota based on life history characteristics and expert advice, and these are summarised in the sections below.

4.2.1 Mobile invertebrates

Traits such as mobility, feeding mode, morphology and reproductive strategy contribute to the net vulnerability of a particular species to a dredging event (Essink, 1999). Mobile invertebrates are generally less vulnerable than sessile taxa to sedimentation, as they are able to move to areas with less sediment accumulation or by more efficiently physically removing particles. Some adult bivalves for example are known to be able to reach the surface of sediment after being buried by 40 centimetres of sediment and some polychaete worms can dig themselves out from under 16 centimetres (Powilleit et al, 2009 in Fraser et al, 2017). However, mobility alone does not indicate that these groups are resistant to dredging as certain critical life stages are still susceptible to several indirect effects of sedimentation.

In addition to the potential impacts on this group from burial, dredging and disposal can trigger ecological succession in all of the groups of species discussed below, such that more opportunistic species are likely to dominate shortly following a dredging event (Newell et al, 1998).

4.2.2 Sessile invertebrates

Sessile invertebrates are particularly vulnerable to sedimentation because they are generally unable to reorientate themselves to mitigate a build-up of particulates. Some sessile taxa, including species of sponges and bivalves, have the capacity to filter out or to physically remove particulates, however this can be metabolically costly and unsustainable (Gerrodette and Flechsig, 1979; Cortés and Risk, 1985; Aldridge et al, 1987; Roberts et al, 2006; Pineda et al, 2016). Morphology also plays a critical role since upright morphologies are generally more resistant to burial than encrusting forms (Marszalek, 1981).

Diet and feeding mode also effect vulnerability to turbidity, sedimentation and light attenuation. Sedimentation can be particularly detrimental for suspension-feeding organisms since suspended particles can be mistaken for food (Bell et al, 2015). In addition, the mechanical or abrasive action of suspended sediments may be harmful to suspension feeders, clogging their feeding apparatus and impairing respiratory and excretory function (Sherk, 1972). Several sessile invertebrate taxa such as sponges possess photosynthetic symbionts (Lemloh et al, 2009; Keesing et al, 2012) and light attenuation has the potential to disrupt these relationships (Roberts et al, 2006).

There is potential for negative effects from dredging operations if they are done during the key periods of species life stages (eg larval release, settlement and recruitment).

4.2.3 Seagrasses

Seagrasses are sensitive to changes in water quality and sediment loading. Given the widespread distribution and environmental and economic value of seagrass ecosystems (Orth et al, 2006), these organisms are a priority for protection during dredging (Waycott et al, 2009).

Seagrasses can be affected by dredging in several ways. They can be directly affected at the dredge and disposal sites, when they can be physically removed or buried, or indirectly by changes in water quality or bathymetric changes which may sometimes occur as a result of dredging activities (Erftemeijer and Lewis, 2006). Seagrasses are also affected by the increased turbidity, resulting in reductions in light available for photosynthesis, and increased levels of sedimentation, which can result in negative effects on seagrass shoot density, leaf biomass, physiology and productivity (Erftemeijer and Lewis, 2006).

The ability of seagrasses to resist and recover from disturbances caused by dredging is species-specific and related to a number of life-history characteristics (LHCs). Recently, Kilminster et al (2015) summarised seagrass vulnerability to disturbance by grouping species into three categories:

- Persistent species: defined as those with long turnover times, that are slow to reach sexual maturity and with less investment in sexual reproduction such that the presence of a seed bank is rare. Persistent species are more resistant to disturbance but take longer to recover than colonising species
- Opportunistic species: share traits with the previous and next classifications, with the ability to colonise quickly, produce seeds and to recover from seed when necessary
- Colonising species: short ramet (generational) turnover times that are quick to reach sexual maturity and display a high investment in sexual reproduction to produce seeds, usually resulting in the presence of a seed bank. Species within this group generally have a limited resistance to disturbance but have the ability to recover quickly.

Opportunistic seagrass genera (eg Zostera) have variable resistance to dredging and Zostera occurs in the study area. *Zostera* spp. have shown limited resilience to burial (70–90 per cent mortality under two to four centimetres of sediment) (Mills and Fonseca, 2003; Cabaco and Santos, 2007), and large losses of *Zostera tasmanica* and *Zostera muelleri* have been attributed to dredging and sediment build up on leaves (Kirkman, 1978; Clarke and Kirkman, 1989). Most opportunistic seagrass genera have high rates of recovery following disturbance. Seagrass species within the *Zostera* genus also show a relatively high capacity for recovery, both from seed reserves and clonal growth. Thus, maintenance of seed banks may be critical to the recovery of damaged Zostera beds and dredging operations timed after seed release are more likely to facilitate natural regrowth from seed reserves. However, in other meadows of the same species recovery from loss may be nearly exclusively from clonal growth (Rasheed, 1999) with poor recovery if the entire standing crop is lost.

Colonising seagrass genera (eg *Halophila* spp.), which occurs in the study area, have low resistance to short term pulses of increased turbidity and sedimentation in comparison to larger-bodied persistent or opportunistic species (Vermaat et al, 1997). *Halophila ovalis* has been reported to have a relatively low tolerance to burial (Vermaat et al, 1997). However, *Halophila ovalis* was able to withstand burial under four centimetres for 27 days, though burial depths greater than eight centimetres resulted in large reductions in biomass (Ooi et al, 2011). Furthermore, clonal integration is less important for the recovery of this genera following burial than for some of the other seagrasses (Ooi et al, 2011), possibly due to its smaller size and limited communication and resource sharing between ramets (Marba et al, 2006). The relatively fast growth rates and high rates of reproduction characteristic of *Halophila* spp. and other colonising species can decrease their vulnerability to disturbance (Demers et al, 2013; Kilminster et al, 2015). *Halophila* spp. and other colonising species grow quickly from a stored seedbank and may therefore recolonise dredged areas through seed dispersal (Kilminster et al, 2015). As such, *Halophila* spp. can generally recover following sedimentation and burial if seed banks are present (Hovey et al, 2015), unless the seeds are buried under too much sediment, preventing the hypocotyl from penetrating the sediment surface (Birch, 1981). There is a trade-off between fast growth and reproduction, which results in a relatively low tolerance to prolonged periods of decreased light levels compared to more persistent species. *Halophila* spp. are able to adapt to reductions in available light due to their relatively small size. *Halophila ovalis* shows acclimation potential to light levels below their minimum light requirements, but only for three to five days, after which growth rates are reduced (Longstaff et al, 1999; Longstaff and Dennison, 1999). Recovery is possible for this species if light levels is restored within nine days, but periods of low light exceeding 15 days are associated with a greater risk of mortality, with 100 per cent mortality occurring after 30 days of shading (Longstaff et al, 1999).

4.2.4 Macroalgae

4.2.4.1 Leathery macrophytes

The 'leathery macrophyte' group includes genera such as *Sargassum* and *Ecklonia* that are major habitat formers in temperate reefs, and have ecologically important roles such as habitat and food provision (Steneck et al, 2002). *E. radiata* and *Sargassum* spp. occur in the study area. Brown algae within the genus *Sargassum* are common in nearshore ecosystems, and are thought to have an advantage in higher sediment environments resulting in their abundance in turbid, inshore reef habitats. *Sargassum* spp. appear to be resistant to the negative effects of sedimentation if it is already established in a system. In contrast, increased sedimentation levels in a fringing reef environment can lead to decreased rate of recruitment, growth, survival and vegetative regeneration in *Sargassum microphyllum* (Umar et al, 1998). Successful settlement of brown algae such as *E. radiata* on hard bottom substrata is inhibited by sediment, with a direct relationship between settlement success and the thickness of the sediment or some algal species (Chapman and Fletcher, 2002). Thus, the effects of sedimentation on *Sargassum* spp. are variable. Due to the increased sensitivity of leathery macrophytes to sedimentation during reproductive and recruitment phases, it can be beneficial to avoid these periods for dredging.

4.2.4.2 Siphonous algae

The functional group 'siphonous algae' consist entirely of green algae (Phylum: Chlorophyta) from the Order Bryopsidales. The effects of dredging and sedimentation on siphonous algae are similar to the leathery macrophytes. Low levels of sedimentation are unlikely to inhibit algal growth but may affect recruitment, survival and vegetative regeneration.

4.2.4.3 Rhodophyta

Crustose coralline algae (CCA) are a macroalgael growth form in the Phylum Rhodophyta which occurs in the study area (Section 3.5.7). These are ecologically important in the habitats in which they occur, contributing to carbonate accretion, structural complexity and facilitating the settlement and recruitment of many other taxa (Nelson, 2009). As such, their response to sedimentation and burial would have major ecological ramifications on a community-wide scale. Crustose coralline algae (CCA) can survive long periods of burial by sloughing off epithelial cells such that underlying tissue can survive after the sediment is removed (Keats et al, 1997). Despite their resistance to the negative effects of burial, CCA are sensitive to the reductions in light associated with sedimentation (Riul et al, 2008). In contrast, foliose species of red algae are relatively tolerant to reductions in light.

4.2.5 Fish

The effects on fish of dredging-induced turbidity and sedimentation range from small changes in behaviour to mortality, but depend on the species or life history stages discussed below.

4.2.5.1 Behaviour

One of the most commonly observed behaviours by fish to elevated suspended sediment is the avoidance of turbid water (Collin and Hart, 2015). Avoidance behaviour (response type 1) can be induced at very low levels of suspended sediment, but ceases once the disturbance is removed, or if the fish becomes acclimated (Berg, 1983; Berg and Northcote, 1985). Increased turbidity has also produced shifts in local abundance and community composition if the stressor is apparent for a long-term. Avoidance behaviour assemblage shifts by fish can also have a negative impact on fishing at a local scale, if recreationally and commercially important species are affected.

Because turbidity often impairs vision, activities and processes that require vision can be inhibited, leading to behavioural responses other than avoidance. This is particularly important for species with a pelagic larval phase, whereby the ability to find suitable habitat is crucial for development and survival during the very early life-history stages. If individuals settle into suboptimal habitat, they are more vulnerable to predation and experience slower growth rates (Coker, Pratchett Munday, 2009; Feary, McCormick and Jones, 2009) which may have significant flow-on effects for the adult population (Wilson et al, 2016). Once a fish has settled, however, their home range often expands to include a broader array of habitat patches and exploitable resources, thereby offsetting poor habitat choice at settlement (Wilson et al, 2008). Fish that are unable to use the full extent of their home range due to elevated turbidity experience fitness consequences through a reduction in foraging and territorial defence (Lewis, 1997; Lönnstedt and McCormick, 2011).

4.2.5.2 Foraging and predation

Foraging in both planktivorous and piscivorous fish is negatively affected by turbidity and sedimentation affects herbivory (Utne-Palm, 2002). Foraging by planktivorous and drift-feeding species is inhibited by reducing the reactive distance and the vision of individual fish (Asaeda, Park, & Manatunge, 2002; Barrett, Grossman, & Rosenfeld, 1992; Gardner, 1981; Sweka and Hartman, 2003) . Foraging success typically declines at higher levels of turbidity (Johansen and Jones, 2013; Utne-Palm, 2002). Mild levels of turbidity, however, can sometimes enhance the contrast of plankton against its background, making it easier for planktivores to detect their prey (Utne-Palm, 1999; Wenger et al, 2014). Some species have also shown an ability to cope with changing levels of turbidity by shifting their foraging strategies under conditions of high turbidity (30-40 Nephelometric Turbidity Units (NTU); Hazelton and Grossman, 2009; Sweka and Hartman, 2001).

Sedimentation can inhibit foraging ability in benthic feeding species. For example, sediment embedded in algal turfs suppresses herbivory on coral reefs, with sediment removal resulting in a twofold increase in feeding by many herbivorous fish species (Bellwood and Fulton, 2008). Importantly, reduced feeding due to experimentally elevated sediment loads has been observed across different reef habitats, regardless of the natural sedimentation levels (Goatley and Bellwood, 2012). Ultimately, any reduction in foraging success leads to changes in growth, condition and reproductive output. Sweka and Hartman (2001) showed growth rates of Brook trout (S. *fontinalis*, Family: Salmonidae) declined as turbidity increased (up to 40 NTU), due to an increase in energy used to forage. Similarly, increasing levels of suspended sediment reduced growth and body condition of the spiny chromis (*Acanthochromis polyacanthus*, Family: Pomacentridae) such that mortality increased by 50 per cent in the highest suspended sediment concentrations (180 milligrams per litre, Wenger et al, 2012).

Piscivores are especially sensitive to increasing turbidity because many are visual hunters that detect prey from a distance. An increase in suspended sediment reduces both light and contrast, decreasing encounter distances between predator and prey (Fiksen et al, 2002). Accordingly, several studies have shown a linear or exponential decline in piscivore foraging success with increasing turbidity (eg De Robertis et al, 2003; Reid et al, 1999). The influence of turbidity on predation is, however, inconsistent among species.

4.2.5.3 Physiological changes

Increasing exposure to suspended sediment causes damage to gill tissue and structure, including epithelium lifting, hyperplasia and increased oxygen diffusion distance in the orange-spotted grouper (*Epinephelus coioides*, Family: Serranidae) and the orange clownfish (*Amphiprion percula*, Family: Pomacentridae) (Au et al, 2004; Wenger et al, 2015). Under these conditions, increased pathogenic bacteria were also observed in orange clownfish, while Lowe et al, (2015) found an increased parasite load on the gills of the pink snapper (*Chrysophrys auratus*, Family: Sparidae). Any reduction in gill efficiency impairs respiratory ability, nitrogenous excretion and ion exchange (Appleby and Scarratt, 1989; Au et al, 2004; Wong, et al, 2013). The size of the gills is proportional to the size of the fish, meaning that the spaces between lamellae are smaller in larvae. It is therefore likely that sediment can more easily clog the gills and reduce their efficiency in smaller fish and larvae (Appleby and Scarratt, 1989). As larvae have much higher oxygen requirements than other life-history stages, any reduced efficiency in oxygen uptake could increase mortality or sublethal effects (Nilsson et al, 2007). Structural changes in gills elevate haematocrit, plasma cortisol and glucose levels, all of which are consistent with oxygen deprivation (Awata et al, 2011; Collin and Hart, 2015; Wilber and Clarke, 2001). Increased sedimentation and suspended sediment can also reduce the amount of dissolved oxygen in water, exacerbating the direct physical damage to gills (Henley et al, 2000). The sublethal effects described here strongly influence growth, development and swimming ability, all of which may inhibit an individual’s ability to move away from dredging operations and compound any physiological effects (Collin and Hart, 2015).

4.3 Mobilisation of contaminants

There is substantial evidence that direct exposure to contaminants negatively effects fish and invertebrates (Jezierska et al, 2009; Nicolas, 1999).

In addition to contaminant levels in the sediment, the risk of adverse biological effects to biota in the surrounding area depends on the level of contaminant mobilisation from the sediment but this is difficult to determine given the complex nature of the chemical processes involved. The rate of contaminant remobilisation is influenced by the physical and chemical properties of the sediment and the overlying water column, and is a complex process influenced by many factors (Roberts, 2012). For example, the rate of metal desorption during re-suspension is strongly influenced by grain size, sulphides, levels of organic matter and hydrous metal oxides of iron and manganese (Cantwell et al, 2008). In addition, the levels of pH, dissolved oxygen and salinity in the overlying water column influence the rate of contaminant mobilisation to varying degrees (Cantwell et al, 2008). Further complicating factors are diurnal and seasonal variation in temperature, biological oxygen demand (BOD) and the abundance and types of organisms that burrow and use sediment habitat (Roberts, 2012).

Many studies, both laboratory and field based, have showed the ecological impacts on various aquatic organisms from the resuspension of contaminated sediments and the subsequent mobilisation of contaminants. For example, fish can suffer from direct exposure to suspended contaminated sediments which can impair chemosensory functions, impair feeding and reduce their response to external stimuli (Roberts, 2012). As fish accumulate contaminants across gill surfaces and their skin, contaminants such as polycyclic aromatic hydrocarbons (PAHs) have been shown to cause fin erosion and lesions in lab based studies (Gregg et al, 1997). The release of sediment-associated PAHs may cause similar deformities as those observed following exposure to oil. Any activity that exposes fish, regardless of its life stage, to persistent organic pollutants (POPs) or PAHs should be considered high risk to animal health.

Filter feeding organisms such as oysters and mussels are susceptible to suspended contaminants, given their ability to accumulate from both dissolved and particulate bound contaminants (Cruz-Rodriguez and Chu, 2002). Studies have shown that bivalves and polychaete worms can exhibit reduced feeding activity and suffer from a range of histopathological effects which can impact on their reproduction and respiration (Roberts, 2012). In addition, many of the contaminants recorded in the sediment quality assessment for the study area have the ability to bioaccumulate in aquatic organisms, which can lead to a greater risk of chronic poisoning within these organisms.

Studies examining the effects of contaminated sediment on biota also had higher effects than studies on clean sediment alone or noise, suggesting synergistic impacts from dredging-related stressors (Wenger et al, 2017).

Some metals are released more readily than others (Maddock et al, 2007), so the duration for which the contaminated sediment is exposed to the seawater is a critical variable. Fine sediments (silts and clays) remain in suspension longer and therefore release more metals. It is clear that there is a gap in the understanding of the potential for metals adsorbed to sediment to be taken up by fish. Metals impact reproductive output and early development in fish via a range of entry routes and mechanisms (reviewed by Jezierska et al, 2009). Metals accumulate in gonad tissue (Alquezar et al, 2006; Chi, et al, 2007) and in the egg shell and chorion causing developmental delays, changes in time to hatch and larval deformities (Chow and Cheng 2003; Witeska et al, 1995). Heavy metals such as mercury, zinc and cadmium are also known to reduce sperm motility (Abascal et al, 2007; Kime et al, 1996). At higher levels but still within concentrations recorded in the environment (0.1 and 10 milligrams per litre), ionic metals can be lethal to larvae (*Cyprinodon variegatus*, Cyprinidae; Hutchinson).

4.4 Underwater noise

Sounds emitted from vessels, dredging and piling activities is transmitted through bed of the harbour sediments and the water column, and they might be perceived by marine fauna within a certain distance from the construction activities.

Based on the existing information, underwater noise can effect marine animals in a number of ways, including (i) behavioural responses, (ii) masking, (iii) stress and physiological responses, (iv) hearing loss and damage to auditory tissues, (v) structural and cellular damage of non-auditory tissues and total mortality, (vi) impairment of lateral line functions and (vii) particle motion-based effects on eggs and larvae (Popper and Hastings, 2009; Popper et al, 2014).

Death and injury can result from exposure to very high amplitude sounds. In addition, the effects of changes in pressure (barotrauma) must also be considered, especially for impulsive sounds. Barotrauma is tissue injury that results from rapid pressure changes (eg forced change in depth, explosions, and intense sound) (Stephenson et al, 2010; Halvorsen et al, 2011, 2012). Rapid changes in pressure can cause blood gases to come out of solution. Rapid pressure changes can also cause gas volumes (ie swim bladders) to expand

and contract rapidly, damaging surrounding tissues and organs, and sometimes causing rupture of the swim bladder itself.

4.4.1 Dredging noise

Sound levels recorded from dredge operations ranged from 111 to 170 dB re 1 μPa rms. The available evidence indicates that dredging scenarios do not produce intense sounds comparable to impact pile driving and other in-water construction activities, but rather lower levels of continuous sound at frequencies generally below 1 kHz. However, when dredging includes the removal or breaking of rocks, the sound generated is likely to exceed the sound of soft sediment dredging. The exposure to dredging sounds does depend on site-specific factors, including bathymetry and density stratification of the water column (Reine et al, 2014). Exposures to a given sound in relatively deep coastal oceanic waters would be different to those experienced in shallow estuaries with complex bathymetries.

While sound levels produced by dredging can approach, or exceed, the levels tested in the studies, received sound levels would be lower than source levels (Reine et al, 2014). As sound pressure is lower from natural sources compared to that produced by dredging, most fish species do not have the physiology to detect sound pressure (Hawkins et al, 2015; Popper et al, 2014) and therefore show no temporary threshold shift (TTS) (ie temporary hearing loss) in response to long-term noise exposure (Popper et al, 2014). Impacts on fish from dredging-generated noise are therefore likely to be temporary hearing loss in some species, behavioural effects and increased stress-related cortisol levels. Finally, although dredging may not cause levels of sound that can be physiologically damaging to fish, dredging noise may mask natural sounds used by larvae to locate suitable habitat (Simpson et al, 2005).

4.4.2 Piling noise

The project would carry out ‘impact hammering (pile driving)’ to drive subsea piles during the installation of temporary cofferdams at the east/west entries of the crossing at the Sydney Harbour north cofferdam (WHT6) and Sydney Harbour south cofferdam (WHT5) ends of the immersed tube tunnels and ‘pile drilling’ to install piles for the wharves at Yurublin Park (WHT4) and Berrys Bay (WHT7) construction support sites.

For pile drilling, there would be no potential for underwater noise to harm marine mammals, fish or turtles beyond the extents of the dredging or the piling operation.

JASCO (2019) indicates that for most projects involving impact pile driving in shallow-water environments, there is a potential for direct transmission from the sound source to biological receivers, and there are reflected sound paths from the water’s surface and bottom that may be perceived by marine fauna. There are many known cases where unmitigated piling causes damage to marine animals and large-scale fish kills have been reported.

Normally, ground-radiated sound is dominated by low frequencies that cannot propagate efficiently through shallow water. When impact pile driving is the sound source, there is the potential for substrate-borne sound caused when the hammer strikes the pile to be re-radiated back into the water where it may reach a biological receiver. For pile driving, energy transmission through water depends on these factors: 1) direct contact between the pile and the water, 2) the depth of the water column, 3) the size of the pile, 4) the type of hammer, and 5) the hammer energy (Christopherson and Lundberg, 2013). The way sound propagates in water is affected by obstructions (such as barges, other piles, and bridges) and the river channel characteristics (such as the channel width and slope) (Buehler et al., 2015).

Due to the variety of species considered, there are several different thresholds for evaluating effects of impact piling, including: mortality, injury, temporary reduction in hearing sensitivity and behavioural disturbance.

4.4.3 Effects on fish

The effects of anthropogenic sound on fish have been reviewed by Hawkins et al (2015) and Popper and Hastings (2009) and synthesized into guidelines by Popper et al (2014), however, they do not specifically include dredging as a sound source. Data exists for only approximately 100 of the more than 32,000 recorded fish species (Popper and Hastings, 2009)

Effects of dredging noise vary among fish species with one of the most important determinants being the presence or absence of a swim bladder (Popper et al, 2014). Fish species that have a swim bladder used for hearing are more likely affected by continuous noise than those without a swim bladder (Popper et al, 2014).

Gas bladders, and their anatomical location within the body, make fish more susceptible to pressure-mediated (sound pressure and barotrauma) injury to the ears and general body tissues than species lacking gas bladders (Stephenson et al, 2010; Halvorsen et al, 2011; Carlson, 2012). The presence of a gas bladder is also likely to increase the ability of many species of fish to detect sounds over a broader frequency range and at greater distances from the source than fish without such structures, thereby increasing the range from the source over which man-made sound sources have the potential to exert influence. Hearing range and sensitivity varies considerably among species. Some species with a swim bladder are sound pressure-sensitive at higher frequencies (Atlantic cod), while others having a swim bladder are not (Atlantic salmon).

The adaptations that provide fish with a sensitivity to sound pressure are gas-filled structures near the ear and/or extensions of the swim bladder that functionally affect the ear. The enclosed gas changes volume in response to fluctuating sound pressure, generating particle motion. In fish where the swim bladder is near the ear (or connected to it mechanically as in the Otophysi), the particle motion radiated from the bladder is sufficiently large to cause the sensory epithelium to move relative to the otolith. Fish with these adaptations generally have lower sound pressure thresholds and wider frequency ranges of hearing than the purely particle motion-sensitive species.

A range of responses has been observed when the behaviour of wild fish have been studied in the presence of man-made sounds. Some fish have shown changes in swimming behaviour and orientation, including startle reactions (Pearson et al, 1992; Wardle et al, 2001; Hassel et al, 2004). The response may habituate with repeated presentations of the same sound. Sound can also cause changes in schooling patterns and distribution (Pearson et al, 1992).

Masking is a hearing impairment with respect to the relevant sound sources normally detected within the soundscape. However, the consequences of masking for fish have not been fully examined.

Injury to fish from barotrauma can be quite variable, both in cause and effect, depending upon of the pattern of pressure changes and the physiological state of the exposed fish (Stephenson et al, 2010, Halvorsen et al, 2011, 2012). Sudden changes in pressure are more likely to result in damage than gradual changes. Barotrauma endpoints include lethal injury through immediate mortality or delayed mortality (McKinstry et al, 2007) and a number of injuries with varying severity from which full recovery is possible (eg Halvorsen et al, 2011, 2012; Brown et al, 2012; Casper et al, 2012, 2013). Injuries that are potentially recoverable, such as fin hematomas, capillary dilation, and loss of sensory hair cells, may still lead to death if they decrease fitness and the animal is subject to predation or disease. Mortality as a result of reduced fitness that leads to predation or disease is classified as indirect mortality, whereas death as a result of injuries is classified as direct mortality (Halvorsen et al, 2011, 2012).

While few data are available on larval fishes, those species studied appear to have hearing frequency ranges similar to those of adults (Higgs et al, 2002; Egner and Mann, 2005; Zeddies and Fay, 2005; Wright et al, 2011), and similar acoustic startle thresholds (Zeddies and Fay, 2005). Swim bladders may develop during the larval stage and may render larvae susceptible to pressure-related injuries (eg barotrauma). Current concern over the effects of sound upon eggs, and especially for larvae containing gas bubbles, is focused on barotrauma rather than hearing.

4.4.4 Effects on marine mammals

Behavioral responses of marine mammals to noise are highly variable and dependent on a suite of internal and external factors. Internal factors include:

> Individual hearing sensitivity, activity pattern, and motivational and behavioral state at time of exposure
> Past exposure of the animal to the noise, which may have led to habituation or sensitization
> Individual noise tolerance
> Demographic factors such as age, sex, and presence of dependent offspring.

External factors include:

> Non-acoustic characteristics of the sound source, such as whether it is stationary or moving
> Environmental factors that influence sound transmission
> Habitat characteristics, such as being in a confined location
> Location, such as proximity to a shoreline.

Behavioral responses range from subtle changes in surfacing and breathing patterns, to cessation of vocalizations, to active avoidance or escape from the region of the highest sound levels.

Whale strandings indicate that when there is extreme noise there may be acoustic trauma to marine mammals.

4.4.5 Effects on turtles

Data on hearing by sea turtles is very limited but the ear of sea turtles appears to be adapted to detect sound in water. Studies using auditory evoked potentials (AEPs) found similar low-frequency responses to vibrations delivered to the tympanum (the external ear on the surface of the head) for the loggerhead sea turtle (Bartol et al, 1999) and to underwater sound stimuli for the loggerhead, Kemp's Ridley, and green sea turtles (Bartol and Ketten, 2006; Bartol and Bartol, 2011; Lavender et al, 2012).

There is a lack of data regarding responses of turtles to acoustic exposure, and no studies of hearing loss due to exposure to loud sounds. Most recently, a working group analysed existing knowledge of how turtles respond to sound and suggested that, in the absence of data and in consideration of turtle hearing anatomy, criteria for fish that do not hear well should be adopted for turtles (Popper et al, 2014).

4.4.6 Effects on other species

There is also some evidence that a number of crustacean species, such as crabs, have statocysts that are somewhat similar to those found in cephalopods, although they have evolved separately. While there are no data for hearing by marine crabs, a number of species of semi-terrestrial fiddler and ghost crabs are not only able to detect sounds but also use special sounds for communication (reviewed in Popper et al, 2001). In addition, a number of physiological studies of statocysts of marine crabs suggest that some of these species are potentially capable of sound detection (Popper et al, 2001).

4.4.7 Acoustic thresholds

To develop exposure guidelines it is first necessary to place fish in categories depending on how they might be affected by sounds. Popper et al (2014) propose categories based on the presence or absence of a swim bladder and on the potential for that swim bladder to improve the hearing sensitivity and range of hearing.

Based on the above discussion, animals have been grouped into the following categories for analyzing the effects of sounds upon them:

- Fish with no swim bladder or other gas chamber (eg dab and other flatfish). These species are less susceptible to barotrauma and only detect particle motion, not sound pressure. However, some barotrauma may result from exposure to sound pressure
- Fish with swim bladders in which hearing does not involve the swim bladder or other gas volume (eg Atlantic salmon). These species are susceptible to barotrauma although hearing only involves particle motion, not sound pressure
- Fish in which hearing involves a swim bladder or other gas volume (eg Atlantic cod, herring and relatives, Otophysi). These species are susceptible to barotrauma and detect sound pressure as well as particle motion
- Sea turtles
- Fish eggs and larvae.

To assess the potential impacts of a sound-producing activity, it is necessary to first establish exposure criteria (thresholds) for which sound levels may be expected to have a negative impact on animals (ie a change in behaviour, injury or mortality). For impulsive noise such as pile driving, the perceived loudness depends on the rise time, duration, and frequency content of the noise. Several sound level metrics are commonly used to evaluate impulsive noise and its effects on marine life. For acoustic impact analysis, dredging is considered a non-impulsive source, despite the time-dependent variations in sound levels resulting from the usual cycle of dredging activities (eg vessel positioning, sediment breakup, and collection).

Further details about the metrics and sound thresholds for marine mammals and fish used in this study are given in JASCO (2019).

4.5 Altered hydrodynamics

Changes in hydrodynamics associated with the presence of structures (eg cofferdams) could have potential negative impacts on benthic communities through a range of mechanisms. Although an extreme increase in currents could cause physical damage, localised reduction in currents could have negative effects on benthic communities, through reduction in nutrient and plankton supply, reduction of waste removal as well as increases in sediment deposition (PIANC, 2010). Conversely, increased water movement may instead have positive impacts on some species, through increasing the delivery of nutrients and planktonic food, as well as the removal of waste products (Lowe and Falter, 2015; PIANC, 2010).

4.6 Introduction of marine pests

Vessels and movement of offshore equipment have potential to act as vectors for introduced species. Introduced species may be translocated into the study area through the release of ballast water (in the case of planktonic larvae or species) or via reproduction from individuals attached to the hull of a vessel. Marine pests are considered to be a long-term, reversible impact to which marine communities have an existing level of exposure.

5 Impact assessment

The assessment of the impacts of the construction and operation of the project firstly involved a risk assessment on biodiversity values to identify the key issues for impact assessment. These key issues were then assessed to determine the significance of the impact and any potential cumulative impacts. Mitigation measures were then identified so any residual impacts would be acceptable.

The only potential operation stage consideration would be discharges from the wastewater treatment plant at Rozelle which is outside of the study area where only intertidal rocky shore habitat is expected to occur. This would be mitigated as detailed in Sections 1.7 and 6. Accordingly, no residual operational impacts on biodiversity values are expected. The following assessment therefore focuses only on the construction impacts of the project.

5.1 Risk analysis

The first step in the assessment was a risk analysis which involved identifying key risks including a preliminary assessment to identify key issues to be taken through to a more detailed impact assessment. The risk analysis considered project safeguards summarised in Section 1.7 and recommended mitigation measures in Section 6.

5.1.1 Identification of biodiversity values

From the review of existing information and project-specific field investigations, 12 biodiversity values relevant to the project were identified. Of the 12, seven were related to marine habitat and vegetation and five were related to marine fauna which was generally driven by threatened and/or migratory species listed under the FM Act and/or the EPBC Act. Detailed descriptions of these values are found in Section 3 and justifications for their identification (including their associated sensitivity, ie Type) (refer Section 3.5.1) are summarised in Table 5-1.

Table 5-1 Identified biodiversity values within the study area

Biodiversity value	Justification as biodiversity value
Marine habitat and vegetation	
Intertidal rocky shore habitats	▪ Type 2 - Moderately sensitive key fish habitat ▪ Contains marine vegetation protected under the FM Act ▪ Important habitat for many commercially and recreational important fish.
Seagrass habitats	▪ Type 1 - Highly sensitive key fish habitat, or Type 2 (if area <5 m^2) ▪ Contains marine vegetation protected under the FM Act ▪ Potentially sensitive to disturbances ▪ Important habitat for many commercially and recreational important fish.
Mangrove habitats	▪ Type 2 - Moderately sensitive key fish habitat ▪ Contains marine vegetation protected under the FM Act ▪ Provides important ecosystem services and habitats for threat- and migratory-listed fauna.
Intertidal sand and mudflat habitats	▪ Type 2 - Moderately sensitive key fish habitat ▪ Provides foraging habitats for threat- and migratory listed fauna and commercially and recreationally important fish.
Subtidal rocky reef habitats	▪ Type 1 - Highly sensitive key fish habitat (medium and high relief reef is known habitat of threatened black rockcod and all subtidal reef is known habitat of the nominated-for-listing White's seahorse) ▪ Contains marine vegetation protected under the FM Act ▪ Important habitat for many commercially and recreational important fish ▪ Potential habitat for threat-listed fish.
Deepwater soft sediment habitats	▪ Type 3 - Minimally sensitive key fish habitat ▪ Occupies the largest area within the study area ▪ Provides connectivity between habitats

Biodiversity value	Justification as biodiversity value
	▪ Periodically used by important, transient marine fauna.
Open water habitats	▪ Type 3 - Minimally sensitive key fish habitat ▪ Occupies the largest area within the study area ▪ Provides connectivity between habitats ▪ Periodically used by important, transient marine fauna.
Threatened and/or migratory specie listed under the FM Act and/or EPBC Act	
Black rockcod	▪ Listed as vulnerable under the FM Act and EPBC Act ▪ The study area lies within its known distribution and anecdotally recorded within the greater estuary ▪ Usually occurs in Type 1 and Type 2 key fish habitat.
White's seahorse^	▪ Nominated to be listed as threatened under the FM Act ▪ The study area lies within its known distribution and anecdotally recorded within the greater estuary ▪ Usually occurs in Type 1 and Type 2 key fish habitat.
Marine mammals (whales, dolphins and seals)	▪ Threat-, migratory- and/or marine- listed under the EPBC Act ▪ Iconic marine fauna of the greater Sydney region ▪ Usually occurs in Type 3 key fish habitat.
Marine reptiles (turtles)	▪ Threat-, migratory- and/or marine- listed under the EPBC Act ▪ Iconic marine fauna of the greater Sydney region ▪ Usually occurs in Type 3 key fish habitat.
Elasmobranchs (sharks and rays)	▪ Threat-, migratory- and/or marine- listed under the FM Act and/or EPBC Act ▪ Recreationally and commercially important species ▪ Iconic marine fauna of the greater Sydney region ▪ Can occur in Type 1, 2 or 3 key fish habitat.

^ = *nominated listing*

5.1.2 Risk analysis

Risk of the potential project hazards (Section 4) on biodiversity values was determined according to the methodology in Section 2.7.1. The outcome of the analyses is summarised in Table 5-2.

Table 5-2 includes some hazards as not being applicable to some biodiversity values. For example, due to the affiliation of marine mammals and marine reptiles to open water habitats and the explicitness of 'ME8: boat strike to marine mammals and/or reptiles', the analysis of this hazard was excluded for open water habitats and instead included in analyses of marine mammals and marine reptiles. The hazard ME8 was also excluded from analyses of:

> Intertidal rocky shore habitats
> Mangrove habitats
> Intertidal sand and mudflat habitats
> Deepwater soft sediment habitats
> Black rockcod
> Elasmobranchs.

Further, hazards 'ME3: sedimentation' was also not applicable to open water habitats or marine mammals. Hazard 'ME5: introduction/spread of marine pests' was also not applicable to marine mammals.

All 'high' and 'extreme' and some 'moderate' risk levels were considered key issues to be assessed in detail in the impact assessment. A summary of the results of the risk analysis is given in Table 5-2 and justifications for risk levels are given in the following sections.

Table 5-2 Summary of risk analysis

Hazard	Biodiversity values											
	Marine habitat and vegetation							Threatened and/or migratory species (FM Act and EPBC Act)				
	Intertidal rocky shore habitats	Seagrass habitats	Mangrove habitats	Intertidal sand and mudflat habitats	Subtidal rocky reef habitats	Deepwater soft sediment habitats	Open water habitats	Black rockcod	White's seahorse	Marine mammals	Marine reptiles	Elasmobranchs
ME1: Removal of habitat/benthic habitat		✓			✓	✓						
ME2: Turbidity		✓			✓							
ME3: Sedimentation		✓			✓		N/A			N/A		
ME4: Mobilisation of contaminants		✓			✓							
ME5: Introduction/spread of marine pests		✓			✓					N/A		
ME6: Altered hydrodynamics		✓			✓							
ME7: Underwater noise	N/A	✓			✓	✓	✓	✓	✓	✓	✓	✓
ME8: Boat strike to marine mammals and/or reptiles	N/A	✓	N/A	N/A	✓	✓	✓	N/A	N/A	✓	✓	N/A
ME9: Spill of contaminants		✓			✓							

Key	
Extreme risk	Risk is unmanageable and cannot be justified under any circumstances. Measures to reduce risk to a lower level are required.
High risk	Risk is significant and requires significant cost-effective measures for risk reduction and/or management.
Moderate risk	Routine and cost-effective measures required to reduce and/or manage risk. Risk may be acceptable.
Low risk	Risk can be managed by routine procedures and/or no further measures to manage the risk are required.

✓ key issues (see Appendix G)

1. The hazard ME8 was excluded from analyses of intertidal rocky shore habitats, mangrove habitats, saltmarsh habitats, intertidal sand and mudflat habitats, deepwater soft sediment habitats, black rockcod, White's seahorse and elasmobranchs. Although ME8 is applicable to marine mammals and marine reptiles potentially occurring in seagrass, subtidal rocky reef, deepwater soft sediment and open water habitats, to avoid duplication an assessment of impacts (below) for these species was only done in Section 5.2.3.2

2. ME3 was not-applicable to open water habitats or marine mammals

3. ME5 was not-applicable to marine mammals.

5.1.3 Summary of key issues

The risk analysis was used to identify key issues associated with the project. Key issues were determined by consideration of the:

> Level of risk
> Sensitivity of habitats (ie key fish habitat type, see Section 3.5.1), or threatened species, to hazards
> Spatial scale of potential impact relative to the overall extent of unaffected habitat in the harbour.

The risk analyses process identified that there would be no extreme risks.

Hazards with 'high' risk to any key fish habitat were considered a key issue. The risk analysis indicated that there would be one hazard which would be high risk to three biodiversity values. These risks would arise from the removal of habitat/benthic habitat to seagrass, deepwater soft sediment and open water habitats. All other risks identified would be moderate or low (Table 5-2).

Hazards with 'moderate' risk to Type 1 (highly sensitive) key fish habitat were considered a key issue. Potentially at risk Type 1 key fish habitats included seagrass (beds that are greater than five square metres) and low, medium and high relief subtidal rocky reef habitat, noting that the latter is considered Type 1 because it is expected habitat of a threatened species (black rockcod and/or the nominated-for-listing White's seahorse) (see Section 3.5.1).

Hazards with 'moderate' risk to Type 2 (moderately sensitive) and Type 3 (the least sensitive) key fish habitat were considered a key issue where there would be potential for a large area of the habitat to be affected. This included risk from the hazards of underwater noise from piling and direct removal of some areas of the Type 3 key fish habitats of deepwater soft sediment and open water.

Hazards with 'moderate' risk to threatened, migratory and/or marine species listed under the EPBC Act (MNES) were considered a key issue where there would be potential for harm to individuals within a large area. This included risk from the hazards of underwater noise from piling and boat strike.

The risk analysis process identified 26 key issues relating to Type 1 or Type 3 key fish habitats as well as seven key issues associated with threatened, migratory and/or marine species listed under the EPBC Act (MNES). There were no key issues relating to Type 2 key fish habitat. For simplicity, the 33 key issues were grouped into 12 over-arching key issues, according to the hazard, whether it affects Type 1 or 3 key fish habitats, or MNES (Table 5-3).

Table 5-3 Key issues identified from the risk analysis

Key issue	Over-arching key issues for impact assessment
Type 1 'highly sensitive' key fish habitat	
Removal of habitat/benthic habitat to seagrass habitats	Potential for direct removal of seagrass or low/medium/high relief rocky reef
Removal of habitat/benthic habitat to subtidal rocky reef habitat	
Turbidity to seagrass habitats	Excessive turbidity and sedimentation (from dredging) in seagrass or low/medium/high relief rocky reef habitat
Sedimentation to seagrass habitats	
Turbidity to subtidal rocky reef habitats	
Sedimentation to subtidal rocky reef habitats	
Mobilisation of contaminants to seagrass habitats	Mobilisation of contaminants to seagrass or low/medium/high relief rocky reef
Mobilisation of contaminants to subtidal rocky reef habitats	
Introduction/spread of marine pests to seagrass habitats	Introduction/spread of marine pests to seagrass or low/medium/high relief rocky reef
Introduction/spread of marine pests to subtidal rocky reef habitats	
Altered hydrodynamics to seagrass habitats	Altered hydrodynamics in seagrass or low/medium/high relief rocky reef
Altered hydrodynamics to subtidal rocky reef habitats	

Key issue	Over-arching key issues for impact assessment
Underwater noise to seagrass habitats	Underwater noise impacts on fish and elasmobranchs in seagrass or low/medium/high relief rocky reef
Underwater noise to subtidal rocky reef habitats	
Boat strike to marine mammals and/or reptiles to seagrass habitats	Boat strike to marine mammals and marine reptiles (in MNES)
Boast strike to marine mammals and/or reptiles to subtidal rocky reef habitats	
Spill of contaminants to seagrass habitats	Spill of contaminants in seagrass or low/medium/high relief rocky reef
Spill of contaminants to subtidal rocky reef habitats	
Type 3 'minimally sensitive' key fish habitat	
Removal of habitat/benthic habitat to deepwater soft sediment habitats	Direct removal of deepwater soft sediment habitat
Underwater noise to deepwater soft sediment habitats	Underwater noise impact to fish and elasmobranchs in deepwater soft sediment habitat (including open water)
Underwater noise to open water habitats	
Boat strike to marine mammals and/or reptiles to deepwater soft sediment habitats	Boat strike to marine mammals and marine reptiles (in MNES)
Boat strike to marine mammals and/or marine reptiles to open water habitats	
MNES	
Removal of habitat/benthic habitat of the black rockcod	Potential for direct removal of seagrass or medium/high relief subtidal rocky reef (same key issue as per Type 1 above)
Underwater noise on black rockcod	Underwater noise impacts on fish and elasmobranchs in seagrass or medium/high relief subtidal rocky reef (same key issue as per Type 1 above)
Underwater noise on marine mammals	Underwater noise impact to marine reptiles, marine mammals and elasmobranchs (same key issue as per Type 1 or 3 above)
Underwater noise on marine reptiles	
Underwater noise on elasmobranchs	
Boat strike on marine mammals	Boat strike to marine mammals and marine reptiles (same key issue as per Type 1 or 3 above)
Boat strike on marine reptiles	

An assessment of these impacts based on the project description as detailed in chapters 5 and 6 of the environmental impact statement is provided in the following section.

5.2 Assessment of impacts

The assessment of impact to key issues to biodiversity values is based on the risk assessment as described in the sections above and the results of field surveys that identify any unique attributes of particular habitats or biota and regional extent (Section 3.5). The assessment is based on whether there has been direct loss of habitat or modification of their physical attributes (eg hydrodynamics) but also indirect effects on biota through loss of prey or physiological changes to biochemical processes. The relative importance of each potential risk to biodiversity values is also considered. For example, small permanent changes to habitat in the long-term could exceed the impacts caused by temporary effects of stressors during construction (including substantial mortality to some individuals within a population) to biota. Consequently, benthic habitats have been explicitly accounted for in recommendations. Further, some impacts can combine which can compound the effects to habitat or biota, leading to further impacts. The precautionary principle was considered where there was lack of scientific certainty.

5.2.1 Type 1 'highly sensitive' key fish habitat

5.2.1.1 Potential for direct removal of seagrass or subtidal rocky reef habitat

Seagrass habitat does not occur within the project area so removal of seagrass for the purposes of project construction is not predicted. However, a small patch of Zostera (less than 0.01 hectares) occurs between the Yurublin Point construction support site (WHT4) and the Sydney Harbour south cofferdam (WHT5) (see Figure 5-1). Activities at the Yurublin Point construction support site (WHT4) and the Sydney Harbour south cofferdam (WHT5) have the potential to directly impact this patch of Zostera include scour from vessel movement and wastewater treatment plant discharge. Indirect impacts with potential to facilitate dieback of this patch of Zostera and others in close vicinity include alterations to water and sediment quality as a result of the project.

Removal of seagrass from scouring is likely to follow one or more of the following pathways:

> Shear stress associated with fast water velocities generated from wash

> Abrasion from scoured sediment while suspended in the wash.

Seagrass meadows generally prefer low energy environments and high density meadows (greater than 50 per cent seagrass cover) and have been shown to be associated with current velocities less than 0.25 metres per second (Fonseca & Bell, 1998). Seagrass can be uprooted when near-bed of the harbour current speeds exceed about one metre per second. This assertion is based on experience in southern Botany Bay, where seagrass was damaged severely during an intense storm (Cardno Lawson and Treloar, unpublished). It is worth noting that the identified Zostera patch occurs adjacent to Birchgrove Wharf and is likely to have experienced some level of propeller wash from ferry activities. Without appropriate management of vessel activities and wastewater treatment plant discharge velocities, frequent scour as a result of project activities is likely to denude part or all of this patch. Key management or mitigation measures can include implementation of exclusion zones; velocity dampeners at and before the point of wastewater treatment plant discharge; and routine and event-based monitoring (Section 6.10).

It is proposed that less than 0.01 hectares of subtidal rocky reef that would be removed on either side of the crossing is reinstated following the construction phase (see Section 5.1). There is great natural variability among assemblages in this habitat in the study area and a temporary removal of a small amount during construction would not be of concern to biodiversity in Sydney Harbour given the extent of the remaining habitat and reinstatement of the areas to be removed is proposed at the completion of construction. Biota in the reinstated habitat would recover quickly (including the threatened black rockcod or nominated-for-listing White’s seahorse).

Marine habitats within an estuary can play a vital role as ‘connecting’ habitat for many species of fish, particularly juveniles (NSW DPI, 2013) and as such there may be a temporary loss of connectivity among nearshore habitats on either side of the coffer dams. Juvenile fish are often reluctant to cross expanses of open bare substrata, with most species displaying a strong preference for habitats such as seagrass and rocky reefs. These habitats provide shelter from predators and a variety of food sources, and therefore provide for optimum growth and survival of juvenile fish. Subtidal vegetation fringing the shoreline at the cofferdams (eg macroalgae on rocky reef habitat) can therefore form habitat corridors which facilitate the dispersal or migration of juvenile fish, up and down estuaries. Although some fish would swim around the cofferdams, there would be a temporary reduction to fish passage for some species due to the cofferdams. Given the short construction period this temporary impact would not be of concern (including to the threatened black rockcod or nominated-for-listing White’s seahorse).

The wastewater treatment plant at Yurublin Point construction support site (WHT4) would discharge treated ground and surface water directly into the estuary in the approximate location of the previously identified patch of Zostera and macroalgae on rocky reefs. This input is likely to be freshwater with potential to temporarily alter the local salinity. Discharges from this wastewater treatment plant would occur in addition to natural freshwater runoff during wet weather. Impacts of salinity changes to seagrass or macroalgae cannot be determined in isolation of other factors such as season, light availability, temperature and exposure (McKenzie, 1994). Zostera and macroalgae in the estuary may be relatively resilient to salinity fluctuations as the estuary currently receives high volumes of tidal and catchment flows. Furthermore, one laboratory study found that Zostera seed germination was unaffected by salinities of 15 and 30 parts per thousand (Brenchley & Probert, 1998). Hence, the weight of evidence suggests that seagrass is unlikely to be permanently removed as a result of salinity alterations. However, measures would need to be implemented to ensure the salinity of wastewater treatment plant discharges do not deviate far from ambient conditions and the volume and flow regime mimics that of natural conditions (Section 1.7).

Seagrass and macroalgae on rocky reef is protected as marine vegetation under the FM Act. Thus, potential loss of seagrass habitats or macroalgae would require consultation with NSW DPI (Fisheries). However, Zostera is the most common seagrass species in the study area. Although different in density and morphology from patch to patch, the patch at Yurulbin Point is not unique. The potential loss of this patch of Zostera only amounts to 0.16 per cent of its occurrence in the study area with potential for recovery upon completion of the project as these defined impacts are temporary.

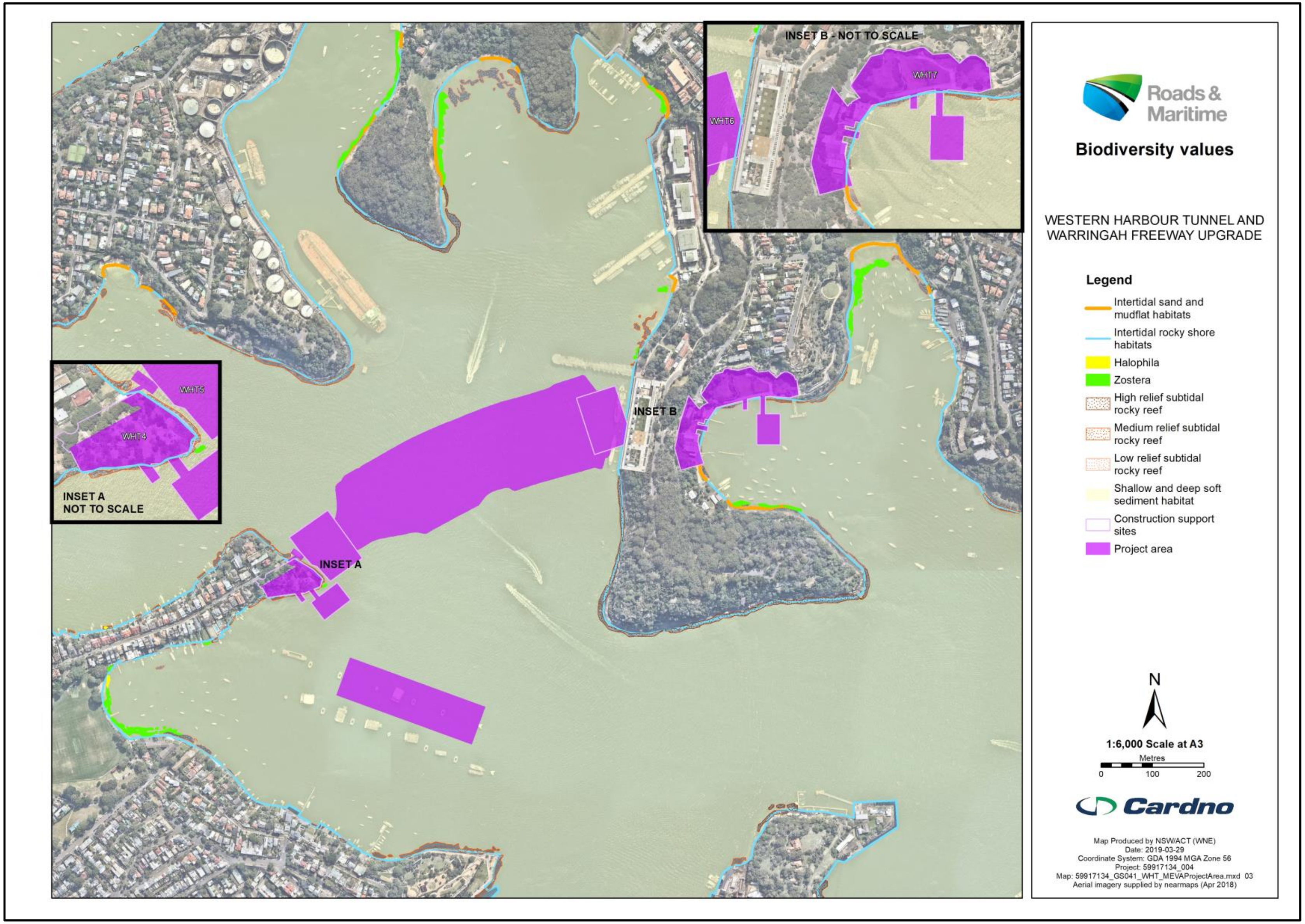

Figure 5-1 **Biodiversity values within Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay (WHT7) construction support sites (ZoHI)**

5.2.1.2 Excessive turbidity and sedimentation (from dredging) in seagrass or subtidal rocky reef habitat

No seagrass habitats occur within the ZoMI while two small patches of Zostera (totalling about 0.03 hectares) occur within ZoI but are not expected to be greatly impacted by turbidity in this zone (Figure 5-2). The same two patches occur within areas with predicted sedimentation of five to 10 millimetres (Figure 5-3). Loss of these patches is not expected as controls would be implemented to protect these patches from turbidity and sedimentation (ie silt curtains would be placed around these patches; Section 6). Furthermore, seagrasses have exhibited tolerance to elevated turbidity (Abal, et al., 1994; Longstaff & Dennison, 1999), frequently experienced in bays of Sydney Harbour.

Only a very small area of high relief reef (ie the habitat of the threatened black rockcod) occurs within the ZoMI (less than 0.01 hectares) representing less than one per cent of the extent of similar habitat in the study area which would result in the impact of biota on the reef. Further, given biota would recover quickly after construction through natural recruitment and immigration, the removal of biota in this small area of high relief rocky reef would not compromise populations of fish (including the threatened black rockcod or nominated-for-listing White’s seahorse) or assemblages of communities in this habitat. Other areas of Zostera and medium/high relief rocky reef would be close to project activities at Yurublin Point construction support site (WHT4), Sydney Harbour south cofferdam (WHT5), Sydney Harbour north cofferdam (WHT6) and Berrys Bay construction support site (WHT7) albeit outside of the modelled sedimentation and ZoMI. During dredging, these areas would be protected from small changes (ie on the scale of metres) to the extent of the ZoMI or areas of sedimentation by silt curtains placed around these patches (see Section 6).

As a precautionary approach, routine and event-based monitoring would assist in ensuring that controls were adequate (Section 6.8).

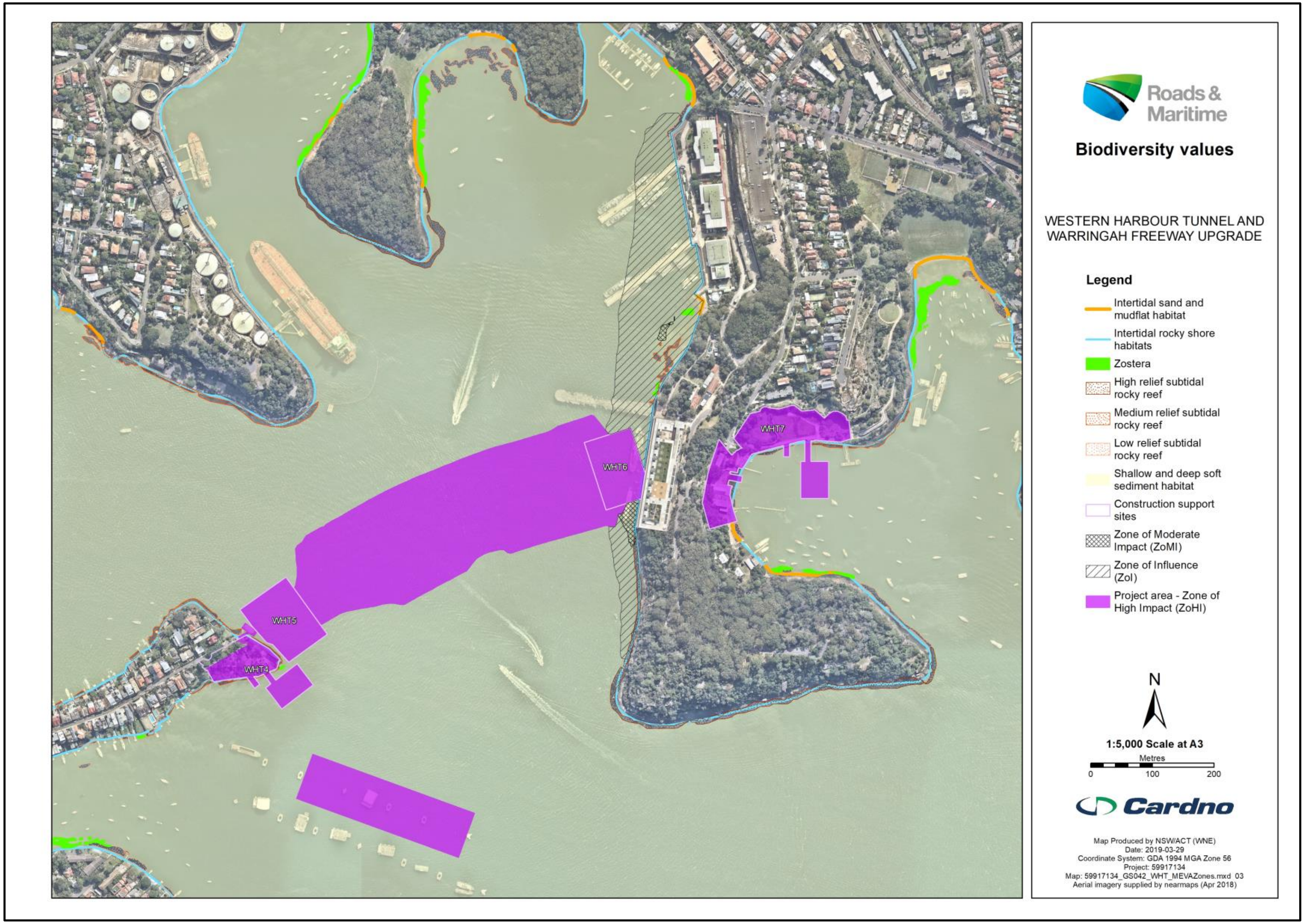

Figure 5-2 Biodiversity values within ZoI and ZoMI (source: Cardno, 2020)

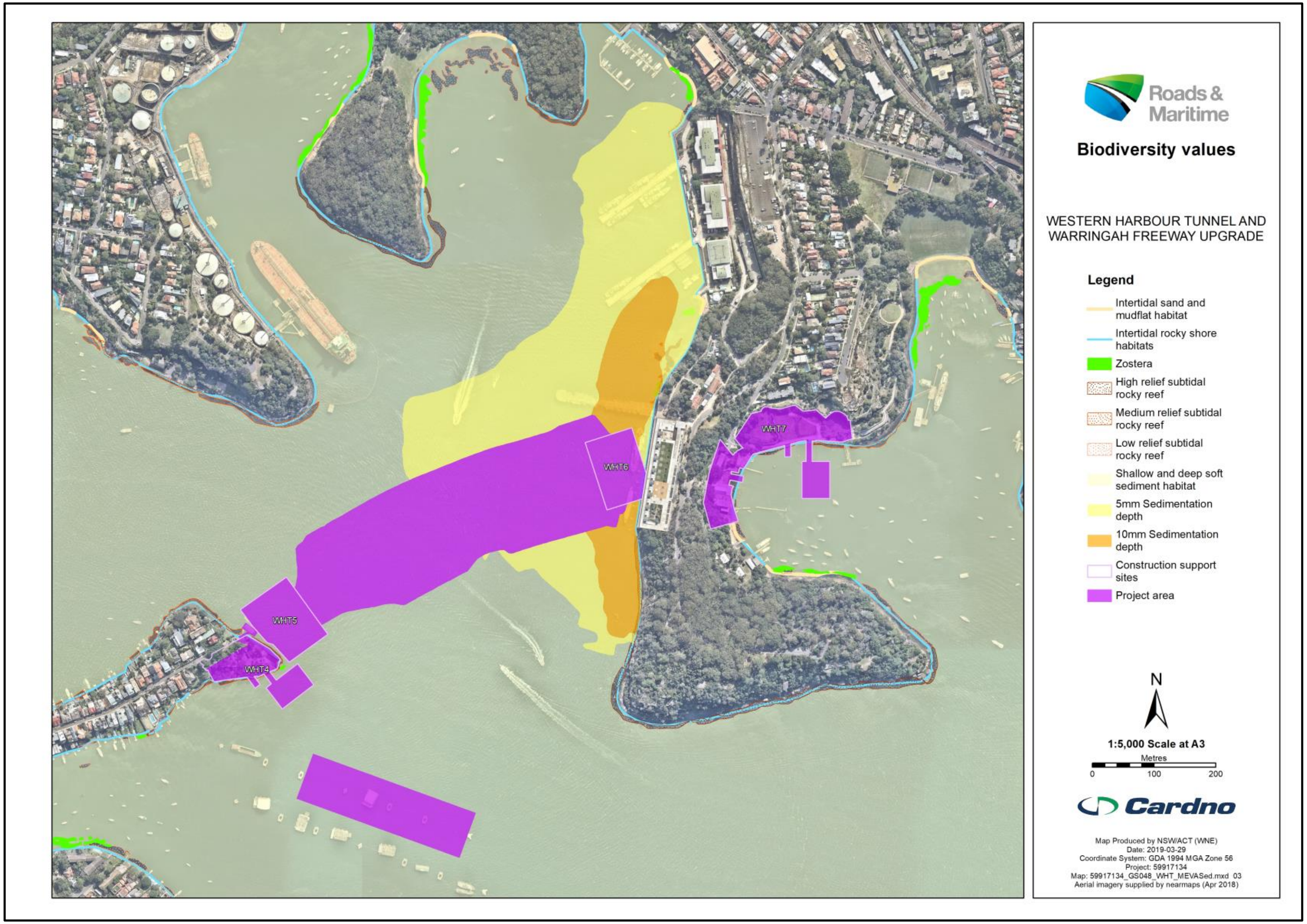

Figure 5-3 **Potential levels of sedimentation on biodiversity values (source: Cardno, 2020)**

5.2.1.3 *Mobilisation of contaminants to seagrass or subtidal rocky reef habitat*

Contaminants would occur in the top layer of soft sediment to be dredged for the crossing. Other studies for the proposed Sydney Metro City & Southwest (Geochemical Assessments, 2015), demonstrated that trace metals and all organic contaminants are likely to remain bound to sediment particles (when dredged) and are not likely to dissociate and be released into the water column as dissolved phases. The minor component of contaminants that might be released to dissolved phases would be expected to re-adsorb to suspended particulate materials and resettle to the estuary bed. This means that the pathway for spread of contaminants would be restricted to the component of dredged sediment that 'leaks' from the closed environmental bucket or from disposal barges or hoppers and settles back onto the bed of the harbour. Modelling indicates that deposition would be confined to areas within and nearby the project areas (Sydney Harbour south cofferdam [WHT5] and Sydney Harbour north cofferdam [WHT6]) including small areas of seagrass or medium or high relief rocky reef habitat.

Impacts of mobilised contaminants on seagrass and rocky reef assemblages would vary with species, concentration, contaminant and a variety of environmental conditions. Tolerances to contaminants may also vary at a population level due to phenotypic or genotypic variation (Ralph, et al., 2007). For example, three populations of Zostera in the Sydney region exhibited varying declines in photosynthetic efficiencies when exposed to copper (Macinnis-Ng & Ralph, 2004). The majority of studies show accumulation of contaminants in seagrass rather than physiological impacts. A small number of studies have shown impacts of heavy metals on photosynthetic apparatus and reduced growth of Zostera following exposure of as little as 10 days (Conroy, et al., 1991; Clijsters, et al., 1999) while petrochemicals such as PAHs are able to freely pass through lipid membranes and accumulate in chloroplasts (Ren, et al., 1994). Mobilisation of contaminants would likely occur through natural hydrodynamics (Roberts, 2012) therefore seagrass meadows are likely to currently be exposed to these contaminants. Seagrasses are able to recover from exposure one year after oil spills (Kenworthy, et al., 1993; Dean, et al., 1998). It is worth noting that exposure to petrochemicals from oils spills are likely to be orders of magnitude greater than mobilisation from sediments.

Fish can suffer from direct exposure to suspended contaminated sediments which can impair chemosensory functions, impair feeding and reduce their response to external stimuli (Roberts, 2012). As fish accumulate contaminants across gill surfaces and their skin, contaminants such as PAHs have been shown to cause fin erosion and lesions in lab based studies (Gregg et al, 1997). The release of sediment-associated PAHs may cause similar deformities as those observed following exposure to oil. Any activity that exposes fish, regardless of its life stage, to POPs or PAHs should be considered high risk to animal health and, in exploited long-lived predators, a potential risk to human consumers.

Filter feeding organisms such as oysters, mussels, ascidians etc are particularly susceptible to suspended contaminants, given their ability to accumulate from both dissolved contaminant and particulate bound exposure pathways (Cruz-Rodriguez and Chu, 2002). Studies have shown that bivalves and polychaete worms can exhibit reduced feeding activity and suffer from a range of histopathological effects which can ultimately impact on their reproduction and respiration (Roberts, 2012). In addition, many of the contaminants recorded in the sediment quality assessment for the study area have the ability to bioaccumulate in aquatic organisms, which can lead to a greater risk of chronic poisoning within these organisms.

Importantly, most of the dredge-induced accumulations of sediment would most likely be uncontaminated sediment that has dispersed during the dredging phases of deeper uncontaminated sediment. The management of contaminated sediments have been outlined as a management priority and with appropriate controls, such as the closed environmental bucket and silt curtains containing the dredge plume, they are unlikely to permanently impact seagrass or rocky reef habitats. Additional mitigation would include placement of silt curtains placed around sensitive nearshore areas (see Section 6.4).

5.2.1.4 *Introduction/spread of marine pests to seagrass or subtidal rocky reef habitat*

The introduction/spread of pest species has potential to alter seagrass or rocky reef habitats via a number of interactions including competitive exclusion or excessive grazing. These interactions are species-specific and rely on suitable environmental conditions for the establishment of the pest species. Marine pests have potential to be spread by vessels and equipment used in the estuary during construction. However, the number of additional vessels in the estuary associated with project activities is likely to be proportionally small relative to the total number of commercial vessels. The risk of marine pest introductions needs to be managed as it poses a risk to seagrass or rocky reef habitats. One identified marine pest, *C. taxifolia*, currently occurs at Neutral Bay in the study area and at a number of other locations further east. Efforts must be made to avoid its spread to the project area as it is known to outcompete seagrass (see proposed controls in Section 6).

5.2.1.5 *Altered hydrodynamics in seagrass or subtidal rocky reef habitat*

Cofferdams would have some impact, mostly reductions, on tidal currents near these structures. During both ebb and flood tide, differences would be more pronounced in the surface layer when compared to bottom layers. Also, at a location downstream of the Greenwich Baths, the modelled increase in current speeds occurred during the flood tide only and was most prominent during spring tides. Although these changes would be relatively large in some locations at some parts of the tidal cycle, any reductions would not likely cause an adverse impact to biota (including to the threatened black rockcod or nominated-for-listing White's seahorse) given the alterations to currents are temporary and not outside of the range in current speeds found where seagrass or medium and high relief rocky reef habitat exist in other parts of the study area. Where current speed is increased, however, it is also not expected to cause scour to seagrass or medium and high relief rocky reef habitat.

Given the bed of the harbour at the tunnel crossing would be restored to the existing profile, there would be no alterations to hydrodynamics in the operation phase of the project.

5.2.1.6 *Underwater noise impacts on fish and elasmobranchs in seagrass or medium/high relief subtidal rocky reef habitat*

Direct impacts from underwater noise generally manifest in the following ways, in order of distance from the source:

- Organ trauma and mortality
- Permanent threshold shift (PTS) (ie permanent hearing loss)
- Temporary threshold shift (TTS) (ie temporary hearing loss)
- Masking, avoidance
- Behavioural disturbance, declining to limits of audibility (Richardson, et al., 1995).

The modelling indicates that dredging operations or pile drilling would not cause harm to fish beyond the confinements of the dredging or pile drilling operations but impulsive noise from impact piling could cause mortality or potential mortal injury to the most sensitive fish group (and potentially sharks) within 0.43 kilometres of the source of underwater noise (JASCO, 2019).

In terms of permanent fish populations, fish habitat areas affected (TTS) would be in 0.02 hectares of seagrass (Table G1 in Appendix G; Figure 5-4 and Figure 5-5), 0.35 hectares of high relief rocky reef and 0.44 hectares of medium relief rocky reef (Table G2 in Appendix G; Figure 5-4 and Figure 5-5), with the most diverse assemblages and greatest abundances occurring in subtidal rocky reef habitat. The seagrass and the subtidal rocky reef is potential habitat of the nominated-for-listing White's seahorse, and the subtidal rocky reef is habitat for the black rockcod, although very few individuals, if any, are expected to be within the potentially affected areas. Some threatened sharks (ie grey nurse shark and white shark) may also occur in the potentially affected areas (TTS). However, as the study area is suboptimal foraging habitat for these species combined with their migratory nature very few individuals - if any - would probably occur during construction.

Given different species of fish and sharks have different tolerance thresholds to underwater noise, there would be a range, among species, of the potential responses to impact piling noise given above.

Some fish (including some black rockcod) are likely to die, but the affected areas are very small (ie less than one per cent) relative to the extent of these habitats in Sydney Harbour. Field studies indicated great variability in assemblages of fish among areas of subtidal rocky reef in Sydney Harbour. Importantly, the same taxa were observed at most sites and differences in assemblages were due to differences in abundance of generally the same species rather than taxonomic differences. Further, the hazard of underwater noise is temporarily associated with impact piling activity which would be staged between Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6), and it is expected that assemblages would recover within one to two years through natural processes of recruitment and immigration. Hence, this type of impact would not be of concern to the broader ecological functioning of fish communities, or the viability of a local population of black rockcod, the grey nurse shark or white shark (see also Section 5.2.2.2).

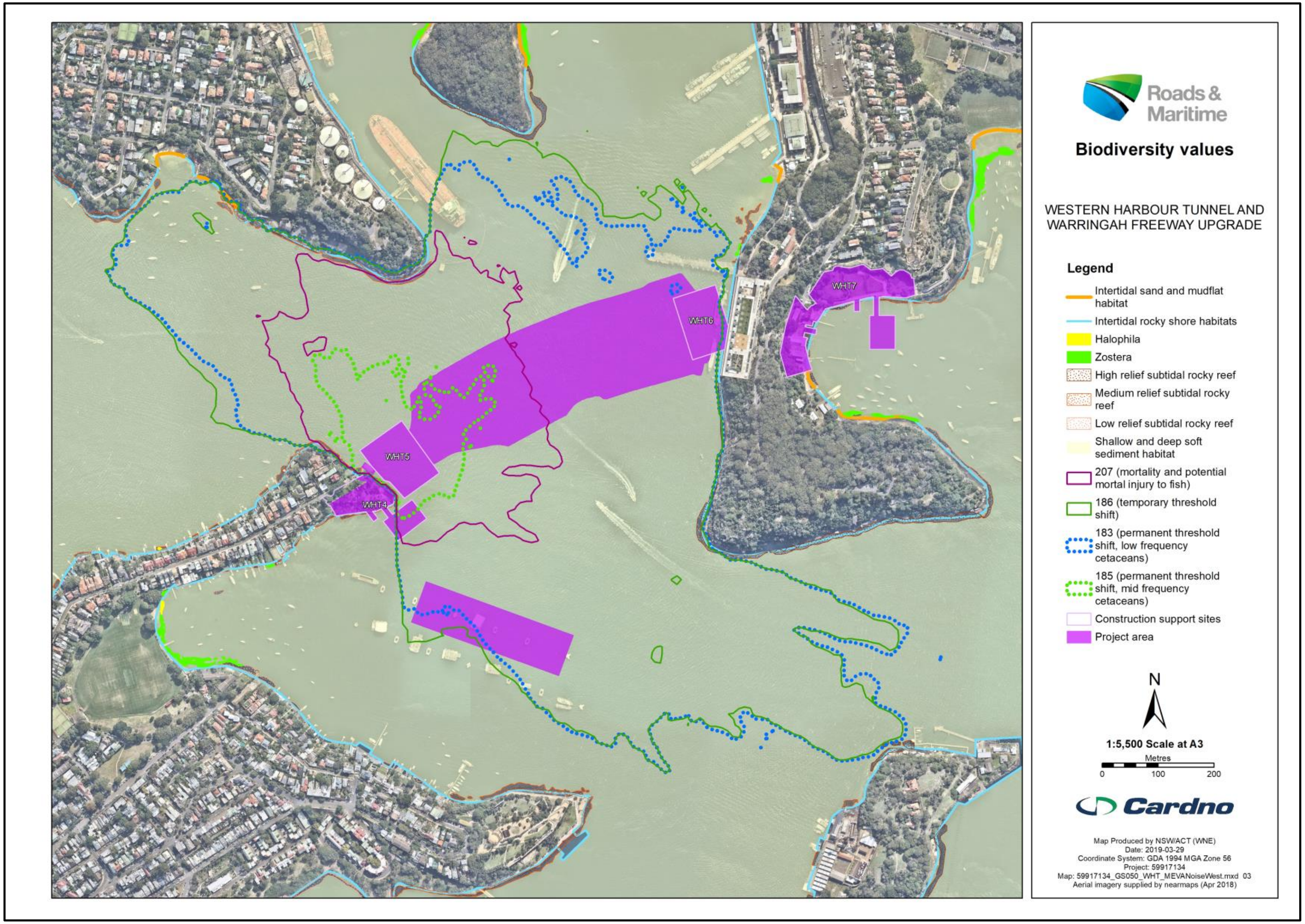

Figure 5-4 Potential impact of underwater noise at Sydney Harbour south cofferdam (WHT5) on biodiversity values (no mitigation)

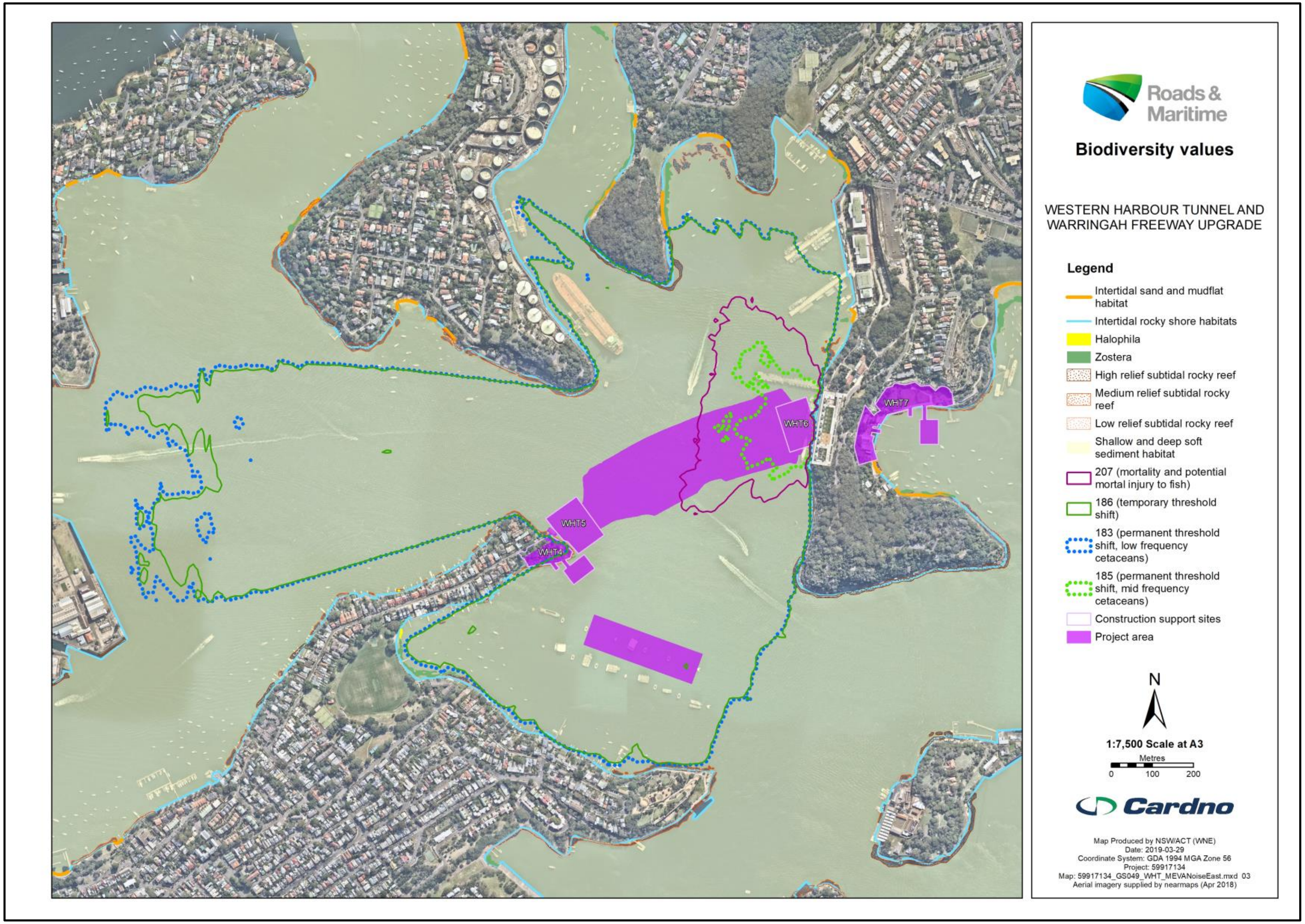

Figure 5-5 Potential impact of underwater noise at Sydney Harbour north cofferdam (WHT6) on biodiversity values (no mitigation)

5.2.1.7 *Spill of contaminants in seagrass habitat or subtidal rocky reef habitat*

Contaminant spills associated with the project includes sediment spills and accidental discharges of contaminated bilge water and spills of oil and grease. These are likely to occur during dredging (ie barge loading), refuelling and other vessel activities. Spills have potential to impact water quality by increasing turbidity and contaminants arising from oil and grease and contaminated bilge water. Most of these suspected contaminants have been found in the estuary sediments (Douglas Partners and Golder Associates, 2017). However, strict management measures would be implemented to ensure either no spills occur as a result of the project and/or that accidental spills are managed quickly and effectively (see proposed controls in Section 6.5).

5.2.2 Type 3 'minimally sensitive' key fish habitat

5.2.2.1 *Direct removal of deepwater soft sediment habitat*

The removal of 10.51 hectares of deepwater soft sediment habitat in the dredging footprint for placement of the immersed tube tunnel units for the crossing would result in only a temporary loss of epifauna and infauna. Further, given field surveys detected as many differences in the composition of infauna among areas in the footprint as outside of it, it would appear that the area to be removed within the dredge footprint does not hold any unique characteristics that would render its removal a loss to biodiversity.

Given fill would be placed over the tunnel so that its profile would be flush with the existing bed of the harbour, and soft sediment is expected to accumulate on top of the fill and integrate with it the soft sediment community would be expected to re-establish in the short-term (ie within two years). This would also re-establish direct connectivity between deepwater soft sediment habitat across the tunnel after construction.

Given these results, it is considered that the temporary impact is not of concern to the broader ecological functioning of these communities.

5.2.2.2 *Underwater noise impacts on fish and elasmobranchs in deepwater soft sediment habitat (including open water)*

Direct impacts from underwater noise on fish and sharks have been discussed above. Fish and sharks would be affected (TTS) in 121.25 hectares of soft sediment habitat (including open water) during impact piling at the Sydney Harbour south cofferdam (WHT5) and 75.42 hectares during impact piling at the Sydney Harbour north cofferdam (WHT6). Some fish or sharks may succumb to mortality or mortal injury in smaller areas (11.64 hectares and 17.59 hectares during impact piling at the Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) respectively) Some threatened sharks (ie grey nurse shark and white shark) may also occur in the potentially affected areas, although given the study area is suboptimal foraging habitat for these species very few individuals - if any - would probably occur during construction.

Given different species of fish and sharks have different tolerance thresholds to underwater noise, there would be a range, among species, of the potential responses (to impact piling noise) given the above. Some fish are likely to die, but the affected areas are very small (ie less than one per cent) relative to the extent of these habitats in Middle Harbour and Sydney Harbour. Other studies have indicated great variability in assemblages of fish among areas of subtidal soft sediment in Sydney Harbour. Importantly, the same taxa were observed at many sites and differences among assemblages are due to differences in abundance of more or less the same species rather than taxonomic differences. Further, the hazard of underwater noise is temporarily associated with impact piling activity and it is expected that assemblages would recover within one to two years through natural processes of recruitment and immigration. This type of impact is not of a concern to the broader ecological functioning of fish communities, or the viability of populations of the grey nurse shark or white shark (see also Section 5.2.1.5).

5.2.3 Matters of National Environmental Significance

5.2.3.1 *Underwater noise impacts on marine reptiles, marine mammals and elasmobranchs*

Impacts of underwater noise on elasmobranchs are discussed in sections 5.2.1.5 and 5.2.2.2.

The main project pathways that underwater noise can impact marine mammals and reptiles are through dredging and impact piling activities. Increased vessel traffic can also increase underwater noise in the estuary; however, this increase is considered negligible in proportion to the existing vessel traffic. Indirect impacts on marine mammals and reptiles can include alterations to predator/prey behaviour. However, due to the temporary nature of underwater noise generated as a result of the project and the broad scale of similar or higher condition habitat within the estuary, these indirect impacts on marine mammals and reptiles are considered negligible.

The manifestation of direct impacts of underwater noise on marine mammals and reptiles depends partially on characteristics of the noise (ie distance from the sound source, sound frequency and intensity) and biological characteristics of the species (ie hearing, vocalisation). Direct impacts from underwater noise are outlined in Section 5.2.1.5.

The modelling indicated that dredging operations would not cause harm to fauna beyond the confinements of the dredge area. Dredging would not result in permanent hearing loss for low frequency cetaceans (ie baleen whales) any further than the extent to the dredging footprint and not at all for mid-frequency cetaceans (ie dolphins, toothed whales, beaked whales, and bottlenose whales) during dredging.

Impact piling impacts on marine mammals were modelled for permanent hearing loss with the area of impact to low frequency cetaceans being far greater than mid-frequency cetaceans (JASCO, 2019). Based on a multiple strike (ie during pile driving) required for the cofferdams, the area of impact to low frequency cetaceans during the installation of the Sydney Harbour south cofferdam (WHT5) is 71.50 hectares and 125.93 hectares during the installation of Sydney Harbour north cofferdam (WHT6) (Section 5.6 in Appendix G). Although these areas occupy the width of the estuary, the majority of low frequency cetaceans are migratory and rarely observed this far upstream of the estuary. Furthermore, as marine mammals can be observed on the surface of the water, impacts on marine mammals can be easily mitigated so that mortality or mortal injury would be prevented or minimised during impact piling activities (see further details on these controls in Section 6).

Although seals are known as migrants, sightings in the estuary are more frequent than other marine mammals and marine turtles and one individual appears to have taken up residency in the estuary. Therefore underwater noise impacts on seals as a result of the project are considered more likely than on other marine mammals and marine turtles, for which the estuary is suboptimal habitat and where occurrence of individuals of any species is very low. Seals produce underwater vocalisations which sound like barks and clicks with frequencies ranging from below one to four kilohertz (Government of South Australia, 2012). They are particularly vocal during the breeding season however no breeding population is known in the Sydney region.

In comparison to mid-frequency cetaceans, seals generally have lower frequencies of maximum hearing sensitivity, are less sensitive at frequencies of maximum hearing sensitivity and have lower high frequency hearing cut-offs. The underwater noise exposure criteria for permanent hearing loss during impact impact piling is SEL 186 dB(M_{pw}) re 1 μPa^2.s similar to that of mid-frequency cetaceans (SEL_{24h} 185 dB re 1 μPa^2.s) (Government of South Australia, 2012; JASCO, 2019). As such, permanent hearing loss impacts during dredging are unlikely to occur to seals. However, as mentioned earlier, the area of potential permanent hearing loss impacts during impact piling for mid-frequency cetaceans was smaller than for low frequency cetaceans. During the Sydney Harbour south cofferdam (WHT5) impact piling it was modelled as 4.77 hectares and 4.07 hectares during the Sydney Harbour north cofferdam (WHT6) impact piling. However, this area lies within the greater permanent hearing loss impact areas for low frequency cetaceans (see Table G3 in Appendix G) thus, mitigation for low frequency cetaceans would also protect seals from underwater noise within the impact areas.

The mortality and potential mortal injury thresholds for marine reptiles (ie turtles) was similar to fish that involve swim bladders in hearing (primarily pressure detection) (JASCO, 2019). Mortality and potential mortal injury from dredging noise was considered low risk to marine turtles while moderate risks were predicted for temporary threshold shift (TTS) (ie temporary hearing loss) up to 0.08 kilometres from the source and high risks for masking, avoidance and behavioural disturbance. The maximum distance for temporary hearing loss impacts on marine turtles during impact piling was far greater extending to 1.7 kilometres from the source. Similar to the modelled impact area for seals and mid-frequency cetaceans, this area lies within the impact area for low frequency cetaceans. As such, management of marine turtles would occur concurrently with low frequency cetaceans.

5.2.3.2 Boat strike to marine reptiles, marine mammals and elasmobranchs

Sharks are not susceptible to boat strike but marine turtles and marine mammals are susceptible to harm from boat strike which can occur in all subtidal habitats within the project areas. On balance, however, the project area would be suboptimal habitat for these species and very few individuals, if any, would occur there during construction. Increased vessel traffic in the project area during construction has the potential to increase the risk of collision between vessels and marine turtles and marine mammals. The increased risk, however, is proportional to the increase in vessel traffic for the project relative to overall vessel traffic. This proportional increase is considered to be very small.

Given marine turtles and marine mammals regularly breach the surface to breathe, the risk of vessel strike to these species would be managed by having observers monitoring potential encroachment of individuals into the project area. Vessel strike can also be mitigated by slow boat speeds that minimise collisions or result in minor harm from which fauna may recover (see further details on these controls in Section 6).

5.3 Key threatening processes (KTPs)

Five KTPs were identified to have potential to be triggered or exacerbated by the project. These are assessed below.

5.3.1 Human-caused climate change (FM Act)

The project construction and operation has potential to increase greenhouse gas emissions associated with this KTP. However, greenhouse gases emitted during project construction is negligible in comparison to that emitted in the wider Sydney region and would not continue beyond the construction phase. Increases in vehicles on the roads, although likely to occur in the Sydney region, are unlikely to be a result of the project. Identified threat abatement actions for this KTP includes:

> Community and stakeholder liaison, awareness and education

> Research/monitoring

> Habitat rehabilitation for threatened species impacted by climate change.

The project is unlikely to interfere with any of these actions. Although marine vegetation does occur within the study area and retractions in macroalgae and seagrass populations in NSW were identified as manifestation of this KTP, no threatened marine vegetation occurs within the study area. Furthermore, the project is unlikely to hinder any rehabilitation actions carried out in the greater Sydney region. Thus, it is unlikely that the project would further exacerbate or trigger this KTP.

5.3.2 Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams (FM Act)

The project would involve the installation of cofferdams and other instream structures to support the construction of the project. The size of these structures are small in comparison to the extent of the estuary with cofferdams occupying the largest areas. These structures would not interfere with fish passage and removal of these structures and reinstatement of any impacted marine habitat is proposed following completion of the project. Due to the size of these structures in proportion to the estuary, alterations to hydrodynamics are likely to be localised and unlikely to impact any threatened species listed under the FM Act.

The identified threat abatement actions for this KTP include advice to consent authorities, community and stakeholder engagement, research and monitoring and habitat rehabilitation and protection. The project is unlikely to interfere with these actions with habitat rehabilitation proposed following project completion. Thus, the project is unlikely to further exacerbate or trigger this KTP.

5.3.3 Introduction of non-indigenous fish and marine vegetation to the coastal waters of New South Wales (FM Act)

Project activities which require the movement of vessels and equipment has potential to introduce non-indigenous fish and marine vegetation to the coastal waters of NSW. Species identified in the State include:

> Black-striped mussel (*Mytilopsis sallei*)

> C. taxifolia

> European green crab

> Northern pacific sea star (*Asterias amurensis*)

> Japanese seaweed (*Undaria pinnatifida*).

Non-indigenous fish and marine vegetation have currently and/or historically been recorded in the study area and the greater estuary. However, recommendations (Section 6) would be implemented to prevent the spread of these species and the introduction of new non-indigenous species.

Prioritised threat abatement actions include community and stakeholder liaison and awareness, legislative development and implementation, eradication, control, research, monitoring and mapping. The project is unlikely to interfere with any of these threat abatement actions. Thus, project activities are unlikely to further exacerbate this KTP.

5.3.4 Novel biota and their impact on biodiversity (EPBC Act)

Threat abatement guidelines for this KTP outline objectives for community and stakeholder liaison and awareness, legislative development and implementation and research and monitoring. The project is unlikely to interfere with the objectives of these guidelines. However the potential remains to introduce and spread novel biota as it is currently widely distributed throughout the estuary as exotic fish and marine vegetation. Strict controls would be implemented to prevent novel biota from spreading further than their current distribution or introduce new species as a result of the project (Section 6). Hence, the project is unlikely to trigger or further exacerbate this KTP.

5.3.5 Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris (EPBC Act)

This KTP relates to the disposal of plastic garbage, fishing gear and other non-biodegradable materials. Waste is likely to be generated by the project during construction and has potential to eventuate in the marine environment causing harm to marine vertebrates. However, the predicted volume of this category of waste generated as a result of the project is likely to be small and strict controls would be implemented (Section 6) to ensure none are disposed in the marine environment. Thus, the project is unlikely to further exacerbate or trigger this KTP.

5.4 Assessments of significance

Threatened or protected species, populations or endangered ecological communities listed, or nominated to be listed, under the FM Act, BC Act or EPBC Act that are most likely to be affected by the project are those that would reside, forage or transit through habitat that would be affected during construction activities. This includes the black rockcod because of its potential to reside in moderate or high relief rocky reef habitat, and White’s seahorse which may reside in seagrass or rocky reef. However only a very few individuals at most of these species would occur in the small areas of this habitat where individuals would potentially be harmed.

Some marine mammals, marine turtles and elasmobranchs could also occur because of their potential to either forage on or transit through seagrass, rocky reef or deepwater soft sediment habitats. Their potential for occurrence in the small parts of these habitats where species could be harmed from the project would be low given the habitat is suboptimal. As marine mammals and marine turtles can be observed above the water, impacts on marine mammals would be manageable.

Given few individuals of any threatened species would potentially be killed by the project and most potential for impact would be a temporary disturbance to some individuals during the construction phase, the potential for significant impacts on any threatened species would be negligible and would not affect the viability of local populations.

It is concluded that the project is not considered to have a significant impact on any threatened species, population or endangered ecological community (including those which are MNES); therefore a referral under the EPBC Act is not considered to be required.

5.5 Cumulative impacts

Although the potential effects of the various project hazards have been considered separately, there are likely to be interactions among hazards that could reduce or magnify the intensity of a response or raise or lower the threshold of response. Interactive effects of multiple hazards are poorly understood but given most of the impacts affect similar areas within the study area and a worse case scenario has been assumed for each hazard (ie mortality to biota), then cumulative impacts would not change conclusions. Cumulative impacts may lengthen the recovery time in some areas for some habitats but not to the extent that it would change conclusions.

6 Mitigation of impacts

Details of these measures have been made in addition to those summarised in Section 1.7 and are specific to mitigating residual impacts on marine ecology. These should be included in the construction environmental management plan and any associated sub-plans prior to construction.

6.1 Mitigating potential impacts from propeller wash

Inadvertent impacts on sensitive nearshore habitats, and biota within, and adjacent to the project area have potential to occur from propeller wash.

Transit routes for vessels entering and departing from construction support sites would be marked out with consideration for propeller wash and distances to sensitive habitats. Exclusion zones would be implemented to avoid disturbance to sensitive habitats not proposed to be directly impacted by the project. These include any intertidal sand and mudflats, intertidal rocky shore, subtidal rocky reef and seagrass habitats with potential to occur within or adjacent to transit routes and vessel movements. Routine inspections and maintenance of exclusion fencing would be detailed in the construction environmental management plan and all contractors be made aware of locations and protocols of these areas.

6.2 Mitigating impacts from groundwater treatment plant discharge

To minimise scour impacts of wastewater treatment plant discharge on the marine environment (at Rozelle Rail Yards [WHT1], Yurublin Point [WHT4] and Berrys Bay [WHT7] construction support sites), water velocity should be reduced and the water stream dispersed as much as practicable before entering the waterway. The most suitable way to achieve water discharge velocity reduction depends on the location and the nature of the discharge point, however one common method is to discharge water into a rock-lined culvert prior to entry into the waterway (velocity dampeners). The volume and quality of discharge should also be managed as such to mimic natural runoff conditions through a dewatering work method statement (WMS) in accordance with the Roads and Maritime *Technical Guideline: Environmental Management of Construction Site Dewatering* (RTA, 2011). These details would be refined in the detailed design stage. Water quality monitoring at discharge locations is recommended during construction (for all discharge locations in the harbour) and operation (for Rozelle) to ensure that the residual impacts of wastewater treatment plant discharges are as predicted and no further impacts on marine ecology occur.

6.3 Mitigating impacts from turbidity and sedimentation

To reduce the potential impact of turbidity (suspended sediment) on sensitive marine vegetation and habitats it is recommended that silt curtains be installed around seagrass patches contained within the ZoI (Zone of Influence), including Zostera patches at Yurulbin Point and Balls Head Bay. To avoid direct damage to seagrass from silt curtain movement, there should be a suitable buffer distance between the seagrass bed and the silt curtain to account for curtain movement due to tides and currents and to prevent shading of the seagrass bed from the silt curtain. The silt curtain should be anchored to bare sediment where practicable to avoid movement.

To reduce the potential impact on subtidal rocky reef adjacent to dredging works the use of silt curtains along the edges of rocky reef within the ZoI should be considered to mitigate suspended sediment impacts and excessive sedimentation on the reef. The installation of these silt curtains would also need consideration of potential movement and subsequent scouring and shading.

These installations should be monitored for effectiveness, particularly following inclement weather, and maintenance of these installations should be carried out when necessary. Records of monitoring and maintenance should be kept.

6.4 Mitigating potential introduction/spread of marine pests

To eliminate the risk of marine pest introduction locally sourced vessels and equipment should be used where practicable. Where this is not possible, and particularly if any vessel is sourced internationally, the vessels should be inspected for potential marine pests, including any bio-fouling evident on the hull as well as any marine organisms or organic matter attached to dredging, anchoring and other vessel equipment. The vessel operators should complete these inspections prior to departing from their home or previous port and thoroughly wash down the vessel and equipment of any marine organisms or marine material, including sediment, prior to entering the harbour. This is of particular importance to any dredging vessel, dredging equipment or dredge spoil barges, which come into contact with large quantities of marine material and potential marine pests. Inspection specification should be detailed in the construction environmental management plan and provided to the contractor to ensure conformance. A confirmation inspection should be carried out by a suitably qualified individual once vessels and equipment arrive at the construction support site. Vessels and equipment should be rejected from participating in project activities if non-conformance is suspected. Inspections should be documented and non-conformance recorded.

Certain vessels take on board ballast water to provide stability during transit, which if then emptied on arrival at a new port can introduce large quantities of marine organisms and larvae carried in the water. To mitigate the risk of introduction of marine pests in ballast water any vessels arriving from foreign or other Australian ports, which have a ballast water system, must comply with the Australian Ballast Water Management Requirements of the *Biosecurity Act 2015*. This includes having in place a Ballast Water Management Plan and a Ballast Water Record System. In addition, the vessel must comply with all the ballast water management and reporting requirements of the Maritime Arrivals and Reporting System (MARS) with ballast water being disposed of in an acceptable manner and location.

As well as the risk of introducing marine pests to the project site, there is a risk that locally occurring marine pests could spread from the project area to other areas as vessels and equipment leave. To avoid the risk of carrying any marine organisms to new ports, vessels and equipment should wash down all marine material prior to departure.

There is also potential for marine pests to be spread locally during dredging and spoil disposal activities (eg *C. taxifolia*). Disposal of any dredge spoil containing *C.taxifolia* risks introducing this pest into areas which it doesn't currently occur. To reduce the risk of transporting *C.taxifolia* from the dredge site to the dredge spoil disposal location a targeted survey should be conducted of the dredge footprint to locate any areas of *C.taxifolia*. If *C.taxifolia* was identified within the dredging footprint, surface sediments from these areas should be disposed of onshore rather than in the marine environment. Finally, all construction vessel operators should be made aware of its presence, how to identify it and prevent its spread by removing any *C.taxifolia* found on equipment and containing fragments in the vessels' general waste facilities for land based disposal.

6.5 Mitigating impacts of underwater noise from impact piling

While the assessment indicates that impacts from underwater noise from impact piling is not likely to be major, any observed fish kills would be investigated, and if required, additional protection measures would be considered for mitigation.

6.6 Mitigating potential for spills

Throughout the project there would be an ongoing risk of oil or other contamination spills occurring due to the number of vessels as well as numerous land-based activities associated with the project occurring adjacent to waterways. The greatest spill risk would be during the refuelling of vessels. To minimise this risk all vessels should comply with spill management procedures detailed in the construction environmental management plan during refuelling operations including being securely moored.

There is also potential for small spills of liquids stored and used on vessels. To reduce the likelihood of any spills occurring during operation of vessels, vessel operators should comply with *AS1940:2017 The storage and handling of flammable and combustible liquids* and have secure fuel, oil and chemical storage facilities and handling procedures in places. In addition, the volumes stored on vessels should be minimised as much as practical to reduce the severity of any potential spill. All vessels must also have a spill management plan and a spill kit.

The construction environmental management plan should detail effective spill containment methods and an emergency shut down procedure in the event of a spill. All construction support sites should have spill kits accessible to all contractors and all contractors are made aware of the location of these spill kits. In the unlikely event of a catastrophic spill occurring due to a vessel collision or grounding a suitable oil spill response plan should be in place to contain any spill.

6.7 Reinstatement of nearshore habitat requiring removal during construction

Some aspects of the project would result in the unavoidable removal of nearshore habitats, and as such must be managed through compensatory activities to comply with the NSW DPI (Fisheries) policy of 'no net loss'. The removal of a small amount of subtidal rocky reef habitat and intertidal rocky shore habitat would occur along the shore line of the crossing at the Sydney Harbour south cofferdam (WHT5) and the Sydney

Harbour north cofferdam (WHT6). This impact can be mitigated through re-instatement of habitat of a similar nature to the habitat removed.

The exact design of reef rehabilitation and mitigation works would be dependent on constraints at the site and would be determined during detailed design. This could be achieved through the below approaches:

> Re-instatement of the intertidal and subtidal rocky reef using natural reef materials, such as the rock removed during construction, so that it would be as similar as possible to pre-existing habitat
> Design the project elements at the nearshore areas of the crossings so they provide sufficient structural complexity to that of natural intertidal or subtidal rocky reef habitat (ie an artificial reef environment), with guideance provided by the Department of Environment and Climate Change (DECC) (2009) *Environmentally Friendly Seawalls: A Guide to Improving the Environmental Value of Seawalls and Seawall-lined Foreshores in Estuaries*.

6.8 Mitigating potential impacts on marine mammals and marine reptiles

Impacts on marine mammals and reptiles can be avoided by the implementation of a stop-work procedure upon sighting marine mammal and reptile activity. This would be detailed in the CEMP. On board observers should be used during impact piling. Any marine mammal or reptile observed within 1.7 kilometres of the impact piling operations (high risk area) would trigger the stop-work procedure until the animal has moved at least 100 metres away from the high risk area or has not been seen for at least 20 minutes. During all other overwater activities, vessel operators are to adhere to transit speed limits and initiate the stop-work procedure if marine mammals and/or reptiles are observed within 100 metres of the vessel.

6.9 Salvage of fish and other aquatic organisms

Salvage of live fish and other native marine organisms (eg large, mobile macroinvertebrates) would occur during cofferdam dewatering. Depending on the cofferdam dewatering and construction schedule and safety of the suitably qualified marine ecologist, this may occur repeatedly during site establishment. This would require cofferdam dewatering to occur slowly (ie slow flow). All salvaged native fish and other marine organisms would be immediately relocated to similar habitat nearby by a suitably qualified marine ecologist with appropriate catch and release experience.

6.10 Recommended monitoring and management plans

The implementation and management of the above measures would be included in the CEMP. However, marine vegetation and sensitive habitat would be managed through additional, adaptive sub-plans which would include monitoring and rehabilitation throughout the construction phase. These sub-plans would include:

> Seagrass monitoring and management plan
> Intertidal and subtidal rocky reef management plan
> Marine mammals and reptiles management plan
> Water quality monitoring and management plan.

The seagrass and water quality monitoring and management plans would detail routine and event-based monitoring of these sensitive assets during the construction and operation to meet project-specific objectives. Monitoring would consider the collection of baseline data as well as the selection of reference areas in the estuary. Results of monitoring and inspections would be captured in reporting and any actions arising from these would be reflected in the corresponding adaptive sub-plans.

7 Offset strategy

The NSW Government's *Biodiversity Offsets Policy for Major Projects* (NSW OEH, 2014) provides guidance for compensating unavoidable losses to aquatic biodiversity after all possible avoidance and mitigation measures have been applied. The policy recognises the special circumstances that exist to offset losses to aquatic biodiversity given potential offsetting sites are largely located on public land, but still considers offset sites to be preferred over supplementary measures (ie through monetary compensation). Examples of supplementary measures may include funding towards achieving actions outlined in threat abatement or species recovery plans, biodiversity research or rehabilitation programs.

If aquatic habitat is to be removed or irreparably damaged in construction for a major project the policy outlines steps in determining the area of aquatic habitat that would be lost, including its quality (ie through GIS mapping in conjunction with categorisation of key fish habitat 'Type' according to *Policy and Guidelines for Fish Habitat Conservation and Management* [NSW DPI, 2013a]). Although NSW DPI considers all estuarine habitat to contribute to aquatic biodiversity, in the mapping process it is important to note the 'Types' of key fish habitat that would be lost. This is so their value can be adequately compensated either through creating like-for-like habitat or through enhancing or protecting more sensitive, or threatened, key fish habitats.

The policy requires a minimum 2:1 offset for the total area of the three 'Types' of key fish habitat lost (see NSW DPI, 2013a for definitions) to help redress direct and indirect impacts of development. NSW DPI (2013a) uses a rate of $52 per square metre, or $104 per square metre to meet the 2:1 offsetting requirement. This rate is consistent with aquatic ecosystem services rates calculated by Costanza et al (1997), and is subject to annual inflation from 1 July each financial year. The rate above is for the 2013–14 financial year and is subject to an annual increase in line with the Consumer Price Index per financial year. Fisheries NSW officers can confirm the current rate but for the purposes of this assessment the current rate has been estimated (from annual rates of CPI of 1.5 per cent in 2014-15, 1.0 per cent in 2015-16 and 1.9 per cent in 2016-17) to be $109 per square metre.

The assessment for the project indicates that there would be no residual impacts on key fish habitat from hazards, either because the habitats or biota are expected to recover fully or because any habitats that would be directly removed during construction would be reinstated following the construction phase.

Were residual impacts to occur it is worth noting that the *Biodiversity Offsets Policy for Major Projects* (NSW OEH, 2014) indicates seagrass habitat cannot be rehabilitated. If any aquatic habitats – including - seagrass were lost, an alternative to monetary compensation would be for Roads and Maritime to carry out a site-based offset. The NSW DPI policy (2013a) and guidelines require the offset to meet guidelines in the *Biodiversity Offsets Policy for Major Projects* (NSW OEH, 2014). The cost of this type of offsetting is variable but would be likely to include rehabilitation and monitoring costs and, if offsetting is not done on Crown Land, the purchase costs of land from a private landholder.

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APPENDIX

A

LIKELIHOOD OF OCCURRENCE - THREATENED SPECIES

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
Marine flora							
Posidonia australis	*Posidonia australis* seagrass – Port Hacking, Botany Bay, Sydney Harbour, Pittwater, Brisbane Waters and Lake Macquarie populations	E (ecological community)	EP	-	Only member of the Posidoniaceae family that occurs in NSW waters. Occurs in six estuaries within the Sydney and Central Coast regions. This species can grow in coarse sandy to fine silty sediments between the low tide line and about 10 metres depth. It may also occur in deeper water if water clarity is good. Can occur as monospecific stands or in mixed stands with other species of seagrass.	DPI	High. Patches of this species have been recorded within the study area during field surveys.
Fish							
Epinephelus daemelii	Black rockcod	V	V	-	In Australia, the distribution of black cod ranges from southern Queensland through NSW to northern Victoria. However, records from Queensland and Victoria are rare, and the NSW coastline forms the species' main range, both in Australia and internationally. Adults are usually found in saves, gutters and beneath bommies on rocky reefs from nearshore areas to at least 50 metres depth. Small juveniles are often recorded in coastal rock pools while larger juveniles are found around rocky shores in estuaries. The use of estuaries may be an important part of the ecology of juvenile black cod in NSW waters. The black cod is territorial and often has a high site fidelity.	PMST DPI	High. There is suitable habitat for the species and juveniles are known to utilise the estuary.
Prototroctes maraena	Australian grayling	V	E	-	The Australian grayling occurs in rivers and streams on the eastern and southern flanks of the Great Dividing Range but is diadromous. During the freshwater phase of the life cycle, this species inhabits lower altitude reaches of both large rivers and smaller streams spawning in the tidal freshwater reaches of rivers, presumably among a gravel streambed. Very little is known of the Australian grayling's specific habitat requirements during the estuarine or marine phase of the life cycle.	PMST DPI	Unlikely. The study area resides outside of the predicted distribution for the species (NSW DPI, 2016a).
Thunnus maccoyii	Southern bluefin tuna	-	E	-	Southern bluefin tuna are highly migratory pelagic fish usually found seaward of the continental shelf. The worldwide occurrence of the species is considered as a single population only spawning in one location between the tropical waters of Java and north-western Australia between September and March. Larvae and small juveniles are carried southwards along the West Australian coastline with juveniles moving out to sea after spending three years near the coast. In Australian waters they range from northern	DPI	Unlikely. This species is unlikely to utilise estuarine habitat typical of the study area.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
					NSW around southern Australia to north-western Australia. They tend to form large surface schools in offshore waters off southern Australia at certain times of the year.		
Elasmobranchs							
Carcharias taurus	Grey nurse shark	CE	CE	-	Grey nurse sharks are usually found in inshore coastal waters usually less than 40 metres in depth. This species congregates at a number of rocky reef sites with gravel or sand filled gutters, overhangs or caves known as 'aggregate sites'. Key aggregate sites refer to those areas occupied by a larger number of grey nurse sharks. Individuals spend most of their time within or in close proximity to aggregate sites but may carry out excursions of varying lengths of time away from site. In NSW, aggregations of grey nurse sharks (east coast population as listed under the EPBC Act) can be found at reefs off the following locations: Byron Bay, Brooms Head, Solitary Islands, South West Rocks, Laurieton, Forster, Seal Rocks, Port Stephens, Sydney, Bateman's Bay, Narooma and Montague Island. Relatively little is known about the migratory habits of grey nurse sharks in Australian waters but tagged sharks have been recorded moving over 800 kilometres between sites in relatively short periods of time.	DPI PMST	Moderate. The study area forms the species' habitat range. However, the species is highly transient and the study area does not form optimal habitat.
Carcharodon carcharias	White shark	V, M	V	-	In Australia, white sharks have been recorded from central Queensland around the south coast to north-west Western Australia, but may occur further north on both coasts. White sharks are widely, but not evenly, distributed in Australian waters. This species can be found from close inshore around rocky reefs, surf beaches and shallow coastal bays to outer continental shelf and slope areas. The majority of recorded white shark movements occur between the coast and 100 metres in depth but have been recorded to dive to depths of over 1200 metres. Individuals may travel long distances in a relatively short time, but can remain in the same areas for weeks to months. In NSW, the Stockton Beach/Hawks Nest area are identified as primary residency areas for juvenile white sharks.	DPI PMST	Moderate. The study area forms the species' habitat range. However, the species is highly transient and the study area does not form optimal habitat.
Rhincodon typus	Whale shark	V, M	-	-	In Australia, the whale shark is known from NSW, Queensland, Northern Territory, Western Australia and occasionally Victoria and South Australia, but it is most commonly seen in waters off northern Western Australia, Northern Territory and Queensland.	PMST	Unlikely. No suitable habitat within the study area. This species

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
					The whale shark is an oceanic and coastal, tropical to warm-temperate pelagic shark. It is often seen far offshore, but also comes close inshore and sometimes enters lagoons of coral atolls. The whale shark is generally encountered close to or at the surface, as single individuals or occasionally in schools or aggregations of up to hundreds of sharks. This species is generally found in areas where the surface temperature is 21–25 °C, preferably with cold water of 17 °C or less upwelling into it, and salinity of 34 to 34.5 parts per thousand (ppt).		mostly occurs offshore or inshore areas in the tropics.
Sphyrna lewini	Scalloped hammerhead shark	-	E	-	The scalloped hammerhead shark has a circumglobal distribution in tropical and warm temperate seas between 45° N to 34° S, but occurs more frequently at higher latitudes during the warmer months. Scalloped hammerhead sharks may be found throughout the seas around northern Australia as far south as Sydney (34° S) and Geographe Bay, Western Australia (33° S). They inhabit deep waters next to continental shelves in water depth ranging from the surface to at least 275 metres. Juveniles are found close to shore in nursery habitats. Juveniles often occur in large migratory schools while adults may be seen alone, in pairs or small schools.	DPI	Unlikely. No suitable habitat within the study area. This species mostly occurs in coastal and pelagic areas.
Sphyrna mokarran	Great hammerhead shark	-	V	-	The great hammerhead shark has a circumglobal distribution in tropical and warm temperate seas from latitudes 40° N to 35° S and has been recorded as far south as Sydney (34° S). This species is coastal-pelagic and semi-oceanic occurring along coastlines, continental shelves and near drop-offs to about 80 metres in depth. This species is typically nomadic and migrate to cooler waters in the summer months. In NSW, the great hammerhead shark is most likely to occur north of Sydney and mainly during warmer months.	DPI	Unlikely. No suitable habitat within the study area. This species mostly occurs in coastal and pelagic areas.
Marine mammals							
Arctocephalus forsteri	New Zealand fur seal	Ma	-	V	This species occurs in Australia and New Zealand. There are reports of non-breeding animals along the southern NSW coast particularly on Montague Island, but also at other isolated locations to the north of Sydney. They prefer rocky parts of islands with jumbled terrain and boulders. One or a few individuals are sometimes observed in Port Jackson.	2 OEH	High. There are no breeding habitat or refuges in the study area however the species might rest or swim through.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
Arctocephalus pusillus doriferus	Australian fur seal	Ma	-	V	Reported to breed at Seal Rocks, near Port Stephens, and Montague Island in southern NSW. Haul outs are observed at isolated places along the NSW coast. Prefers rocky parts of islands with flat, open terrain. They occupy flatter areas than New Zealand fur seals where they occur together. The Australian fur seal prefers oceanic waters of the continental shelf for foraging and generally does not dive deeper than 150 m. One or a few individuals are sometimes observed in Port Jackson.	8 OEH	Moderate. There are no breeding habitat or refuges in the study area however the species might rest or swim through.
Balaenoptera borealis	Sei whale	V, M	-	-	Sei whales have been infrequently recorded in Australian waters. The similarity in appearance of sei whales and Bryde's whales (*Balaenoptera edeni*) has resulted in confusion about distributional limits and frequency of occurrence, particularly in warmer waters (greater than 20 °C) where Bryde's whales are more common. Sei whales were thought to be the most common whales reported by whalers off Albany, Western Australia while hunting sperm whales (*Physeter macrocephalus*), however, these may have been misidentified Bryde's whales. There were several reports of presumed sei whale sightings by fishermen around the shelf edge (50 kilometres offshore) off the coast of NSW. The Australian Antarctic waters are important feeding grounds for sei whales, as are temperate, cool waters. Sightings of sei whales feeding in the Bonney Upwelling area indicate that this area is potentially also an important feeding ground. Breeding occurs in tropical and subtropical waters.	PMST	Unlikely. No suitable habitat within the study area. This species mostly occurs offshore.
Balaenoptera musculus	Blue whale	E, M	-	-	Oceanic within Southern Hemisphere between 20° to 70° S including NSW waters. However, much of the Australian continental shelf and coastal waters have no particular significance to the whales and are only used for migration and opportunistic feeding. The only known areas of significance to the blue whale are feeding areas around the southern continental shelf, notably Perth Canyon, in Western Australia, and the Bonney Upwelling and near by upwelling areas of South Australia and Victoria. They prefer open seas rather than coastal waters. While breeding areas have not yet been identified, it is likely that they occur in tropical areas of high localised biological production, as, unlike the humpback whale (Megaptera novaeangliae) and southern right whale (Eubalaena australis), the blue whale has a thin blubber layer, which implies they cannot fast during the winter season. This is supported by the	PMST	Unlikely. No suitable habitat within the study area. This species mostly occurs offshore.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
					occurrence of the blue whale in tropical upwelling areas in the eastern tropical Pacific Ocean such as the Costa Rica Dome and the waters west of the Galapagos Islands. Wintering areas, where some blue whale sightings have been reported, include the Indonesian archipelago and the waters next to the Solomon Islands and other island groups of the south-west Pacific (Paton & Gibbs 2003). Satellite tagging has confirmed the pygmy blue whale feeds off the Perth Canyon and heads north in March/April to potential breeding grounds in Indonesian waters by June.		
Balaenoptera physalus	Fin whale	V, M	-	-	Fin whales are widely distributed in both hemispheres between latitudes 20 to75° S. This species is common in temperate waters, the Arctic Ocean and Southern Ocean. In the Southern Ocean/Subantarctic this species is often found in areas of complex and steep bathymetry, such as deep ravines, where fish and other prey are known to concentrate. Fin whales have been observed during aerial surveys in South Australian waters between November and May. The Australian Antarctic waters are important feeding grounds for fin whales. Sightings of fin whales feeding in the Bonney Upwelling area indicate that this area is also a potentially important feeding ground. There are no known mating or calving areas in Australian waters.	PMST	Unlikely. No suitable habitat within the study area. This species mostly occurs offshore.
Dugong dugon	Dugong	M, Ma	-	E	Major concentrations of dugongs along the Queensland coast occur in wide, shallow, protected bays and mangrove channels, and in the inside edge of large inshore islands. These areas coincide with significant seagrass beds. They also use deep-water habitats. Large numbers have been sighted in water more than 10 metres deep in several areas including the Torres Strait, the northern Great Barrier Reef region, and Hervey Bay in southeast Queensland. A large proportion of the world's dugong population is found in northern Australian waters from Moreton Bay in the east to Shark Bay in the west. Dugongs are also occasionally reported much further south in NSW.	PMST	Unlikely. The study resides outside of this species usual distribution.
Eubalaena australis	Southern right whale	E, M	-	E	This species occurs in temperate and subpolar waters of the Southern Hemisphere, with a circumpolar distribution between about 20° S and 55° S with some records further south to 63° S. The southern right whale migrates between summer feeding grounds in Antarctica and winter breeding grounds around the	3 OEH PMST	Moderate. This species usually occurs in coastal waters but can enter

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
					coasts of southern Australia, New Zealand, South Africa and South America. This species feeds in the open oceans in summer and moves inshore in winter for calving and mating with calving females usually remaining very close to the coast. The southern right whale is not believed to feed in Australian waters at all. The southern right whale is constrained in their ability to colonise unused areas of potentially suitable habitat due to a high degree of site fidelity (individuals returning to the same breeding site each year).		the estuary during migration.
Megaptera novaeangliae	Humpback whale	V, M	-	V	Occurs in oceanic and coastal waters worldwide. The population on Australia's east coast migrates from summer, cold-water feeding grounds in subantarctic waters to warm water winter breeding grounds in the central Great Barrier Reef. They are regularly observed in NSW waters in June and July, on the northward migration and October and November, on the southward migration. As with the western Australian population, the eastern Australian population also tend to migrate further offshore during their northward migration. Three major aggregation areas have been previously identified for the eastern Australian population in Queensland around the southern end of the Great Barrier Reef, Hervey Bay and in the Gold Coast region. The southern end of the Great Barrier Reef is a suspected calving area. The breeding area for the eastern population of the humpback whale is presumed to be off the coast between central and northern Queensland. Some feeding has been observed in Australia's coastal waters but this is thought to primarily be opportunistic and forms only a small portion of their nutritional requirements. Feeding has been observed close to shore off Eden, NSW, from late September until late November. Feeding behaviour has also been reported off Fraser Island, Queensland. Feeding may also occur in northern waters of the Great Barrier Reef, as well as Victoria, as sightings of humpback whales have been reported in these areas in summer months.	54 OEH PMST	Moderate. This species usually occurs in coastal waters but can enter the estuary during migration.
Marine reptiles							
Caretta caretta	Loggerhead turtle	E, M, Ma	-	E	Loggerhead turtles are found in tropical and temperate waters off the Australian coast. In NSW, they are seen as far south as Jervis Bay and have been recorded nesting on the NSW north coast and feeding around Sydney. Loggerhead turtles are ocean-dwellers, foraging in deeper water for fish, jellyfish and bottom-dwelling	PMST	Moderate. This species usually occurs in coastal waters but can enter

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
					animals. The female comes ashore to lay her eggs in a hole dug on the beach in tropical regions during the warmer months.		the estuary during migration.
Chelonia mydas	Green turtle	V, M, Ma	-	V	Green turtles occur in seaweed-rich coral reefs and coastal seagrass pastures in tropical and subtropical areas of Australia. Usually ocean-dwelling but also occurs in coastal waters on the north or central coast with some straying south of the central coast. Green turtles spend their first five to ten years drifting on ocean currents. During this pelagic (ocean-going) phase, they are often found in association with driftlines and rafts of *Sargassum* sp. (floating marine algae carried by currents). Once green turtles reach 30 to 40 centimetres curved carapace length, they settle in shallow benthic foraging habitats such as tropical tidal and subtidal coral and rocky reef habitat or inshore seagrass beds. The shallow foraging habitat of adults consist of seagrass beds or algae mats on which green turtles mainly feed. In Australia, there are seven separate genetic management units for the green turtle, and three of these occur in Queensland. The entire Great Barrier Reef area is an important feeding area for turtles nesting locally, as well as for those that nest in other regions and countries.	10 OEH PMST	Moderate. The study area does not lie within the core range for the species although rare strays may be sighted.
Dermochelys coriacea	Leatherback turtle	E, M, Ma	-	E	The leatherback turtle has the widest distribution of any marine turtle, occurring in tropical, temperate and sub-polar waters from the North Sea and Gulf of Alaska in the Northern Hemisphere, to Chile and New Zealand in the Southern Hemisphere. Leatherback turtles occur in tropical and temperate waters off Australia. Large numbers of leatherback turtles feed off the southern Queensland and NSW coasts and off Western Australia's coast, south of Geraldton, but they are less abundant in the tropical waters of northern Australia. Most sightings are along the more heavily populated eastern seaboard of Australia where large adults are found year round in larger bays, estuaries and rivers. The frequency of sightings suggests that the species actively seeks out temperate feeding grounds, rather than simply straying to the south.	2 OEH PMST	Moderate. This species usually occurs in coastal waters but can enter the estuary during migration.
Eretmochelys imbricata	Hawksbill turtle	V, M, Ma	-	-	Major nesting of hawksbill turtles in Australia occurs at Varanus Island and Rosemary Island in Western Australia, and in the northern Great Barrier Reef and Torres Strait, Queensland. Hawksbill turtles spend their first five to ten years drifting on ocean currents. During this pelagic phase they are often found in	PMST	Moderate. This species usually occurs in coastal waters but can enter

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
					association with rafts of *Sargassum* sp. (floating marine algae carried by currents). Once they reach 30 to 40 centimetres curved carapace length, they settle and forage in tropical tidal and subtidal coral and rocky reef habitat. They primarily feed on sponges and algae. They have also been found, though less frequently, within seagrass habitats of coastal waters, as well as the deeper habitats of trawl fisheries. Hawksbill turtles have been seen in temperate regions as far south as northern NSW.		the estuary during migration.
Natator depressus	Flatback turtle	V, M, Ma	-	-	The flatback turtle is only found in the tropical waters of northern Australia, Papua New Guinea and Irian Jaya and is one of only two species of sea turtle without a global distribution. Post-hatchling and juvenile flatback turtles do not have the wide dispersal phase in the oceanic environment like other sea turtles. Adults inhabit soft bottom habitat over the continental shelf of northern Australia, extending into Papua New Guinea and Irian Jaya although the extent of their range is not fully known. Hatchling to subadult flatback turtles lack a pelagic life stage and reside in the Australian continental shelf. Flatback turtles require sandy beaches to nest. Sand temperatures between 25 °C and 33 °C are needed for successful incubation. Beaches free from light pollution are required to prevent disorientation, disturbance, and to allow nesting females to come ashore.	PMST	Moderate. This species usually occurs in coastal waters but can enter the estuary during migration.
Marine birds							
Eudyptula minor	Little penguins in the Manly Point area (being the area on and near the shoreline from Cannae Point generally northward to the point near the intersection of Stuart Street and Oyama Cove Avenue, and extending 100 metres offshore from that shoreline)	Ma	-	E (population)	Little penguins are only found in southern Australia and New Zealand. In Australia little penguin colonies are scattered around the coastline from near Perth on the west coast, to Sydney on the east coast, and around Tasmania. Phillip Island has only one remaining little penguin colony, part of which can be seen at the Penguin Parade which offers up-close views of little penguins. On land little penguins live in holes in the ground (burrows) which provide a place for them to rest, nest and moult. Burrows also provide protection from predators and extreme heat. While on land little penguins remain inside their burrows during the day to avoid predators. Little penguins spend about 80 per cent of their lives at sea, returning to land to breed, moult and rest. Researchers use satellite and GPS trackers to record where penguins go at sea and tracking from Phillip Island Nature Parks shows that Phillip Island's little penguins swim an average of 15 to	11 OEH	Moderate. The EP of this species breeds and roosts in a bay adjoining Middle Harbour and has potential to forage within the study area.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source +	Potential likelihood to occur in the study area
					50 kilometres a day. This includes diving up and down as they look for fish. The deepest little penguin dive recorded is 72 metres. An average dive in search of fish is between five and 20 metres.		

* Distribution and habitat requirement information adapted from:

- Australian Government DoEE www.environment.gov.au/biodiversity/threatened/species.
- NSW OEH www.environment.nsw.gov.au/threatenedSpeciesApp/. and
- NSW DPI listed threatened species, populations and ecological communities www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current#key.

+ Data source includes

- The NSW DPI (Fisheries) Listed threatened species, populations and ecological communities and key threatening processes www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current#key.
- Number of records from the NSW Office of Environment and Heritage Wildlife Atlas record data (Accessed January 2018) www.bionet.nsw.gov.au/. and
- Identified from the Protected Matters Search Tool (PMST) Australian Government Department of Environment and Energy www.environment.gov.au/epbc/protected-matters-search-tool.

Key:

EP = endangered population

CE = critically endangered

E = endangered

V = vulnerable

M = migratory (EPBC Act)

Ma = marine (EPBC Act)

APPENDIX

B

LIKELIHOOD OF OCCURRENCE – MIGRATORY SPECIES

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
Elasmobranchs							
Lamna nasus	Mackerel shark	M	-	-	The mackerel shark is wide-ranging and inhabits temperate, subarctic and subantarctic waters of the North Atlantic and Southern Hemisphere. This species primarily inhabits oceanic waters and areas around the edge of the continental shelf. They occasionally move into coastal waters, but these movements are temporary. The mackerel shark utilises a broad vertical range of the water column and is known to dive to depths exceeding 1300 metres. The mackerel shark is thought to be reasonably flexible in the types of habitat used for foraging.	PMST	Unlikely. No suitable habitat within the study area. This species mostly occurs offshore.
Manta alfredi	Reef manta ray	M	-	-	Distributed in the Indo-West Pacific: Red Sea, South Africa, Thailand to Western Australia; north to Japan (Yaeyama Island), Solitary Island, Australia as far east as French Polynesia and the Hawaiian Islands. Reported in the Atlantic (Canary and Cape Verde islands) but this species may be restricted more or less to the Indian and Western Pacific only. Adults are commonly sighted inshore, within a few kilometres of land; found around coral and rocky reefs as well as along productive coastlines with consistent upwelling, tropical island groups, atolls and bays.	PMST	Unlikely. No suitable habitat within the study area. This species is not known to enter estuaries in temperate waters.
Manta birostris	Giant manta ray	M	-	-	The giant manta ray occurs in tropical, subtropical and temperate waters of the Atlantic, Pacific and Indian Oceans. Commonly sighted along productive coastlines with regular upwelling, oceanic island groups and particularly offshore pinnacles and seamounts. Widespread, although relatively uncommon in Australian waters; also occurs at Cocos (Keeling) Islands and Christmas Island in the eastern Indian Ocean. Elsewhere the species is circumglobal, usually offshore, often around oceanic islands, sometimes coastal, and most common in tropical waters. Giant manta rays aggregate around Ningaloo Reef during autumn and winter.	PMST	Unlikely. No suitable habitat within the study area. This species is not known to enter estuaries in temperate waters.
Marine mammals							
Balaenoptera edeni	Bryde's whale	M	-	-	Bryde's whales occur in temperate to tropical waters, both oceanic and inshore, bounded by latitudes 40° N and 40° S, or the 20 °C isotherm. Bryde's whales have been recorded from all Australian states except the Northern Territory, including one sighting each in Victoria and NSW and 11 reported strandings in South Australia (7), NSW (2), Victoria (1) and Queensland (1). Bryde's whales are found year-round primarily in temperatures exceeding 16.3 °C. The coastal form of Bryde's whale appears to be limited to the 200 metres depth isobar, moving along the coast in response to availability of suitable prey. The offshore form is found in deeper water (500 metres to 1000 metres). Dive times are relatively short, averaging 1.27 minutes but potentially lasting nine minutes. This suggests that Bryde's whales use the upper layers of the ocean, and can therefore be considered pelagic.	PMST	Unlikely. No suitable habitat within the study area. This species mostly occurs offshore.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
Caperea marginata	Pygmy right whale	M	-	-	Records of pygmy right whales in Australian waters are distributed between 32° S and 47° S, but are not uniformly spread around the coast. The northern distribution of pygmy right whales may be limited on the west and east coasts of Australia by the warm, south-flowing Leeuwin and East Australian currents. Few or no records are available for NSW, eastern Victoria, and the northern part of the Great Australian Bight, while Western Australia has fewer records than comparative eastern Australian states. Concentrations of stranded animals have occurred at the entrance of the gulfs in South Australia and around Tasmania, but live sightings have predominated in the former region. The numerous strandings in Tasmania may be due to the proximity of the Subtropical Convergence, an apparently important feeding zone for pygmy right whales. Pygmy right whales have primarily been recorded in areas associated with upwellings and with high zooplankton abundance, particularly copepods and small euphausiids, which constitute their main prey. There is some evidence to indicate that the area south of 41° S is important for weaned pygmy right whales, possibly because of the higher prey abundance in these waters.	PMST	Unlikely. No suitable habitat within the study area. This species mostly occurs offshore and is rare on the east coast of Australia.
Lagenorhynchus obscurus	Dusky dolphin	M	-	-	In Australia, dusky dolphins are known from only 13 reports since 1828, with two sightings in the early 1980s. They occur across southern Australia from Western Australia to Tasmania, with unconfirmed sightings south off continental Australia but confirmed sightings near Kangaroo Island, South Australia, and off Tasmania, and a recent stranding in the latter State. Given the lack of understanding of the species' distribution in Australian waters, no key localities have yet been identified. Dusky dolphins occur mostly in temperate and subantarctic waters. They are considered to primarily inhabit inshore waters but may also be pelagic at times.	PMST	Low. Mostly a coastal species with NSW waters being the northern-most extent of its distribution.
Orcinus orca	Orca	M	-	-	In Australia, orcas are recorded from all states, with concentrations reported around Tasmania. Sightings are also frequent in South Australia and Victoria. A sighting at Yirrkala in April 1999 provides evidence that they also occur in Northern Territory waters. Orcas are frequently seen in the Antarctic south of 60° S and have been recorded from Heard and Macquarie islands. Macquarie Island appears to be a key locality, with orcas regularly reported there. The preferred habitat of orcas includes oceanic, pelagic and neritic (relatively shallow waters over the continental shelf) regions, in both warm and cold waters. They may be more common in cold, deep waters, but off Australia, orcas are most often seen along the continental slope and on the shelf, particularly near seal colonies. Orcas have regularly been observed within the Australian territorial waters along the ice edge in summer.	PMST	Unlikely. No suitable habitat within the study area. This species mostly occurs offshore.
Sousa chinensis	Indo-Pacific humback dolphin	M	-	-	In Australia, Indo-Pacific humpback dolphins are known to occur along the northern coastline, extending to Exmouth Gulf on the west coast (25° S), and the Queensland/NSW border region on the east coast (34° S). Within their geographical range, Australian humpback dolphins are found primarily in coastal waters however,	PMST	Low. The species may swim through the study area

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
					this species is known to inhabit shallow coastal, estuarine, and occasionally riverine habitats, in tropical and subtropical regions.		however is rarely sighted.

* Distribution and habitat requirement information adapted from:

- Australian Government DoEE www.environment.gov.au/biodiversity/threatened/species.
- NSW OEH www.environment.nsw.gov.au/threatenedSpeciesApp/. and
- NSW DPI listed threatened species, populations and ecological communities www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current#key.

\+ Data source includes

- The NSW DPI (Fisheries) Listed threatened species, populations and ecological communities and key threatening processes www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current#key.
- Number of records from the NSW Office of Environment and Heritage Wildlife Atlas record data (Accessed January 2018) www.bionet.nsw.gov.au/. and
- Identified from the Protected Matters Search Tool (PMST) Australian Government Department of Environment and Energy www.environment.gov.au/epbc/protected-matters-search-tool.

Key:

M = migratory (EPBC Act)

APPENDIX

C

LIKELIHOOD OF OCCURRENCE –
PROTECTED SPECIES

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
Fish							
Acentronura tentaculata	Shortpouch pygmy pipehorse	Ma	P	-	This species is found on tropical inshore reefs. It also occurs in temperate waters associated with shallow sandflats in protected and somewhat silty coastal areas among sparse low plant growth and in algae on rocks. This species inhabits waters of seven to 40 metres in depth. Pipefishes feed on small living crustaceans.	DPI PMST	Low. There is no optimal habitat within the study area.
Anampses elegans	Elegant wrasse	-	P	-	Elegant wrasse are a widespread but uncommon species found on coral reef and rocky reef habitats at depths from two to 35 metres. The distribution of elegant wrasse extends from southern Queensland to Montague Island on the NSW south coast, particularly around inshore islands. The species is also found at Lord Howe Island, especially in the shallow lagoon habitat, and at nearby Elizabeth and Middleton Reefs, and they have also been recorded from Norfolk Island, the Kermadec Islands, New Zealand and Easter Island. Elegant wrasse are a subtropical, warm-temperate species that are active during the day.	DPI	Unlikely. This species prefers coastal/oceanic habitats to estuarine areas.
Epinephelus coioides	Estuary cod	-	P	-	Occurs in tropical and warm temperate marine waters of the Indo-Pacific including the Persian Gulf, India, the Philippines, Singapore, Hong Kong, Taiwan, Fiji and around numerous other islands. In Australia they are most common in Queensland, the Northern Territory and Western Australia. However, they are known to occur as far southwards as the Sydney area. Estuary cod inhabit turbid coastal reefs and are often found in brackish water over mud and rubble. They are frequently misidentified as greasy grouper (Epinephelus tauvina) or Malabar grouper (Epinephelus malabaricus), which look similar and have overlapping distributions.	DPI	Moderate. The study area constitutes potential habitat albeit the southern extent of its distribution.
Festucalex cinctus	Girdled pipefish	Ma	P	-	Endemic to tropical and temperate waters of the Northern Territory, Queensland and NSW. Usually inhabits sheltered coastal bays and estuaries, on patches of rubble, sand or in areas of sparse seagrass, algal and sponge growth. Most specimens were dredged or trawled in depths of eight to 31 metres but divers collected some specimens over rubble bottoms in depths of 12 metres. In Sydney Harbour it is most common in depths of 10 to 20 metres.	DPI PMST	High. Abundant habitat within the study area and commonly occurring.
Filicampus tigris	Tiger pipefish	Ma	P	-	The tiger pipefish is relatively common in subtropical waters of Australia's east and west coasts. A relic population also occurs in the warmer waters of Spencer Gulf, South Australia. Inhabits areas near channels in inshore sheltered bays and estuaries with sandy or muddy bottoms, or along seagrass bed edges at	DPI PMST	High. Potential habitat occurs within the study area.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
					two to 30 metres. Feeds on aggregations of mysid shrimps in sheltered bays next to tidal channels.		
Girella cyanea	Blue drummer	-	P	-	Occurs along the east coast of Australia from Flinders Reef off Cape Moreton in Queensland to Eden in southern NSW. Bluefish are also found at Elizabeth and Middleton Reefs, Lord Howe and Norfolk Islands, the Kermadec Islands and the North Island of New Zealand. Generally ocean dwellers found on rocky reefs between five to 30 metres. Juveniles live in tidal pools while adults school over reef areas.	DPI	Unlikely. This species prefers coastal/oceanic habitats to estuarine areas.
Heraldia nocturna	Upside-down pipefish	Ma	P	-	Endemic to temperate waters of southern and south-eastern Australia, from about Hastings, NSW, southwards to Victoria, to Port Davey on the west coast of Tasmania, westwards through South Australia to Geographe Bay, Western Australia. Upside-down Pipefish inhabit sheltered inshore rocky reefs in harbours, bays and coves where they are found under ledges, in holes, crevices and small caves at two to 30 metres.	DPI PMST	High. Potential habitat occurs within the study area.
Hippichthys penicillus	Beady pipefish	Ma	P	-	Widespread in the tropical Indo-west-central Pacific, from the Red Sea and East Africa across the Indian Ocean to north-eastern Australia, north to Taiwan, Japan, Micronesia and east to Samoa and Tonga. This species usually inhabits brackish waters in mangrove estuaries, tidal creeks and sometimes in freshwater reaches in the lower parts of rivers and streams.	DPI PMST	High. Potential habitat occurs within the study area.
Hippocampus abdominalis	Big-belly seahorse	Ma	P	-	Known from temperate waters of New Zealand and southern Australia, where it occurs from about South West Rocks, NSW, southwards to the northern Great Australian Bight, South Australia, and south to the Derwent Estuary, Tasmania. Big-belly seahorses live in a range of habitats from low rocky reefs in shallow estuaries, to deep tidal channels and deeper coastal reefs to 100 metres. They cling to seagrasses, sponges, macroalgae such as kelp holdfasts and other structures on reefs.	DPI PMST	High. Potential habitat occurs within the study area.
Hippocampus whitei	White's seahorse	Ma	P	-	Endemic temperate Australian species found only between Forster and Wollongong, NSW. White's seahorse inhabits shallow inshore areas in estuaries, harbours and bays, where it lives on rocky reefs, sponges, seagrass beds, and under piers and jetties to 25 metres.	DPI PMST	High. Potential habitat occurs within the study area.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
Histiogamphelus briggsii	Crested pipefish	Ma	P	-	Endemic to temperate waters of south-eastern Australia, from New South Wales, south to Victoria and Tasmania, and westwards to Gulf St Vincent. Crested pipefish inhabit inshore sandy areas, singly or in small aggregations, often amongst detached seaweed or along the margins of Posidonia seagrass beds and in open sandy areas at three to 20 metres; most common in Bass Strait.	DPI PMST	Low. Little to no preferred habitat within the study area.
Lissocampus runa	Javelin pipefish	Ma	P	-	Endemic to temperate waters of southern and eastern Australia; known from southern Queensland, southwards to Tasmania, and across to about Rottnest Island, south-western Australia. Usually inhabits tidepools and sheltered bays, usually in seagrass and algal beds, and rocky and shelly rubble substratum to about 20 m.	DPI PMST	High. Potential habitat occurs within the study area.
Maroubra perserrata	Sawtooth pipefish	Ma	P	-	Endemic to temperate southern Australian waters from southern Queensland to Rottnest Island, Western Australia. The sawtooth pipefish inhabits coastal rocky reefs at three to 25 metres, sheltering beneath ledges and in caves during day.	DPI PMST	Low. This species is more a coastal species.
Notiocampus ruber	Red pipefish	Ma	P	-	Endemic to temperate waters of southern and south-eastern Australia from Sydney Harbour, south and west to Flinders Island in Bass Strait, Tasmania, Victoria, South Australia and the Recherche Archipelago, Western Australia; usually inhabits rocky reefs, often in crevices, in association with sponges and encrusting and filamentous red algae at five to 20 metres.	DPI PMST	High. Potential habitat occurs within the study area.
Odontaspis ferox	Herbst nurse shark	-	P	-	Herbsts nurse sharks are a rarely encountered species that looks very similar to the grey nurse shark. Grey nurse sharks are found in shallower inshore waters, while Herbsts nurse sharks are generally found at depths of 150 to 600 metres off the NSW coast. The species has a wide but irregular distribution throughout the warm temperate and tropical waters of the Atlantic, Indian and Pacific oceans, and the Mediterranean Sea. In Australasia, they have been recorded off NSW, eastern Victoria, north-western Australia, New Zealand and the Kermadec Islands. Herbsts nurse sharks usually live in relatively deep water on insular and continental shelves and upper slopes, and around seamounts. They have been caught off NSW in depths up to 850 m, and there are also records of the species from open waters of the Indian Ocean.	DPI	Unlikely. This species prefers coastal/oceanic habitats to estuarine areas.
Paraplesiops bleekeri	Eastern blue devil	-	P	-	Eastern blue devil are a shy, secretive fish found in caves, crevices and under ledges on inshore reefs and estuaries. Eastern blue devils are distributed from southern Queensland to Montague Island on the NSW south coast. They can be	DPI	High. Potential habitat occurs within the study area.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
					found in waters between three to 30 metres and are generally solitary occupying caves, crevices or under ledges.		
Family Pegasidae	Seamoths	-	P	-	The short-bodied little dragon fish (Eurypegasus draconis) and the slender seamoth (Pegasus volitans) are the only two species found in NSW waters. These bottom-dwelling species usually inhabit sheltered bays, estuaries and coral reefs from depths of three to 90 metres, usually living on rubble, shelly or sandy substrates amongst the seagrass Halophila sp. and on isolated coral patches.	DPI	High. Potential habitat occurs within the study area.
Phyllopteryx taeniolatus	Common seadragon	Ma	P	-	Endemic to temperate coastal waters of southern Australia, from about Newcastle NSW south to Actaeon Island, Tasmania and across southern Australia to about Geraldton, Western Australia. Common seadragons inhabit shallow estuaries to deeper offshore reefs, living seagrass beds and on rocky reefs covered in macroalgae, especially kelp beds, in depths of one to 50 metres. Individuals usually remain within a broad home range.	DPI PMST	High. Potential habitat occurs within the study area.
Solegnathus spinosissimus	Spiny pipefish	Ma	P	-	Known from temperate waters of Australia and New Zealand. In Australian waters, spiny pipehorses have been recorded from off Caloundra, southern Queensland, to southern Tasmania, throughout Bass Strait to south of Cape Otway, Victoria. In the southern part of their range, spiny pipehorses inhabit relatively shallow waters. Specimens have been collected from muddy, silty, shelly and rubble substrates, and rocky reefs, and may be washed ashore after storms. Spiny pipehorses use their prehensile tails to cling to macroalgae and sessile invertebrates on the substrate.	DPI PMST	High. Potential habitat occurs within the study area.
Solenostomus cyanopterus	Robust ghost pipefish	Ma	P	-	Widespread in the tropical Indo-west Pacific, from East Africa and the Red Sea, eastwards to Fiji and southern Japan, and south to Australia. Known in Australian waters from the Shark Bay region, Western Australia, around the tropical north and southwards to at least Sydney Harbour. Robust ghost pipefish live in protected coastal and lagoon reefs, deeper coastal reefs and deep, clear estuaries with seagrass or macro-algae in 15 to 25 metres.	DPI PMST	Moderate. Suboptimal habitat occurs within the study area.
Solenostomus paegnius	Rough-snout ghost pipefish	Ma	P	-	Occurs in the Indo-Pacific from East Africa to Australia, north to Japan and confirmed East Indian records from Indonesia and Malaysia. Found in algal/rubble reefs and sandy bottoms, often at depths below 10 metres. Mostly pelagic until they settle on the substrate for breeding.	DPI PMST	Low. This species is mostly a coastal, pelagic species.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
Solenostomus paradoxus	Ornate ghost pipefish	Ma	P	-	Widespread in tropical and warm-temperate regions of the Indo-west Pacific, from East Africa, eastwards to Fiji and Tonga, north to southern Japan, south to Australia and New Caledonia. Ornate ghost pipefish inhabit protected coastal, lagoon and outer reef areas with drop-offs or rock faces, in depths of three to 35 metres. They often associate with Crinoids (featherstars), Gorgonians and black corals. Although usually solitary, they may be seen in pairs, or even in small groups.	DPI PMST	Unlikely. No suitable habitat within the study area.
Stigmatopora argus	Spotted pipefish	Ma	P	-	Found from the Hawkesbury River, NSW to Shark Bay, Western Australia in temperate waters. Usually among vegetation in bays and estuaries, but sometimes offshore among floating Sargassum sp.	DPI PMST	High. Potential habitat occurs within the study area.
Stigmatopora nigra	Widebody pipefish	Ma	P	-	Known from temperate waters of southern Australia and New Zealand. The widebody pipefish occurs from about Fraser Island in southern Queensland to north of Perth, Western Australia and around Tasmania. It is common in sheltered seagrass and algal beds from intertidal depths to 35 metres.	DPI PMST	High. Potential habitat occurs within the study area.
Stigmatopora olivacea	Gulf pipefish	Ma	P	-	See Stigmatopora argus.	DPI PMST	High. Potential habitat occurs within the study area.
Syngnathoides biaculeatus	Double-end pipefish	Ma	P	-	In Australian waters, known from Geraldton to Shark Bay, and north to Ashmore and Cartier Reefs, Western Australia, and from the Timor Sea, the Northern Territory, eastwards to Queensland and south to Batemans Bay (NSW). Inhabits shallow, protected waters of bays, lagoons and estuaries including mangrove areas, in association with seagrass beds and macroalgae in depths at 0 to 10 metres. Juveniles sometimes found clinging to floating algae and plant debris including Sargassum sp. rafts.	DPI PMST	High. Potential habitat occurs within the study area.
Trachyrhamphus bicoarctatus	Bentstick pipefish	Ma	P	-	Widespread in the tropical Indo-west Pacific. Bentstick pipefish are known in Australian waters from the central coast of Western Australia, northwards throughout the waters of the Northern Territory and Queensland to central NSW. They live in sheltered coastal lagoon and reef areas on sandy and rubble habitats among seagrasses and macroalgae at one to 30 metres.	DPI PMST	Low. This species is mostly a coastal species.
Urocampus carinirostris	Hairy pipefish	Ma	P	-	In Australia, known from the Shoalwater Bay region (Queensland) to northern Tasmania, Victoria, and to the Ceduna region of South Australia, and in south-western Australia where it reaches the Perth region. Rare in South Australia. Inhabits the lower reaches of rivers, sheltered estuaries and shallow reefs in	DPI PMST	High. Potential habitat occurs within the study area.

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
					seagrass and algal beds a 0 to 6 metres. One of the most common estuarine pipefishes in eastern Australia, occurring year-round in seagrass beds in Western Port (Victoria), and abundant in seagrass beds in Moreton Bay (Queensland).		
Vanacampus margaritifer	Mother-of-pearl pipefish	Ma	P	-	Endemic to sub-tropical and temperate Australia, from North Stradbroke Island, Queensland, southwards to Jurien Bay, Western Australia, absent from Tasmania. Inhabits shallow estuarine and coastal waters in seagrass beds, macroalgae (Ecklonia spp. and other brown algae), rocky reef, boulder, rubble, sandy and muddy habitats between two to15 metres.	DPI PMST	High. Potential habitat occurs within the study area.
Marine reptiles							
Pelamis platurus	Yellow-bellied seasnake	Ma	-	-	The yellow-bellied seasnake is the most widely distributed of all sea snake species. In the beginning of the 21st century, the species was found to range from the east coast of Africa through the Indian and Pacific Oceans to the west coast of the Americas. It was found in most Australian waters with the exception of the colder southern coastline. The greatest density of populations was thought to exist south of the tropics where it was most commonly found on beaches after storms. Populations were also found in tropical seas and the Gulf of Carpentaria. The population living near the central coast of NSW was thought to be permanent and breeding, though no new studies have confirmed this. Most Australian specimens have been washed ashore by a combination of ebbing tides and onshore winds. The yellow-bellied seasnake is usually found within a few kilometres of the coast and prefers shallow inshore waters between 11.7–36 °C.The species is the most pelagic of all known sea snakes, occurring in the open waters well away from coasts and reefs.	PMST	Unlikely. This species is mostly pelagic.

* Distribution and habitat requirement information adapted from:

- Australian Government DoEE www.environment.gov.au/biodiversity/threatened/species.
- NSW OEH www.environment.nsw.gov.au/threatenedSpeciesApp/. and
- NSW DPI listed threatened species, populations and ecological communities www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current#key.

+ Data source includes

- The NSW DPI (Fisheries) Listed threatened species, populations and ecological communities and key threatening processes www.dpi.nsw.gov.au/fishing/species-protection/conservation/what-current#key.
- Number of records from the NSW Office of Environment and Heritage Wildlife Atlas record data (Accessed January 2018) www.bionet.nsw.gov.au/. and

Scientific name	Common name	EPBC Act	FM Act	BC Act	Distribution and habitat*	No. of records and source+	Potential likelihood to occur in the study area
					▪ Identified from the Protected Matters Search Tool (PMST) Australian Government Department of Environment and Energy www.environment.gov.au/epbc/protected-matters-search-tool. Key: Ma = marine (EPBC Act) P = protected (FM Act)		

APPENDIX

D

ASSESSMENTS OF SIGNIFICANCE

Preamble

The Assessments of Significance (AoSs) have been conducted by Craig Blount (BSc, BSc Hons.), an ecologist for Cardno, for marine threatened species listed under the FM Act, the *Biodiversity Conservation Act 2016* (BC Act) and the EPBC Act that was identified as occurring or having a moderate to high potential to occur within the study area from the results of the field survey or due to the presence of nearby records and/or the presence of suitable habitat. This species was identified in Section 3.8.

Part 7A of the FM Act lists threatened species, populations and ecological communities and key threatening processes (KTPs) for species, populations and ecological communities in NSW waters. Section 220ZZ of the FM Act outlines significant impact considerations to threatened species, populations and ecological communities listed under the FM Act. Under the FM Act, a '7-part test' is carried out to assess the likelihood of significant impact upon threat-listed species, populations or ecological communities listed under the FM Act. The document *Threatened Species Assessment Guidelines: The Assessment of Significance* (NSW DPI, 2008b) outlines a set of guidelines to help proponents of a development or activity with interpreting and applying the factors of assessment in the 7-part test. The guidance provided by the NSW DPI (2008b) has been used here in preparing the 7-part test.

Under the BC Act a 5-part test of significance is applied to determine whether an activity is likely to have a significant impact on listed threatened species, ecological communities, or their habitats, or will be carried out in a declared area of outstanding biodiversity value. The test of significance is set out in section 7.3 of the BC Act.For the species listing under the EPBC Act, a significance assessment has been completed in accordance with the *Matters of National Environmental Significance: Significant Impact Guidelines 1.1* (DoE, 2013). Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment that is affected, and upon the intensity, duration, magnitude and geographic extent of the impacts (DoE, 2013). Importantly, for a 'significant impact' to be 'likely', it is not necessary for a significant impact to have a greater than 50 per cent chance of happening. It is sufficient if a significant impact on the environment is a real or not remote chance or possibility (DoE, 2013).

Species and communities listed under both the FM Act and the EPBC Act have been assessed using both assessment guidelines separately. Species with similar life stage/habitat requirements (ie cetaceans) have been assessed together.

Assessment of Significance (AoS)

Assessments of Significance (AoSs) have been completed for the following endangered populations and species listed under the *Fisheries Management Act 1994* (FM Act), *Biodiversity Conservation Act 2016* (BC Act) and *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act):

- *P. australis* in Port Hacking, Botany Bay, Sydney Harbour, Pittwater, Brisbane Waters and Lake Macquarie endangered populations (*P. australis* EPs) under the FM Act
- Black rockcod (*Epinephelus daemelii*) listed as vulnerable under the FM Act and EPBC Act
- Grey nurse shark (*Carcharias taurus*) listed as critically endangered under the FM Act and EPBC Act
- White shark (*Carcharodon carcharias*) listed as vulnerable under the FM Act and EPBC Act
- Marine mammals:
  - Southern right whale (*Eubalaena australis*) listed as endangered under the BC Act and EPBC Act
  - Humpback whale (*Megaptera novaeangliae*) listed as vulnerable under the BC Act and EPBC Act
  - New Zealand fur seal (*Arctocephalus forsteri*) listed as vulnerable under the BC Act and EPBC Act
  - Australian fur seal (*Arctocephalus pusillus doriferus*) listed as vulnerable under the BC Act and EPBC Act

- Marine reptiles:
  - Loggerhead turtle (*Caretta caretta*) listed as endangered under the BC Act and EPBC Act
  - Green turtle (*Chelonia mydas*) listed as vulnerable under the BC Act and EPBC Act
  - Leatherback turtle (*Dermochelys coriacea*) listed as endangered under the BC Act and EPBC Act
  - Hawksbill turtle (*Eretmochelys imbricata*) listed as vulnerable under the EPBC Act
  - Flatback turtle (*Natator depressus*) listed as vulnerable under the EPBC Act.

Some of the species listed under the BC Act or EPBC Act have been grouped together for assessment due to their similar adult habitat requirements and sensitivities to potential threats from the project. The three groupings were the ‘whales’, ‘fur seals’ and ‘marine turtles’. For those which have been assessed together but are under different categories of listing under the EPBC Act, the assessments were completed for the higher protection level (eg AoS completed for the endangered listing for marine turtles).

An additional assessment under the FM Act has been completed for the proposed White’s seahorse listing for completeness.

The assessments are provided in the following sections.

7-part test (FM Act)

Black rockcod

An AoS has been completed for black rockcod (*Epinephelus daemelii*) and guided by the 7-part test for determining whether the proposed activity is likely to significantly effect on the threatened species listed under the FM Act.

The following questions tests whether a proposed development or activity is likely to significantly affect threatened species, populations or ecological communities:

a. ***In the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction***

Black rockcod, also known as saddled rockcod, occur from southern Queensland to Kangaroo Island in South Australia and are found offshore at Lord Howe Island, Norfolk Island, Kermadec Islands and the North Island of New Zealand (Heemstra and Randall, 1993). NSW is the centre of the species distributional range in Australia. They are protogynous hermaphrodites (ie change sex from female to male) and at the time of spawning males establish a harem within their territory. Black rockcod are opportunistic carnivores, eating mainly other fish and crustaceans.

Black rockcod are mostly found in caves and gutters in coastal areas. Dispersal of eggs is thought to be pelagic and juveniles can recruit to rockpools (Griffiths, 2003). Adults are highly territorial, usually adopting a cave as a core territory. Black rockcod have been observed by divers or caught by anglers in estuaries, including Sydney Harbour. Although the locations of these occurrences has generally been at the mouths of estuaries and involved juvenile fish, there is anecdotal evidence that black rockcod have been caught in the study area. In many estuaries suitable black rockcod habitat is also available further upstream. Although very few, if any, black rockcod may occur in suitable habitat within the study area now, more individuals probably occurred there in the past when the species was more prevalent as there are past reports of many large individuals being caught in estuaries (NSW Industry and Investment, 2009). In the future, if populations of black rockcod were to recover, the medium to high relief rocky reef areas in the study are may again become more commonly occupied. It is unlikely that viable populations of black rockcod currently occur in estuaries. The few individuals that occur are more likely to be part of one or many populations in adjacent coastal areas. Although no populations are listed as endangered, the loss of some individuals could still affect the viability of local populations.

The available evidence suggests that very few individuals would occur in potentially affected rocky reef habitat and hence it is reasonable to assume that at worst, only a small number of individuals would potentially die due to elevated turbidity, sedimentation or underwater noise (from impact piling) were they not to flee. The precise number of affected black rockcod, although likely to be small, is uncertain but can be estimated by considering the area of potentially affected black rockcod habitat relative to the area of similar unaffected Black rockcod habitat in Sydney Harbour or Middle Harbour. This is a very small proportion and indicates that the number of affected black rockcod would be negligible and would not affect the viability of local populations.

b. ***In the case of an endangered population, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction***

Not applicable.

c. ***In the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity:***

i. ***is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or***

ii. ***is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction***

Not applicable.

d. ***In relation to the habitat of a threatened species, population or ecological community:***

i. ***the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and***

ii. ***whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and***

iii. ***the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the threatened species, population or ecological community in the locality***

As indicated in (a), black rockcod are mostly found in caves and gutters in coastal areas. Dispersal of eggs is thought to be pelagic and juveniles can recruit to rockpools (Griffiths, 2003). Adults are highly territorial, usually adopting a cave as a core territory. Some high or medium relief reef in the study area is suitable for the species and would be affected by various hazards from the project. Importantly, given the area of affected habitat would be very small and it would be reinstated or recover soon after the construction phase of the project was completed, the risk to black rockcod would be negligible.

e. ***Whether the proposed development or activity is likely to have an adverse effect on any critical habitat (either directly or indirectly)***

Critical habitat refers only to those areas listed in the Register of Critical Habitat kept by NSW DPI (Fisheries). This question is not applicable, as no critical habitat has been listed for black rockcod.

f. ***Whether the proposed development or activity is consistent with a recovery plan or threat abatement plan***

A draft recovery plan for the black rockcod was placed on public exhibition in November 2009 (NSW Industry and Investment, 2009)

The specific objectives of the recovery plan are to:

- Mitigate medium and high risk threats to black rockcod
- Initiate and support scientific research to increase knowledge of the distribution, abundance, reproductive biology, life history, ecology, migratory patterns and genetics of black rockcod
- Monitor fishery management strategies where necessary to reduce potential for interaction with black rockcod (either directly or indirectly)
- Establish an on-going monitoring program to document the status of black rockcod populations and their habitats and to evaluate the effectiveness of recovery actions
- Provide enhanced compliance and protection for important black rockcod habitats
- Educate the community about the identification of black rockcod, increase awareness of the status of and threats to black rockcod populations, and enhance community support for recovery actions
- Improve understanding of the threats to the survival of black rockcod and contribute to management actions to ameliorate identified threats.

The key objective of the recovery plan is to mitigate medium and high risk threats to black rockcod. Included among these are that juvenile black rockcod are also impacted by the loss or degradation of estuarine and intertidal nursery habitats.

As the project would have only a temporary impact to a very small amount of black rockcod habitat and is unlikely to affect more than a few individuals, at most, it is otherwise consistent with the objectives of the recovery plan.

g. ***Whether the proposed development constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.***

A KTP is a process that threatens, or may have the capability to threaten, the survival or evolutionary development of species, population or ecological community. The key threatening process of *Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams* (FM Act) is of relevance given instream structures would be placed in or adjacent to black rockcod habitat during the construction phase. However, these structures would have limited impact on natural tidal flow and therefore would not affect black rockcod.

Conclusion

Black rockcod are known to occur in estuaries, particularly on rocky reefs. The project would not have any significant direct or indirect impacts on the habitat critical to the survival of black rockcod nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of a local population of the species.

Given the environmental controls on the project, the project would not place a population of black rockcod at risk of extinction.

Grey nurse shark

An AoS has been completed for the grey nurse shark (*Carcharias taurus*) and guided by the 7-part test for determining whether the proposed activity is likely to significantly effect on the threatened species listed under the FM Act.

The following questions tests whether a proposed development or activity is likely to significantly affect threatened species, populations or ecological communities:

a. ***In the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction***

Grey nurse sharks typically occur on shallow rocky reefs along the NSW coast (Last and Stevens 1994). Young occur on shallow rocky reefs, often segregated from the adults. Grey nurse sharks can be observed at day hovering or slowly swimming around high-relief reefs. It is thought that the species becomes more active at night where it hunts over rocky reef and soft substrata for a wide range of bony fish, rays, sharks, squids and crustaceans (Smale, 2005). There is also evidence to suggest that grey nurse sharks migrate along the NSW coast (northwards in autumn/winter and southwards in summer (Pollard et al, 1996, Otway and Parker, 2000).

The grey nurse shark has been listed as critically endangered under FM Act and recent surveys estimate the population to be small (Otway and Burke, 2004, Cardno Ecology Lab 2010). In such a small population the loss of only a few individuals could seriously affect the viability of the whole population.

Potential impacts from the project that could lead to mortality of grey nurse sharks include underwater noise from impact piling during the construction phase. Although it is probable that grey nurse sharks would enter the estuary to forage it is not their core habitat and it is unlikely any individuals would occur during the day in areas where underwater noise from impact piling could cause mortality during construction. Hence, it is unlikely that the proposal would cause adverse impacts that would result in or lead to a long-term decrease in the size of the east coast population.

Underwater noise, excessive turbidity or sedimentation could also lead to impacts on their prey in small areas nearby the project area. Although it is probable that grey nurse sharks would enter the estuary to forage there is no evidence to suggest that they depend on estuarine habitat in particular. It is possible that some estuarine prey items of grey nurse sharks could be killed but would recover soon after construction, so that the project does not disrupt the ecological balance of estuaries, availability or competition for food and other resources, trophic impacts would potentially not occur.

b. ***In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.***

Not applicable.

c. ***In the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity:***

   i. ***is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or***

   ii. ***is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction***

Not applicable.

d. ***In relation to the habitat of a threatened species, population or ecological community:***

   i. ***the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and***

   ii. ***whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and***

   iii. ***the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the threatened species, population or ecological community in the locality***

The major habitat utilised by grey nurse sharks comprises offshore rocky reefs, with small sandy gutters within the reef matrix being often preferred microhabitat. There is some likelihood that the species ranges away from reefs to feed at night. While the extent of this range is unknown (Smale, 2005) it is probable that grey nurse sharks would enter estuaries to forage on occasion. Although there would be temporary affects to a very small amount of forage habitat in the estuary, the proposal would not permanently modify or remove any core reef habitat or estuarine habitat of grey nurse sharks. The proposal would not isolate or fragment any reef or estuarine habitat from other habitat used by the species.

e. ***Whether the proposed development or activity is likely to have an adverse effect on any critical habitat (either directly or indirectly)***

Many of the known aggregation sites for grey nurse sharks in NSW waters have been declared critical habitat for the species and are protected by the Fisheries Management (General) Regulation 2010 Schedule 1A administered by Industry and Investment NSW. There are currently 10 aggregation sites along the NSW coast that have been declared as critical habitats and none of these are within the estuary. Many of these sites have also been further protected in marine parks or aquatic reserves administered by Department of Environment, Climate Change and Water. The project would not take place in or around any known aggregation sites or critical habitats. Therefore, no critical habitat would be directly or indirectly affected by the project.

f. ***Whether the proposed development or activity is consistent with a recovery plan or threat abatement plan***

State and Commonwealth recovery plans have been developed for the grey nurse shark. The specific objectives of the NSW recovery plan are to:

> Improve our understanding of the abundance, reproductive biology, life history, ecology, migratory patterns and genetics of grey nurse shark populations

> Address the key threats to grey nurse sharks

> Provide enhanced protection for key grey nurse shark habitats

> Coordinate action by community groups, local councils, government agencies, scuba diving groups and other stakeholders

> Increase awareness of the status of and threats to grey nurse shark populations, and enhance community support for recovery actions

> Establish an on-going monitoring program to document the status of grey nurse shark populations and habitat and evaluate the effectiveness of recovery actions.

Given that the majority of activities associated with the project would take place in the estuary away from known aggregation areas and core habitat of grey nurse sharks the impacts upon the species as a result of the project are most likely to be negligible and would not directly contravene the objectives of the State recovery plan.

g. ***Whether the proposed development constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.***

The KTP of *Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams* (FM Act) is of relevance given instream structures would be placed in or adjacent to grey nurse forage habitat during the construction phase. However, these structures would have limited impact on natural tidal flow and therefore would not affect grey nurse sharks.

Conclusion

The project would not have any significant direct or indirect impacts on the core habitat of the critically endangered grey nurse shark. It is possible, however, that grey nurse sharks could occur, on occasion, in the study area. The entire east coast population of grey nurse sharks is critically endangered and the loss of only a few individuals could seriously affect the viability of the small population. Given the greatest threat of mortality to individuals from the project is from underwater noise from impact piling during the day and that grey nurse sharks are more likely to be in the study area at night, the project is unlikely to cause any substantial mortality to individuals. Trophic impacts on grey nurse sharks that range into estuaries are unlikely given the small areas of habitat and associated biota affected by the project would recover soon after construction was completed.

White shark

An AoS has been completed for the white shark (*Carcharodon carcharias*) and guided by the 7-part test for determining whether the proposed activity is likely to significantly effect on the threatened species listed under the FM Act.

The following questions tests whether a proposed development or activity is likely to significantly affect threatened species, populations or ecological communities:

a. ***In the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction***

White sharks are large, highly predatory animals whose life cycle is poorly understood. They occur from cold temperate to tropical waters worldwide and generally frequent coastal waters, often close to shore. They also swim into bays and estuaries. Stockton Bight (Newcastle) is considered an important area for juvenile white sharks. White sharks are live bearers that do not appear to frequent specific habitats. The exception is when they take up residence adjacent to rocky shores, particularly where seals or sea lions are present. Emerging evidence suggests that juveniles and adults can range widely, with one tagged individual recorded travelling from Tasmania along the NSW coast into southern Queensland. There is also anecdotal evidence that the species follows large schools of migrating fish (eg sea mullet, Australian salmon) and migrating whales, particularly those with calves. The sharks' prey also includes a wide array of teleost fishes (Environment Australia, 2002).

Potential impacts from the project that could lead to mortality of white sharks include underwater noise from impact piling during the construction phase. Although it is probable that white sharks would enter the estuary to forage it is not their core habitat. Their occurrence would be rare in areas where underwater noise from impact piling could cause mortality during construction. Therefore, it is unlikely that the proposal would cause adverse impacts that would result in or lead to a long-term decrease in the size of the east coast population.

Underwater noise, excessive turbidity or sedimentation could also lead to impacts on their prey in small areas nearby the project area. Although it is probable that white sharks would enter the estuary to forage there is no evidence to suggest that white sharks depend on estuarine habitat in particular. It is possible that some estuarine prey items of white sharks could be killed but would recover soon after construction, so that the project does not disrupt the ecological balance of estuaries, availability or competition for food and other resources, trophic impacts would potentially not occur.

b. ***In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.***

Not applicable.

c. ***In the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity:***

   i. ***is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or***

   ii. ***is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction***

Not applicable.

d. ***In relation to the habitat of a threatened species, population or ecological community:***

   i. ***the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and***

   ii. ***whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and***

   iii. ***the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the threatened species, population or ecological community in the locality***

It is unknown if white sharks do prefer a particular habitat, however the area of sea close to rocky shores with seals or sea lions are likely to be important. There is also evidence to suggest that the species may also follow schools of migrating fish along the coast. On this basis, habitat within estuaries is not likely to represent significant habitat for white sharks and given the very small areas to be removed would be reinstated, there would be no risk of modifying, fragmenting or isolating habitat to the extent that the long-term survival of the species would be affected.

e. ***Whether the proposed development or activity is likely to have an adverse effect on any critical habitat (either directly or indirectly)***

Not applicable.

f. ***Whether the proposed development or activity is consistent with a recovery plan or threat abatement plan***

There is an approved Commonwealth Great White Shark Recovery Plan (Environment Australia 2002). The specific objectives of this recovery plan are to:

> Monitor and reduce the impact of commercial fishing on white sharks

> Investigate and evaluate the impact of recreational fishing on white sharks

> Monitor and reduce the impact of shark control activities on white sharks

> Identify and manage the impact of tourism on white sharks

> Monitor and reduce the impact of trade in white shark products

> Develop research programs toward the conservation of white sharks

> Identify habitat critical to the survival of white sharks and establish suitable protection of this habitat from threatening activities

> Promote community education and awareness in relation to white sharks

> Develop a quantitative framework to assess the recovery of the white shark.

Given that the majority of activities associated with the project would take place in the estuary away from core habitat of white sharks the impacts upon the species as a result of the project are most likely to be negligible and would not directly contravene the objectives of the recovery plan.

g. ***Whether the proposed development constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.***

The key threatening process of *Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams* (FM Act) is of relevance given instream structures would be placed in or adjacent to white shark forage habitat during the construction phase. However, these structures would have limited impact on natural tidal flow and therefore would not affect white sharks.

Conclusion

The project would not have any significant direct or indirect impacts on the core habitat of white sharks. It is possible, however, that a few individuals could occur, on occasion, in the study area and hence would be vulnerable to underwater noise from impact piling. Given very few individuals if any, would be affected, the project is unlikely to cause any substantial mortality to individuals so that the viability of a population would be affected. Trophic impacts on white sharks that range into estuaries are unlikely given the small areas of habitat and associated biota affected by the project would recover soon after construction was completed.

White's seahorse

White's seahorse has been nominated for threat-listing under the FM Act (NSW Fisheries Scientific Committee, 2018).

An AoS has been completed for White's seahorse (*Hippocampus whitei*) and guided by the 7-part test for determining whether the proposed activity is likely to significantly effect on the proposed threatened species listed under the FM Act.

The following questions tests whether a proposed development or activity is likely to significantly affect threatened species, populations or ecological communities:

a. ***In the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction***

White's seahorse has limited geographical distribution in Australia and appears to be endemic to just nine estuaries, coastal lakes and embayments from Wallis Lake in the north to Lake Illawarra in the south, along approximately 300 km of the NSW coast (Harasti, et al, 2014). White's seahorse is known to occur at depths of between one and 15 metres and can be found utilising a wide range of habitat types (both natural and artificial). Natural habitat for White's seahorse in estuaries is marine vegetation (ie seagrass, macroalgae on rocky reef and mangroves) as well as sponges and corals (Australian Museum, 2018; Kuiter, 2009; Harasti, et al, 2014). In Sydney, they are often found associated with artificial structure, particularly protective swimming net enclosures and jetty pylons. Their use of artificial habitats appears to be most common in areas where natural habitat such as seagrass, sponges and soft corals has been lost within Sydney Harbour (NSW Fisheries Scientific Committee, 2018). The species is found to prefer habitats with dense epibiotic growth and avoids areas devoid of growth, possibly in relation to the greater availability of shelter and prey in these areas (Harasti, et al, 2010). Densities in artificial habitats such as swimming nets can be as much as one metre^{-2}, but estimates in natural habitat have been around an order of magnitude less (Harasti, et al, 2012). The study area is considered to provide suitable habitat for White's seahorse. Suitable habitat for White's seahorse within the study area include subtidal, low, medium and high relief, rocky reef areas (about 17.63 hectares) and the seagrasses Halophila (0.32 hectares) and Zostera (2.5 hectares). Data collected on breeding pairs found that White's seahorse displays life-long monogamy, with three pairs observed remaining bonded over three consecutive breeding years (Harasti et al, 2012). The breeding season for *H. whitei* is from October to April (Australian Museum 2018).

Although White's seahorse is known mostly from the lower parts of the estuary (ie downstream of the study area, it is likely that viable populations of White's seahorse currently occur in the study area. Although no populations are listed as endangered, the loss of many individuals could still affect the viability of local populations. The available evidence suggests that very few individuals would occur in potentially affected nearshore habitats and hence it is reasonable to assume that at worst, some individuals would potentially die due to elevated turbidity, sedimentation or underwater noise from impact piling given their small size and site fidelity would provide limited opportunity for them to flee. The precise number of affected White's seahorse, although likely to be small, is uncertain but can be estimated by considering the area of potentially affected White's seahorse habitat relative to the area of similar unaffected White's seahorse habitat in Sydney Harbour. This is a very small proportion and indicates that the number of affected White's seahorse would be small relative to the total in the estuary. Given the life history parameters of *H. whitei* suggest it may be reasonably resilient (Harasti et al, 2012), it is considered that a potential loss of a very small number of individuals would not affect the viability of local populations.

b. ***In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.***

Not applicable.

c. ***In the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity:***

   i. ***is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or***

   ii. ***is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction***

Not applicable.

d. ***In relation to the habitat of a threatened species, population or ecological community:***

i. ***the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and***

ii. ***whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and***

iii. ***the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the threatened species, population or ecological community in the locality***

As indicated in (a), White's seahorse are found in subtidal rocky reef and seagrass areas. Some subtidal rocky reef and seagrass habitat in the study area is suitable for the species and would be affected by various hazards from the project. Importantly, given the area of affected habitat would be very small and it would be reinstated or recover soon after the construction phase of the project was completed, the risk to White's seahorse would be negligible.

e. ***Whether the proposed development or activity is likely to have an adverse effect on any critical habitat (either directly or indirectly)***

Critical habitat refers only to those areas listed in the Register of Critical Habitat kept by NSW DPI (Fisheries). This question is not applicable, as no critical habitat has been listed for White's seahorse.

f. ***Whether the proposed development or activity is consistent with a recovery plan or threat abatement plan***

There is no recovery plan, threat abatement plan or saving our species report card for this species. It is, however, the opinion of the Fisheries Scientific Committee that White's seahorse is eligible to be listed nationally as endangered under the Common Assessment Method (NSW Fisheries Scientific Committee 2018). The Scientific Committee's Management recommendations for White's seahorse are to:

> Collate and synthesise data collected to quantify the significance of high and moderate risk threat interactions with *H. whitei* (Medium priority)
> Reduce the impact of public and private boat moorings that impact on *H. whitei* habitats (High priority).
> Council to maintain best practice management of protective swimming nets by using the suggested NSW DPI seahorse-friendly cleaning methods (High Priority)
> Consider information on *H. whitei* distribution, abundance and habitat preferences during development and review of Marine Park Zoning Plans (Medium priority)
> Negotiate with relevant authorities to encourage the identification, assessment and modification of natural resource management plans and policies to minimise impacts on *H. whitei* habitats (Medium priority)
> Continue to monitor the distribution and abundance of *H. whitei* at important sites (Port Stephens and Sydney Harbour) to inform population status and to assist in determining the effectiveness of recovery actions (High priority)
> Develop and trial artificial habitats to promote recovery of *H. whitei* populations (High priority).
> Implement research using eDNA to investigate the occurrence of *H. whitei* in estuaries and embayments across its range (High priority)
> Implement genetics research to investigate population structure of *H. whitei* across its entire range (NSW and QLD) (Medium priority)
> Encourage the reporting of sightings of seahorses along the east coast of Australia to iSeahorse and iNaturalist (Medium priority).

The project would not be inconsistent with any of the above recommendations.

g. ***Whether the proposed development constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.***

A KTP is a process that threatens, or may have the capability to threaten, the survival or evolutionary development of species, population or ecological community. The key threatening process of *Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams* (FM Act) is of relevance given instream structures would be placed in or adjacent to White's seahorse habitat during the construction phase. However, these structures would have limited impact on nearshore natural tidal flow and therefore would not affect White's seahorse.

Conclusion

White's seahorse are known to occur in Sydney Harbour on subtidal rocky reefs and in seagrass. The project would not have any significant direct or indirect impacts on the habitat critical to the survival of White's seahorse nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of a local population of the species.

Given the environmental controls on the project, the project would not place a population of White’s seahorse at risk of extinction.

Test of Significance (BC Act)

Whales (vulnerable and endangered species)

A Test of Significance has been completed for the humpack whale and southern right whale and guided by the test criteria given in section 7.3 of the BC Act.

A proposed development or activity is likely to significantly affect threatened species or ecological communities, or their habitats if:

a. ***in the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction***

Humpback and southern right whales are baleen whales. Baleen whales as a group form the Mysticeti, one of two suborders of the Cetacea (whales, dolphins, and porpoises). Baleen whales are characterized by having baleen plates for filtering food from water, rather than having teeth. This distinguishes them from the other suborder of cetaceans, the toothed whales or Odontoceti. Baleen whales feed mainly on zooplankton, crustaceans (eg krill) and small schooling fish.

Southern right whales are known to be present along the east coast of Australia between May and November where they occasionally enter estuaries such as Port Jackson, Botany Bay, Jervis Bay and Twofold Bay. Females travel to temperate waters to give birth and anecdotal evidence shows that mother and calf sightings are becoming more common in the Sydney region as the species' population increases. Twofold Bay is used intermittently by southern right whales for calving (DEH, 2005a).

The east coast population of humpback whales migrates along the Victorian, NSW and Queensland coasts to the Coral Sea from late autumn to early winter and back along the coast in late spring and early summer. Often on the return trip, adults swim close to the shore and are accompanied by newborn calves. At this time, humpback whales may rest in some of the larger estuarine embayments (DEH, 2005b).

Although humpback or southern right whales and their calves can enter Port Jackson occasionally, there is less potential for them to occur as far upstream as the study area. Were an individual (and potentially its calf) to occur in the study area, the main project pathways that could impact these whales is through underwater noise from dredging and impact piling activities, and boat strike. As whales can be observed above the water, impacts on whales from these activities can be easily mitigated through a marine mammal management plan that would implement a stop work procedure during construction were these animals present (see Section 6.7), Hence, mortality or mortal injury would be prevented or minimised and the risk to these species of a viable local population being placed at risk of extinction is considered negligible.

b. ***in the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity:***

(i) is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction

Not applicable.

c. ***in relation to the habitat of a threatened species or ecological community:***

(i) the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species or ecological community in the locality

The important areas of habitat to the southern right whale are the feeding areas of the Southern Ocean, the mating and birthing areas of southern Australia (eg Great Australian Bight) and to a lesser extent some birthing areas along the east and west coasts, primarily adjacent to coastal sandy beaches and in some of the deeper bays.

Major habitats for humpback whales include the feeding, breeding and mating areas in the southern and northern extents of their range, respectively, and the migration corridors which extend at least the width of the continental shelf. In addition, some large coastal bays or estuaries are also potentially important areas as they may be used by the whales for resting or lay ups during annual migrations.

Given the very occasional occurrence of these species in Sydney Harbour, there would be no reduction to the area of occupancy of these species, fragmentation or isolation of habitat from other areas, or modification of core habitat as a consequence of the project.

d. ***whether the proposed development or activity is likely to have an adverse effect on any declared area of outstanding biodiversity value (either directly or indirectly)***

Areas of outstanding biodiversity value (AOBVs) are special areas that contain irreplaceable biodiversity values that are important to the whole of NSW, Australia or globally. The only relevant AOBV is the declared critical habitat of the little penguin population in Sydney's North Harbour, which includes land above the high tide mark important for nesting as well as nearshore areas (extending 50 metres out from the mean high water mark) important to penguins landing. This area is not within Sydney Harbour (ie where the project occurs) and is located more than six kilometres from the eastern edge of the study area. The nearshore component of the AOBV is not potential habitat for whales given the shallow water depth. Further, given this area is not within Sydney Harbour (ie where the project occurs) and is located more than six kilometres from the eastern edge of the study area it has negligible potential to be directly or indirectly affected by any of the project’s potential hazards.

e. ***whether the proposed development or activity is or is part of a key threatening process or is likely to increase the impact of a key threatening process***

Key Threatening Processes (KTP) are listed under the FM Act, BC Act and EPBC Act. Of these KTPs, four could affect marine mammals and have relevance to the project. These include:

> Human-caused climate change (FM Act)

> Introduction of non-indigenous fish and marine vegetation to the coastal waters of New South Wales (FM Act)

> Novel biota and their impact on biodiversity (EPBC Act)

> Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris (EPBC Act).

The assessment of the potential of the project to trigger or further exacerbate or any of these KTPs is given in Section 5.3 was that it would be unlikely given the proposed controls to activities.

Conclusion

Although humpback and southern right whales are known to occur in Port Jackson this is not their core habitat. The project would not have any significant long-term direct or indirect impacts on the habitat important to the survival of whales nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of populations of these species.

Given the controls on project activities, the project would not place a population of humpback whales or southern right whales at risk of extinction.

Fur seals (vulnerable species)

A Test of Significance has been completed for the New Zealand fur seal and Australian fur seal and guided by the test criteria given in section 7.3 of the BC Act.

A proposed development or activity is likely to significantly affect threatened species or ecological communities, or their habitats if:

a. ***in the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction***

Australian fur seals are coastal mammals that range over the continental slope and shelf waters of south-eastern Australia (Shaughnessy 1999). They may also move into estuaries occasionally. Australian fur seals eat pelagic and mid-water fish and cephalopods and can dive to depths of around 200 metres while chasing food. They breed on 10 islands in the Bass Strait. Pregnant females feed intensively at sea in early spring before returning to colonies in late October/early November to give birth to a single pup (Menkhorst and Knight 2001). In the past, Australian fur seals were reported to have bred in NSW (prior to commercial sealing) at Seal Rocks and Montague Island but they no longer do so. There are other non-breeding (haul-out) colonies between Kangaroo Island in South Australia and Jervis Bay in NSW. These are Green Cape, Montague Island and Steamers Beach near Jervis Bay. In addition, other various locations along the NSW coast are used irregularly as haul-out sites. Although the species no longer breeds in NSW, habitat and resources within the State remain important to non-breeding individuals.

New Zealand fur seals occur in coastal waters of Australia and New Zealand. In Australian waters, New Zealand fur seals have been recorded in all of the southern States as well as in Queensland (south of Fraser Island). They eat fish and cephalopods and to a lesser extent birds such as penguins, both in shallow waters and around the margins of the continental shelf. Breeding colonies in Australia are known from islands off Western Australia, South Australia and Tasmania, including Macquarie Island. Although the species does not breed in NSW, habitat and resources within the State remain important to non-breeding individuals. Montague Island is a regular haul-out site in NSW (Shaughnessy 1999).

On any day, up to a few individuals of either species may be found in the eastern end of Port Jackson, but there is less potential for an individual to occur as far upstream as the study area. Were an individual of either species to occur in the study area, the main project pathways that could impact fur seals would be through underwater noise impact piling activities and boat strike. As fur seals can be observed above the water, potential impacts from these activities can be easily mitigated through a marine mammal management plan that would implement a stop work procedure during construction were these animals present (see Section 6.7), Hence, mortality or mortal injury would be prevented or minimised and the risk to these species of a viable local population being placed at risk of extinction is considered negligible

b. ***in the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity:***

(i) is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction

Not applicable.

c. ***in relation to the habitat of a threatened species or ecological community:***

(i) the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species or ecological community in the locality

Both Australian and New Zealand fur seals may occasionally forage in estuaries although this is not generally considered a core habitat (see [a]). Given the occasional occurrence of these species in Sydney Harbour, there would be no reduction to the area of occupancy of these species, fragmentation or isolation of habitat from other areas, or modification of core habitat as a consequence of the project.

d. ***whether the proposed development or activity is likely to have an adverse effect on any declared area of outstanding biodiversity value (either directly or indirectly)***

Areas of outstanding biodiversity value (AOBVs) are special areas that contain irreplaceable biodiversity values that are important to the whole of NSW, Australia or globally. The only relevant AOBV is the declared critical habitat of the little penguin population in Sydney's North Harbour, which includes land above the high tide mark important for nesting as well as nearshore areas (extending 50 metres out from the mean high water mark) important to penguins landing. The nearshore component of the AOBV is potential habitat for fur seals but given this area is not within Sydney Harbour (ie where the project occurs) and is located more than six kilometres from the eastern edge of the study area it has negligible potential to be directly or indirectly affected by any of the project's hazards.

e. ***whether the proposed development or activity is or is part of a key threatening process or is likely to increase the impact of a key threatening process***

Key Threatening Processes (KTP) are listed under the FM Act, BC Act and EPBC Act. Of these KTPs, four could affect marine mammals and have relevance to the project. These include:

> Human-caused climate change (FM Act)

> Introduction of non-indigenous fish and marine vegetation to the coastal waters of New South Wales (FM Act)

> Noval biota and their impact on biodiversity (EPBC Act)

> Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris (EPBC Act).

The assessment of the potential of the project to trigger or further exacerbate or any of these KTPs is given in Section 5.3 was that it would be unlikely given the proposed controls to activities.

Conclusion

Although New Zealand fur seals and Australian fur seals are known to occur in Port Jackson this is not their core habitat. The project would not have any significant long-term direct or indirect impacts on the habitat important to the survival of fur seals nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of populations of these species.

Given the controls on project activities, the project would not place a population of New Zealand fur seals or Australian fur seals at risk of extinction.

Marine reptiles (vulnerable and endangered species)

A Test of Significance has been completed for the loggerhead turtle, green turtle and leatherback turtle and guided by the test criteria given in section 7.3 of the BC Act.

A proposed development or activity is likely to significantly affect threatened species or ecological communities, or their habitats if:

a. ***in the case of a threatened species, whether the proposed development or activity is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction***

The marine turtles tend to prefer warmer waters, ranging from tropical to warm temperate seas (Marquez, 1990). For a large part of their life cycle, marine turtles are pelagic, particularly leatherbacks, although green turtles tend to stay in coastal waters. The green turtle is generally found in the more northern latitudes of Australia although resident groups of green turtles have been found in NSW, with some as far south as Jervis Bay. Resident populations also appear to have established in some other estuaries particularly near warm water outfalls such as Lake Macquarie where a study is underway to assess the apparently resident populations of several turtle species in the vicinity of warm water outfalls from a power generation facility. Green turtle juveniles are pelagic and appear to be omnivorous. At 35 to 40 centimetres they begin to be primarily herbivorous, feeding on seagrasses, algae and mangrove fruit. They will also eat plankton such as jellyfish and *Physalia*.

Loggerhead turtles occur in coral reefs, bays and estuaries in tropical and warm temperate waters off the coast of Queensland, Northern Territory, Western Australia and NSW. Like green turtles, there are also resident groups of loggerhead turtles in the waters of northern NSW. Immature and adult loggerhead turtles are carnivorous and consume a variety of benthic invertebrates including molluscs, crustaceans, and echinoderms.

The leatherback turtle has a wide distribution and may be observed all around the coast of southern Queensland and NSW. Leatherbacks are carnivorous feeding mainly in the open ocean on jellyfish and soft-bodied invertebrates. They are a highly pelagic species and as such would rarely occur in estuaries apart from some of the coastal bays.

NSW populations of each species of marine turtles are generally considered to belong to a single eastern Australian stock.

Although marine turtles spend the majority of their lives in the ocean, adult female marine turtles come ashore to lay eggs in the sand above the high tide. Females lay on average two to six clutches per season. Temperature during incubation determines the sex of hatchlings, with higher temperatures producing predominantly females. Nesting is mainly confined to tropical beaches although successful nesting has been recorded in northern NSW for loggerhead, green and leatherback turtles.

Marine turtles are probably most vulnerable when they come ashore to nest. At this time adults, eggs and hatchlings are subject to direct harvesting, predation by native fauna, feral animals and pets and various forms of human disturbance. Although these species occur within NSW estuaries, the southern estuaries are outside the range of the main nesting and mating areas for the turtle species (although there is a record of leatherbacks nesting on Ballina Beach). The main nesting and mating grounds for the listed turtle species generally occur in more northern latitudes. Hence, the project would not affect breeding cycles for any of the species.

Marine turtles do not breed as far south as Port Jackson but all three species have potential to occur in Sydney Harbour, although it is sub-optimal foraging habitat. The main project pathways that could impact marine turtles would be through underwater noise from dredging and impact piling activities and boat strike. As marine turtles can be observed above the water, potential impacts on marine turtle from these activities would be easily mitigated through a management plan that would implement a stop work procedure during construction when these animals were present (see Section 6.7). Hence, mortality or mortal injury would be prevented or minimised and the risk to these species of a viable local population being placed at risk of extinction is considered negligible.

b. ***in the case of an endangered ecological community or critically endangered ecological community, whether the proposed development or activity:***

(i) is likely to have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or

(ii) is likely to substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to be placed at risk of extinction

Not applicable.

c. ***in relation to the habitat of a threatened species or ecological community:***

(i) the extent to which habitat is likely to be removed or modified as a result of the proposed development or activity, and

(ii) whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed development or activity, and

(iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species or ecological community in the locality

As indicated in (a), marine turtles do not breed as far south as Port Jackson but all three species have potential to occur in Sydney Harbour, although it is sub-optimal foraging habitat. The important areas of habitat to the marine turtles are further north than Port Jackson.

Given the very occasional occurrence of these species in Sydney Harbour, there would be no reduction to the area of occupancy of these species, fragmentation or isolation of habitat from other areas, or modification of core habitat as a consequence of the project.

d. ***whether the proposed development or activity is likely to have an adverse effect on any declared area of outstanding biodiversity value (either directly or indirectly)***

Areas of outstanding biodiversity value (AOBVs) are special areas that contain irreplaceable biodiversity values that are important to the whole of NSW, Australia or globally. The only relevant AOBV is the declared critical habitat of the little penguin population in Sydney's North Harbour, which includes land above the high tide mark important for nesting as well as nearshore areas (extending 50 metres out from the mean high water mark) important to penguins landing. The nearshore component of the AOBV is potential habitat for marine turtles but given this area is not within Sydney Harbour (ie where the project occurs) and is located more than six kilometres from the eastern edge of the study area it has negligible potential to be directly or indirectly affected by any of the project’s potential hazards.

e. ***whether the proposed development or activity is or is part of a key threatening process or is likely to increase the impact of a key threatening process***

Key Threatening Processes (KTP) are listed under the FM Act, BC Act and EPBC Act. Of these KTPs, four could affect marine turtles and have relevance to the project. These include:

- Human-caused climate change (FM Act)
- Introduction of non-indigenous fish and marine vegetation to the coastal waters of New South Wales (FM Act)
- Noval biota and their impact on biodiversity (EPBC Act)
- Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris (EPBC Act).

The assessment of the potential of the project to trigger or further exacerbate or any of these KTPs is given in Section 5.3 was that it would be unlikely given the proposed controls to activities.

Conclusion

Although three species of marine turtles are known to occur in Port Jackson this is not their core habitat. The project would not have any significant long-term direct or indirect impacts on the habitat important to the survival of marine turtles nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of populations of these species.

Given the controls on project activities, the project would not place a population of marine turtles at risk of extinction.

Significance assessment (EPBC Act)

Black rockcod

An AoS has been completed for black rockcod and guided by the Significant Impact Guidelines for determining whether the proposed activity is likely to significantly effect a threatened species listed under the EPBC Act.

An action is likely to have a significant impact on a vulnerable species if there is a real chance or possibility that it will:

a. ***Lead to a long-term decrease in the size of an important population of a species***

Black rockcod occur from southern Queensland to Kangaroo Island in South Australia and are found offshore at Lord Howe Island, Norfolk Island, Kermadec Islands and the North Island of New Zealand (Heemstra and Randall 1993). NSW is the centre of the species distributional range in Australia. They are protogynous hermaphrodites (ie change sex from female to male) and at the time of spawning males establish a harem within their territory. Black rockcod are opportunistic carnivores, eating mainly other fish and crustaceans.

Black rockcod are mostly found in caves and gutters in coastal areas. Dispersal of eggs is thought to be pelagic and juveniles can recruit to rockpools (Griffiths, 2003). Adults are highly territorial, usually adopting a cave as a core territory. Black rockcod have been observed by divers or caught by anglers in estuaries, including Sydney Harbour. Although the locations of these occurrences has generally been at the mouths of estuaries and involved juvenile fish, there is anecdotal evidence that black rockcod have been caught in the study area. In many estuaries suitable black rockcod habitat is also available further upstream. Although very few, if any, black rockcod may occur in suitable habitat within the study area now, more individuals probably occurred there in the past when the species was more prevalent as there are past reports of many large individuals being caught in estuaries (NSW Industry and Investment, 2009b). In the future, if populations of black rockcod were to recover, the medium to high relief rocky reef areas in the study area may again become more commonly occupied. It is unlikely that viable populations of black rockcod currently occur in estuaries. The few individuals that occur are more likely to be part of one or many populations in adjacent coastal areas that have been suggested to be genetically connected to one another (DSEWPAC 2012). Given the small number of individuals that may occur in Port Jackson potentially contribute to the genetic diversity of the broader population these individuals are considered to be part of an ‘important population’ of the species.

Although no populations are listed as endangered, the loss of some individuals could still affect the viability of the broader population given black rockcod’s geographic distribution along inshore areas of the NSW coastline is precarious for the species’ survival (DSEWPAC 2012).The available evidence suggests that very few individuals would occur in potentially affected rocky reef habitat and hence it is reasonable to assume that at worst, only a small number of individuals would potentially die due to elevated turbidity, sedimentation or underwater noise (from impact piling) were they not to flee. The precise number of affected black rockcod, although likely to be small, is uncertain but can be estimated by considering the area of potentially affected black rockcod habitat relative to the area of similar unaffected black rockcod habitat in Sydney Harbour or Middle Harbour. This is a very small proportion and indicates that the number of affected black rockcod would be negligible and would not affect the viability of local populations (if present) or lead to a long-term decrease in the size of an important population of a species.

b. ***Reduce the area of occupancy of an important population***

As indicated in (a), black rockcod are mostly found in caves and gutters in coastal areas. Dispersal of eggs is thought to be pelagic and juveniles can recruit to rockpools (Griffiths, 2003). Adults are highly territorial, usually adopting a cave as a core territory. Some high or medium relief reef in the study area is suitable for the species and would be affected by various hazards from the project. Importantly, given the area of affected habitat would be very small and it would be reinstated or recover soon after the construction phase of the project was completed, the risk to black rockcod habitat would be negligible.

c. ***Fragment an existing important population into two or more populations***

See (b).

d. ***Adversely affect habitat critical to the survival of a species***

See (b).

e. ***Disrupt the breeding cycle of an important population***

Black rockcod are protogynous hermaphrodites (ie change sex from female to male) and at the time of spawning males establish a harem within their territory. The available evidence suggests that very few individuals would occur in potentially affected rocky reef habitat and hence it is reasonable to assume that at worst, only a small number of individuals would potentially die due to elevated turbidity, sedimentation or underwater noise (from impact piling) were they not to flee. The precise number of affected black rockcod, although likely to be small, is uncertain but can be estimated by considering the area of potentially affected black rockcod habitat relative to the area of similar unaffected black rockcod habitat in Sydney Harbour or Middle Harbour. This proportion would be small in terms of the population size and indicates that the number of affected black rockcod would be negligible and would not affect breeding opportunity between individuals.

f. ***Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline***

See (b).

g. ***Result in invasive species that area harmful to a vulnerable species becoming established in the vulnerable species' habitat***

Vessels and movement of offshore equipment have potential to act as vectors for introduced species. However, there are no known invasive species that could be introduced that could potentially cause black rockcod to decline.

h. ***Introduce disease that may cause the species to decline***

See (g).

i. ***Interfere substantially with the recovery of the species***

State and Commonwealth recovery plans have been developed for the black rockcod. The specific objectives of the Commonwealth recovery plan are to:

> Mitigate moderate and high risk threats to black rockcod

> Initiate and support scientific research to increase knowledge of the distribution, abundance,reproductive biology, life history, ecology, migratory patterns and genetics of black rockcod

> Monitor fishery management strategies where necessary to reduce potential for interaction with black rockcod (either directly or indirectly)

> Establish an on-going monitoring program to document the status of black rockcod populations and their habitats and to evaluate the effectiveness of recovery actions

> Provide enhanced compliance and protection for important black rockcod habitats

> Educate the community about the identification of 'best practice' catch and release methods for black rockcod, increase awareness of the status of and threats to black rockcod populations, and enhance community support for recovery actions

> Improve understanding of the threats to the survival of black rockcod and contribute to management actions to ameliorate identified threats.

As the project would have only a temporary impact to a very small amount of black rockcod habitat and is unlikely to affect more than a few individuals, at most, it is otherwise consistent with the objectives of the Commonwealth recovery plan.

Conclusion

Black rockcod are known to occur in estuaries, particularly on rocky reefs. The proposal would not have any significant direct or indirect impacts on the habitat critical to the survival of black rockcod nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of a local population of the species or an important population of the species.

Given the environmental controls on the project, the project would not place a population of black rockcod at risk of extinction and a Referral is not recommended.

Grey nurse shark

An AoS has been completed for the grey nurse shark (*Carcharias taurus*) for determining whether the proposed activity is likely to significantly effect on the threatened species listed under the EPBC Act.

An action is likely to have a significant impact on an endangered population if there is a real chance or possibility that it will:

a. ***Lead to a long-term decrease in the size of a population***

Grey nurse sharks typically occur on shallow rocky reefs along the NSW coast (Last and Stevens, 1994). Young occur on shallow rocky reefs, often segregated from the adults. Grey nurse sharks can be observed at day hovering or slowly swimming around high-relief reefs. It is thought that the species becomes more active at night where it hunts over rocky reef and over soft substrata for a wide range of bony fishes, rays, sharks, squids and crustaceans (Smale, 2005). There is also evidence to suggest that grey nurse sharks migrate along the NSW coast (northwards in autumn/winter and southwards in summer (Pollard et al,,1996, Otway and Parker, 2000).

The east coast population of grey nurse sharks has been listed as critically endangered under EPBC Act and recent surveys estimate the population to be small (Otway and Burke, 2004, Cardno Ecology Lab, 2010). In such a small population the loss of only a few individuals could seriously affect the viability of the whole population.

Potential impacts from the project that could lead to mortality of grey nurse shark include underwater noise from impact piling during the construction phase. Although it is probable that grey nurse sharks would enter the estuary to forage, it is not their core habitat and it is unlikely any individuals would occur during the day in areas where underwater noise from impact piling could cause mortality during construction. Hence, it is unlikely that the proposal would cause adverse impacts that would result in or lead to a long-term decrease in the size of the east coast population.

Underwater noise, excessive turbidity or sedimentation could also lead to impacts on their prey in small areas nearby the project area. Although it is probable that grey nurse sharks would enter the estuary to forage there is no evidence to suggest that they depend on estuarine habitat in particular. It is possible that some estuarine prey items of grey nurse sharks could be killed but would recover soon after construction, so that the project does not disrupt the long-term ecological balance of estuaries, availability or competition for food and other resources, trophic impacts would potentially not occur.

b. ***Reduce the area of occupancy the species***

The major habitat utilised by grey nurse sharks comprises offshore rocky reefs, with small sandy gutters within the reef matrix being often preferred microhabitat. There is some likelihood that the species ranges away from reefs to feed at night. While the extent of this range is unknown (Smale, 2005) it is probable that grey nurse sharks would enter estuaries to forage on occasion. Although there would be temporary affects to a very small amount of forage habitat in the estuary, the proposal would not permanently modify or remove any core reef habitat or estuarine habitat of grey nurse sharks. The proposal would not isolate or fragment any reef or estuarine habitat from other habitat used by the species.

c. ***Fragment an existing important population into two or more populations***

See (b).

d. ***Adversely affect habitat critical to the survival of a species***

Many of the known aggregation sites for grey nurse sharks in NSW waters have been declared critical habitat for the species and are protected by the *Fisheries Management (General) Regulation 2010* Schedule 1A administered by Industry and Investment NSW. There are currently 10 aggregation sites along the NSW coast that have been declared as critical habitats and none of these are within Sydney Harbour. Many of these sites have also been further protected in marine parks or aquatic reserves administered by Department of Environment, Climate Change and Water. The project would not take place in or around any known aggregation sites or critical habitats. Therefore no critical habitat would be directly or indirectly affected by the project.

e. ***Disrupt the breeding cycle of a population***

Core habitat for grey nurse sharks are the shallow rocky reefs along the NSW coast (Last and Stevens, 1994). Young are born live and also occur on shallow rocky reefs, often segregated from the adults. Grey nurse sharks can be observed at day hovering or slowly swimming around high relief reefs. It is thought that the species becomes more active at night where it hunts over rocky reef and over soft substrata for a wide range of bony fishes, rays, sharks, squids and crustaceans (Smale, 2005) and individuals enter estuaries to forage on occasion (see Part a of this assessment).

As discussed in (a), potential impacts from the project that could lead to mortality of grey nurse shark include underwater noise from impact piling during the construction phase. Although it is probable that grey nurse sharks would enter the estuary to forage it is not their core habitat and it is unlikely any individuals would occur during the day in areas where underwater noise from impact piling could cause mortality during construction. Hence, it is unlikely that the proposal would cause adverse impacts that would affect any sharks so that their breeding cycle was disrupted.

f. ***Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline***

The major habitat utilised by grey nurse sharks comprises offshore rocky reefs, with small sandy gutters within the reef matrix being often preferred microhabitat. There is some likelihood that the species ranges away from reefs to feed at night. However the extent of this range is unknown (Smale, 2005) and grey nurse sharks would enter estuaries to forage on occasion. As discussed in (b), (c) and (d), the proposal would not modify, destroy, isolate or remove any core reef habitat, estuarine habitat or any other habitat of grey nurse sharks.

g. ***Result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat***

No invasive species harmful to grey nurse sharks are likely to be released or have their populations enhanced as a consequence of the proposal.

h. ***Introduce disease that may cause the species to decline***

Vessels and movement of offshore equipment have potential to act as vectors for disease. However, there are no known diseases that could be introduced that could potentially cause sharks to decline.

i. ***Interfere with the recovery of the species***

State and Commonwealth recovery plans have been developed for the grey nurse shark. The specific objectives of the Commonwealth recovery plan are to:

> Reduce the impact of commercial fishing on grey nurse sharks
> Reduce the impact of recreational fishing on grey nurse sharks
> Reduce the impact of shark finning on grey nurse sharks
> Reduce the impact of shark control activities on grey nurse sharks
> Manage the impact of ecotourism on grey nurse sharks
> Eliminate the impact of aquaria on grey nurse sharks
> Identify and establish conservation areas to protect grey nurse sharks from threatening activities such as commercial and recreational fishing
> Develop research programs to assist conservation of grey nurse sharks
> Develop population models to assess grey nurse shark populations and monitor their recovery
> Promote community education about grey nurse sharks
> Develop a quantitative framework to assess the recovery of the species.

Given that the majority of activities associated with the project would take place in Sydney Harbour away from known aggregation areas and core habitat of grey nurse sharks the impacts upon the species as a result of the project are most likely to be negligible and would not directly contravene the objectives of the recovery plan.

Conclusion

Grey nurse sharks are known to occur in estuaries although this is not their core habitat and they are more likely to only occur there at night. The project would not have any significant long-term direct or indirect impacts on the habitat critical to the survival of grey nurse sharks nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of the east coast population of the species.

Given the controls on the proposal, the project would not place a population of white sharks at risk of extinction and a Referral is not recommended.

White shark

An AoS has been completed for White shark (*Carcharodon carcharias*) for determining whether the proposed activity is likely to significantly effect on the threatened species listed under the EPBC Act.

An action is likely to have a significant impact on a vulnerable species if there is a real chance or possibility that it will:

a. ***Lead to a long-term decrease in the size of an important population of a species***

White sharks are large, highly predatory animals whose life cycle is poorly understood. They occur from cold temperate to tropical waters worldwide and generally frequent coastal waters, often close to shore. They also swim into bays and estuaries. Stockton Bight (Newcastle) is considered the nearest important area for the species, particularly for juvenile white sharks. White sharks are live bearers that do not appear to frequent specific habitats. The exception is when they take up residence adjacent to rocky shores, particularly where seals or sea lions are present. Emerging evidence suggests that juveniles and adults can range widely, with one tagged individual recorded travelling from Tasmania along the NSW coast into southern Queensland. There is also anecdotal evidence that the species follows large schools of migrating fish such as sea mullet and Australian salmon and migrating whales, particularly those with calves. The sharks' prey also includes a wide array of teleost fishes (Environment Australia, 2002). White sharks have a very low potential for population recovery due to their low reproductive rate, late maturation, long lifespan and low natural mortality.

There is evidence of genetic structuring within the Australian white shark population. Recent genetic evidence provides support for maternal structuring between the eastern and south-western coastal regions (Blower et al, 2012). Given the small number of individuals that may occur in Port Jackson potentially contribute to the genetic diversity of the broader east coast population, these individuals are considered to be part of an 'important population' of the species. Potential impacts from the project that could lead to mortality of white shark include underwater noise from impact piling during the construction phase. Although it is probable that white sharks would enter the estuary to forage it is not their core habitat and their occurrence would be rare in areas where underwater noise from impact piling could cause mortality during construction. Hence, the number of potentially affected white sharks would be negligible and would not lead to a long-term decrease in the size of an important population of a species.

Underwater noise, excessive turbidity or sedimentation could also lead to impacts on their prey in small areas nearby the project area. Although it is probable that white sharks would enter the estuary to forage there is no evidence to suggest that white sharks depend on estuarine habitat in particular. It is possible that some estuarine prey items could be killed but would recover soon after construction, so the project does not disrupt the ecological balance of estuaries, availability or competition for food and other resources.

b. ***Reduce the area of occupancy of an important population***

It is unknown if white sharks do prefer a particular habitat, however the area of sea close to rocky shores with seals or sea lions is likely to be important. There is also evidence to suggest that the species may also follow schools of migrating fish along the coast. On this basis, habitat within Sydney Harbour is not likely to represent significant habitat for white sharks and it would not be permanently removed, modified, fragmented or isolated to an extent that it would reduce the area of occupancy of a population.

c. ***Fragment an existing important population into two or more populations***

See (b).

d. ***Adversely affect habitat critical to the survival of a species***

Not applicable.

e. ***Disrupt the breeding cycle of an important population***

White sharks are live bearers and Stockton Bight (Newcastle) is considered an important area for juvenile white sharks, suggesting they may breed nearby. The available evidence suggests that very few individuals would occur in potentially affected rocky reef habitat in the study area and hence it is reasonable to assume that at worst, only a small number of individuals would potentially due to underwater noise (from impact piling) were they not to flee. The precise number of affected individuals, although likely to be small, is uncertain but would not affect breeding opportunity between individuals.

f. ***Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline***

See (b).

g. ***Result in invasive species that area harmful to a vulnerable species becoming established in the vulnerable species' habitat***

No invasive species harmful to white sharks are likely to be released or have their populations enhanced as a consequence of the proposal.

h. ***Introduce disease that may cause the species to decline***

Vessels and movement of offshore equipment have potential to act as vectors for introduced species. Introduced species may be translocated into the study area through the release of ballast water (in the case of planktonic larvae or species) or via reproduction from individuals attached to the hull of a vessel. Marine pests are considered to be a long-term, reversible impact to which marine communities have an existing level of exposure. However none harmful to white sharks are likely to be released or have their populations enhanced as a consequence of the project.

i. ***Interfere substantially with the recovery of the species***

There is an approved Commonwealth Great White Shark Recovery Plan (Environment Australia 2002). The specific objectives of this recovery plan are to:

> Monitor and reduce the impact of commercial fishing on white sharks
> Investigate and evaluate the impact of recreational fishing on white sharks
> Monitor and reduce the impact of shark control activities on white sharks
> Identify and manage the impact of tourism on white sharks
> Monitor and reduce the impact of trade in white shark products
> Develop research programs toward the conservation of white sharks
> Identify habitat critical to the survival of white sharks and establish suitable protection of this habitat from threatening activities
> Promote community education and awareness in relation to white sharks
> Develop a quantitative framework to assess the recovery of the white shark.

Given that the majority of activities associated with the project would take place in the estuary away from core habitat of white sharks the impacts upon the species as a result of the project are most likely to be negligible and would not directly contravene the objectives of the recovery plan.

Conclusion

White sharks are known to occur in estuaries although this is not their core habitat. The proposal would not have any significant long-term direct or indirect impacts on the habitat critical to the survival of white sharks nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of an important population of the species.

Given the controls on the proposal, the project would not place a population of white sharks at risk of extinction and a Referral is not recommended.

Marine mammals

An AoS has been completed for marine mammals including the endangered Southern right whale (*Eubalaena australis*) and the vulnerable Humpback whale (*Megaptera novaeangliae*). As a conservative approach the assessment was based on the 'significant impact criteria' for endangered species, set out in the *Matters of National Environmental Significance: Significant Impact Guidelines 1.1* (DoE, 2013).

An action is likely to have a significant impact on an endangered species if there is a real chance or possibility that it will:

a. ***Lead to a long-term decrease in the size of a population***

The two listed species are baleen whales, which as a group form the Mysticeti, one of two suborders of the Cetacea (whales, dolphins, and porpoises). Baleen whales are characterized by having baleen plates for filtering food from water, rather than having teeth. This distinguishes them from the other suborder of cetaceans, the toothed whales or Odontoceti.

Baleen whales feed mainly on zooplankton, crustaceans (eg krill) and small schooling fish. There are three listed threatened species of baleen whales that occur in coastal waters of NSW and have potential to enter deep estuaries along the NSW coastline. Due to the potential overlap in habitat with the study area, these species may be affected on some level by project activities.

Southern right whales are known to be present along the east coast of Australia between May and November where they occasionally enter estuaries such as Port Jackson, Botany Bay, Jervis Bay and Twofold Bay. Females travel to temperate waters to give birth and anecdotal evidence shows that mother and calf sightings are becoming more common in the Sydney region as the species' population increases. Twofold Bay is used intermittently by southern right whales for calving (DEH, 2005a).

The east coast population of humpback whales migrates along the Victorian, NSW and Queensland coasts to the Coral Sea from late autumn to early winter and back along the coast in late spring and early summer. Often on the return trip, adults swim close to the shore and are accompanied by new-born calves. At this time, humpback whales may rest in some of the larger estuarine embayments (in particular, Twofold Bay) (DEH, 2005b).

The main project pathways that can impact marine mammals is through underwater noise from impact piling activities and boat strike. As marine mammals can be observed above the water, impacts on marine mammals from these activities can be easily mitigated through a marine mammal management plan that shuts down construction work when these animals are present, and as such mortality or mortal injury would be prevented or minimised and the risk to these species is considered negligible.

b. ***Reduce the area of occupancy of the species***

The important areas of habitat to the southern right whale are the feeding areas of the Southern Ocean, the mating and birthing areas of southern Australia (eg Great Australian Bight) and to a lesser extent some birthing areas along the east and west coasts, primarily adjacent to coastal sandy beaches and in some of the deeper bays. Calving may occur intermittently in Twofold Bay.

Major habitats for humpback whales include the feeding, breeding and mating areas in the southern and northern extents of their range, respectively, and the migration corridors which extend at least the width of the continental shelf. In addition, some large coastal bays such as Twofold Bay are also potentially important areas as they may be used by the whales for resting or lay ups during annual migrations.

Given the very occasional occurrence of these species in Sydney Harbour, there would be no reduction to the area of occupancy of these species from the project.

c. ***Fragment an existing important population into two or more populations***

See (b).

d. ***Adversely affect habitat critical to the survival of a species***

Critical habitat refers only to those areas listed in the Register of Critical Habitat kept by Commonwealth DoEE. This question is not applicable, as no critical habitat has been listed for these marine mammals.

e. ***Disrupt the breeding cycle of a population***

Southern right whales migrate between summer feeding grounds in Antarctica and winter breeding grounds around the coasts of southern Australia, New Zealand, South Africa and South America. They are thought to feed in the open ocean in summer and are known to move inshore in winter for calving and mating. Calving females and females with young usually remain very close to the coast, often where the depth of water is only five to 10 metres. Females travel to temperate waters to give birth and anecdotal evidence shows that mother and calf sightings are becoming more common in the Sydney region as the species' population increases. Twofold Bay is used intermittently by southern right whales for calving (DEH 2005a). Adult humpback whales may swim into Sydney Harbour accompanied by new-born calves during migration.

As indicated in (a), the main project pathways that can impact marine mammals is through underwater noise from impact piling activities and boat strike. As marine mammals can be observed above the water, impacts on marine mammals from these activities can be easily mitigated through a marine mammal management plan that shuts down construction work when these animals are present, and as such mortality or mortal injury would be prevented or minimised and the risk of interruption to breeding of these species is considered negligible.

f. ***Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline***

See (b).

g. ***Result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat***

No invasive species harmful to marine mammals are likely to be released or have their populations enhanced as a consequence of the project.

h. ***Introduce disease that may cause the species to decline***

Vessels and movement of offshore equipment have potential to act as vectors for disease. However, there are no known diseases that could be introduced that could potentially cause marine mammals to decline.

i. ***Interfere substantially with the recovery of the species***

As indicated in (a), the main project pathways that can impact marine mammals is through underwater noise from dredging and impact piling activities and boat strike. As marine mammals can be observed above the water, impacts on marine mammals from these activities can be easily mitigated through a marine mammal management plan that shuts down construction work when these animals are present, and as such mortality or mortal injury would be prevented or minimised and the risk of interruption to breeding of these species is considered negligible. Hence, there would be no interference with the recovery of these species or conflict with Recovery Plans.

Conclusion

Although whales are known to occur in estuaries this is not their core habitat. The proposal would not have any significant long-term direct or indirect impacts on the habitat critical to the survival of whales nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of populations of these species.

Given the controls on the project, the project would not place a population of humpback whales or southern right whales at risk of extinction and a Referral is not recommended.

Marine reptiles

An AoS has been completed for marine reptiles including endangered Loggerhead (*Caretta* caretta) and Leatherback turtles (*Dermochelys coriacea*) and the vulnerable Green (*Chelonia mydas*), Hawksbill (*Eretmochelys imbricate*) and Flatback turtles (*Natator depressus*). As a conservative approach the assessment was based on the 'significant impact criteria' for endangered species, set out in the *Matters of National Environmental Significance: Significant Impact Guidelines 1.1* (DoE, 2013).

An action is likely to have a significant impact on an endangered species if there is a real chance or possibility that it will:

a. ***Lead to a long-term decrease in the size of a population***

Within Australia, marine turtles are predominantly found in waters of Queensland, Northern Territory and north Western Australia. Leatherback turtles forage and migrate through the waters of the Northern Territory, Queensland, NSW, Tasmania, Victoria and South Australia. The green, loggerhead and hawksbill turtles are resident in the waters of NSW. The flatback turtle is endemic to Australian tropical continental shelf waters while the others have global distributions that include breeding and foraging populations within Australia. Because of this global distribution and identified genetic variation, NSW populations of marine turtles are generally considered to belong to a single eastern Australian stock for each species.

Most of the threatened marine turtles that could potentially be affected in some way by the project tend to prefer warmer waters, ranging from tropical to warm temperate seas (Marquez, 1990). For a large part of their life cycle, marine turtles are pelagic, particularly leatherbacks, although green turtles tend to stay in coastal waters. The green turtle is generally found in the more northern latitudes of Australia although resident groups of green turtles have been found in NSW, with some as far south as Jervis Bay. Regular reports of green turtles in Jervis Bay and in some other more southerly estuaries suggest that some individuals may make regular visits to these southern locations. Resident populations also appear to have established in some other estuaries particularly near warm water outfalls such as Lake Macquarie where a study is underway to assess the apparently resident populations of several turtle species in the vicinity of warm water outfalls from a power generation facility. Green turtles feed on seaweeds and seagrasses although juveniles may be carnivorous.

Loggerhead turtles occur in coral reefs, bays and estuaries in tropical and warm temperate waters off the coast of Queensland, Northern Territory, Western Australia and NSW. Like green turtles, there are also resident groups of loggerhead turtles in the waters of northern NSW. Immature and adult loggerhead turtles are carnivorous and consume a variety of benthic invertebrates including molluscs, crustaceans, and echinoderms, which they crush before eating. They also sometimes eat fish and jellyfish. Immature and adult hawksbill turtles are carnivorous, primarily feeding on sponges but also other benthic invertebrates such as bryozoans, soft corals, echinoderms, molluscs, shrimp, and jellyfish.

The leatherback turtle has a wide distribution and may be observed all around the coast of southern Queensland and NSW. They are a highly pelagic species and as such would rarely occur in estuaries apart from some of the coastal bays. Immature and adult leatherback turtles are carnivorous turtles specialising in macroplankton such as jellyfish and salps/tunicates. The low nutritive value of the prey items means a large intake is required.

Flatback turtle adults consume jellyfish, squid and softbodied benthic invertebrates. They have also been fed on prawns and small pieces of fish while temporarily held in captivity. Green turtle juveniles are pelagic and appear to be omnivorous. At 35 to 40 centimetres they begin to be primarily herbivorous, feeding on seagrasses, algae and mangrove fruit. They will also eat plankton both micro and macro such as jellyfish and Physalia.

All five species have potential to occur in Middle Harbour although it is sub-optimal foraging habitat. The main project pathways that can impact marine turtles is through underwater noise from impact piling activities and boat strike. As marine turtles can be observed above the water, impacts on marine mammals from these activities can be easily mitigated through a marine mammal management plan that would implement a stop work procedure during construction when these animals are present (Section 6.7), and as such mortality or mortal injury would be prevented or minimised and the risk to these species is considered negligible.

b. ***Reduce the area of occupancy of the species***

The important areas of habitat to the marine turtles are further north than Port Jackson. Given the very occasional occurrence of these species in Sydney Harbour, there would be no reduction to the area of occupancy of these species from the project.

c. ***Fragment an existing important population into two or more populations***

See (b)

d. ***Adversely affect habitat critical to the survival of a species***

No “Critical Habitat” as defined under Section 207A of the EPBC Act (Register of Critical Habitat) has been identified and listed for marine turtles.

e. ***Disrupt the breeding cycle of a population***

Marine turtles are highly migratory, utilising widely dispersed habitats throughout their life cycle. Marine turtles require both terrestrial and marine habitats to fulfil different life history stages. They display late maturation and experience high juvenile mortality. These traits mean that they are slow to recover from population declines and are vulnerable to a wide range of threats.

Although marine turtles spend the majority of their lives in the ocean, adult female marine turtles come ashore to lay eggs in the sand above the high tide. Females lay on average two to six clutches per season. Temperature during incubation determines the sex of hatchlings, with higher temperatures producing predominantly females. Nesting is mainly confined to tropical beaches although successful nesting has been recorded in NSW for Loggerhead, Green and Leatherback turtles.

Marine turtles are probably most vulnerable when they come ashore to nest. At this time adults, eggs and hatchlings are subject to direct harvesting, predation by native fauna, feral animals and pets and various forms of human disturbance. Although these species occur within NSW estuaries, the southern estuaries are outside the range of known nesting and mating areas for the turtle species. The nesting and mating grounds for the listed turtle species generally occur in more northern latitudes. Hence, the project would not affect breeding cycles for any of the species.

f. ***Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline***

See (b)

g. ***Result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat***

Vessels and movement of offshore equipment have potential to act as vectors for introduced species. Introduced species may be translocated into the study area through the release of ballast water (in the case of planktonic larvae or species) or via reproduction from individuals attached to the hull of a vessel. Marine pests are considered to be a long-term, reversible impact to which marine communities have an existing level of exposure.

h. ***Introduce disease that may cause the species to decline***

Disease are considered to be a long-term, reversible impact to which marine communities have an existing level of exposure.

i. ***Interfere substantially with the recovery of the species***

An approved Commonwealth Recovery Plan for Marine Turtles in Australia was released in 2003 (Environment Australia 2003) and reviewed in 2013. From this review came the recommendation to remake the recovery plan. The Draft Recovery Plan for Marine Turtles in Australia was released in 2016 (Department of the Environment and Energy)

The recovery objectives of the 2016 plan are to minimise anthropogenic threats and allow for the conservation status of marine turtles to improve so as to remove marine turtles from the EPBC Act threatened species list. Recognising that this objective is unlikely to be achieved within the 10 year lifespan of the document the interim objectives are:

- Current levels of legal and management protection for marine turtles are maintained or improved both domestically and throughout the migratory range of Australia's marine turtles
- The management of marine turtles is supported
- Anthropogenic threats are demonstrably minimised
- Trends at index beaches, and population demographics at important foraging grounds are described.

The project would provide no interference with the recovery of these species or conflict with Recovery Plans.

Conclusion

Although marine turtles are known to occur in Port Jackson this is not their core habitat. The proposal would not have any significant long-term direct or indirect impacts on the habitat critical to the survival of marine turtles nor would it cause mortality to individuals that would be sufficient to cause risk to the viability of populations of these species.

Given the controls on the project, the project would not place a population of marine turtles at risk of extinction and a Referral is not recommended.

APPENDIX

E

CHAPTER PLATES

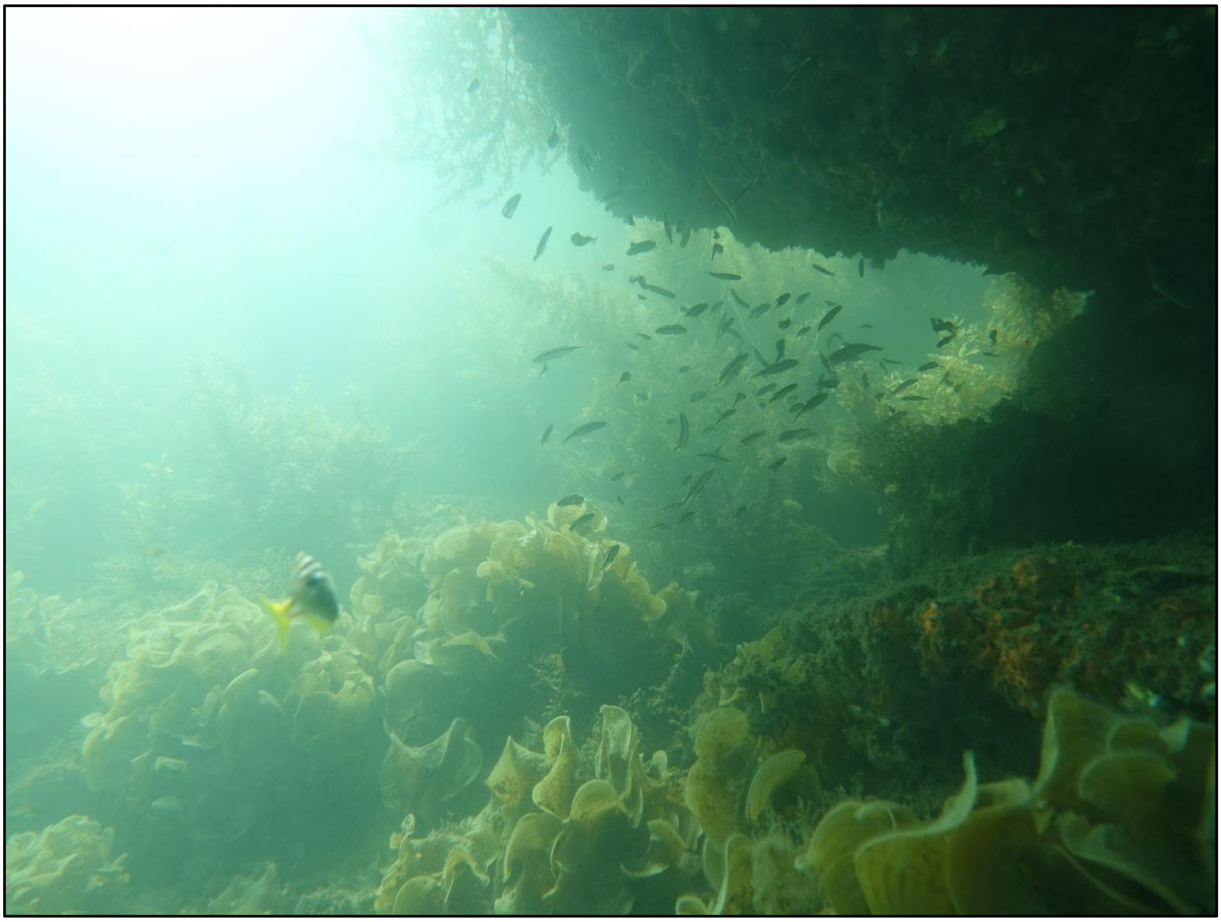

Plate E1 Example of high relief subtidal rocky reef in the study area

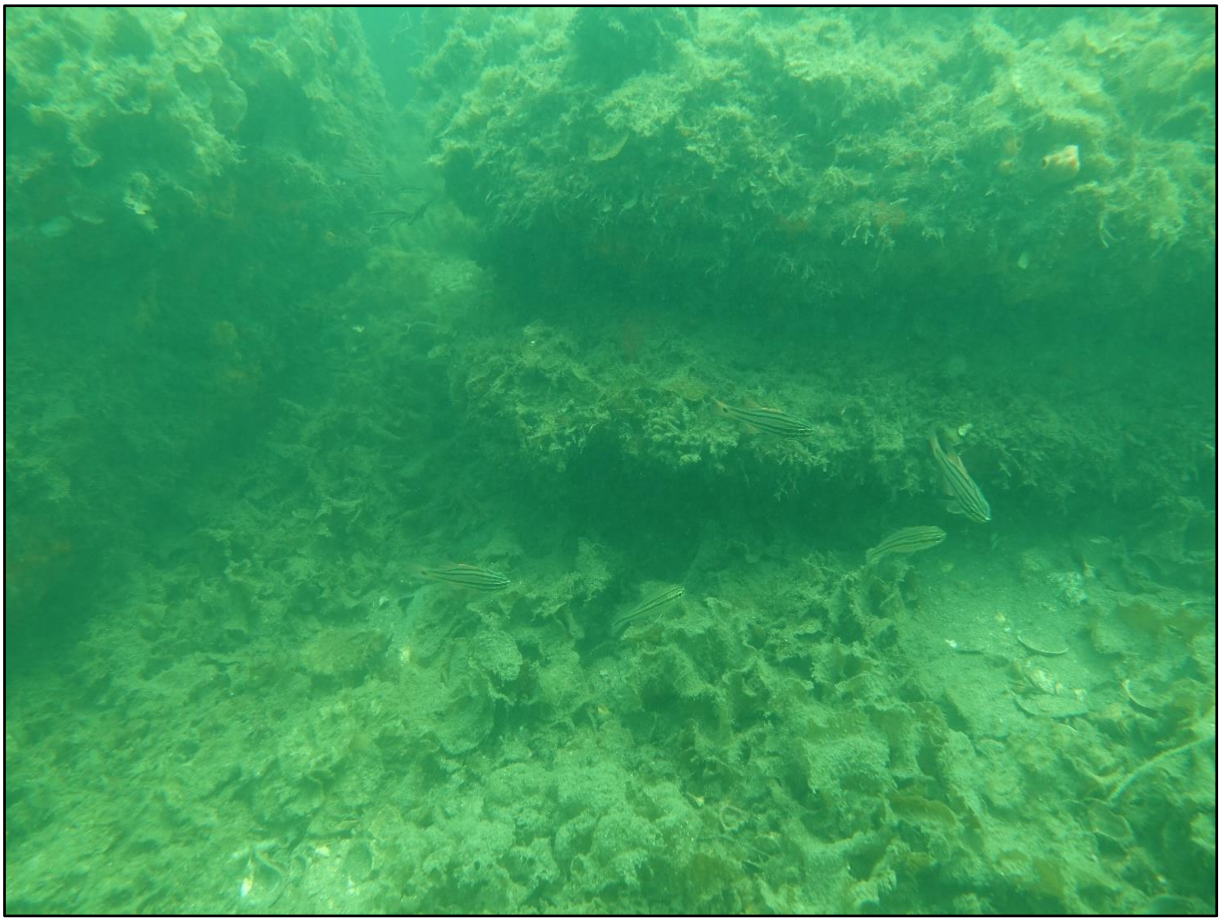

Plate E2 Example of medium relief subtidal rocky reef in the study area

Plate E3 Example of low relief subtidal rocky reef in the study area

Plate E4 Evidence of deepwater soft sediment infauna activity

APPENDIX

F

STATISTICAL ANALYSES RESULTS

(i) INTERTIDAL ROCKY SHORES

PERMANOVAs comparing biota in quadrats in high and low shores, RED = redundant test

A: Algae and sessile invertebrates

Source of Variation	df	SS	MS	*F*	*P*
Height (He)	1	49373	49373	13.861	RED
Site (Si)	7	16973	2424.8	1.4688	RED
He x Si	**7**	**24935**	**3562.1**	**2.1577**	**0.0016**
Residual (Pooled)	48	79241	1650.9		
Total	63	1.7052E5			

B. Pair-wise comparisons for term Height x Site

Comparisons between heights at each site	t	p-value
sInter 1		
Low, High	**2.2475**	**0.0266**
Inter 2		
Low, High	2.1895	0.0588
Inter 3		
Low, High	**2.7804**	**0.0304**
Inter 4		
Low, High	1.7111	0.061
Inter 5		
Low, High	2.1675	0.0628
RInter 1		
Low, High	**2.7828**	**0.0284**
RInter 2		
Low, High	**3.7773**	**0.0264**
RInter 3		
Low, High	**2.0621**	**0.0244**

Comparisons among sites at heights	t	p-value
Within Level 'Low'		
Inter 3, Inter 2	0.75842	0.7354
Inter 3, Inter 4	0.9525	0.516
Inter 3, Inter 1	0.89127	0.6268
Inter 3, RInter 3	1.0588	0.3506
Inter 3, RInter 2	**1.8862**	**0.0296**
Inter 3, RInter 1	**1.8645**	**0.0306**
Inter 3, Inter 5	**1.4951**	**0.0278**
Inter 2, Inter 4	1.4243	0.1104
Inter 2, Inter 1	1.0279	0.374
Inter 2, RInter 3	**1.6535**	**0.0258**
Inter 2, RInter 2	**2.35**	**0.0342**
Inter 2, RInter 1	**1.9988**	**0.0296**
Inter 2, Inter 5	**2.4747**	**0.0296**
Inter 4, Inter 1	1.1729	0.2896
Inter 4, RInter 3	0.78533	0.7472
Inter 4, RInter 2	2.1726	0.0598
Inter 4, RInter 1	1.5822	0.0504
Inter 4, Inter 5	1.4993	0.0786
Inter 1, RInter 3	1.5475	0.118
Inter 1, RInter 2	**2.3506**	**0.0264**

Comparisons among sites at heights	t	p-value
Inter 1, RInter 1	**1.9332**	**0.0342**
Inter 1, Inter 5	**2.3817**	**0.0498**
RInter 3, RInter 2	**2.0993**	**0.0334**
RInter 3, RInter 1	1.403	0.1212
RInter 3, Inter 5	1.1617	0.2838
RInter 2, RInter 1	**2.0783**	**0.027**
RInter 2, Inter 5	**2.4793**	**0.0284**
RInter 1, Inter 5	**2.3525**	**0.0292**
Within Level 'High		
Inter 3, Inter 2	0.85658	0.6236
Inter 3, Inter 4	0.41019	0.945
Inter 3, Inter 1	0.95759	0.5382
Inter 3, RInter 3	1.1433	0.2562
Inter 3, RInter 2	1.9659	0.087
Inter 3, RInter 1	1.7209	0.0586
Inter 3, Inter 5	1.28	0.1668
Inter 2, Inter 4	0.38538	0.9436
Inter 2, Inter 1	1.0227	0.4878
Inter 2, RInter 3	0.82683	0.5676
Inter 2, RInter 2	0.98098	0.4928
Inter 2, RInter 1	1.0822	0.3422
Inter 2, Inter 5	0.55046	0.7736
Inter 4, Inter 1	0.77346	0.569
Inter 4, RInter 3	0.76379	0.5712
Inter 4, RInter 2	1.4578	0.1742
Inter 4, RInter 1	1.1792	0.2896
Inter 4, Inter 5	Negative	
Inter 1, RInter 3	1.0737	0.43
Inter 1, RInter 2	**1.9998**	**0.0262**
Inter 1, RInter 1	1.5474	0.0914
Inter 1, Inter 5	1.2667	0.1154
RInter 3, RInter 2	1.5725	0.1106
RInter 3, RInter 1	0.83182	0.5432
RInter 3, Inter 5	0.64579	0.8128
RInter 2, RInter 1	1.3397	0.2072
RInter 2, Inter 5	1.7792	0.123
RInter 1, Inter 5	1.0269	0.4316

C: Mobile invertebrates

Source of Variation	df	SS	MS	*F*	*P*
Height (He)	1	23689	23689	7.7956	RED
Site (Si)	7	34934	4990.5	3.5192	RED
He xSi	**7**	**21272**	**3038.8**	**2.1429**	**0.0004**
Residual (Pooled)	48	68067	1418.1		
Total	63	1.4796E5			

D. Pair-wise comparisons for term Height x Site

Comparisons between heights at each site	t	p-value
Inter 1		
Low, High	**3.7051**	**0.0248**
Inter 2		
Low, High	**3.2654**	**0.0314**
Inter 3		
Low, High	**3.28**	**0.0278**
Inter 4		
Low, High	**2.0903**	**0.0306**
Inter 5		
Low, High	1.1181	0.383
RInter 1		
Low, High	0.84905	0.5126
RInter 2		
Low, High	1.7629	0.1528
RInter 3		
Low, High	0.84715	0.6766

Comparisons among sites at heights	t	p-value
Within Level 'Low'		
Inter 3, Inter 2	Negative	
Inter 3, Inter 4	0.73691	0.6548
Inter 3, Inter 1	0.5043	0.8224
Inter 3, RInter 3	1.494	0.0566
Inter 3, RInter 2	**1.902**	**0.0246**
Inter 3, RInter 1	0.87798	0.5322
Inter 3, Inter 5	2.1548	0.0554
Inter 2, Inter 4	0.99129	0.4322
Inter 2, Inter 1	0.33197	1
Inter 2, RInter 3	1.4045	0.1108
Inter 2, RInter 2	2.3173	0.0558
Inter 2, RInter 1	0.87016	0.6566
Inter 2, Inter 5	**2.2847**	**0.0298**
Inter 4, Inter 1	1.3167	0.4254
Inter 4, RInter 3	1.2854	0.1388
Inter 4, RInter 2	1.6216	0.0576
Inter 4, RInter 1	0.99053	0.4912
Inter 4, Inter 5	**2.0759**	**0.0318**
Inter 1, RInter 3	**1.7109**	**0.032**
Inter 1, RInter 2	**3.1909**	**0.0272**
Inter 1, RInter 1	1.138	0.2658
Inter 1, Inter 5	**2.7239**	**0.03**
RInter 3, RInter 2	**2.1415**	**0.0278**

Comparisons among sites at heights	t	p-value
RInter 3, RInter 1	0.63695	0.9166
RInter 3, Inter 5	1.4888	0.1106
RInter 2, RInter 1	**1.7853**	**0.0294**
RInter 2, Inter 5	**3.4694**	**0.0336**
RInter 1, Inter 5	1.4046	0.0572
Within Level 'High		
Inter 3, Inter 2	0.93981	0.5516
Inter 3, Inter 4	**1.9335**	**0.0268**
Inter 3, Inter 1	0.94119	0.5788
Inter 3, RInter 3	**2.4293**	**0.031**
Inter 3, RInter 2	**1.9202**	**0.0288**
Inter 3, RInter 1	**1.9831**	**0.0288**
Inter 3, Inter 5	1.7015	0.1216
Inter 2, Inter 4	**2.2515**	**0.03**
Inter 2, Inter 1	0.65914	0.7634
Inter 2, RInter 3	**2.2433**	**0.0296**
Inter 2, RInter 2	**2.2281**	**0.0276**
Inter 2, RInter 1	1.883	0.0528
Inter 2, Inter 5	**1.9662**	**0.0324**
Inter 4, Inter 1	**2.0415**	**0.0346**
Inter 4, RInter 3	1.6005	0.0558
Inter 4, RInter 2	**1.9749**	**0.0284**
Inter 4, RInter 1	1.4909	0.15
Inter 4, Inter 5	**2.1807**	**0.0294**
Inter 1, RInter 3	**1.9859**	**0.0292**
Inter 1, RInter 2	**2.1916**	**0.0278**
Inter 1, RInter 1	1.8453	0.0582
Inter 1, Inter 5	**1.8315**	**0.0258**
RInter 3, RInter 2	**2.0349**	**0.027**
RInter 3, RInter 1	1.0784	0.3348
RInter 3, Inter 5	**1.7024**	**0.0254**
RInter 2, RInter 1	1.3761	0.1344
RInter 2, Inter 5	1.58	0.1676
RInter 1, Inter 5	1.7053	0.0536

(ii) SEAGRASS

PERMANOVAs comparing seagrass in quadrats, RED = redundant test

A: Zostera shoot density

Source of Variation	df	SS	MS	*F*	*P*
Site	**7**	**1.31E+05**	**18731**	**5.4263**	**0.0014**
Residual	24	82847	3451.9		
Total	31	2.14E+05			

B. Pair-wise comparisons for term site

Comparisons among sites	t	p-value
Zos1, Zos2	2.4986	0.0626
Zos1, Zos3	2.2467	0.0836
Zos1, Zos4	**2.9093**	**0.028**
Zos1, Zos5	0.48726	0.8046
Zos1, RZos1	2.1311	0.0608
Zos1, RZos2	2.0053	0.097
Zos1, RZos3	0.36455	0.741
Zos2, Zos3	0.67372	0.6044
Zos2, Zos4	0.7553	0.5572
Zos2, Zos5	**4.4057**	**0.0278**
Zos2, RZos1	0.98529	0.3884
Zos2, RZos2	1.2481	0.2316
Zos2, RZos3	2.9939	0.062
Zos3, Zos4	1.6192	0.1802
Zos3, Zos5	**4.2487**	**0.0316**
Zos3, RZos1	0.33309	0.9118
Zos3, RZos2	0.63971	0.5126
Zos3, RZos3	**2.6905**	**0.0266**
Zos4, Zos5	**5.8042**	**0.0276**
Zos4, RZos1	2.0179	0.091
Zos4, RZos2	2.3068	0.055
Zos4, RZos3	**3.6576**	**0.0302**
Zos5, RZos1	**4.1007**	**0.0298**
Zos5, RZos2	**3.7609**	**0.03**
Zos5, RZos3	0.10707	0.8866
RZos1, RZos2	0.32408	0.8028
RZos1, RZos3	2.5368	0.0304
RZos2, RZos3	2.3477	0.0588

C: Zostera leaf length

Source of Variation	df	SS	MS	*F*	*P*
Site	**7**	**4773.6**	**681.95**	**3.3703**	**0.011**
Quadrat (Site)	**24**	**4856.2**	**202.34**	**16.093**	**0.0002**
Residual	288	3621.1	12.573		
Total	319	13251			

D. Pair-wise comparisons for term site

Comparisons among sites	t	p-value
Zos1, Zos2	**3.3047**	**0.0282**
Zos1, Zos3	2.171	0.0572
Zos1, Zos4	1.6496	0.191
Zos1, Zos5	**4.2746**	**0.031**
Zos1, RZos1	1.5409	0.1918
Zos1, RZos2	0.69955	0.46
Zos1, RZos3	0.33863	0.7522
Zos2, Zos3	0.29494	0.7994
Zos2, Zos4	2.0804	0.1192
Zos2, Zos5	1.3676	0.229
Zos2, RZos1	2.7254	0.0518
Zos2, RZos2	**3.4394**	**0.0324**
Zos2, RZos3	1.1443	0.3474
Zos3, Zos4	1.2404	0.3072
Zos3, Zos5	1.4263	0.2516
Zos3, RZos1	1.592	0.2586
Zos3, RZos2	2.4511	0.054
Zos3, RZos3	0.88777	0.3906
Zos4, Zos5	**3.2692**	**0.03**
Zos4, RZos1	0.56871	0.6462
Zos4, RZos2	2.0109	0.1474
Zos4, RZos3	0.23511	0.8362
Zos5, RZos1	**3.8336**	**0.0318**
Zos5, RZos2	**4.3566**	**0.0318**
Zos5, RZos3	1.896	0.1418
RZos1, RZos2	1.908	0.1678
RZos1, RZos3	8.40E-02	0.9432
RZos2, RZos3	0.62524	0.5948

E. Halophila shoot density

Source of Variation	df	SS	MS	*F*	*P*
Site	**7**	**1.12E+06**	**1.60E+05**	**23.382**	**0.0002**
Residual	24	1.65E+05	6859.3		
Total	31	1.29E+06			

F. Pair-wise comparisons for term site

Comparisons among sites	t	p-value
Hal1, Hal2	**8.077**	**0.0322**
Hal1, Hal3	2.7172	0.056
Hal1, Hal4	3.0156	0.0552
Hal1, Hal5	**7.2245**	**0.0256**
Hal1, RHal1	**5.2903**	**0.028**
Hal1, RHal2	**5.6494**	**0.0272**
Hal1, RHal3	**6.089**	**0.03**
Hal2, Hal3	**8.1109**	**0.0306**
Hal2, Hal4	**5.1588**	**0.03**
Hal2, Hal5	3.0596	0.0914
Hal2, RHal1	**15.005**	**0.0276**
Hal2, RHal2	**6.4427**	**0.028**
Hal2, RHal3	**4.0569**	**0.0292**
Hal3, Hal4	0.70586	0.5686
Hal3, Hal5	**6.5877**	**0.0332**
Hal3, RHal1	**3.5038**	**0.027**
Hal3, RHal2	**4.042**	**0.029**
Hal3, RHal3	**4.6888**	**0.0308**
Hal4, Hal5	**4.1654**	**0.0314**
Hal4, RHal1	1.7773	0.1368
Hal4, RHal2	2.3454	0.1186
Hal4, RHal3	2.9287	0.082
Hal5, RHal1	**7.4388**	**0.0258**
Hal5, RHal2	**3.7039**	**0.0264**
Hal5, RHal3	1.9892	0.149
RHal1, RHal2	1.5879	0.1412
RHal1, RHal3	**2.7788**	**0.0294**
RHal2, RHal3	1.1482	0.2604

G. Halophila leaf length

Source of Variation	df	SS	MS	*F*	*P*
Site	**7**	**224.44**	**32.063**	**11.669**	**0.0002**
Quadrat (Site)	**24**	**65.944**	**2.7477**	**7.9992**	**0.0002**
Residual	288	98.925	0.34349		
Total	319	389.31			

H. Pair-wise comparisons for term site

Comparisons among sites	t	p-value
Within Level 'High'		
Hal1, Hal2	**7.2369**	**0.0262**
Hal1, Hal3	**6.384**	**0.0258**
Hal1, Hal4	**2.8071**	**0.0272**
Hal1, Hal5	**11.307**	**0.029**
Hal1, RHal1	**16.904**	**0.0292**
Hal1, RHal2	**8.5785**	**0.03**
Hal1, RHal3	**5.484**	**0.0296**
Hal2, Hal3	**3.3828**	**0.0286**
Hal2, Hal4	0.38733	0.771
Hal2, Hal5	2.941	0.0572
Hal2, RHal1	2.9827	0.0548
Hal2, RHal2	**3.4811**	**0.029**
Hal2, RHal3	1.3315	0.257
Hal3, Hal4	1.1876	0.3188
Hal3, Hal5	**7.1231**	**0.028**
Hal3, RHal1	**9.3741**	**0.0302**
Hal3, RHal2	0.18732	0.9392
Hal3, RHal3	**3.4205**	**0.0258**
Hal4, Hal5	2.0306	0.1174
Hal4, RHal1	1.8532	0.1408
Hal4, RHal2	1.1537	0.3598
Hal4, RHal3	1.2759	0.1694
Hal5, RHal1	0.6005	0.5928
Hal5, RHal2	**7.4565**	**0.0284**
Hal5, RHal3	0.62621	0.6232
RHal1, RHal2	**10.556**	**0.026**
RHal1, RHal3	0.32376	0.808
RHal2, RHal3	**3.4263**	**0.0292**

(iii) SUBTIDAL ROCKY REEF

PERMANOVAs comparing algae and sessile invertebrates in quadrats and fish in timed swims, RED = redundant test

A: Algae and Sessile Invertebrates

Source of Variation	df	SS	MS	*F*	*P*
Relief	1	1286	1286		0.9448
Site (Relief)	**15**	**44239**	**2949.3**	**2.8334**	**0.0002**
Residual	47	48921	1040.9		
Total	63	94661			

B. Pair-wise comparisons for term site

Comparisons among Sites	t	p-value
Within Level 'High'		
RH Sub1, RH Sub2	**1.4137**	**0.025**
RH Sub1, RH Sub3	0.89808	0.589
RH Sub1, H Sub1	1.3354	0.2278
RH Sub1, H Sub 2	1.2552	0.2866
RH Sub1, H Sub3	1.4234	0.2044
RH Sub1, H Sub4	1.0612	0.455
RH Sub1, H Sub5	1.2343	0.1926
RH Sub2, RH Sub3	**1.5962**	**0.03**
RH Sub2, H Sub1	**1.7447**	**0.0312**
RH Sub2, H Sub 2	**1.7937**	**0.0268**
RH Sub2, H Sub3	**1.6056**	**0.026**
RH Sub2, H Sub4	**1.6248**	**0.0312**
RH Sub2, H Sub5	1.415	0.0612
RH Sub3, H Sub1	1.0139	0.4852
RH Sub3, H Sub 2	1.2022	0.2388
RH Sub3, H Sub3	1.1731	0.2584
RH Sub3, H Sub4	0.87524	0.5846
RH Sub3, H Sub5	1.5268	0.1184
H Sub1, H Sub 2	1.2981	0.1486
H Sub1, H Sub3	**1.5977**	**0.0296**
H Sub1, H Sub4	1.1808	0.3426
H Sub1, H Sub5	**1.7624**	**0.0272**
H Sub 2, H Sub3	**1.7073**	**0.027**
H Sub 2, H Sub4	1.0268	0.4084
H Sub 2, H Sub5	1.2497	0.1758
H Sub3, H Sub4	1.1346	0.265
H Sub3, H Sub5	1.6287	0.119
H Sub4, H Sub5	**1.3804**	**0.0252**
Within Level 'Medium'		
M Sub1, M Sub2	**1.8524**	**0.0308**
M Sub1, M Sub3	1.3148	0.1122
M Sub1, M Sub4	**1.7128**	**0.032**
M Sub1, M Sub 4	1.3358	0.1958
M Sub1, M Sub5	**1.642**	**0.032**
M Sub1, RM Sub1	**1.6008**	**0.0298**
M Sub1, RM Sub2	1.0762	0.3642
M Sub1, RM Sub3	**1.8067**	**0.0272**
M Sub2, M Sub3	1.0735	0.3598
M Sub2, M Sub4	**1.8453**	**0.0316**
M Sub2, M Sub 4	1.5046	0.1954

Comparisons among Sites	t	p-value
M Sub2, M Sub5	**1.9969**	**0.0254**
M Sub2, RM Sub1	**2.1257**	**0.0288**
M Sub2, RM Sub2	**2.1428**	**0.0304**
M Sub2, RM Sub3	**2.1915**	**0.0286**
M Sub3, M Sub4	**2.0256**	**0.0286**
M Sub3, M Sub 4	1.5028	0.2086
M Sub3, M Sub5	1.28	0.1456
M Sub3, RM Sub1	**2.1711**	**0.0278**
M Sub3, RM Sub2	1.5703	0.092
M Sub3, RM Sub3	**1.95**	**0.024**
M Sub4, M Sub 4	1.5868	0.2524
M Sub4, M Sub5	**2.6637**	**0.028**
M Sub4, RM Sub1	1.8509	0.0584
M Sub4, RM Sub2	**2.5758**	**0.0306**
M Sub4, RM Sub3	**1.6372**	**0.0274**
M Sub 4, M Sub5	1.4772	0.2004
M Sub 4, RM Sub1	1.2733	0.3986

C. Fish

Source of Variation	df	SS	MS	*F*	*P*
Relief	1	2981.9	2981.9		0.5848
Site (Relief)	**14**	**51741**	**3695.8**	**1.8527**	**0.0002**
Residual	32	63833	1994.8		
Total	47	1.1856E5			

D. Pair-wise comparisons for term site

Comparisons among Sites	t	p-value
Within Level 'High'		
RH Sub 1, RH Sub 2	**2.4708**	**0.0162**
RH Sub 1, RH Sub 3	1.7468	0.0842
RH Sub 1, H Sub 1	1.1259	0.3222
RH Sub 1, H Sub 2	1.3367	0.1934
RH Sub 1, H Sub 3	**1.9453**	**0.0406**
RH Sub 1, H Sub 4	1.2414	0.2514
RH Sub 1, H Sub 5	1.5959	0.1094
RH Sub 2, RH Sub 3	**2.2233**	**0.0218**
RH Sub 2, H Sub 1	1.6308	0.085
RH Sub 2, H Sub 2	1.3572	0.169
RH Sub 2, H Sub 3	1.2841	0.2084
RH Sub 2, H Sub 4	**1.9183**	**0.0432**
RH Sub 2, H Sub 5	1.7119	0.0644
RH Sub 3, H Sub 1	0.73728	0.6586
RH Sub 3, H Sub 2	1.0198	0.4018
RH Sub 3, H Sub 3	1.3904	0.1604
RH Sub 3, H Sub 4	1.7404	0.0744
RH Sub 3, H Sub 5	1.2949	0.2274
H Sub 1, H Sub 2	0.60412	0.7812
H Sub 1, H Sub 3	1.0959	0.3518
H Sub 1, H Sub 4	1.0104	0.4092
H Sub 1, H Sub 5	0.9514	0.457
H Sub 2, H Sub 3	0.82069	0.617
H Sub 2, H Sub 4	0.95702	0.4616
H Sub 2, H Sub 5	1.0457	0.3922
H Sub 3, H Sub 4	1.4633	0.142
H Sub 3, H Sub 5	1.402	0.1584
H Sub 4, H Sub 5	1.4715	0.1562
Within Level 'Medium'		
RM Sub 1, RM Sub 2	1.364	0.1896
RM Sub 1, RM Sub 3	0.87916	0.5139
RM Sub 1, M Sub 1	0.99326	0.4084
RM Sub 1, M Sub 2	1.2276	0.2544
RM Sub 1, M Sub 3	1.4855	0.1302
RM Sub 1, M Sub 4	1.1055	0.3434
RM Sub 1, M Sub 5	1.459	0.1462
RM Sub 2, RM Sub 3	1.3234	0.2046
RM Sub 2, M Sub 1	1.3705	0.1864
RM Sub 2, M Sub 2	1.5185	0.1398
RM Sub 2, M Sub 3	0.73957	0.641
RM Sub 2, M Sub 4	1.3205	0.2024
RM Sub 2, M Sub 5	1.4235	0.1706
RM Sub 3, M Sub 1	0.70767	0.6994
RM Sub 3, M Sub 2	1.5461	0.1084

Comparisons among Sites	t	p-value
RM Sub 3, M Sub 3	1.5077	0.1194
RM Sub 3, M Sub 4	1.293	0.2064
RM Sub 3, M Sub 5	1.5798	0.096
M Sub 1, M Sub 2	1.6909	0.1006
M Sub 1, M Sub 3	1.6913	0.082
M Sub 1, M Sub 4	1.4845	0.121
M Sub 1, M Sub 5	1.916	0.0568
M Sub 2, M Sub 3	1.4872	0.1344
M Sub 2, M Sub 4	1.4154	0.1596
M Sub 2, M Sub 5	0.71907	0.6456
M Sub 3, M Sub 4	1.3454	0.1742
M Sub 3, M Sub 5	1.3274	0.203
M Sub 4, M Sub 5	1.6206	0.0888

(iv) DEEP SOFT SEDIMENT

PERMANOVAs comparing infauna in quadrats and benthic grabs, RED = redundant test

A: Infauna

Source of Variation	df	SS	MS	*F*	*P*
Depth	1	10425	10425	1.6011	0.1164
Site (Depth)	**22**	**1.4324E5**	**6511**	**3.726**	**0.0002**
Residual	48	83877	1747.4		
Total	71	2.3754E5			

B. Pair-wise comparisons for term site

Comparisons among sites	t	p-value
Within Level 'Shallow'		
Shallow1, Shallow2	**1.9975**	**0.0378**
Shallow1, Shallow3	**2.0898**	**0.0326**
Shallow1, Shallow4	**3.0241**	**0.0066**
Shallow1, Shallow5	1.0912	0.3608
Shallow1, Shallow6	**2.5605**	**0.0128**
Shallow1, Shallow7	**2.544**	**0.0136**
Shallow1, Shallow8	**2.5493**	**0.0118**
Shallow1, Shallow9	**2.17**	**0.0274**
Shallow1, RShallow1	**2.1245**	**0.027**
Shallow1, RShallow2	**2.4215**	**0.0172**
Shallow1, RShallow3	**2.9988**	**0.0078**
Shallow2, Shallow3	**2.0336**	**0.036**
Shallow2, Shallow4	**3.0012**	**0.0074**
Shallow2, Shallow5	1.426	0.1394
Shallow2, Shallow6	1.1337	0.3132
Shallow2, Shallow7	1.4362	0.134
Shallow2, Shallow8	**2.4504**	**0.0154**
Shallow2, Shallow9	**2.1051**	**0.0306**
Shallow2, RShallow1	**2.0843**	**0.0282**
Shallow2, RShallow2	**2.3779**	**0.0128**
Shallow2, RShallow3	**2.8668**	**0.0076**
Shallow3, Shallow4	1.8312	0.0712
Shallow3, Shallow5	**1.9243**	**0.037**
Shallow3, Shallow6	**2.1061**	**0.0292**
Shallow3, Shallow7	**2.2923**	**0.0242**
Shallow3, Shallow8	1.5279	0.125
Shallow3, Shallow9	1.5665	0.0966
Shallow3, RShallow1	1.3806	0.1774
Shallow3, RShallow2	1.5221	0.1128
Shallow3, RShallow3	1.8585	0.0622
Shallow4, Shallow5	**2.5781**	**0.0144**
Shallow4, Shallow6	**3.1668**	**0.005**
Shallow4, Shallow7	**3.5756**	**0.0032**
Shallow4, Shallow8	1.7853	0.0718
Shallow4, Shallow9	1.2319	0.249
Shallow4, RShallow1	0.75312	0.646
Shallow4, RShallow2	1.7776	0.0686

Comparisons among sites	t	p-value
Shallow4, RShallow3	**2.5477**	**0.0317**
Shallow5, Shallow6	**1.9191**	**0.0494**
Shallow5, Shallow7	1.5825	0.1126
Shallow5, Shallow8	2.245	0.0172
Shallow5, Shallow9	**1.9343**	**0.041**
Shallow5, RShallow1	**1.919**	**0.0374**
Shallow5, RShallow2	**2.223**	**0.0216**
Shallow5, RShallow3	**2.6533**	**0.0118**
Shallow6, Shallow7	**2.057**	**0.0308**
Shallow6, Shallow8	**2.424**	**0.0122**
Shallow6, Shallow9	**2.2132**	**0.0264**
Shallow6, RShallow1	**2.0282**	**0.0346**
Shallow6, RShallow2	**2.3995**	**0.0182**
Shallow6, RShallow3	**2.9306**	**0.0112**
Shallow7, Shallow8	**2.6659**	**0.0104**
Shallow7, Shallow9	**2.4823**	**0.018**
Shallow7, RShallow1	**2.3667**	**0.0196**
Shallow7, RShallow2	**2.7024**	**0.0118**
Shallow7, RShallow3	**3.4502**	**0.0056**
Shallow8, Shallow9	1.6684	0.0858
Shallow8, RShallow1	1.1447	0.3164
Shallow8, RShallow2	1.0927	0.3506
Shallow8, RShallow3	2.3184	0.0226
Shallow9, RShallow1	1.2948	0.2056
Shallow9, RShallow2	1.6874	0.0774
Shallow9, RShallow3	1.7807	0.0974
RShallow1, RShallow2	1.0339	0.3696
RShallow1, RShallow3	1.9003	0.0538
RShallow2, RShallow3	**2.2143**	**0.0252**
Within Level 'Deep'		
Deep1, Deep2	1.457	0.1262
Deep1, Deep3	1.5494	0.1036
Deep1, Deep4	1.3924	0.157

Comparisons among sites	t	p-value
Deep1, Deep5	1.3795	0.172
Deep1, Deep6	1.603	0.0836
Deep1, Deep7	1.2631	0.2356
Deep1, Deep8	**1.9139**	**0.043**
Deep1, Deep9	**2.8186**	**0.0078**
Deep1, RDeep1	**2.5114**	**0.0136**
Deep1, RDeep2	**2.5698**	**0.0134**
Deep1, RDeep3	1.4173	0.1502
Deep2, Deep3	0.70092	0.7204
Deep2, Deep4	1.0822	0.3616
Deep2, Deep5	1.6426	0.082
Deep2, Deep6	1.0336	0.3898
Deep2, Deep7	0.84084	0.5804
Deep2, Deep8	1.1974	0.2548
Deep2, Deep9	**2.3177**	**0.0234**
Deep2, RDeep1	**1.5828**	**0.094**
Deep2, RDeep2	**2.0297**	**0.0386**
Deep2, RDeep3	1.217	0.2606
Deep3, Deep4	1.26	0.227
Deep3, Deep5	**1.8895**	**0.0422**
Deep3, Deep6	1.4297	0.1368
Deep3, Deep7	0.92836	0.4768
Deep3, Deep8	1.5876	0.1014
Deep3, Deep9	**2.6736**	**0.0172**
Deep3, RDeep1	1.7597	0.0636
Deep3, RDeep2	**2.1936**	**0.027**
Deep3, RDeep3	1.2392	0.2544
Deep4, Deep5	1.735	0.071
Deep4, Deep6	1.3233	0.1794
Deep4, Deep7	1.2931	0.2058
Deep4, Deep8	1.6036	0.0802
Deep4, Deep9	**2.3838**	**0.0176**
Deep4, RDeep1	**2.124**	**0.0266**
Deep4, RDeep2	**2.1783**	**0.022**
Deep4, RDeep3	1.315	0.1964
Deep5, Deep6	2.1517	0.0332
Deep5, Deep7	1.6115	0.0904
Deep5, Deep8	1.7683	0.064
Deep5, Deep9	**2.68**	**0.0098**
Deep5, RDeep1	**2.2935**	**0.0222**
Deep5, RDeep2	**2.6703**	**0.013**
Deep5, RDeep3	1.3795	0.1694
Deep6, Deep7	1.0696	0.3624
Deep6, Deep8	1.7206	0.0616
Deep6, Deep9	**2.8534**	**0.0106**
Deep6, RDeep1	**2.3747**	**0.0178**
Deep6, RDeep2	**2.4209**	**0.0164**
Deep6, RDeep3	1.2719	0.2258
Deep7, Deep8	1.5417	0.1134
Deep7, Deep9	**2.6905**	**0.0128**
Deep7, RDeep1	**1.9816**	**0.0388**
Deep7, RDeep2	**2.2325**	**0.026**
Deep7, RDeep3	1.1075	0.33
Deep8, Deep9	**2.0013**	**0.0358**
Deep8, RDeep1	1.7499	0.0692
Deep8, RDeep2	**1.9575**	**0.0366**
Deep8, RDeep3	1.0468	0.378

Comparisons among sites	t	p-value
Deep9, RDeep1	**2.0842**	**0.0352**
Deep9, RDeep2	**2.4884**	**0.0152**
Deep9, RDeep3	**1.9883**	**0.0422**
RDeep1, RDeep2	**1.9291**	**0.0406**
RDeep1, RDeep3	1.5402	0.1158
RDeep2, RDeep3	1.6328	0.0974

APPENDIX

G

RISK ANALYSIS RATIONALE

Intertidal rocky shore habitats

Hazard	Rationale	Risk level	Key issue
ME1	Intertidal rocky shore habitat would be removed for construction of the crossing in Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6) cofferdams and small amounts of intertidal habitat would be shaded due to temporary structures in the Yurulbin Point (WHT4) and Berrys Bay (WHT7) construction support sites (Figure 5-1). Shaded algae would likely die due to insufficient light. Hence, it is almost certain that biota in intertidal areas would be affected from this hazard. It is proposed that intertidal areas that are to be removed would be reinstated following the construction phase (see 6.6). There is great natural variability among assemblages of intertidal biota in the study area hence, the small temporary losses would amount to a minor localised impact that would recover through natural recruitment of biota within one to two years once construction had been completed (ie once the jetties had been dismantled).	Moderate	No
ME2 and ME3	Intertidal rocky shore habitats are within the ZoMI and ZoI and within areas where excess sediment (greater than five millimetres) from dredging would be deposited based on modelling results (Figure 5-2 and Figure 5-3). Although species of sessile biota (macroalgae and invertebrates) and fish show variable responses to elevated turbidity that are species-dependent (see sections 4.2.1 to 4.2.5), this assessment has assumed that it is almost certain the entire intertidal rocky shore assemblage within the ZoMI and modelled excess sedimentation (ie about 0.06 kilometres) would perish. Other areas of intertidal habitat in the ZoI and at the other project areas may also be inadvertently exposed to, and experience impacts from, occasional elevated turbidity and sedimentation resulting from general construction activity at the crossing sites but also at the other project areas. However, at worst, the effects would be minor given they would localised and recoverable shortly after construction had ceased	Moderate	No
ME4	Contaminants of various types are known to occur as deep as one metre below the bed of the harbour in some areas and contamination is generally greater in the main arm of Sydney Harbour than in other parts (Douglas Partners and Golder Associates, 2017). Data regarding contaminant levels within the harbour crossing show levels of contaminants within the top one metre of sediments would largely exceed guideline criteria (Section 3.3.2) (Douglas Partners and Golder Associates, 2017). Furthermore, in a study for the Sydney Metro City project (Geochemical Assessments 2015), mean concentrations in sediment of lead, mercury, and normalised concentrations of DDT group contaminants, various individual and total PAHs and TBT exceeded relevant sediment quality guideline values at one or more of the sampling locations. Concentrations of polycyclic dibenzo dioxins and furans (PCDD/Fs) also exceeded a safe sediment value and a probable effects level. The behaviour of sediment-bound contaminants when resuspended into the water column is important for determining the potential for adverse environmental effects from dredging. In the study for the Sydney Metro City project, Geochemical Assessments (2015) carried out laboratory elutriation tests (by simulating resuspension of sediment in ambient seawater) for identified contaminants, apart from total petroleum hydrocarbons (TPHs). These tests demonstrated that trace metals and all organic contaminants, including PCDD/Fs, are likely to remain bound to sediment particles and are not likely to dissociate and be released into the water column as dissolved phases. The minor component of contaminants that might be released to dissolved phases would be expected to re-adsorb to suspended particulate materials and resettle to the estuary bed. In contrast to organic contaminants, only a small amount of most sediment-bound (inorganic) trace metals and arsenic reported from total extractions are usually available for uptake by biota, and with the exception of mercury (and possibly selenium), trace elements are unlikely to accumulate in biota. For the Sydney Metro City project, weak acid extractions designed to mimic the release of trace metals in the guts of organisms showed that less than 30 per cent of total mercury in sediment was bioavailable. Unlike mercury, and what is generally known about bioavailability of trace metals, lead in sediment was extracted by weak acid digestions and was therefore assumed to be available for uptake by biota. Further, although organic contaminants are generally considered to be bioavailable, additional assessments were recommended by Geochemical Assessments (2015) to	Moderate	No

Hazard	Rationale	Risk level	Key issue
	determine whether organic contaminants present in the Sydney Metro Harbour Tunnel project site would be likely to cause adverse environmental effects. Most contaminants are likely to remain bound to sediment during dredging and have limited potential for uptake by biota. A closed environmental bucket has been proposed during removal of the top one metre layer of contaminated sediment and most of the dredge-induced accumulations of sediment in intertidal areas are most likely to be uncontaminated sediment dispersed during the dredging phases of deeper uncontaminated sediment (Douglas Partners and Golder Associates, 2017). Implementation of recommended safeguards in conjunction with the behaviour of sediment bound contaminants, means it is unlikely that intertidal areas would be exposed to contaminants from dredging.		
ME5	Vessels and movement of offshore equipment have potential to act as vectors for introduced species. Introduced species may be translocated into the project area through the release of ballast water (in the case of planktonic larvae or species) or via reproduction from individuals attached to the hull of a vessel. Marine pests are considered to be a long-term, reversible impact to which marine communities have an existing level of exposure. Mitigation measures include standard practice procedures such as compliance with Australia's mandatory ballast water management requirements, with the addition of regular inspection of niche areas of high risk vessels (see Section 6.4). With these controls in place it is considered unlikely that intertidal areas would be exposed to marine pests but given recovery from any pests would be slow, the effects would be moderate.	Moderate	No
ME6	Royal Haskoning (2020) modelled temporary changes to current speeds associated with silt curtains and at Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6) cofferdams. During the ebb tide, the cofferdam at WHT5 would cause a reduction in the current speed downstream of the structure. This is offset by a small increase in speeds in the middle of the channel and around Balls Head. The Sydney Harbour north cofferdam (WHT6) would have a very minor impact on current speeds during the ebb tide. This is because near the Coal Loader Wharf ebb current speeds are very low in both existing and cofferdam scenarios resulting in the structure not significantly impacting on flow conditions. During the flood tide, a similar pattern would occur at the south-west cofferdam with currents significantly reduced downstream of the structure and a corresponding increase in the middle of the channel and along the northern bank (near Birchgrove Wharf). At the Sydney Harbour north cofferdam (WHT6) larger reductions in current speeds surrounding the cofferdam and Coal Loader Wharf would occur. During both ebb and flood tide the differences are more pronounced in the surface layer when compared to bottom layers. Also, at a location downstream of the Greenwich Baths, the modelled increase in current speeds would occur during the flood tide only and be prominent during spring tides. At this location spring flood current speeds would increase from 0.36 metres per second to around 0.41 metres per second, a relative increase of 14 per cent. Although these changes are relatively large in some locations at some parts of the tidal cycle, they are not likely to cause an adverse impact given intertidal biota exist in other parts of Sydney Harbour where current speeds would be similar. Where current speed is increased, however, it is also not expected to cause scour to rocky intertidal habitats. Given the bed of the harbour at the tunnel crossing would be restored to the existing profile, there would be no changes to hydrodynamics in the operational phase. Given the modelling results it is almost certain that there would be changes to hydrodynamics in intertidal rocky shore areas. The temporary changes during construction would be minor.	Moderate	No
ME7 and ME8	N/A	N/A	N/A
ME9	Best-practice vessel management and site management would be used to minimise the risk of contaminant spillage. Hence spills would be unlikely. In the event of a spill, recovery would be likely hence, impacts of spills are considered to be moderate, short-term and reversible.	Moderate	No

Seagrass habitats

Hazard	Rationale	Risk level	Key issue
ME1	Removal of seagrass habitats would be unlikely as no seagrass meadows occur within the project area. Seagrass meadows within close proximity to the project area are small and fragmented. Unintentional removal of all or part of these meadows would limit local reproduction and/or vegetative growth as recolonisation pathways, although Zostera are known to recolonise within a year of removal (Peterken & Conacher, 1997). One of these small patches of Zostera occurs between Sydney Harbour south cofferdam (WHT5) and Yurulbin Point (WHT) (Figure 5-1). Although removal of this patch of Zostera has not been proposed, activities in adjacent areas (eg wastewater treatment plant discharge from Yurlbin Point construction support site (WHT4) and vessel movements) have potential, albeit small if mitigated (Section 6), to scour the patch.	Moderate	Yes
ME2 and ME3	Turbidity and sedimentation incident on seagrass habitats is almost certain as the Balls Head Bay patches of Zostera (about 0.03 hectares) would lie within the ZoI and have potential to be exposed to a modelled five to ten millimetres of additional sedimentation (Figure 5-2 and Figure 5-3). The main impact pathway of turbidity on seagrass would be light attenuation while sedimentation would result in burial, both affecting photosynthesis, physiology and morphology. Seagrasses have exhibited tolerance to elevated turbidity (Abal, et al., 1994; Longstaff & Dennison, 1999), frequently experienced in bays of the estuary (see Section 3.4). Other species of the *Zostera* genus have exhibited rapid adaptation to changes in sediment dynamics by relocating rhizomes to preferred sediment depths in the event of burial, noting these responses were triggered by burial an order of magnitude greater than what is predicted (Han, et al., 2012). Furthermore, elevated turbidity during the dredging campaign are likely to be pulse impacts (refer Western Harbour Tunnel and Warringah Freeway Upgrade *Technical working paper: Marine water quality* (Cardno, 2020)) with hours to weeks between dredging to allow ambient conditions to return in a tide-dominated estuary and exposure to hazard ME2 and ME3 would be temporary (only during construction). Therefore, with opportunities for recovery and existing potential tolerance to periodically elevated turbidity and exposure to relatively low modelled sedimentation loads, the consequences of hazards ME2 and ME3 were considered to be minor.	Moderate	Yes
ME4	Mobilisation of existing contaminants to seagrass habitats would be unlikely, as this hazard would be managed during construction (Section 1.7). Sediment contaminants are known to occur within the study area and mobilisation during construction has potential impacts on seagrass and associated biota with varying responses depending on compounds, concentrations and species. A closed environmental bucket is proposed during removal of the top one metre layer of contaminated sediment and most of the dredge-induced accumulations of sediment in seagrass habitats are most likely to be uncontaminated sediment dispersed during the dredging phases of deeper uncontaminated sediment (Douglas Partners and Golder Associates, 2017). Implementation of recommended safeguards in conjunction with the behaviour of sediment bound contaminants means it is unlikely that seagrass habitats would be exposed to contaminants from dredging. Given that recovery from any contamination would be slow, the effects would be moderate.	Moderate	Yes
ME5	Introduction/spread of marine pests to seagrass habitats would be unlikely, as the hazard would be managed during construction (Section 6.4). The consequence of marine pest impacts on seagrass habitats was considered to be major due to the severity of marine pest impacts and remediation difficulties once they are established (eg *C. taxifolia*).	Moderate	Yes
ME6	With the installation of cofferdams as well as other instream structures to support the construction of the project, the likelihood of this hazard is almost certain. However, due to the temporary nature of the installations and the proportion of proposed impact area to the greater estuary, this hazard to seagrass habitats was considered minor.	Moderate	Yes
ME7	Fish including sharks, some small marine mammals (ie dolphins) and reptiles have potential to use seagrass habitats for shelter, breeding and feeding, the latter two of which are transient species. The extent of the conservative models of underwater noise impacts on fish and marine mammals in seagrass are outlined in Table G1. Within these areas, the likelihood of underwater noise impacts were considered to be	Moderate	Yes

<table>
<tr><th>Hazard</th><th>Rationale</th><th>Risk level</th><th>Key issue</th></tr>
<tr><td></td><td>
almost certain (Figure 5-4 and Figure 5-5) as modelled impact areas without mitigation would coincide with seagrass meadows. Furthermore, seagrass meadows are important nursery areas for juvenile fish which are likely to take up residency in seagrass meadows. However small marine mammals and reptiles are mostly transient species.

Seagrass habitat conditions are likely to be restored immediately following the removal of the acoustic disturbance but there would be potential for localised injury/mortality to marine fauna within seagrass habitats. However, the temporary nature of the disturbance would allow for fast recruitment of fish from adjacent, unimpacted seagrass meadows. Recruitment and dispersal of juvenile fish is partly driven by water circulation and spawning location (Hannan & Williams, 1998). Recruitment of ocean-spawners have been shown to occur during spring and initially congregate around the mouth of estuaries before dispersing while estuary/lagoon spawners are generally widely distributed. Hence, recovery of impacts on marine biota in seagrass habitats were considered to occur within two years in support of a minor consequence.

Table G1 Areas of seagrass habitats impacted by noise (source: JASCO, 2019)
<table>
<tr><th rowspan="2">Location</th><th rowspan="2">Largest area of impact category for fish and marine mammals (JASCO, 2019)</th><th>Area of seagrass habitat (ha)</th></tr>
<tr><th>Unmitigated</th></tr>
<tr><td rowspan="3">Sydney Harbour north cofferdam (WHT6)</td><td>186 Temporary Threshold Shift (TTS)</td><td>0.02</td></tr>
<tr><td>207 (Mortality and potential mortal injury, Fish III (ie fish with swim bladders used for hearing))</td><td>-</td></tr>
<tr><td>183 (Permanent threshold shift (PTS), permanent hearing loss), low frequency cetaceans (LFC) (eg baleen whales)-weighted)</td><td>0.02</td></tr>
<tr><td rowspan="3">Sydney Harbour south cofferdam (WHT5)</td><td>186 (TTS)</td><td><0.01</td></tr>
<tr><td>207 (Mortality and potential mortal injury, Fish III)</td><td><0.01</td></tr>
<tr><td>183 (PTS, LFC-weighted)</td><td><0.01</td></tr>
</table>
</td><td></td><td></td></tr>
<tr><td>ME8</td><td>Boat strike to marine mammals and/or reptiles in seagrass habitats is unlikely as impacts on marine mammals and reptiles would be managed as detailed in Section 6 and the transient nature of these species in the estuary. A consequence of hazard ME8 was considered as moderate in relation to the generation times of species previously recorded within the study area</td><td>Moderate</td><td>Yes</td></tr>
<tr><td>ME9</td><td>The spill of contaminants would be managed during construction (Section 6.6) thus, it is unlikely that this hazard would occur in seagrass habitats. However, the consequence of this hazard was considered moderate under similar justifications as hazard ME4 (wide-ranging impacts and persistence).</td><td>Moderate</td><td>Yes</td></tr>
</table>

Mangrove habitats

Hazard	Rationale	Risk level	Key issue
ME1	The likelihood of impact on mangrove habitats would be rare as no mangrove habitats occur within or close to the project area. Although mangrove habitats in the study area were limited to small corridors in bays, these areas are considered widespread thus, the consequence of hazard ME1 was considered as moderate.	Moderate	No
ME2 and ME3	The likelihood of these hazards to mangrove habitat occurring is unlikely as no mangrove habitats are within the ZoMI or ZoI and modelled sedimentation within these habitats is not greater than one millimetre above ambient levels, the latter of which was considered to have negligible impacts. Mangrove habitats are well adapted to suspended sediments and sedimentation and are excellent at natural flocculation and improving water quality (Wolanski, 1995; Furukawa & Wolanski, 1996). Thus, the consequences of hazards ME2 and ME3 to mangrove habitats were considered to be minor.	Low	No
ME4	Mobilisation of existing contaminants to mangrove habitats is unlikely as mangrove habitats are distant from the project area. Contaminant mobilisation would be managed during construction (Section 1.7). Sediment contaminants are known to occur within the study area and mobilisation during construction has potential impacts on mangroves and associated biota with varying responses depending on compounds, concentrations and species. Although recurrent natural disturbances (eg waves and tides) may cause the majority of contaminant releases in many environments (Roberts, 2012), the wide-ranging impacts of this hazard combined with the persistence in an environment which characteristically traps suspended particles contributes to a moderate consequence.	Moderate	No
ME5	Introduction/spread of marine pests (to mangrove habitats) is unlikely as mangrove habitats are distant from the project area and the hazard would be managed during construction (Section 6.4). The consequence of marine pest impacts on mangroves was considered to be major due to the severity of marine pest impacts and remediation difficulties once they are established.	Moderate	No
ME6	Localised changes to hydrodynamics are predicted due to the installation of cofferdams as well as other instream structures to support the construction of the project. However, no mangrove habitats occur within or close to the project areas thus, the likelihood of hazard ME6 is unlikely. Due to the temporary nature of the structures and localised nature of impacts, the consequence to mangrove habitats was considered minor.	Low	No
ME7	Fish (and small sharks) have potential to use inundated mangrove habitats for shelter, breeding and feeding. The likelihood of underwater noise impacts (hazard ME7) were considered to be unlikely as modelled impact areas for fish do not coincide with mangrove habitats. There is potential for localised injury/behavioural changes to marine fauna within mangrove habitats if underwater noise did reach these areas. However, the temporary nature of the disturbance and the distance from the source would allow for fast recovery and/or avoidance of fish and sharks. Hence, the consequence of hazard ME7 was considered to be minor.	Low	No
ME8	N/A	N/A	N/A
ME9	The spill of contaminants would be managed during construction (Section 6.6) and unlikely to impact mangrove habitats. However, the consequence of this hazard was considered moderate under similar justifications as hazard ME4 (wide-ranging impacts and persistence)	Moderate	No

Intertidal sand and mudflat habitats

Hazard	Rationale	Risk level	Key issue
ME1	The removal these habitats would be unlikely as no intertidal sand and mudflat habitats occur within the project area. However, it is worth noting that areas close to Berrys Bay construction support site (WHT7) and Sydney Harbour north cofferdam (WHT6) contain two small stretches of sandflat habitat located in Balls Head Bay and Berrys Bay. This presents a small chance of exposure to hazard ME1 if construction activities are not contained within the project area. In the event this habitat is removed as a result of the project, habitat of the same type and quality would be reinstated following the completion of the project (Section 6.7). Thus, the consequence of hazard ME1 to intertidal sand and mudflat habitats was considered to be minor.	Low	No
ME2 and ME3	The likelihood of excess turbidity or sedimentation to intertidal sand and mudflat habitats is possible as a small stretch of intertidal sandflat habitat occurs immediately shoreward of the ZoI and the modelled five millimetre sedimentation boundary in Balls Head Bay. Intertidal sand and mudflat habitats have naturally dynamic sedimentation regimes and are frequently exposed to elevated turbidity in the estuary during wet and extreme weather events. As such, the consequences of hazards ME2 and ME3 were considered to be minor.	Moderate	No
ME4	Mobilisation of existing contaminants to intertidal sand and mudflat habitats are unlikely as hazard ME4 would be managed during construction (Section 1.7). Sediment contaminants are known to occur within the study area and mobilisation during construction has potential impacts on biota associated with this habitat with varying responses depending on compounds, concentrations and species. An existing level of sediment contamination is currently persistent throughout the study area (Section 3.3.2) and the potential regime of mobilisation from natural hydrodynamics (Roberts, et al., 2006) results in the exposure of intertidal sand and mudflat habitats to sediment contaminants. Thus, the consequence of hazard ME4 was considered minor.	Low	No
ME5	Introduction/spread of marine pests (hazard ME5) to intertidal sand and mudflat habitats is unlikely as the hazard would be managed during construction (Section 6.4). The consequence of marine pest impacts on intertidal sand and mudflat habitats was considered to be minor as the habitat is not optimal for identified marine pests with potential to occur within the study area (Section 3.13).	Low	No
ME6	Localised changes to hydrodynamics are predicted due to the installation of cofferdams as well as other instream structures to support the construction of the project. However, these changes are unlikely to affect intertidal sand and mudflat habitats as there are none in the vicinity of where the major changes to hydrodynamics would occur around the cofferdams and also because temporary structures would be removed following project completion. However, intertidal sand and mudflat habitats are highly reliant on hydrodynamics to drive sediment transport thus, the consequence of hazard ME6 to intertidal sand and mudflat habitats was considered to be moderate.	Moderate	No
ME7	The risk analysis of underwater noise in intertidal sand and mudflat habitat did not include fish utilising this habitat when inundated. This is addressed in open water habitats. This risk analysis for ME7 assessed other biota which use intertidal sand and mudflat habitats (eg inverterbrates). It was considered unlikely for underwater noise to occur in this habitat with a minor consequence to biota. This was attributed to the limited exposure time (only when inundated), the temporary nature of underwater noise associated with the project and fast recovery expected of biota.	Low	No
ME8	N/A	N/A	N/A
ME9	The spill of contaminants would be managed during construction (Section 1.7) thus, the likelihood is unlikely. However, the consequence of this hazard was considered moderate under similar justifications as hazard ME4 (wide-ranging impacts and persistence).	Moderate	No

Subtidal rocky reef habitats

Hazard	Rationale	Risk level	Key issue
ME1	Less than 0.01 hectares of medium relief subtidal reef habitat would be removed for construction of the crossing in Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6) cofferdams (Figure 5-1). Hence, it is almost certain that biota in these habitats would be affected from this hazard. It is proposed that subtidal reef that would be removed are reinstated following the construction phase (see Section 6.7). There is great natural variability among assemblages of subtidal reef biota in the study area and hence the small temporary losses would only amount to a minor localised impact that would recover through natural recruitment of biota within one to two years once construction had been completed (ie once the habitat was reinstated).	Moderate	Yes
ME2	Nearshore subtidal rocky reef is within the ZoMI and ZoI. Although species of sessile biota (macroalgae and invertebrates) and fish show variable responses to elevated turbidity (see sections 4.2.1 to 4.2.5), this assessment has assumed that the entire subtidal rocky reef assemblage within the ZoMI would perish. The area of subtidal rocky reef within the ZoMI amounts to less than 0.01 hectares and includes high relief reef (Figure 5-2). This area only amounts to a small proportion of the extent of this habitat in Sydney Harbour and would recover through natural recruitment of biota within one to two years once construction had finished. The loss of biota would only amount to a minor localised impact. Further, given one of the most commonly observed behaviours by fish even to very low levels of suspended sediment is the avoidance of turbid water, elevated turbidity may lead to shifts in local abundance and community composition in areas directly adjacent to the ZoMI and ZoI. However, given it is considered that the displacement of fish to areas outside of the ZoMI and ZoI and the resultant inflation of abundance would be within the natural variability observed in abundance of species among sites in the study area, this is not considered an additional risk.	Moderate	Yes
ME3	Taylor et al (2004) used the exponential decay of lead and radium isotopes to estimate sedimentation rates for 12 sites in Port Jackson, including 10 in Sydney Harbour. Average sedimentation rates in Port Jackson ranged from 0.63 to 2.68 centimetres per year. Modelling of total sedimentation associated with dredging indicated there are some small areas of subtidal rocky reef where one centimetre of sedimentation (from dredging) is expected (Figure 5-3). Depending on site-specific ambient levels, this would be an addition of between 15 and 74 per cent addition to the annual average. Excessive sedimentation could potentially affect sessile biota (macroalgae and invertebrates) and fish through a variety of pathways (see sections 4.2.1 to 4.2.5) and notwithstanding that impacts are species-dependent, the risk of this hazard to subtidal reef biota is almost certain. Similar to the effects of excessive turbidity discussed above, excessive sedimentation may lead to shifts in local abundance and community composition of fish in areas directly adjacent to affected areas but this has not been considered as an additional impact (see argument above). The area of subtidal rocky reef affected by excess sedimentation (greater than five millimetres) amounts to less than 0.01.hectares and includes high relief reef (Figure 5-3). This area only amounts to a small proportion of the extent of this habitat in Sydney Harbour and given affected areas would recover through natural recruitment of biota within one to two years once construction has ceased, the loss of biota would only amount to a minor localised impact.	Moderate	Yes
ME4	As already indicated in the discussion for intertidal rocky reef habitat, contaminants of various types can be found as deep as one metre below the bed of the harbour in some areas of Sydney Harbour (Douglas Partners and Golder Associates, 2017). Given contaminants are sediment bound and that a closed environmental bucket is proposed during removal of the top one metre layer of contaminated sediment (Douglas Partners and Golder Associates, 2017) there would little potential for spread of contaminants. Most of the dredge-induced accumulations of sediment in the subtidal rocky reef areas are most likely to be uncontaminated sediment that has dispersed during the dredging phases of deeper uncontaminated sediment. This means it is unlikely that subtidal rocky reef areas would be exposed to contaminants from dredging. However, given recovery from any contamination would be slow, the effects would be moderate.	Moderate	Yes
ME5	Vessels and movement of offshore equipment have potential to act as vectors for introduced species. Introduced species may be translocated into the project area	Moderate	Yes

Hazard	Rationale	Risk level	Key issue
	through the release of ballast water (in the case of planktonic larvae or species) or via reproduction from individuals attached to the hull of a vessel. Marine pests are considered to be a long-term, reversible impact to which marine communities have an existing level of exposure. Mitigation measures include standard practice procedures such as compliance with Australia's mandatory ballast water management requirements, with the addition of regular inspection of niche areas of high risk vessels. With these controls in place it is considered unlikely that intertidal areas would be exposed to marine pests but given recovery from any pests would be slow, the effects would be moderate.		
ME6	As already indicated in the discussion for intertidal rocky shore habitat, Royal Haskoning DHV (2020) modelled temporary changes to current speeds associate with silt curtains and cofferdams at Balls Head and Birchgrove at the harbour crossing. During the ebb tide, the Sydney Harbour south cofferdam (WHT5) was predicted to cause a reduction in the current speed downstream of the structure. This is offset by a small increase in speeds in the middle of the channel and around Balls Head. The Sydney Harbour north cofferdam (WHT6) would have a very minor impact on current speeds during the ebb tide. This is because near the Coal Loader Wharf ebb current speeds are very low in both existing and cofferdam scenarios resulting in the structure not significantly impacting on flow conditions. During the flood tide, a similar pattern was observed at the Sydney Harbour south cofferdam (WHT5) with currents significantly reduced downstream of the structure and a corresponding increase in the middle of the channel and along the northern bank (near Birchgrove Wharf). At the Sydney Harbour north cofferdam (WHT6) larger reductions in current speeds would occur in the areas surrounding the cofferdam and Coal Loader Wharf. During both ebb and flood tide the differences are more pronounced in the surface layer when compared to bottom layers. Also, at a location downstream of the Greenwich Baths, the modelled increase in current speeds occurred during the flood tide only and was most prominent during spring tides. At this location spring flood current speeds would increase from 0.36 metres per second to around 0.41 metres per second, a relative increase of 14 per cent. Although these changes are relatively large in some locations at some parts of the tidal cycle, they are not likely to cause an adverse impact given subtidal rocky reef biota exist in other parts of Sydney Harbour where current speeds would be similar. Where current speed is increased, however, it is also not expected to cause scour to subtidal rocky reef habitats. Given the modelling results it is almost certain that there would be changes to hydrodynamics in subtidal rocky reef areas. The temporary changes during construction would be minor.	Moderate	Yes
ME7	In-water construction activities have the potential to generate underwater noise sufficient to impact fish on subtidal rocky reefs. JASCO carried out an acoustic modelling study of underwater noise generated during the in-water construction activities of dredging and pile installation through impact driving. Modelling results were compared against recognised thresholds for injury or behavioural response in fish (including sharks) (see NMFS, 2016 and Popper et al, 2014), and used to delineate potential areas around the proposed construction sites where thresholds are likely to be exceeded. The modelling indicated that dredging operations would not cause harm to fish beyond the confinements of where the dredge operates. Dredging only has potential to cause temporary hearing loss in fish (including sharks) within 0.08 kilometres from the source of disturbance but this would cause no permanent harm (JASCO, 2019). The modelling indicated that impulsive noise from impact piling would cause mortality or mortal injury to the most sensitive fish group within 0.43 kilometres from the source of disturbance (JASCO, 2019). Cardno determined the potential risk and impact to fish from piling noise by considering the following: ▪ The sensitivity of fish within areas potentially affected by noise ▪ The severity of impact (ie harm or behavioural change) ▪ The scale of impact, or the amount of individuals affected relative to local population sizes (as determined by the extent of the potentially affected areas relative to unaffected areas).	Moderate	Yes

<table>
<tr><th>Hazard</th><th>Rationale</th><th>Risk level</th><th>Key issue</th></tr>
<tr><td></td><td>The area of subtidal rocky reef potentially affected by impact piling is given in Table G2. The majority of subtidal rocky reef within the noise impacts were considered medium and high relief reef.

Table G2 Areas of subtidal rocky reef habitat impacted by noise (source: JASCO, 2019)
<table>
<tr><th rowspan="2">Location</th><th rowspan="2">Largest area of impact category for fish and marine mammals (JASCO, 2019)</th><th>Area of subtidal rocky reef habitat (ha)</th><th>Area of medium and high relief subtidal rocky reef habitat (ha)</th></tr>
<tr><th>Unmitigated</th><th>Unmitigated</th></tr>
<tr><td rowspan="2">Sydney Harbour north cofferdam (WHT6)</td><td>186 (TTS)</td><td>0.56</td><td>0.55</td></tr>
<tr><td>207 (Mortality and potential mortal injury, Fish III)</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Sydney Harbour south cofferdam (WHT5)</td><td>186 (TTS)</td><td>0.46</td><td>0.46</td></tr>
<tr><td>207 (Mortality and potential mortal injury, Fish III)</td><td>0.11</td><td>0.11</td></tr>
</table>
Given different species of fish have different tolerance thresholds to underwater noise it is almost certain that some species among the diverse assemblages in affected areas of subtidal rocky reef habitat would be affected. The consequence of the hazard to fish and sharks is considered to be minor given modelling by JASCO (2019) that shows the areas of potentially affected habitat are very small relative to the extent of these habitats within Sydney Harbour. Further, although some fish may die, impacts are also recoverable within one or two years given annual recruitment of fish and dispersal into the impacted areas would occur shortly after the impact piling campaigns had ceased.</td><td></td><td></td></tr>
<tr><td>ME8</td><td>Marine mammals and turtles can occur in subtidal rocky reef habitat. Justification for the level of risk is given in hazard ME8 in the risk analyses for marine reptiles and marine mammals.</td><td>Moderate</td><td>Yes</td></tr>
<tr><td>ME9</td><td>Best-practice vessel management and site management would be used to minimise the risk of contaminant spillage. Best practice surface water treatment can be expected to result in a negligible amount of other pollutant material from shore structures entering the marine environment. Hence spills would be unlikely, recovery is likely and hence spills are considered to be moderate short-term, reversible impacts.</td><td>Moderate</td><td>Yes</td></tr>
</table>

Deepwater soft sediment and open water habitats

Hazard	Rationale	Risk level	Key issue
ME1	Up to 10.51 hectares of deepwater soft sediment habitat would be dredged so the immersed tube tunnel units for the crossing can be placed on the bed of the harbour at the appropriate depth and sediment fill placed on top so the existing profile of the bed of the harbour would be restored. Fill would be placed over the tunnel and soft sediment is expected to accumulate on top of the fill, and integrate with it, so that the soft sediment community would be able to re-establish in the short-term (ie within two years). Impact piling at Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6) cofferdams would also result in this loss albeit very small. Hence, it is almost certain that deepwater soft sediment and the overlying open water habitat habitat would be affected but the consequence would be minor given the deepwater soft sediment habitat can be reinstated.	Moderate	Yes (deepwater soft sediment habitat) No (open water habitat)
ME2	Nearshore deepwater soft sediment habitat is within the ZoMI and ZoI (Figure 5-2). Although species show variable responses to elevated turbidity and that fish may avoid the area, the mechanical or abrasive action of elevated suspended sediments may be harmful to suspension feeders, clogging their feeding apparatus and impairing respiratory and excretory function (see Section 4.2.2). Given it is assumed that the assemblage in the ZoMI would perish the hazard is considered almost certain. Given these areas only amount to a small proportion of the extent of this habitat in Sydney Harbour and soft sediment biota would recover through natural recruitment within one to two years once construction had finished, the loss of biota would be temporary and amount to a minor localised impact.	Moderate	No
ME3	As discussed above, average sedimentation rates in Port Jackson range from 0.63 to 2.68 centimetres per year and modelling of total sedimentation associated with dredging indicate there are some small areas of deepwater soft sediment habitat where five to 10 millimetres of sedimentation (from dredging) from the project would be expected. Depending on site-specific ambient levels, this would be a 15 to 74 per cent addition to the annual average. Mobile invertebrates are generally less vulnerable than sessile taxa to sedimentation, as they are able to move to areas with less sediment accumulation or by more efficiently physically removing particles and some bivalves and polychaete worms can dig themselves out from under deep burial (see Section 4.2.1). However, mobility alone does not indicate that these groups are resistant as certain critical life stages are still susceptible to several indirect effects of sedimentation. Impacts would be species-dependent, however the risk of this hazard to deepwater soft sediment biota is almost certain. The area of deepwater soft sediment affected by excess sedimentation would amount to about 26.91 hectares. Given this area only amounts to a small proportion of the extent of this habitat in Sydney Harbour and that affected areas are expected to recover through natural recruitment of biota within one to two years once construction has ceased, the loss of biota would only amount to a minor localised impact. This hazard is not applicable to open water habitats.	Moderate	No

Hazard	Rationale	Risk level	Key issue
ME4	As already indicated in discussions above, contaminants of various types can be found as deep as one metre below the bed of the harbour in some areas of Sydney Harbour (Douglas Partners and Golder Associates, 2017). A closed environmental bucket is proposed during removal of the top one metre layer of contaminated sediment (see Section 1.7) there would little potential for spread of contaminants. Most of the dredge-induced accumulations of sediment in the deepwater soft sediment and open water habitat areas are most likely to be uncontaminated sediment that has dispersed during the dredging phases of deeper uncontaminated sediment. Further, were any resuspension of sediment by proposed dredging to disperse contaminated sediment, these activities are unlikely to change the ambient contaminant status in existing areas as contaminant concentrations at the crossings are similar to, or less than, baseline concentrations throughout large areas of either Sydney Harbour. This means it would be unlikely that soft sediment and open water areas would be exposed to contaminants from dredging. However, given recovery from any contamination would be slow, the effects would be moderate.	Moderate	No
ME5	Vessels and movement of offshore equipment have potential to act as vectors for introduced species. Introduced species may be translocated into the project area through the release of ballast water (in the case of planktonic larvae or species) or via reproduction from individuals attached to the hull of a vessel. Marine pests are considered to be a long-term, reversible impact to which marine communities have an existing level of exposure. Mitigation measures include standard practice procedures such as compliance with Australia's mandatory ballast water management requirements, with the addition of regular inspection of niche areas of high risk vessels. With these controls in place it is considered unlikely that intertidal areas would be exposed to marine pests but given recovery from any pests would be slow, the effects would be moderate.	Moderate	No
ME6	As already indicated in the discussions above, Royal Haskoning DHV (2020) modelled temporary changes to current speeds associate with silt curtains and cofferdams at Balls Head and Birchgrove at the harbour crossing. During the ebb tide, the Sydney Harbour south cofferdam (WHT5) would cause a reduction in the current speed downstream of the structure. This would be offset by a small increase in speeds in the middle of the channel and around Balls Head. The Sydney Harbour north cofferdam (WHT6) would have a very minor impact on current speeds during the ebb tide. This is because near the Coal Loader Wharf ebb current speeds are very low in both existing and cofferdam scenarios resulting in the structure not significantly impacting on flow conditions. During the flood tide, a similar pattern would occur at the Sydney Harbour south cofferdam (WHT5) with currents significantly reduced downstream of the structure and a corresponding increase in the middle of the channel and along the northern bank (near Birchgrove Wharf). At the Sydney Harbour north cofferdam (WHT6) larger reductions in current speeds surrounding the cofferdam and Coal Loader Wharf would occur. During both ebb and flood tide the differences would be more pronounced in the surface layer when compared to bottom layers. Also, at a location downstream of the Greenwich Baths, the modelled increase in current speeds would occur during the flood tide only and be prominent during spring tides. At this location spring flood current speeds would increase from 0.36 metres per second to around 0.41 metres per second, a relative increase of 14 per cent. Given the bed of the harbour at the tunnel crossing would be restored to the existing profile, there would be no changes to hydrodynamics in the operational phase. Given the modelling results it is almost certain that there would be changes to hydrodynamics in deepwater soft sediment and open water areas particularly close to the coffer dams although not to the extent that there would be scour. The temporary changes during construction would be minor.	Moderate	No
ME7	In-water construction activities have the potential to generate underwater noise sufficient to impact fish on deepwater soft sediment and open water habitats. JASCO carried out an acoustic modelling study of underwater noise generated during the in-water construction activities of dredging and pile installation through impact driving. Modelling results were compared against	Moderate	Yes

Hazard	Rationale	Risk level	Key issue
	recognised thresholds for injury or behavioural response in fish including sharks (see NMFS, 2016 and Popper et al, 2014), and used to delineate potential areas around the proposed constuction sites where thresholds are likely to be exceeded. The modelling indicated that dredging operations would not cause harm to fish beyond the confinements of where the dredge operates. Dredging only has potential to cause temporary threshold shift (TTS) (ie temporary hearing loss) in fish (including sharks) within 0.08 kilometres from the source of disturbance but this would cause no permanent harm(JASCO, 2019). The modelling indicated that impulsive noise from impact piling would cause mortality or mortal injury to the most sensitive fish group within 0.43 kilometres from the source of disturbance (JASCO, 2019). The area of deepwater soft sediment habitat potentially affected by impact piling is given in Table G3.		

Table G3 Areas of shallow and deepwater soft sediment habitat impacted by noise (source: JASCO, 2019)

Location	Largest area of impact category for fish and marine mammals (JASCO, 2019)	Area of shallow and deepwater soft sediment and open water habitat (ha)
		Unmitigated
Sydney Harbour north cofferdam (WHT6)	186 (TTS)	121.25
	207 (Mortality and potential mortal injury, Fish III)	11.64
	183 (PTS, (LFC) (eg baleen whales)-weighted)	125.93
Sydney Harbour south cofferdam (WHT5)	186 (TTS)	75.42
	207 (Mortality and potential mortal injury, Fish III)	17.59
	183 (PTS, LFC-weighted)	71.50

Hazard	Rationale	Risk level	Key issue
	Given different species of fish have different tolerance thresholds to underwater noise it is almost certain that some species among the diverse assemblages in affected areas of deepwater soft sediment habitat would be affected. There is potential for this hazard to impact fauna transiting through these areas during pile driving. However, the consequence of the hazard to fish and sharks is considered to be minor given modelling by JASCO (2019) that shows the areas of potentially affected habitat are very small relative to the extent of these habitats within Sydney Harbour which eludes to a lower potential for fauna to transit through these areas during acoustic disturbances. Further, although some fish may die, impacts are also recoverable within one or two years given annual recruitment of fish and dispersal into the impacted areas would occur shortly after the impact piling campaigns had ceased.		
ME8	Marine mammals and turtles can occur in deepwater soft sediment and open water habitat. Justification for the level of risk is given in the risk analyses for marine reptiles and marine mammals.	Moderate	Yes
ME9	Best-practice vessel management and site management would be used to minimise the risk of contaminant spillage. Best practice surface water treatment can be expected to result in a negligible amount of other pollutant material from shore structures entering the marine environment. Hence spills would be unlikely, recovery is likely and spills are considered to be moderate short-term, reversible impacts.	Moderate	No

Black rockcod

Hazard	Rationale	Risk level	Key issue
ME1	Some of the high or medium relief rocky reef habitat is suitable for the Commonwealth and State-listed black rockcod and there is anecdotal evidence that individuals potentially reside in the project study area. Less than 0.01 hectares of medium relief subtidal reef habitat is expected to be removed for construction of the crossing in Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6) cofferdams (Figure 5-1). Hence, it would be almost certain that any black rockcod in these habitats would be affected from this hazard. It is proposed that subtidal reef that would be removed is reinstated following the construction phase (see Section 6.7). Hence in the unlikely event that a very small amount of benthic habitat was removed accidentally its loss would only amount to a minor localised impact given the extent of this habitat in the study area. Any habitat to be removed could easily be reinstated at the end of construction. Reinstated habitat would recover through natural recruitment of biota within one to two years once construction had been completed.	Moderate	No
ME2	Some high and medium relief nearshore subtidal rocky reef is within the ZoMI or ZoI associated with dredging. The area of subtidal rocky reef within the ZoMI amounts to less than 0.01 hectares and includes high relief reef (Figure 5-2). One of the most commonly observed behaviours by fish to elevated suspended sediment is the avoidance of turbid water and hence any individuals living in the ZoMI may flee to other nearby unaffected areas rather than perish (see Section 4.2.5). The available evidence suggests that very few individuals would occur in potentially affected rocky reef habitat and hence it is reasonable to assume that at worst, only a small number of individuals would potentially die due to elevated turbidity were they not to flee. The precise number of affected black rockcod, although likely to be small, is uncertain but can be estimated by considering the area of potentially affected black rockcod habitat relative to the area of similar unaffected black rockcod habitat in Sydney Harbour or Middle Harbour. This is a very small proportion and indicates that the number of affected black rockcod would be negligible and would not affect the viability of local populations. For the purposes of assessing risk, the likelihood of the hazard of turbidity affecting black rockcod is almost certain. However, given that affected areas would recover through natural recruitment of biota within one to two years once construction had finished the risk would only amount to a minor localised temporary impact to black rockcod habitat.	Moderate	No
ME3	As indicated above, average sedimentation rates in Port Jackson ranged from 0.63 to 2.68 centimetres per year. Predicted total sedimentation associated with dredging indicated there would be some small areas of high and medium relief subtidal rocky reef where five to 10 millimetres of sedimentation (from dredging) is expected (Figure 5-3), amounting to an addition of between 15 and 74 per cent addition to the annual average to a total area of about 0.14 hectares (Figure 5-3). Excessive sedimentation could potentially affect black rockcod or their subtidal rocky reef habitat through a variety of pathways (see Section 4.2.5). As indicated above it is not clear how many individuals would occur in the potentially affected areas but for the purposes of this assessment the risk of this hazard to black rockcod is almost certain. Given the affected area only amounts to a small proportion of the extent of this habitat in Sydney Harbour, affected areas would recover through natural recruitment of reef biota and black rockcod within one to two years once construction has ceased, the loss of any black rockcod or their habitat would only amount to a minor localised impact.	Moderate	No
ME4	As already indicated in discussions above, contaminants would occur in soft sediment as deep as one metre below the bed of the harbour in some areas of Sydney Harbour (Douglas Partners and Golder Associates, 2017). Most of the dredge-induced accumulations of sediment in the subtidal rocky reef areas are most likely to be uncontaminated sediment that has dispersed during the dredging phases of deeper uncontaminated sediment. This means it is unlikely that subtidal rocky reef areas would be exposed to contaminants from dredging. However, given recovery from any contamination would be slow, the effects would be moderate.	Moderate	No
ME5	Vessels and movement of offshore equipment have potential to act as vectors for introduced species. Introduced species may be translocated into the project area through the release of ballast water (in the case of planktonic larvae or species) or via reproduction from individuals attached to the hull of a vessel. Marine pests are	Moderate	No

Hazard	Rationale	Risk level	Key issue
	considered to be a long-term, reversible impact to which marine communities have an existing level of exposure. Mitigation measures include standard practice procedure such as compliance with Australia's mandatory ballast water management requirements, with the addition of regular inspection of niche areas of high risk vessels. With these controls in place it is considered unlikely that black rockcod habitat would be exposed to marine pests but given habitat recovery from any pests would be slow, the effects would be moderate.		
ME6	As already indicated in the discussion for intertidal rocky reef habitat, Royal Haskoning DHV (2020) modelled temporary changes to current speeds associated with silt curtains and cofferdams at Balls Head and Birchgrove at the harbour crossing. During the ebb tide, the Sydney Harbour south cofferdam (WHT5) caused a reduction in the current speed downstream of the structure. This is offset by a small increase in speeds in the middle of the channel and around Balls Head. The Sydney Harbour north cofferdam (WHT6) would have a very minor impact on current speeds during the ebb tide. This is because near the Coal Loader Wharf ebb current, speeds would be very low in both existing and cofferdam scenarios resulting in the structure not significantly impacting on flow conditions. During the flood tide, a similar pattern would be observed at the Sydney Harbour south cofferdam (WHT5) with currents significantly reduced downstream of the structure and a corresponding increase in the middle of the channel and along the northern bank (near Birchgrove Wharf). At the Sydney Harbour north cofferdam (WHT6) larger reductions in current speeds would occur in the areas surrounding the cofferdam and Coal Loader Wharf. During both ebb and flood tide the differences are more pronounced in the surface layer when compared to bottom layers. Also, at a location downstream of the Greenwich Baths, the modelled increase in current speeds occurred during the flood tide only and was most prominent during spring tides. At this location spring flood current speeds increase from 0.36 metres per second to around 0.41 metres per second, a relative increase of 14 per cent. Although these changes are relatively large in some locations at some parts of the tidal cycle, they are not likely to cause any adverse impacts given subtidal rocky reef biota exist in other parts of Sydney Harbour where current speeds would be similar. Where current speed is increased, however, it is also not expected to cause scour to subtidal rocky reef habitats. Modelling results show it is almost certain that there would be changes to hydrodynamics in subtidal areas. The temporary changes during construction would be minor and there would be no long-term changes from the immersed tube tunnel given it has been designed to be built below the existing bed of the harbour.	Moderate	No
ME7	In-water construction activities have the potential to generate underwater noise sufficient to impact fish on subtidal rocky reefs. JASCO carried out an acoustic modelling study of underwater noise generated during the in-water construction activities of dredging and pile installation through impact driving. Modelling results were compared against recognised thresholds for injury or behavioural response in fish including sharks (see NMFS, 2016 and Popper et al, 2014), and used to delineate potential areas around the proposed construction sites where thresholds are likely to be exceeded. Similar to that discussed for this hazard to subtidal rocky reef habitat, the modelling indicated that dredging operations would not cause harm to fish beyond the confinements of where the dredge operates (JASCO, 2019) . Due to the black rockcod's high site fidelity (unlike sharks, marine mammals and turtles) and inability to be effectively detected by spotters, there is potential for mortality to some individuals from exposure to impact piling noise. The available evidence suggests that very few individuals would occur in potentially affected rocky reef habitat and hence it is reasonable to assume that at worst, only a small number of individuals would potentially die due to impact piling noise. The precise number of affected black rockcod, although likely to be small, is uncertain. However, by considering the area of potentially affected black rockcod habitat relative to the area of similar unaffected black rockcod habitat in Sydney Harbour or Middle Harbour, the number of affected black rockcod would not affect the viability of a local population. The area of medium and high relief subtidal rocky reef (ie black rockcod habitat) potentially affected by impact piling is given in Table G2. Given different species of fish have different tolerance thresholds to underwater noise it is almost certain that some species among the diverse assemblages in affected areas of subtidal rocky reef habitat would be affected. The consequence of the hazard	Moderate	Yes

Hazard	Rationale	Risk level	Key issue
	to black rockcod is considered to be minor given modelling by JASCO (2019) that shows the areas of potentially affected habitat would be very small relative to the extent of these habitats within Sydney Harbour. Further, although some fish may die, impacts are also recoverable within one or two years given annual recruitment of fish and dispersal into the impacted areas which would occur shortly after the impact piling campaigns had ceased.		
ME8	N/A	N/A	N/A
ME9	Best-practice vessel management and site management will be used to minimise the risk of contaminant spillage. Best practice surface water treatment can be expected to result in a negligible amount of other pollutant material from shore structures entering the marine environment. Hence spills would be unlikely, recovery is likely and hence spills are considered to be moderate short-term, reversible impacts.	Moderate	No

White's seahorse

Hazard	Rationale	Risk level	Key issue
ME1	Seagrass and low, medium or high relief subtidal rocky reef is suitable habitat for the nominated-for-listing White's seahorse. Given White's seahorse is known from areas further towards the mouth of the estuary, it is expected that individuals potentially reside in the project study area. Less than 0.01 hectares of subtidal reef habitat is expected to be removed for construction of the crossing in Sydney Harbour south (WHT5) and Sydney Harbour north (WHT6) cofferdams (Figure 5-1). Seagrass habitat does not occur within the project area thus removal of seagrass for the purposes of project construction is not predicted. However, a small patch of Zostera (less than 0.01 hectares) occurs between the Yurublin Point construction support site (WHT4) and the Sydney Harbour south cofferdam (WHT5) (see Figure 5-1). It would be almost certain that any White's seahorse in these habitats would be affected from this hazard. It is proposed that subtidal reef that would be removed is reinstated following the construction phase (see Section 6.7). Hence in the unlikely event that a very small amount of benthic habitat was removed accidentally its loss would only amount to a minor localised impact given the extent of this habitat in the study area. Any habitat to be removed could easily be reinstated at the end of construction. Reinstated habitat would recover through natural recruitment of biota within one to two years once construction had been completed.	Moderate	No
ME2	Some nearshore seagrass and subtidal rocky reef is within the ZoMI or ZoI associated with dredging. The area of subtidal rocky reef within the ZoMI amounts to less than 0.01 hectares and includes high relief reef (Figure 5-2) and the area of Zostera in the ZoI (in Balls Head Bay) amounts to about 0.03 hectares. The main impact pathway of turbidity on seagrass would be light attenuation affecting photosynthesis, physiology and morphology (see above) but seagrasses have exhibited tolerance to elevated turbidity frequently experienced in bays of the estuary (see Section 3.4). One of the most commonly observed behaviours by fish generally to elevated suspended sediment is the avoidance of turbid water and some individuals living in the ZoMI may flee to other nearby unaffected areas rather than perish (see Section 4.2.5). However members of the seahorse group of fish would have limited ability to flee given their speeds relative to other fish. The available evidence suggests that very few individuals would occur in potentially affected seagrass and rocky reef habitat and hence it is reasonable to assume that at worst, only a small number of individuals would potentially die due to elevated turbidity were they not to flee. The precise number of affected White's seahorse, although likely to be small, is uncertain but can be estimated by considering the area of potentially affected White's seahorse habitat relative to the area of similar unaffected White's seahorse habitat in Sydney Harbour or Middle Harbour. This is a very small proportion and indicates that the number of affected White's seahorse would be negligible and would not affect the viability of local populations. For the purposes of assessing risk, the likelihood of the hazard of turbidity affecting White's seahorse, or its habitat, is almost certain. However, given that affected areas would recover through natural recruitment of biota within one to two years once construction had finished the risk would only amount to a minor localised temporary impact to White's seahorse habitat.	Moderate	No
ME3	As indicated above, average sedimentation rates in Port Jackson ranged from 0.63 to 2.68 centimetres per year. Predicted total sedimentation associated with dredging indicated there would be some small areas of seagrass and subtidal rocky reef where five to 10 millimetres of sedimentation (from dredging) is expected (Figure 5-3), amounting to an addition of between 15 and 74 per cent addition to the annual average to a total area of about 0.14 hectares (Figure 5-3). Excessive sedimentation could potentially affect White's seahorse or their seagrass and subtidal rocky reef habitat through a variety of pathways (see Section 4.2.5). As indicated above it is not clear how many individuals would occur in the potentially affected areas but for the purposes of this assessment the risk of this hazard to White's seahorse is almost certain. Given the affected area only amounts to a small proportion of the extent of this habitat in Sydney Harbour, it is considered that affected areas would recover through natural recruitment of reef biota and White's seahorse within one to two years once construction has ceased, the loss of any White's seahorse or their habitat would only amount to a minor localised impact.	Moderate	No

Hazard	Rationale	Risk level	Key issue
ME4	As already indicated in discussions above, contaminants would occur in soft sediment as deep as one metre below the bed of the harbour in some areas of Sydney Harbour (Douglas Partners and Golder Associates, 2017). Most of the dredge-induced accumulations of sediment in the seagrass or subtidal rocky reef areas are most likely to be uncontaminated sediment that has dispersed during the dredging phases of deeper uncontaminated sediment. This means it is unlikely that seagrass or subtidal rocky reef areas would be exposed to contaminants from dredging. However, given recovery from any contamination would be slow, the effects would be moderate.	Moderate	No
ME5	Vessels and movement of offshore equipment have potential to act as vectors for introduced species. Introduced species may be translocated into the project area through the release of ballast water (in the case of planktonic larvae or species) or via reproduction from individuals attached to the hull of a vessel. Marine pests are considered to be a long-term, reversible impact to which marine communities have an existing level of exposure. Mitigation measures include standard practice procedure such as compliance with Australia's mandatory ballast water management requirements, with the addition of regular inspection of niche areas of high risk vessels. With these controls in place it is considered unlikely that White's seahorse habitat would be exposed to marine pests but given habitat recovery from any pests would be slow, the effects would be moderate.	Moderate	No
ME6	As already indicated in the discussion for intertidal rocky reef habitat, Royal Haskoning DHV (2020) modelled temporary changes to current speeds associated with silt curtains and cofferdams at Balls Head and Birchgrove at the harbour crossing. During the ebb tide, the Sydney Harbour south cofferdam (WHT5) caused a reduction in the current speed downstream of the structure. This is offset by a small increase in speeds in the middle of the channel and around Balls Head. The Sydney Harbour north cofferdam (WHT6) would have a very minor impact on current speeds during the ebb tide. This is because near the Coal Loader Wharf ebb current, speeds would be very low in both existing and cofferdam scenarios resulting in the structure not significantly impacting on flow conditions. During the flood tide, a similar pattern would be observed at the Sydney Harbour south cofferdam (WHT5) with currents significantly reduced downstream of the structure and a corresponding increase in the middle of the channel and along the northern bank (near Birchgrove Wharf). At the Sydney Harbour north cofferdam (WHT6) larger reductions in current speeds would occur in the areas surrounding the cofferdam and Coal Loader Wharf. During both ebb and flood tide the differences are more pronounced in the surface layer when compared to bottom layers. Also, at a location downstream of the Greenwich Baths, the modelled increase in current speeds occurred during the flood tide only and was most prominent during spring tides. At this location spring flood current speeds increase from 0.36 metres per second to around 0.41 metres per second, a relative increase of 14 per cent. Although these changes are relatively large in some locations at some parts of the tidal cycle, they are not likely to cause any adverse impacts given subtidal rocky reef biota exist in other parts of Sydney Harbour where current speeds would be similar. Where current speed is increased, however, it is also not expected to cause scour to subtidal rocky reef habitats. Given the modelling results it is almost certain that there would be changes to hydrodynamics in small areas of subtidal reef and seagrass close to the coffer dams. The temporary changes during construction would be minor and there would be no long-term changes from the immersed tube tunnel given it has been designed to be built below the existing bed of the harbour.	Moderate	No
ME7	In-water construction activities have the potential to generate underwater noise sufficient to impact fish on subtidal rocky reefs and in seagrass. JASCO carried out an acoustic modelling study of underwater noise generated during the in-water construction activities of dredging and pile installation through impact driving. Modelling results were compared against recognised thresholds for injury or behavioural response in fish including sharks (see NMFS, 2016 and Popper et al, 2014), and used to delineate potential areas around the proposed construction sites where thresholds are likely to be exceeded. Similar to that discussed for this hazard to subtidal rocky reef habitat, the modelling indicated that dredging operations would not cause harm to fish beyond the confinements of where the dredge operates (JASCO, 2019).	Moderate	Yes

Hazard	Rationale	Risk level	Key issue
	Due to the White's seahorse high site fidelity (unlike sharks, marine mammals and turtles) and inability to be effectively detected by spotters, there is potential for mortality to some individuals from exposure to impact piling noise. The available evidence suggests that very few individuals would occur in potentially affected rocky reef habitat or seagrass and hence it is reasonable to assume that at worst, only a small number of individuals would potentially die due to impact piling noise. The precise number of affected White's seahorse, although likely to be small, is uncertain. However, by considering the area of potentially affected White's seahorse habitat relative to the area of similar unaffected White's seahorse habitat in Sydney Harbour or Middle Harbour, the number of affected White's seahorse would not affect the viability of a local population. The area of seagrass and subtidal rocky reef (ie White's seahorse habitat) potentially affected by impact piling is given in Table G1 and Table G2. Given different species of fish have different tolerance thresholds to underwater noise it is almost certain that some species among the diverse assemblages in affected areas of seagrass and subtidal rocky reef habitat would be affected. The consequence of the hazard to White's seahorse is considered to be minor given modelling by JASCO (2019) that shows the areas of potentially affected habitat would be very small relative to the extent of these habitats within Sydney Harbour. Further, although some seahorses may die, impacts are also recoverable within one or two years given annual recruitment and likely dispersal into the impacted areas which would occur shortly after the impact piling campaigns had ceased.		
ME8	N/A	N/A	N/A
ME9	Best-practice vessel management and site management will be used to minimise the risk of contaminant spillage. Best practice surface water treatment can be expected to result in a negligible amount of other pollutant material from shore structures entering the marine environment. Hence spills would be unlikely, recovery is likely and hence spills are considered to be moderate short-term, reversible impacts.	Moderate	No

Marine mammals

Hazard	Rationale	Risk level	Key issue
ME1	The likelihood of hazard ME1 occurring to marine mammals was considered to be almost certain as White Bay (WHT3), Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) construction support sites would involve the installation of instream features resulting in the removal of some open water habitat for marine mammals. The consequence of this hazard to marine mammals was considered to be minor as not only would the instream structures be removed following the completion of the project, the total area of removal is very small in relation to the greater estuary.	Moderate	No
ME2	This hazard is likely as potential habitat for marine mammals occurs within the ZoI. The likelihood considers the transient nature of marine mammals which are mostly infrequently visitors to the greater estuary. Due to their high mobility and the large areas of similar, available habitats within the estuary, the consequences of hazard ME2 was considered minor.	Moderate	No
ME3	N/A	N/A	N/A
ME4	The exposure of mobilised contaminants to marine mammals would be unlikely as contaminant mobilisation would be managed during construction (Section 1.7). Sediment contaminants are known to occur within the study area and mobilisation during construction has potential impacts on the health of marine mammals. Howver visitors to the estuary are likely to already be exposed to contaminants as recurrent natural disturbances (eg waves and tides) may cause the majority of contaminant releases in many environments (Roberts, 2012). Under similar justifications for hazard ME2, the consequence of hazards ME4 as a result of the project was considered to be minor.	Low	No
ME5	N/A	N/A	N/A
ME6	With the installation of cofferdams as well as other instream structures to support the construction of the project, the likelihood of hazard ME6 to marine mammals would be almost certain. This hazard to marine mammals was considered minor due to the temporary nature of the structures and the proportion of impact area to similar habitat in the greater estuary.	Moderate	No
ME7	The likelihood of underwater noise impacts (hazard ME7) to marine mammals was considered to be almost certain as modelled impact areas coincide with potential marine mammal habitat. However, marine mammal habitat conditions are likely to be restored immediately following the removal of the acoustic disturbance. This in combination with the temporary nature of the disturbance, the migratory nature of species and implementation of appropriate management during high risk activities (Section 5) resulted in a minor consequence to marine mammals.	Moderate	Yes
ME8	Vessel strike is unlikely as impacts on marine mammals would be managed (Section 6). Furthermore, marine mammals are transient and potentially adapt to the volume of existing vessel traffic in the estuary. In the event hazard ME8 eventuates, the consequence was considered major attributed to the generation times of species previously recorded in the study area.	Moderate	Yes
ME9	The potential for spill of contaminants would be managed during construction (Section 6.6) thus, the likelihood is unlikely. The consequence of this hazard was considered minor under similar justifications as hazard ME4.	Low	No

Marine reptiles

Hazard	Rationale	Risk level	Key issue
ME1	The likelihood of habitat removal occurring to marine reptiles would be almost certain as construction sites White Bay (WHT3), Yurulbin Point (WHT4), Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) would involve the installation of instream features resulting in the removal of some open water and benthic habitat for marine reptiles. The consequence of this hazard to marine reptiles was considered to be minor as not only would the instream structures be removed following the completion of the project, the total area of removal is very small in relation to that available in the greater estuary.	Moderate	No
ME2 and ME3	These hazards would likely occur as the potential habitat for marine reptiles occurs within the ZoI and area of modelled sedimentation. The likelihood rating considers the transient nature of marine reptiles which are mostly infrequently visitors to the greater estuary. Due to their high mobility and the large areas of similar, available habitats within the estuary, the consequences of hazards ME2 and ME3 were considered minor.	Moderate	No
ME4	The exposure of mobilised contaminants (hazard ME4) to marine reptiles would be unlikely as contaminant mobilisation would be managed during construction (Section 5). Sediment contaminants are known to occur within the study area and mobilisation during construction has potential impacts on the health of marine reptiles. However it is difficult to determine specific toxicological impacts for these species as they are highly migratory and long-lived (Kelleway, et al., 2007). Furthermore, visitors to the estuary are likely to already be exposed to contaminants as recurrent natural disturbances (eg waves and tides) may cause the majority of contaminant releases in many environments (Roberts, 2012). Under similar justifications for hazards ME2 and ME3, the consequence of hazard ME4 as a result of the project to marine reptiles was considered to be minor.	Low	No
ME5	Introduction/spread of marine pests (hazard ME5) to marine reptiles would be unlikely as the hazard would be managed during construction (Section 5). The consequence of marine pest impacts on marine reptiles was considered to be minor as impacts from this hazard are likely to be localised in relation to their overall distribution.	Low	No
ME6	With the installation of cofferdams as well as other instream structures to support the construction of the project, the likelihood of hazard ME6 to marine reptiles would be almost certain. This hazard to marine mammals was considered minor due to the temporary nature of the structures and the proportion of impact area to similar habitat in the greater estuary.	Moderate	No
ME7	The likelihood of underwater noise impacts (hazard ME7) to marine reptiles would be almost certain as modelled impact areas coincide with potential marine reptile habitat. However, marine reptile habitat conditions are likely to be restored immediately following the removal of the acoustic disturbance. This, combined with the temporary nature of the disturbance, the transient nature of species and the implementation of appropriate management during high risk activities (Section 6), would result in a minor consequence to marine reptiles.	Moderate	Yes
ME8	Boat strike is unlikely as impacts on marine reptiles would be managed (Section 6). Furthermore, marine reptiles are transient and visitors are potentially able to adapt to the volume of existing vessel traffic in the estuary. In the event hazard ME8 eventuates, the consequence was considered major attributed to the generation times of species (eg marine turtles) previously recorded within the study area.	Moderate	Yes
ME9	The spill of contaminants (hazard ME9) would be managed during construction (Section 6.6) thus, the likelihood is unlikely. The consequence of this hazard was considered minor under similar justifications as hazard ME4.	Low	No

Elasmobranchs (sharks and rays)

Hazard	Rationale	Risk level	Key issue
ME1	The likelihood of habitat removal occurring to elasmobranchs would be almost certain asboth Sydney Harbour south cofferdam (WHT5) and Sydney Harbour north cofferdam (WHT6) would involve the installation of instream features resulting in the removal of some open water and benthic habitat for sharks and rays. The consequence of this hazard to sharks was considered to be minor as not only would the instream structures be removed following the completion of the project, the total area of removal is very small in relation to that available in the greater estuary.	Moderate	No
ME2 and ME3	These hazards would likely occur as the potential habitat for sharks and rays occurs within the ZoI and ZoMI and area of modelled sedimentation. The likelihood rating considers the transient nature of sharks which are mostly infrequently visitors to the greater estuary. Due to their high mobility and the large areas of similar, available habitats within the estuary, the consequences of hazards ME2 and ME3 were considered minor.	Moderate	No
ME4	The exposure of mobilised contaminants to sharks and rays would be unlikely as contaminant mobilisation would be managed during construction (Section 1.7). Sediment contaminants are known to occur within the study area and mobilisation during construction has potential impacts on the health of sharks and rays. Howver it is difficult to determine specific toxicological impacts for these species as they are highly migratory and long-lived (Kelleway, et al., 2007). Furthermore, visitors to the estuary are likely to already be exposed to contaminants as recurrent natural disturbances (eg waves and tides) may cause the majority of contaminant releases in many environments (Roberts, 2012). Under similar justifications for hazards ME2 and ME3, the consequence of hazards ME4 as a result of the project to sharks and rays was considered to be minor.	Low	No
ME5	Introduction/spread of marine pests (hazard ME5) to sharks would be unlikely as the hazard would be managed during construction (Section 6.4). The consequence of marine pest impacts on sharks was considered to be minor as impacts from this hazards are likely to be localised in relation to their overall distribution.	Low	No
ME6	With the installation of cofferdams as well as other instream structures to support the construction of the project, the likelihood of hazard ME6 to sharks would be almost certain. This hazard was considered minor due to the temporary nature of the structures and the proportion of impact area to similar habitat in the greater estuary.	Moderate	No
ME7	The likelihood of underwater noise impacts (hazard ME7) to sharks was considered to be almost certain as modelled impact areas coincide with potential shark habitat. However, marine reptile habitat conditions are likely to be restored immediately following the removal of the acoustic disturbance. This, combined with the temporary nature of the disturbance, the transient/migratory nature of species, and their wide distribution, results in a minor consequence to marine reptiles.	Moderate	Yes
ME8	N/A	N/A	N/A
ME9	The spill of contaminants would be managed during construction (Section 6.6) thus, the likelihood is unlikely. The consequence of this hazard was considered minor under similar justifications as hazard ME4.	Low	No

RMS 19.1441
ISBN 978-1-922338-08-2