APPENDIX 12

ARROW LNG PLANT

Marine and Estuarine Ecology Impact Assessment

arrow energy
go further

coffey environments

SPECIALISTS IN ENVIRONMENTAL, SOCIAL AND SAFETY PERFORMANCE

MARINE AND ESTUARINE ECOLOGY IMPACT ASSESSMENT

Arrow LNG Plant

MARINE AND ESTUARINE ECOLOGY IMPACT ASSESSMENT

Arrow LNG Plant

October 2011

CR 7033_09_v6

Coffey Environments Australia Pty Ltd ABN 65140765902
(formerly Coffey Natural Systems)
Level 2, 12 Creek Street Brisbane QLD 4000 Australia
T (+61) (7) 3002 0400 F (+61) (7) 3002 0444
coffey.com

Project director	David Gwyther		
Project manager	Chelsea Kavanagh		
Version:	**Details:**	**Approved:**	**Date:**
CR 7033_09_v1	Initial draft to client	RL	May 2011
CR 7033_09_v2	Second draft to client	RL	August 2011
CR 7033_09_v3	Third draft to client	EW	September 2011
CR 7033_09_v4	Forth draft to client	EW	September 2011
CR 7033_09_v5	Fifth to client	EW	September 2011
CR 7033_09_v6	Final to client	EW	October 2011

CONTENTS

Figures

Tables

Plates

Attachments

Appendices

EXECUTIVE SUMMARY

Arrow CSG (Australia) Pty Ltd (Arrow Energy) is investigating the development of a liquefied natural gas (LNG) plant on Curtis Island. This technical study assesses the impacts of the project and project infrastructure on the marine and estuarine environment of Port Curtis. This impact assessment has been prepared through desktop and field studies of the study area.

Port Curtis forms a narrow coastal embayment of approximately 200 km^2 that separates Curtis Island from the mainland. The marine and estuarine environment of Port Curtis is characterised by a large tidal range of greater than 4 m and consequentially has high tidal currents and extensive intertidal areas, and is also influenced by freshwater inflow from a number of rivers and creeks, particularly the Calliope River and Boyne River. Port Curtis has naturally high levels of turbidity and suspended sediments.

The high tidal range results in a typical pattern of intertidal and coastal zonation from:

- Saltmarsh and mud flat areas that are inundated only during extreme spring tides.
- Intertidal mudflats and mangroves that dominate estuarine areas of Targinie Creek, The Narrows and North China Bay on the eastern shore of Port Curtis.
- Subtidal mudflats and tidal channels.
- Seagrass beds extending from intertidal to subtidal areas.
- Rock and reef habitats extending intertidally and subtidally from the rocky headlands, predominantly on Curtis Island on the eastern shore of Port Curtis.

Areas in and around Port Curtis also provide important habitats used by a diverse range of species, including the dugong (*Dugong dugon*), six of the world's seven species of protected marine turtles, cetaceans (including the potentially endemic Australian snubfin dolphin (*Orcaella heinsohni*) and Indo-Pacific humpback dolphin (*Sousa chinensis*)), the saltwater crocodile *(Crocodylus porosus)*, and a range of fish, nekton, sea snakes, seahorses and pipefish (syngnathid fishes), macrobenthic and plankton species. The likelihood of occurrence of some of these, especially the estuarine crocodile, is low.

As one of Australia's largest ports, Port Curtis serves numerous large and expanding industries. These include alumina and aluminium processing facilities, a coal-fired power station, a cement works, several chemical refineries and an extensive network of shipping wharves, storage and bulk handling facilities. The commercial wharves and activities that occur in the port are solely managed by the Gladstone Ports Corporation (GPC). Other industries such as recreational fishing, agriculture and tourism also occur in the area.

The potential issues and impacts identified and assessed include:

- Loss and disturbance of marine and estuarine habitat.
- Impacts on marine and estuarine fauna through:
  - Boat strike.
  - Underwater noise.
  - Lighting.
- Loss of commercial and recreational fishing access.

- Introduced species and pest species.
- Shipping activities and accidents.

In recent years, there has been increasing concern that intense, human-generated underwater sounds from activities such as seismic surveys and pile driving, may have the potential to interfere with the behaviour of marine fauna, particularly marine mammals that communicate and or navigate using sound (Richardson *et al*., 1995; McCauley *et al*., 2003a, Bailey *et al*., 2010). The effects of different levels and frequencies of noise on marine fauna are still not fully understood. The main sources of underwater noise arising from project construction will include pile driving, movements of vessels carrying equipment and personnel, and dredging activities.

Artificial light can modify natural illumination and cause disruption to visual cues of marine organisms, particularly marine turtles (Witherington, 1992). Most species of marine turtles nest at night and the impact of brightly lit industrial precincts along coastal margins can disorientate turtles and affect their behaviour (Limpus, 1971a). The closest turtle nesting beach is situated on the eastern side of Curtis Island around South End, approximately 8 km from the centre of the LNG site, and although in a direct line of sight, light glow generated by the Arrow LNG Plant at this distance would partially blend into other background light from other industrial facilities (AECOM, 2011).

The Port Curtis region supports significant recreational and commercial fishing. During the construction and operation of the Arrow LNG Plant, marine and estuarine exclusion zones will need to be created for the safety and security of employees and the community, as well as for overall security of the project.

The greatest risks of adverse shipping activities and accidents leading to oil spills are the frequency of LNG vessels moving in between Port Curtis and foreign ports and non-compliance with operational procedures or pilotage. Between 1987 and 2004, only 33 of the 700 incidents recorded in the Great Barrier Reef World Heritage Area (GBRWHA) were considered significant (Aston, 2006) and since 2006 only five major incidents have occurred (GBRMPA, 2006). For the Arrow LNG Plant, LNG carriers will move in and out of the port approximately 40 times per month (i.e., two LNG carriers per week for two x LNG trains and four LNG carriers per week for four x LNG Trains). However, even at full production (with anticipated LNG development of all plants to four trains), Arrow Energy LNG carriers will comprise less than 20% of all harbour traffic.

Where feasible, engineering design measures have been included to avoid impacts, however, where these are unavoidable, mitigation and management measures are proposed to reduce each impact as far as practicable. In the event that environmentally sensitive areas are severely impacted by the project and mitigation and management measures provide minimal recovery, offset strategies will be developed, in consultation with relevant stakeholders to address the loss.

Any project offsets will follow the principles outlined under the Commonwealth offsets policy including:

- Rehabilitation of ‘like for like’ habitats that demonstrate ecological equivalence in the Gladstone region (where feasible).

- Creation of artificial habitats that provide as similar as possible ecological functions as the area that is to be lost in the Gladstone region.

- Purchase, or otherwise manage under agreement, unprotected habitat and actively manage and protect the habitat as a conservation area. The habitat must demonstrate ecological equivalence to the area that is to be lost. Habitat should be purchased in the Gladstone region if possible, however, if this is not feasible greater conservation value may come from locating offsets elsewhere.

Given the predicted impacts of the project, Arrow Energy will also need to comply with environmental and legal criteria of the Queensland government environmental offsets policy. This is the overarching framework for specific-issue offset policy is the Fish Habitat Management Operational Policy FHMOP 005 (Dickson and Beumer, 2002). This policy follows similar principles to the Commonwealth policy; however, it provides specific information regarding fish habitat areas.

Operators of marine vessels should also:

- Manoeuvre within navigation channels to reduce the area of disturbance and to marine fauna.
- Where appropriate consider installing propeller guards on high speed vessels to reduce the impact of injury in the event of a boat strike.
- Consider operating eco-friendly marine vessels, which are powered by jet propulsion and have shallow drafts.

Underwater noise generated from pile driving and dredging activities can be typically reduced by the following:

- Implementing soft start procedures, where a sequential build-up of warning pulses will be carried out prior to full power pile driving activities.
- Prior to start up, observations should be made of the surrounding area for the presence of turtles, dugongs and dolphins.

In most circumstances underwater noise can be effectively managed, however, for certain impacts such as shipping, there are no practical ways to reduce the noise characteristics from marine vessels. Vessels generally are slow moving and their noise allows detection and avoidance by animals before any physical injury from sound.

Light generated from the LNG plant and associated infrastructure will be minimised by implementing a range of in-principle means such as:

- Using long wavelength lights, including red, orange or yellow lights.
- Filtering the light source to reduce short wavelength light, including white lights.
- Redirection and shielding of the light source onto work away from wider marine areas.
- Lowering the height of light source as far as practicable.
- Reducing reflective surfaces.

By minimising visible light at South End and where possible scheduling maintenance and associated flaring to periods outside turtle nesting seasons, the magnitude of the impact will be considered very low. Assuming mitigation measures are successfully implemented the residual effect of lighting is likely to be negligible. However, if the implementation of all mitigation measures is not feasible the magnitude of the impact will remain the same and light will still be visible to the South End community. Restricting flaring may not be possible given certain processes required for the operation and maintenance of the LNG plant. Given the intermediate frequency and short term effects of flaring on South End nesting beaches, the magnitude of adverse changes to the breeding of the turtle population would be low. Assuming all other mitigation measures are implemented, the residual effect of lighting on marine turtles is likely to be minor.

LNG carriers associated with the Arrow LNG Plant must comply with all listed shipping legislation and conventions, especially when passing through the Great Barrier Reef Marine Park (GBRMP). Project vessels will only traverse the GBRMP using recognised or designated navigation routes and will be under pilot from the port entrance. For spills, discharges, groundings and sinkings in the GBRMP and surrounding waters, Arrow Energy LNG carriers must ensure emergency response plans are in place, personnel are trained and such plans implemented if such an incident occurs. In the event an incident occurs within the port and the incident cannot be adequately contained by personnel of the vessel, then response plans governed by port and other authorities will be initiated. Also all waste generated on the Arrow Energy LNG carrier should be disposed of in facilities provided onboard. A facility will be provided by the LNG plant for the acceptance of Arrow Energy LNG carrier domestic waste as per the waste management plan.

The baseline scenario for this cumulative impact assessment includes all existing industry currently constructed and operating in the port and any project submitted for approval in the timeframe between the initial submission of the Arrow LNG Plant and the start up of the project.

Light generated by all four proposed projects, if approved, could potentially affect the behaviour of turtles at South End. The Arrow LNG Plant is the only one with a direct line of view at South End. However, all LNG projects are expected to cause an indirect glow from light emissions during the construction and operation of each facility, which is also likely to be visible from South End. The assessment of cumulative impacts will therefore be the combination of these direct and indirect sources. Given the distances involved and other background sources of glow, impacts are expected to remain very low.

The magnitude of the impacts generated by Arrow LNG Plant in association with the cumulative impacts of other industry and proposed projects will contribute to the permanent and temporary disturbance of marine and estuarine ecology values within the Port Curtis region. However, the effect of these impacts can be reduced with the implementation of the proposed mitigation measures to eliminate any major residual impact levels.

1. INTRODUCTION

Arrow CSG (Australia) Pty Ltd (Arrow Energy) is investigating the development of a liquefied natural gas (LNG) export facility on Curtis Island. This technical study assesses the impacts of the project and project infrastructure on the marine and estuarine ecological values within and surrounding the proposed Arrow LNG Plant.

1.1 Purpose and Scope

The study describes the proposed Arrow LNG Plant marine facilities and the potential impact that these facilities may have on the marine and estuarine environment during construction, operation and decommissioning. This study takes into account the Commonwealth and state legislative frameworks and international environmental commitments that are in place to protect the values of the marine and estuarine environment of the project study area. It is these frameworks and commitments within which the project must operate.

The study method uses the significance approach to impact assessment. This approach requires that the existing marine and estuarine ecological values (flora and fauna) are outlined along with their relevant sensitivities, which for this study, have been based on existing literature and targeted field investigations.

Impact assessment then compares the magnitude of the impact and sensitivity of the receptor, to determine the overall significance of the impact. The need and options for mitigation (e.g., feasible avoidance or engineering design) are proposed for each of the significant issues.

After the application of the mitigation measures, residual impacts are assessed and addressed along with cumulative impact of the project in association with other projects planned or currently under operation in the Gladstone region. This assessment will determine the degree to which the project contributes to the overall impact.

2. PROJECT DESCRIPTION

2.1 Proponent

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) facility on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project.

The proponent is a subsidiary of Arrow Energy Holdings Pty Ltd which is wholly owned by a joint venture between subsidiaries of Royal Dutch Shell plc and PetroChina Company Limited.

2.2 Arrow LNG Plant

Arrow Energy proposes to construct the Arrow LNG Plant in the Curtis Island Industry Precinct at the southwestern end of Curtis Island, approximately 6 km north of Gladstone and 85 km southeast of Rockhampton, off Queensland's central coast. In 2008, approximately 10% of the southern part of the island was added to the Gladstone State Development Area to be administered by the Queensland Department of Local Government and Planning. Of that area, approximately 1,500 ha (25%) has been designated as the Curtis Island Industry Precinct and is set aside for LNG development. The balance of the Gladstone State Development Area on Curtis Island has been allocated to the Curtis Island Environmental Management Precinct, a flora and fauna conservation area.

The Arrow LNG Plant will be supplied with coal seam gas from gas fields in the Surat and Bowen basins via high-pressure gas pipelines to Gladstone, from which a feed gas pipeline will provide gas to the LNG plant on Curtis Island. A tunnel is proposed for the feed gas pipeline crossing of Port Curtis.

The project is described below in terms of key infrastructure components: LNG plant, feed gas pipeline and dredging.

2.2.1 LNG Plant

Overview. The LNG plant will have a base-case capacity of 16 Mtpa, with a total plant capacity of up to 18 Mtpa. The plant will consist of four LNG trains, each with a nominal capacity of 4 Mtpa. The project will be undertaken in two phases of two trains (nominally 8 Mtpa), with a financial investment decision taken for each phase.

Operations infrastructure associated with the LNG plant includes the LNG trains (where liquefaction occurs; see 'Liquefaction Process' below), LNG storage tanks, cryogenic pipelines, seawater inlet for desalination and stormwater outlet pipelines, water and wastewater treatment, a 110 m high flare stack, power generators (see 'LNG Plant Power' below), administrative buildings and workshops.

Construction infrastructure associated with the LNG plant includes construction camps (see 'Workforce Accommodation' below), a concrete batching plant and laydown areas.

The plant will also require marine infrastructure for the transport of materials, personnel and product (LNG) during construction and operations (see 'Marine Infrastructure' below).

Construction Schedule. The plant will be constructed in two phases. Phase 1 will involve the construction of LNG trains 1 and 2, two LNG storage tanks (each with a capacity of between 120,000 m^3 and 180,000 m^3), Curtis Island construction camp and, if additional capacity is required, a mainland workforce accommodation camp. Associated marine infrastructure will also be required as part of Phase 1. Phase 2 will involve the construction of LNG trains 3 and 4 and potentially a third LNG storage tank. Construction of Phase 1 is scheduled to commence in 2014 with train 1 producing the first LNG cargo in 2017. Construction of Phase 2 is anticipated to commence approximately five years after the completion of Phase 1 but will be guided by market conditions and a financial investment decision at that time.

Construction Method. The LNG plant will generally be constructed using a modular construction method, with preassembled modules being transported to Curtis Island from an offshore fabrication facility. There will also be a substantial stick-built component of construction for associated infrastructure such as LNG storage tanks, buildings, underground cabling, piping and foundations. Where possible, aggregate for civil works will be sourced from suitable material excavated and crushed on site as part of the bulk earthworks. Aggregate will also be sourced from mainland quarries and transported from the mainland launch site to the plant site by roll-on, roll-off vessels. A concrete batching plant will be established on the plant site. Bulk cement requirements will be sourced outside of the batching plant and will be delivered to the site by roll-on roll-off ferries or barges from the mainland launch site.

LNG Plant Power

Power for the LNG plant and associated site utilities may be supplied from the electricity grid (mains power), gas turbine generators, or a combination of both, leading to four configuration options that will be assessed:

- Base case (mechanical drive): The mechanical drive configuration uses gas turbines to drive the LNG train refrigerant compressors, which is the traditional powering option for LNG facilities. This configuration would use coal seam gas and end flash gas (produced in the liquefaction process) to fuel the gas turbines that drive the LNG refrigerant compressors and the gas turbine generators that supply electricity to power the site utilities. Construction power for this option would be provided by diesel generators.
- Option 1 (mechanical/electrical – construction and site utilities only): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains. During construction, mains power would provide power to the site via a cable (30-MW capacity) from the mainland. The proposed capacity of the cable is equivalent to the output of one gas turbine generator. The mains power cable would be retained to power the site utilities during operations, resulting in one less gas turbine generator being required than the proposed base case.
- Option 2 (mechanical/electrical): This configuration uses gas turbines to drive the refrigerant compressors in the LNG trains and mains power to power site utilities. Under this option, construction power would be supplied by mains power or diesel generators.
- Option 3 (all electrical): Under this configuration mains power would be used to supply electricity for operation of the LNG train refrigerant compressors and the site utilities. A switchyard would be required. High-speed electric motors would be used to drive the LNG train

refrigerant compressors. Construction power would be supplied by mains power or diesel generators.

Liquefaction Process

The coal seam gas enters the LNG plant where it is metered and split into two pipe headers which feed the two LNG trains. With the expansion to four trains the gas will be split into four LNG trains.

For each LNG train, the coal seam gas is first treated in the acid gas removal unit where the carbon dioxide and any other acid gases are removed. The gas is then routed to the dehydration unit where any water is removed and then passed through a mercury guard bed to remove mercury. The coal seam gas is then ready for further cooling and liquefaction.

A propane, precooled, mixed refrigerant process will be used by each LNG train to liquefy the predominantly methane coal seam gas. The liquefaction process begins with the propane cycle. The propane cycle involves three pressure stages of chilling to pre-cool the coal seam gas to- 33°C and to compress and condense the mixed refrigerant, which is a mixture of nitrogen, methane, ethylene and propane. The condensed mixed refrigerant and precooled coal seam gas are then separately routed to the main cryogenic heat exchanger, where the coal seam gas is further cooled and liquefied by the mixed refrigerant. Expansion of the mixed refrigerant gases within the heat exchanger removes heat from the coal seam gas. This process cools the coal seam gas from - 33°C to approximately - 157°C. At this temperature the coal seam gas is liquefied (LNG) and becomes 1/600th of its original volume. The expanded mixed refrigerant is continually cycled to the propane precooler and reused.

LNG is then routed from the end flash gas system to a nitrogen stripper column which is used to separate nitrogen from the methane, reducing the nitrogen content of the LNG to less than 1 mole per cent (mol%). LNG separated in the nitrogen stripper column is pumped for storage on site in full containment storage tanks where it is maintained at a temperature of -163°C.

A small amount of off-gas is generated from the LNG during the process. This regasified coal seam gas is routed to an end flash gas compressor where it is prepared for use as fuel gas.

Finally, the LNG is transferred from the storage tanks onto Arrow Energy LNG carriers via cryogenic pipelines and loading arms for transportation to export markets. The LNG will be regasified back into sales specification gas on shore at its destination location.

Workforce Accommodation

The LNG plant (Phase 1), tunnel, feed gas pipeline, and dredging components of the project each have their own workforces with peaks occurring at different stages during construction. The following peak workforces are estimated for the project:

- LNG plant Phase 1 peak workforce of 3,500, comprising 3,000 construction workers: 350 engineering, procurement and construction (EPC) management workers and 150 Arrow Energy employees.
- Tunnel peak workforce of up to 100.
- Feed gas pipeline (from the mainland to Curtis Island) peak workforce of up to 75.
- A dredging peak workforce of between 20 and 40.

Two workforce construction camp locations are proposed: the main construction camp at Boatshed Point on Curtis Island, and a possible mainland overflow construction camp, referred to as a temporary workers accommodation facility (TWAF). Two potential locations are currently being considered for the mainland TWAF; in the vicinity of Gladstone city on the former Gladstone Power Station ash pond No.7 (TWAF7) or in the vicinity of Targinnie on a primarily cleared pastoral grazing lot (TWAF8). Both potential TWAF sites include sufficient space to accommodate camp infrastructure and construction laydown areas. The TWAF and its associated construction laydown areas will be decommissioned on completion of the Phase 1 works.

Of the 3,000 construction workers for the LNG plant, it is estimated that between 5% and 20% will be from the local community (and thus will not require accommodation) and that the remaining fly-in, fly-out workers will be accommodated in construction camps. The 350 EPC management and 150 Arrow Energy employees are expected to relocate to Gladstone with the majority housed in company facilitated accommodation.

The tunnel workforce of 100 people and gas pipeline workforce of 75 people are anticipated to be accommodated in the mainland in company facilitated accommodation. The dredging workforce of 20 to 40 workers will be housed onboard the dredge vessel.

Up to 2,500 people will be housed at Boatshed Point construction camp. Its establishment will be preceded by a pioneer camp at the same locality which will evolve into the completed construction camp.

Marine Infrastructure

Marine facilities include the LNG jetty, materials offloading facility (MOF), personnel jetty and mainland launch site.

LNG Jetty. LNG will be transferred from the storage tanks on the site to the LNG jetty via above ground cryogenic pipelines. Loading arms on the LNG jetty will deliver the product to an LNG carrier. The LNG jetty will be located in North China Bay, adjacent to the northwest corner of Hamilton Point.

MOF. Delivery of materials to the site on Curtis Island during the construction and operations phases will be facilitated by a MOF where roll-on, roll-off or lift-on, lift-off vessels will dock to unload preassembled modules, equipment, supplies and construction aggregate. The MOF will be connected to the LNG plant site via a heavy-haul road.

Boatshed Point (MOF 1) is the base-case MOF option and would be located at the southern tip of Boatshed Point. The haul road would be routed along the western coastline of Boatshed Point (abutting the construction camp to the east) and enters the LNG Plant site at the southern boundary. A quarantine area will be located south of the LNG plant and will be accessed via the northern end of the haul road.

Two alternative options are being assessed, should the Boatshed Point option be determined to be not technically feasible:

- South Hamilton Point (MOF 2): This MOF option would be located at the southern tip of Hamilton Point. The haul road from this site would traverse the saddle between the hills of Hamilton Point to the southwest boundary of the LNG plant site. The quarantine area for this option will be located southwest of the LNG plant near the LNG storage tanks.

- North Hamilton Point (MOF 3): This option involves shared use of the MOF being constructed for the Santos Gladstone LNG Project (GLNG Project) on the northwest side of Hamilton Point (south of Arrow Energy's proposed LNG jetty). The GLNG Project is also constructing a passenger terminal at this site, but it will not be available to Arrow Energy contractors and staff. The quarantine area for this option would be located to the north of the MOF. The impacts of construction and operation of this MOF option and its associated haul road were assessed as part of the GLNG Project and will not be assessed in this EIS.

Personnel Jetty. During the peak of construction, base case of up to 1,100 people may require transport to Curtis Island from the mainland on a daily basis. A personnel jetty will be constructed at the southern tip of Boatshed Point to enable the transfer of workers from the mainland launch site to Curtis Island by high-speed vehicle catamarans (Fastcats) and vehicle or passenger ferries (ROPAX). This facility will be adjacent to the MOF constructed at Boatshed Point. The haul road will be used to transport workers to and from the personnel jetty to the construction camp and LNG plant site. A secondary access for pedestrians will be provided between the personnel jetty and the construction camp.

Mainland Launch Site. Materials and workers will be transported to Curtis Island via the mainland launch site. The mainland launch site will contain both a passenger terminal and a roll-on, roll-off facility. The passenger terminal will include a jetty and transit infrastructure, such as amenities, waiting areas and car parking. The barge or roll-on ,roll-off facility will have a jetty, associated laydown areas, workshops and storage sheds.

The two location options for the mainland launch site are:

- Launch site 1: This site is located north of Gladstone city near the mouth of the Calliope River, adjacent to the existing RG Tanna coal export terminal.
- Launch site 4N: This site is located at the northern end of the proposed reclamation area for the Fishermans Landing Northern Expansion Project, which is part of the Port of Gladstone Western Basin Master Plan. The availability of this site will depend on how far progressed the Western Basin Dredging and Disposal Project is at the time of construction.

2.2.2 Feed Gas Pipeline

An approximately 8-km long feed gas pipeline will supply gas to the LNG plant from its connection to the Arrow Surat Pipeline (formerly the Surat Gladstone Pipeline) on the mainland adjacent to Rio Tinto's Yarwun alumina refinery. The feed gas pipeline will be constructed in three sections:

- A short length of feed gas pipeline will run from the proposed Arrow Surat Pipeline to the tunnel launch shaft, which will be located on a mudflat south of Fishermans Landing, just south of Boat Creek. This section of pipeline will be constructed using conventional open-cut trenching methods within a 40-m wide construction right of way.
- The next section of the feed gas pipeline will traverse Port Curtis harbour in a tunnel to be bored under the harbour from the mainland tunnel launch shaft to a receival shaft on Hamilton Point. The tunnel under Port Curtis will have an excavated diameter of up to approximately 6 m and will be constructed by a tunnel boring machine that will begin work at the mainland launch shaft. Tunnel spoil material will be processed through a de-sanding plant to remove the bentonite and water and will comprise mainly a finely graded fill material, which will be deposited in a spoil placement area established within bund walls constructed adjacent to the

launch shaft. Based on the excavated diameter, approximately 223,000 m^3 of spoil will be treated as required for acid sulfate soil and disposed of at this location.

- From the tunnel receival shaft on Hamilton Point, the remaining section of the feed gas pipeline will run underground to the LNG plant, parallel to the above ground cryogenic pipelines. This section will be constructed using conventional open-cut trenching methods within a 30-m wide construction right of way. A permanent easement up to 30-m wide will be negotiated with the relevant land manager or owner.

Should one of the electrical plant power options be chosen, it is intended that a power connection will be provided by a third party to the tunnel launch shaft, whereby Arrow Energy would construct a power cable within the tunnel to the LNG plant.

Other infrastructure, such as communication cables, water and wastewater pipelines, may also be accommodated within the tunnel.

2.2.3 Dredging

Dredging required for LNG shipping access and swing basins has been assessed under the Gladstone Ports Corporation’s Port of Gladstone Western Basin Dredging and Disposal Project. Additional dredging within the marine environment of Port Curtis may be required to accommodate the construction and operation of the marine facilities. Up to five sites may require dredging:

- Dredge site 1 (dredge footprint for launch site 1): The dredging of this site would facilitate the construction and operation of launch site 1. This dredge site is located in the Calliope River and extends from the intertidal area abutting launch site 1, past Mud Island to the main shipping channel. The worst-case dredge volume estimated at this site is approximately 900,000 m^3.

- Dredge site 2 (dredge footprint for launch site 4N): The dredging of this site would facilitate the construction and operation of launch site 4N. This dredge site would abut launch site 4N and extend east from the launch site to the shipping channel. The worst-case dredge volume identified at this site is approximately 2,500 m^3.

- Dredge site 3 (dredge footprint for Boatshed Point MOF 1): The dredging of this site would facilitate the construction and operation of the personnel jetty and MOF at Boatshed Point. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000 m^3.

- Dredge site 4 (dredge footprint for Hamilton Point South MOF 2): The dredging of this site would facilitate the construction and operation of the MOF at Hamilton Point South. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The worst-case dredge volume identified at this site is approximately 50,000 m^3.

- Dredge site 5 (dredge footprint for LNG jetty): The dredging of this site will facilitate the construction of the LNG jetty at Hamilton Point. This dredge site extends from the berth pocket to be dredged as part of the Western Basin Strategic Dredging and Disposal Project to the shoreline and is required to enable a work barge to assist with construction of the LNG jetty. The worst-case dredge volume identified is approximately 120,000 m^3.

The spoil generated by dredging activities will be placed and treated for acid sulfate soils (as required) in the Port of Gladstone Western Basin Dredging and Disposal Project reclamation area.

2.2.4 Decommissioning

As items of the plant are no longer required they will be decommissioned on an as needs basis. A decommissioning plan will be prepared for the facility at a time to be determined prior to the end of its operational life.

Decommissioning will be carried out in accordance with this plan, which will comply with the regulatory requirements in force at the time of decommissioning. The site will be stabilised to ensure that it does not pose any risk to public safety or the environment. The preparation of the decommissioning plan will be undertaken in consultation with the appropriate regulatory authorities and other stakeholders.

3. LEGISLATIVE CONTEXT

The following section addresses the project specific Commonwealth and state legislation, policies and subordinate legislation enforced to protect the values of the marine and estuarine environments. It also describes internationally protected areas assigned to control the type and level of activities that occur within or in close proximity to these areas.

3.1 Commonwealth Legislation

The following Commonwealth legislation is relevant to the protection of marine and estuarine environmental values during the construction, operation and decommissioning of the project.

Environment Protection and Biodiversity Conservation Act 1999

The Environment Protection and Biodiversity Act 1999 (EPBC Act) is applicable to developments that may have impacts on matters of National Environmental Significance (Protected Matters). It has been implemented to provide protection for the environment and heritage, promote ecologically sustainable development, conservation of biodiversity and management of the environment. Specific to the project, a number of protected matters covered by the EPBC Act are relevant to the project including:

- Commonwealth marine areas (sections 23 and 24A).
- Listed threatened species (sections 18 and 18A).
- Listed migratory species (section 20 and section 20A).
- Listed marine species (sections 18 and 18A).
- World heritage areas (section 12 and section 15A).
- Wetlands of international importance (e.g., RAMSAR wetlands) (section 16 and section 17B)

These are discussed in Section 5 of this report.

Great Barrier Reef Marine Park Act 1975

The Great Barrier Reef Marine Park Act 1975 is the predominant legislative measure to promote and enforce the long-term protection and conservation of environmental, biodiversity and heritage values pertaining to the Great Barrier Reef region. This involves the implementation of a management framework for the ecologically sustainable use of the Great Barrier Reef region while aiding Australia's international responsibilities to world heritage and the environment.

The project is not located within the boundaries of the GBRMP but given the proximity and the proposed navigation of Arrow Energy LNG carriers through approved routes around the marine park in consultation with the Great Barrier Reef Marine Park Authority (GBRMPA) as appropriate.

The Great Barrier Reef Maine Park Regulations 1983, made under the Great Barrier Reef Marine Park Act, outlines offence provisions, compulsory pilotage, Environmental Management Charge, plans of management and review rights of the GBRMP. Specific to the project, the regulations declare Port Curtis and its adjacent waters as part of the Port of Gladstone-Rodds Bay zone B dugong protection area (DPA). The DPAs have been declared as special management areas under the Great Barrier Reef Marine Park Regulations 1983 and the Great Barrier Reef Marine Park Zoning Plan 2003. Section 5.4.1 further discusses dugongs. Bordered by the mainland, the

DPA extends from the lower limits of The Narrows between Friend Point and Laird Point and follows the west coastline of Curtis Island. It then adjoins to North Point, Facing Island and continues along the west coastline across open waters through to Rodds Peninsula.

3.2 State Legislation

The following state legislation is relevant to the protection of marine and estuarine environmental values during the construction and operation of the project.

Coastal Protection and Management Act 1995

The Coastal Protection and Management Act 1995 recognises the need for the protection, conservation and rehabilitation of coastal resources and biodiversity. It provides education and a coastal comprehensive management framework for ecologically sustainable development.

The Coastal Protection and Management (Coastal Management Districts) Regulation 2003 in accordance with the Coastal Protection and Management Act, refers to the Curtis Coast Coastal Management District and management plan. Specific to the project, the plan identifies and sets management for ‘areas of state significance (natural resources)’ that exist within Port Curtis’ growing industry precinct.

Environmental Protection Act 1994

The Environmental Protection Act 1994 (EP Act) has been implemented to protect Queensland’s environment while allowing for ecologically sustainable development,

The Environmental Protection Regulation 2008 in accordance with the Environmental Protection Act lists category A and B environmentally sensitive areas (ESA) that are protected and may be potentially impacted by the proposed project constructions operations and decommissioning. The study area includes category B ESAs such as the World Heritage management area and a critical habitat or major interest identified under a conservation plan (Directory of Important Wetlands of Australia and Port of Gladstone-Rodds Bay DPA). The regulation also addresses water contamination, which is relevant to the project and will be addressed in the coastal processes, water quality and hydrodynamics technical study.

The Environmental Protection (Noise) Policy 2008 in accordance with the Environmental Protection Act identifies environmental values that are to be enhanced or protected. Specific to the project it considers the health and biodiversity of ecosystems and has an acoustic quality objective to preserve the amenity of the marine area.

Fisheries Act 1994

The Fisheries Act 1994 provides for the management, use and protection of fisheries resources and fish habitats in a way that is ecologically sustainable. It further, provides a management framework to regulate community aquaculture and other commercial activities. Specific to the project, the act protects all marine plants, including seagrass, salt couch and mangroves from being intentionally removed, damaged or destroyed. It also identifies the relevant codes that apply if operations are to remove, damage or destroy marine plants.

The Fisheries Regulation 2008, in accordance with the Fisheries Act, declares fish habitat areas (FHAs) to allow for the protection of significant marine and estuarine habitats that support ecosystems and sustain fisheries. At present, 70 fish habitat areas have been assigned along the coast of Queensland. These designated areas are safeguarded from physical disturbance associated with coastal development. The project is not situated and does not disturb any declared fish habitat areas. Colosseum Inlet situated 20 km south of Gladstone and the Fitzroy River located near the northern end of Curtis Island, southeast of Rockhampton, are the closest fish habitat areas to the study area.

Specific to the project, the regulation recognises Port Curtis and its adjacent waters as part of the Port of Gladstone-Rodds Bay zone B DPA. It declares restrictions for netting use and general activities in zone A and B DPAs.

Marine Parks Act 2004

The Marine Parks Act 2004 supports the conservation of the marine environment. The act provides for the declaration and establishment of marine parks and associated zoning and management plans. It further recognises cultural, economic, environmental and social relationships within marine parks and surrounding areas.

The Marine Parks Regulations 2006, in accordance with the Marine Parks Act, includes provisions relating to the zoning and objectives for those areas within marine parks, regulations associated with entry, use and the type of activities permitted within marine parks and review rights. Specific to the project, the regulation declares the zoning and protection of the Great Barrier Reef Coast Marine Park (GBR Coast MP); a state enforced marine park that compliments the Commonwealth GBRMP. The boundary extends the entire length of GBRMP and is described in Schedule 2 of the regulation as the tidal waters and tidal land within the Mackay/Capricorn Management Area, Townsville/Whitsunday Management Area, Cairns/Cooktown Management Area, Far Northern Management Area and the Outer Islands Management Area. The study area is situated outside of, but adjacent to the GBR Coast MP.

Nature Conservation Act 1992

The Nature Conservation Act 1992 (NCA) is the predominant state legislation that supports the conservation of nature. The act provides for the dedication, declaration and management of protected areas, protection of wildlife and its habitat in association with ecologically sustainable use of such wildlife.

The Nature Conservation (Wildlife) Regulation 2006 in accordance with the Nature Conservation Act catalogues the flora and fauna recognized as extinct, endangered, vulnerable, rare, near threatened, least concern, international and prohibited that may be impacted by the project. The regulation further addresses the significance and declared management intent for each class.

The Nature Conservation (Dugong) Conservation Plan 1999 in accordance with the Nature Conservation Act, outlines management strategies necessary to achieve the protection and conservation of the dugong (*Dugong dugon*). Such strategies include, reducing threats to seagrass habitats and minimising the impacts of anthropogenic activities through restricted use and permitting. The plan further declares Port Curtis and its adjacent waters as part of the Port of Gladstone-Rodds Bay zone B (restricted use) DPA.

The Nature Conservation (Whales and Dolphins) Conservation Plan 1997 in accordance with the Nature Conservation Act is designed to protect and conserve whales and dolphins in Queensland waters. The plan outlines management strategies to minimise harm and distress caused by anthropogenic activities such as pollution, noise disturbance and direct contact that may result from the construction and operation of the project.

The Nature Conservation (Estuarine Crocodile) Conservation Plan 2007 in accordance with the Nature Conservation Act outlines the conservation of viable populations of saltwater crocodile and sustainable use of commercial stock that may be impacted by the project. However, crocodile populations, wild or farmed, are not likely to be encountered in the study area.

The Nature Conservation (Protected Areas) Regulation 1994 in accordance with the Nature Conservation Act provides a list of former and current descriptions for protected areas as declared by the state of Queensland. Specific to the project, the regulation identifies national parks, conservation parks, resource reserves and nature refuges that are of particular importance to marine and estuarine ecology in and adjacent to Port Curtis.

Vegetation Management Act 1999

The Vegetation Management Act 1999 (Qld) (VM Act) has been enacted to manage the vegetation clearing in a way that conserves remnant vegetation, prevents land degradation and biodiversity loss and reduce greenhouse gas emissions. .It is assumed that the Arrow LNG Plant study area is located within Queensland Bioregion 8, as per the VM Act.

- The VM Act does not apply on all tenures or vegetation types. The Forestry Act 1959 (Qld) applies in relation to State Forests and authorises any activities such as forest practice within these areas.
- The Nature Conservation Act 1992 (Qld) applies to forest reserves (sections 70A and 70C of NCA), and protected areas including national parks, conservation parks, resources reserves, nature refuges, coordinated conservation areas, wilderness areas, World Heritage management areas, and international agreement areas (section 14 of the NCA).

Section 8 of the VM Act states "..vegetation is a native tree or plant other than the following – (a) grass or non-woody herbage; (b) a plant within a grassland regional ecosystem prescribed under a regulation; (c) a mangrove." Clearing of mangroves is regulated under the Fisheries Act 1994 (Qld). Clearing grasses or other non-woody herbage may requirement permits under the Land Protection (Pest and Stock Route Management) Act 2002 (Qld) in relation to declared pest permits, local law permits under the Local Government Act 2009 (Qld).

Schedule 24, Part 1 of the Sustainable Planning Regulation 2009 (Qld) (SPR) identifies clearing of native vegetation, which is not assessable development under Schedule 3, Part 1, Table 4, Item 1. Schedule 24, Part 1, 1 (6) of the SPR excludes clearing and other activities or matters for land generally relating to "..a mining activity or a chapter 5A activity..". Of relevance to this project, Chapter 5A activity is a petroleum activity, as regulated under the Environmental Protection Act 1994 (Qld). Part 2 of Schedule 24 of the SPR provides further exemptions in relation to the clearing of particular land, being:

- Freehold land.
- Indigenous land.
- Land subject to a lease under the Land Act 1994 (Qld).

- Land that is a road under the Land Act 1994.
- Particular trust land under the Land Act 1994.
- Unallocated State land under the Land Act 1994.
- Land subject to a licence or permit under the Land Act 1994.

The Vegetation Management Regulation 2000 in accordance with the VM Act declares the different categorises of regional ecosystems in Queensland and vegetation clearing approvals and management plan requirements. Specific to the project, the regulation provides a list of ‘endangered’, ‘of concern’ and ‘of least concern’ regional ecosystems for the South Eastern Queensland bioregion, which includes a range of marine and estuarine plants that may be present in the study area, and areas of potential disturbance. Regrowth vegetation was not included within this study. All proposed project infrastructure is located within the South Eastern Queensland bioregion.

3.3 Policies and Subordinate Legislation

The following policies and subordinate legislation are relevant to the protection of marine and estuarine environmental values during the construction and operation of the project:

- Draft Policy Statement: Use of environmental offsets under the Environment Protection and Biodiversity Conservation Act 1999 (Cwlth) 2007.
- Recovery Plan for Marine Turtles in Australia (Cwlth) 2003.
- Great Barrier Reef Marine Park Zoning Plan (Cwlth) 2003.
- Queensland Government Environmental Offsets Policy (Qld) 2008.
- Fish Habitat Management Operational Policy FHMOP 005 (Qld) 2004 (Dixon and Beumer, 2002).
- Policy for Vegetation Management Offsets (Qld) 2006 (Bradley, 2009).
- Marine Parks (Great Barrier Reef Coast) Zoning Plan (Qld) 2004.
- Policy Statement 2.1 Interactions between offshore seismic exploration and whales 2008.

3.4 Internationally Protected Areas

The following internationally protected areas must be considered during the construction and operation of the project.

Great Barrier Reef World Heritage Area

The Great Barrier Reef World Heritage Area (GBRWHA) is renowned for its extensive coral reef framework and rich biodiversity. As a whole, the reef supports broad scale distribution of seagrass, mangrove, benthic and coral reef habitats. The reef was proclaimed as a World Heritage Area in 1981 having met all four world heritage criteria. The criteria for the time included:

- Outstanding example representing a major stage of the earth’s evolutionary history.
- Outstanding example representing significant ongoing geological processes, biological evolution and man’s interaction with his natural environment.

- Contain unique, rare and superlative natural phenomena, formations and features and areas of exceptional natural beauty.
- Provide habitats where populations of rare and endangered species of plants and animals still survive.

The project is situated within the GBRWHA.

Ramsar Wetlands

Under the Ramsar Convention, an international government agreement declared for the conservation and sustainable use of wetlands, five Ramsar sites were listed within Queensland. These sites are Great Sandy Strait, Currawinya Lakes, Shoalwater Bay and Corio Bay, Bowling Green Bay and Moreton Bay. Although Port Curtis is not listed as a Ramsar wetland, it is considered a nationally important wetland under the Directory of Important Wetlands of Australia (Environment Australia (Environment Australia, 2001), as it supports a versatile set of habitat types including salt marshes, mudflats, mangroves and water bodies. These habitats contribute to a complex and intricate ecosystem that sustains fisheries and supports the health of the environment and residing organisms. The study area is situated within the Port Curtis nationally important wetlands.

For information regarding waterbirds and water mouse in regards to Ramsar wetlands, and on legislation regarding bird migration (i.e., Japan-Australia Migratory Bird Agreement (JAMBA), China-Australia Migratory Bird Agreement (CAMBA) and Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA)) please see the terrestrial ecology impact assessment (Ecosure, 2011).

4. STUDY METHOD

The following section addresses the impact assessment method used in order to assess the potential impacts of the Arrow LNG Plant on the marine and estuarine ecological values within the study area.

4.1 Approach to Existing Marine and Estuarine Environment

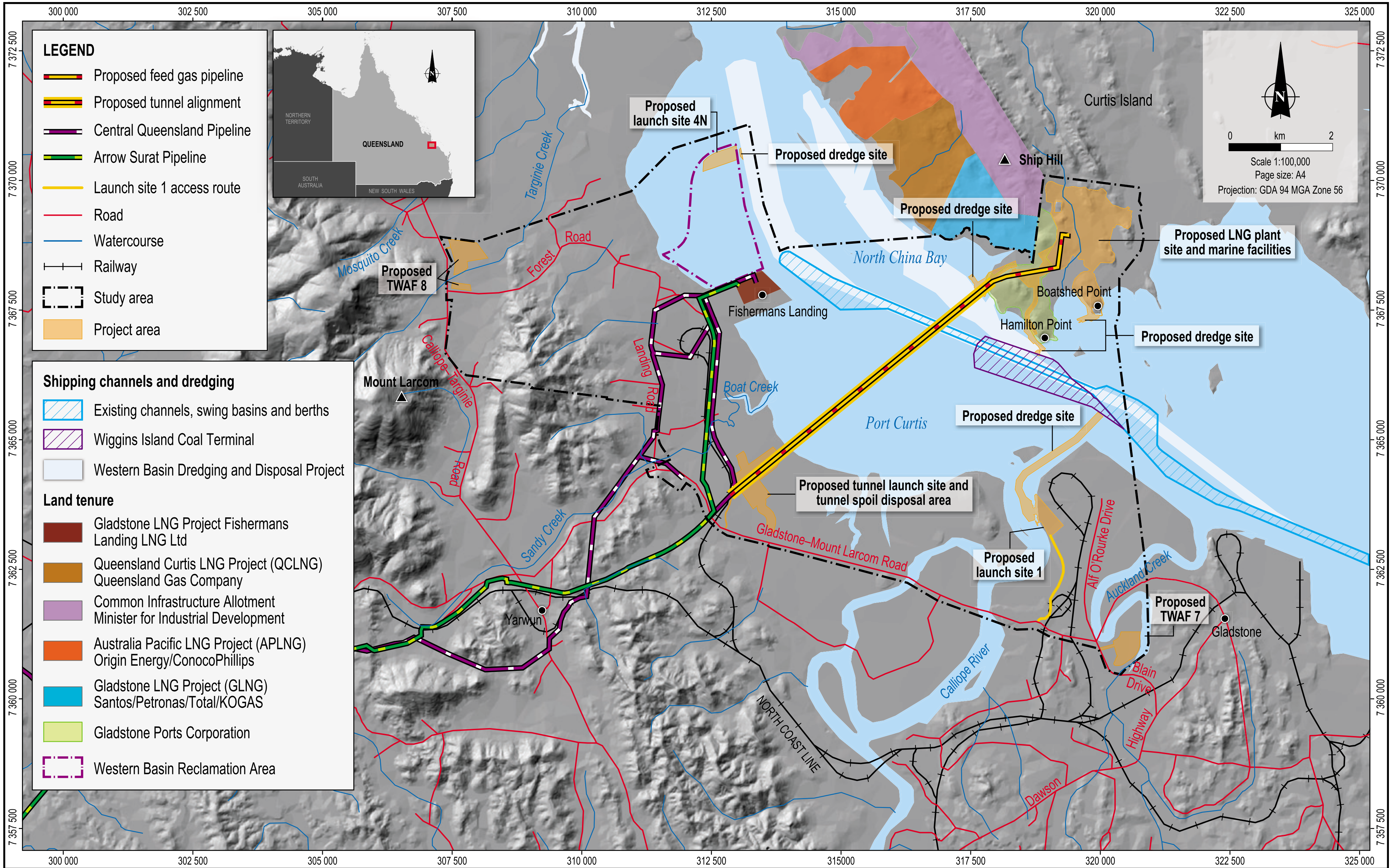
The marine and estuarine environment of Port Curtis has been extensively studied and monitored in recent years. Information available includes research published in the scientific literature as well as reports coordinated through the Port Curtis Integrated Monitoring Program (PCIMP), such as the ecosystem health summaries and other relevant monitoring and impact assessment studies. In this section, Port Curtis is defined as tidal waters and tidal land being bordered by the mainland and extending from between Friend Point and Laird Point (the lower limits of The Narrows) and following the west coastline of Curtis Island. It then adjoins Facing Island and continues along the west coastline of Facing Island and then direct across open waters to Canoe Point, Tannum Sands. This defined area provides context of Port Curtis with greater relevance to the scale of the project as shown in Figure 1.

Additional areas on both the mainland and Curtis Island above the highest astronomical tide (HAT) are not considered as part of the marine and estuarine ecology assessment and are covered in the terrestrial ecology study (Ecosure, 2011). This is with the exception of areas of intertidal mudflat which are assessed for their importance to shorebird species and mangrove habitat for water mouse.

While the existing published information provides adequate characterisation of the overall area, it does not provide specific descriptions of the localities where the Arrow LNG Plant site facilities are proposed. In order to describe the existing environment within the area of disturbance of the project's LNG jetty, MOF and launch site, targeted and supplementary field investigations were undertaken by Central University Queensland to characterise the habitats and environmental values of these areas that may be directly affected by project facilities (Arrow LNG Plant: Estuarine and Marine Ecology Field Investigations 2010-2011 (Phase I & II)). This report can be found in Appendix A.

There is little development at any of these locations at present; hence the intertidal and subtidal habitats are essentially natural and not directly modified from port or other activities. The habitats and resources investigated in the field surveys included mangroves, saltmarsh, intertidal and subtidal benthos, seagrass and fish communities (Appendix A). The broader areas investigated are shown in Figure 2 and included:

- North China Bay: location of an LNG jetty (excluding dredging for swing basin) (base case).
- South Hamilton Point: location of a MOF option (alternative case).
- Boatshed Point: location of the passenger terminal and a MOF option (base case).
- Calliope River: location of a mainland marine terminal option (Launch 1) and associated dredging (base case).
-



Source:
Place names, roads and watercourses from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Proposed feed gas pipeline, proponents and DEM from Coffey Environments.
Western Basin Dredging Master Plan from Gladstone Ports Corporation.

coffey environments

Date:	29.09.2011
MXD:	7033CA_07_GIS034_v1_4
File Name:	7033CA_MNE_F001_GIS_GL

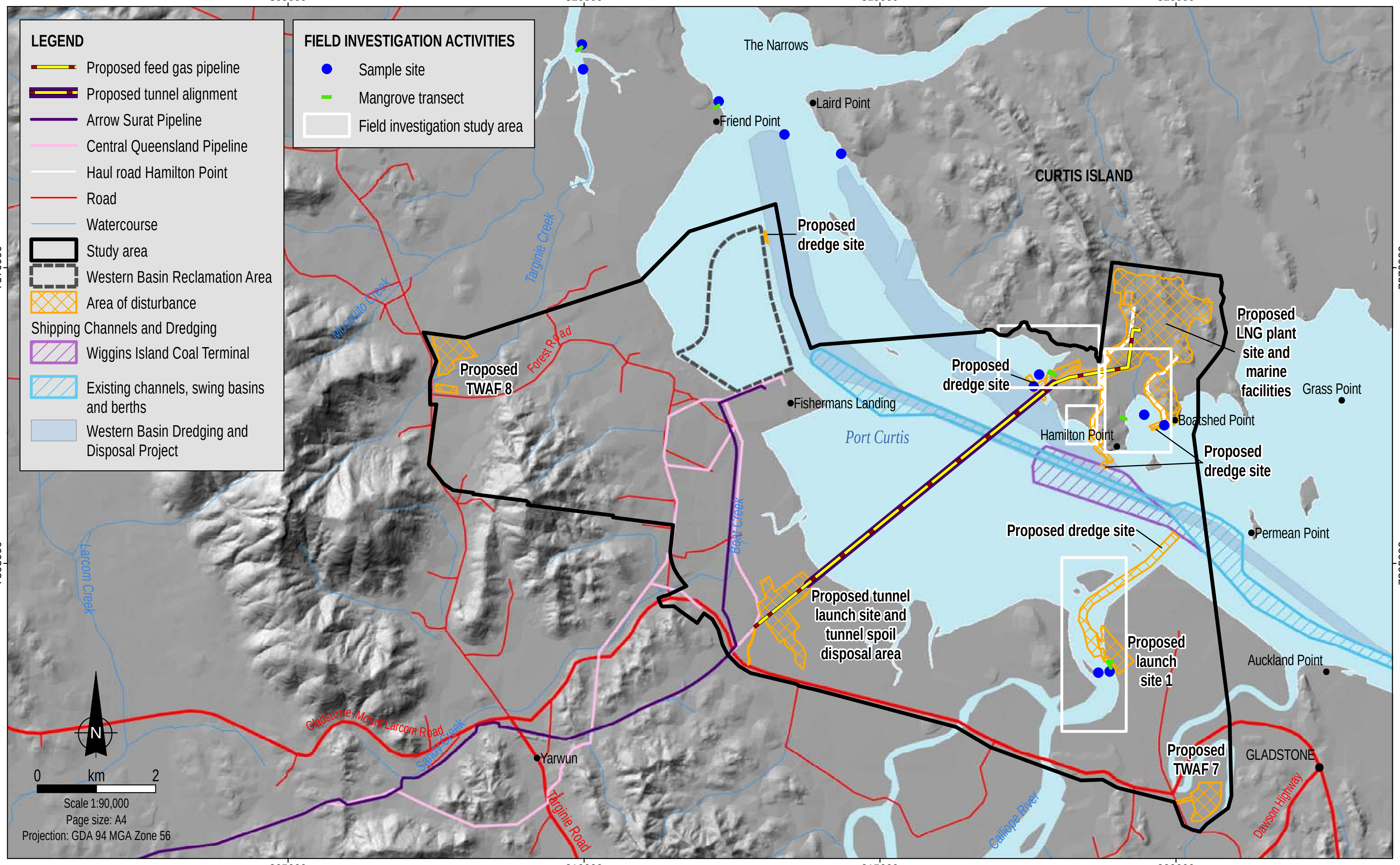
Arrow Energy

Arrow LNG Plant

arrow energy go further

Site locality

Figure No: 1



Source:
Place names, roads and watercourses from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Field investigation study areas, sample sites and mangrove transects from CQU.
Western Basin Dredging Master Plan from Gladstone Ports Corporation.
Proposed feed gas pipeline, area of disturbance and DEM from Coffey Environments.

coffey environments

Date:	03.10.2011
MXD:	7033CA_MNE_GIS002_v1_2
File Name:	7033CA_MNE_F002_GIS

Arrow Energy

Arrow LNG Plant

arrow energy go further

Field investigation study area

Figure No: 2

Fishermans Landing: location of a mainland marine terminal option (Launch 4N) and associated dredging (alternative case).

- The Narrows area: to provide for broader area of habitat comparisons in Port Curtis (although The Narrows is outside the direct project study area).

The aims of the field investigations were to:

- Investigate intertidal and subtidal macroinvertebrate communities within proposed areas of infrastructure for the Arrow LNG Plant.
- Determine sediment particle sizes and organic content at potential development sites within the proposed Arrow LNG Plant study area.
- Determine mangrove habitat distribution and seagrass meadow community composition within the study area.
- Investigate fish assemblages within the mangrove habitat/seagrass and soft-sediment areas of proposed infrastructure.

Macroinvertebrate and sediment samples were taken at random coordinates within the broader field investigation study areas (see Figure 2). The information from the desktop and field investigations was used to determine the environmental values and sensitivity of the marine and estuarine ecology in Port Curtis and characterise the fishing activities.

4.2 Approach to Impact Assessment

The approach to impact assessment is based upon consideration of the existing environment, i.e., the environmental values or sensitivities being impacted, and the assessment of the magnitude of an impact on those values. The interaction between environmental sensitivity and magnitude of impact is expressed in a matrix that takes into account factors such as the duration, geographical extent and severity of impacts, and any formal status or sensitivity of each receptor. The approach is described in this section as the potential scales of impact apply specifically to the marine environment. It draws on information about the existing environment in the nearshore marine characterisation study (Appendix A), and on other sources of literature and databases, which describe the existing nearshore marine and estuarine environment in the study area. The potential impacts and the significance of these impacts associated with the construction, operation and decommissioning of the LNG plant and marine infrastructure (i.e., LNG jetty, MOF, feed gas pipeline and launch site) on marine and estuarine ecology are assessed in Section 6.

The assessment of sensitivity for marine flora and fauna within Port Curtis draws on information on the conservational status of a species provided primarily from the IUCN Red List of Threatened Species (IUCN, 2010). This list provides categories of conservational status, outlined below:

- **Extinct**. A taxon is Extinct when there is no reasonable doubt that the last individual has died.
- **Extinct in the Wild**. A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalized population (or populations) well outside the past range.

- **Critically Endangered**. A taxon is Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered and it is therefore considered to be facing an extremely high risk of extinction in the wild.
- **Endangered**. A taxon is Endangered when the best available evidence indicates that it meets any of the criteria A to E for Endangered and it is therefore considered to be facing a very high risk of extinction in the wild.
- **Vulnerable**. A taxon is Vulnerable when the best available evidence indicates that it meets any of the criteria A to E for Vulnerable and it is therefore considered to be facing a high risk of extinction in the wild.
- **Near Threatened**. A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.
- **Least Concern**. A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa are included in this category.
- **Data Deficient**. A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution are lacking.
- **Not Evaluated**. A taxon is Not Evaluated when it is has not yet been evaluated against the criteria.

Where feasible, engineering design measures have been included to avoid impacts, however, where these are unavoidable, mitigation and management measures are proposed to reduce each impact as far as practicable. In the event that environmentally sensitive areas are severely impacted by the project and mitigation and management measures provide partial recovery, offset strategies are suggested to compensate for the loss. Avoidance, mitigation and management measures are given in Section 7.

The assessment of significance for residual impacts is then applied assuming all avoidance and mitigation measures are successful. Residual impacts are described in Section 8. The cumulative impact of the project in association with other projects planned or currently under operation in the Gladstone region is assessed in Section 9. This assessment will determine the degree to which the project contributes to the overall impact.

4.2.1 Identifying Impacts

The approaches to identifying impacts that may potentially occur as a result of the Arrow LNG Plant are described in this section.

Direct and Indirect Impacts

In the marine and estuarine environment, direct impacts include those that result from physical loss or removal of habitat once occupied by fauna and subsequently replaced by project infrastructure. This applies to habitats in the areas proposed for the locations of infrastructure such as the LNG jetty, MOF, dredge sites and launch site. Some of these direct effects are positive, for example through the creation of habitat not previously present for colonisation by marine and estuarine fauna and flora. Direct impacts would also apply to changes in access to resources (e.g., by people).

Indirect impacts are those arising from project facilities or activities, but with a degree of separation in time or space, for example via changes to water quality or sedimentation. They are by their nature harder to predict, and in the marine environment, rely on modelling of dispersion and dilution.

In order to determine the worst case impact to marine habitat, known habitat distributions were overlayed over known and modelled areas of Arrow LNG Plant direct and indirect disturbance. Direct impacts are those impacts that affect or disturb the environmental values directly, whilst indirect are impacts that occur as a result of the project (i.e., clearing of mangroves is a direct impact on the mangrove habitat being removed, whilst increased turbidity within the marine environment as a result of the clearing may be an indirect impact to the surrounding marine habitats). Once areas of direct and indirect impact were known, the worst cast for each option of marine infrastructure for each habitat type was selected and carried through the impact assessment. This approach ensured that the worst case for each marine habitat type for each infrastructure component was carried forward through the assessment.

Cumulative Impacts

Cumulative Impacts characterises impacts arising from other projects and the actions of third parties as scenarios based on analogous examples about the influence that the project may have on environmental values or what other people may or may not do. For example, in the marine environment, this might apply to the development of other projects with incremental impacts on resources or habitats, or changed patterns of boating or fishing activities. It is notable that the three other LNG proponents are further advanced in their approvals and construction, and as such cumulative impacts from construction may be lessened.

4.2.2 Significance

The concept of significance is an assessment of the product of the sensitivity of the environmental value and the magnitude of change to the environmental value arising from the project. An environmental value is described as “a quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety” (EP Act, 1994 (Qld)).

The significance of an environmental value is derived from its sensitivity, whether that is as a consequence of threatening processes or as a consequence of its conservation status or intrinsic value. The magnitude of change is an assessment of the severity, geographical extent, duration and likelihood of the impact to the environmental value. The sensitivity is generally fixed and cannot be changed by the project: the magnitude of impact can be influenced by engineering design or option selection.

The significance of an impact is assessed pre- and post- mitigation to determine the need for mitigation and how effective the proposed mitigation is in reducing the potential effects of the proposed development. The result of the post mitigation assessment of significance of the impact is the residual impact of the project.

Predicting impact significance is partly objective and partly subjective. It relies on the professional judgement of specialists as well as scientific evidence. However, it is guided by criteria or definitions and the environmental impact assessment sets out the basis of the judgements so that others can understand the rational of the assessment.

Sensitivity of Environmental Value

The sensitivity of the environmental value is determined through desktop studies and field investigations that put the existing environment or baseline conditions of the environmental value into its holistic context (Table 1). If the environmental value has a conservation status under the IUCN, Commonwealth and state government then it prevails over other recognised listings or importance and will determine its sensitivity. If there is no conservation status then the listing or importance of the environmental value will determine its sensitivity.

Table 1 Sensitivity of the Environmental Value

Sensitivity	Definition
Very High	• An environmental value that is listed as ‘critically endangered’ under the IUCN and Commonwealth government or ‘international’ under state government. • An environmental value that has international listing or importance.
High	• An environmental value that is listed as ‘endangered’ under the IUCN, Commonwealth or state governments. • An environmental value that has national importance. • An environmental value of essential (local) commercial/recreational requirement or importance in maintaining ecological integrity (even if not otherwise listed).
Medium	• An environmental value that is listed as ‘vulnerable’ or ‘rare’ under the IUCN, Commonwealth or state governments. • An environmental value that has state importance. • An environmental value of common or frequent recreational/commercial importance locally.
Low	• An environmental value that is listed as ‘near threatened’ under the IUCN or ‘conservation dependent’ under the Commonwealth government or ‘least concern’ under the state government. • An environmental value that has regional importance. • An environmental value of occasional recreational/commercial importance locally.
Very Low	• An environmental value that is common and is not listed under the IUCN, Commonwealth or state governments. • An environmental value with local importance. • An environmental value of no reported recreational/ commercial importance locally.

Magnitude of Impact

The magnitude of an impact should consider severity, geographical extent, duration or probability of an impact (Table 2). Selected criteria have been adopted from the Commonwealth government’s ‘Matters of National Environmental Significance, Significant Impact Guidelines 1.1 Environment Protection and Biodiversity Conservation Act 1999’(MNES,1999) and the IUCN ‘Red List Categories and Criteria’ (IUCN, 2010).

Table 2 Magnitude of the Impact

Magnitude	Definition
Very High	• Widespread and severe impacts, over large geographical areas which may be long lasting and are very likely to happen. • Reduce the extent of an ecological community substantially (e.g. by 90%). • Destroy habitat necessary for an ecological community's survival. • Result in persistent and major adverse changes to an ecological community's life cycle, including breeding, feeding and migration.
High	• Regional impacts which may be long lasting and are likely to happen. • Reduce the extent of an ecological community by ~50%. • Modify habitat necessary for an ecological community's survival. • Result in major adverse changes to an ecological community's life cycle, including breeding, feeding and migration.
Medium	• Localised impacts which may be long lasting and are likely to happen. • Reduce the extent of an ecological community by ~25%. • Fragment habitat necessary for an ecological community's survival. • Result in moderate adverse changes to an ecological community's life cycle, including breeding, feeding and migration.
Low	• Localised impacts which may be short lived and likely to happen. • Reduce the extent of an ecological community by <10%. • Disturb habitat necessary for an ecological community's survival. • Result in minor adverse changes to an ecological community's life cycle, including breeding, feeding and migration.
Very Low	• Impact unlikely to occur. • Extent and population of ecological community stable. • Habitat necessary for an ecological community's survival is unlikely to be impacted. • The life cycle of an ecological community, including breeding, feeding and migration is unlikely to be impacted.

Assessment of Significance

The significance of an impact to an environmental value is determined by the sensitivity of the value itself and the magnitude of the expected change (Table 3).

Table 3 Matrix of Significance of Impact

	Sensitivity of Environmental Value				
Magnitude of impact	**Very High**	**High**	**Medium**	**Low**	**Very Low**
Very High	Major	Major	Major	Minor	Negligible
High	Major	Moderate	Moderate	Minor	Negligible
Medium	Moderate	Moderate	Minor	Minor	Negligible
Low	Moderate	Minor	Minor	Minor	Negligible
Very Low	Negligible	Negligible	Negligible	Negligible	Negligible

The levels of significance of an impact determined using Table 3 is defined below:

- **Major significance**. An impact that is irreversible, widespread or of high consequence, and about which there is considerable uncertainty about the magnitude and duration or frequency of the impact. The values are unique and if lost, cannot be replaced or relocated. An impact that is likely to be a key factor in the decision-making process and raise considerable stakeholder concern.
- **Moderate significance**. The impact has the potential to cause an actual environmental harm. Typically, such impacts are likely to be important at a regional or district scale and require the application of specific environmental controls to be managed. This level of impact will influence decision-making, particularly when combined with other similar effects.
- **Minor significance**. An impact that is not trivial or very low in magnitude, duration or frequency. Typically, its effects would be important at a local scale and when combined with other impacts could have a more material effect. It is likely to have negligible influence on decision-making, but could raise awareness and concern about possible cumulative effects from a range of minor impacts.
- **Negligible**. An impact which will not result in any noticeable environmental change or effects and which would not influence the decision-making process.

5. EXISTING ENVIRONMENTAL VALUES

5.1 Introduction

Port Curtis forms a narrow coastal embayment approximately 200 km^2 in area that separates Curtis Island from the mainland. The marine and estuarine environment of Port Curtis is characterised by a high tidal range of around 4 m, which gives rise to extensive intertidal areas and tidal currents. Port Curtis is also influenced by freshwater inflow from a number of rivers and creeks, particularly the Calliope River and Boyne River. The strong tidal currents that flush the numerous creeks and tributaries maintain naturally high levels of turbidity and suspended sediments.

Many of the region's coastal environments have significant conservation value. The GBRWHA commences at the low water mark on the mainland side of The Narrows and includes Curtis Island, while the offshore areas east of Curtis Island are included within the Mackay/Capricorn section of the GBR Coast MP (GBRMPA, 1998). Port Curtis is also included in the list of nationally important wetlands in Queensland, meeting all six of the criteria for inclusion (Environment Australia, 2001). Areas in and around Port Curtis also provide important habitats that are used by a diverse range of species, including the dugong (*Dugong dugon*), the (potentially endemic) Australian snubfin dolphin (*Orcaella heinsohni*) and Indo-Pacific humpback dolphin (*Sousa chinensis*) and six of the world's seven species of protected marine turtles. For Indigenous communities, these species and others hold spiritual value, meaning and purpose in their culture.

The large tidal range results in a typical pattern of intertidal and coastal zonation from:

- Saltmarsh and mudflat areas that are inundated only during extreme spring tides, including Auckland Creek.
- Intertidal mudflats and mangroves that dominate estuarine areas of Targinie Creek, Calliope River and North China Bay on the eastern shore of Port Curtis.
- Subtidal mudflats and tidal channels.
- Seagrass beds extending from intertidal to subtidal areas.
- Rock and reef habitats extending intertidally and subtidally from the rocky headlands, predominantly on Curtis Island on the eastern shore of Port Curtis.

As one of Australia's largest ports, Port Curtis serves numerous large and expanding industries. These include alumina and aluminium processing facilities, a coal-fired power station, a cement works, several chemical refineries and an extensive network of shipping wharves, storage and bulk handling facilities. The commercial wharves and activities that occur in the port are solely managed by the GPC. Other industries such as recreational fishing, agriculture and tourism also occur in the area.

Port Curtis is also one of the more extensively studied regions of the Australian coastline with surveys having been completed to meet port, industry or government requirements. However, historically, studies have not necessarily been coordinated nor have results been easily accessible. This has now changed with monitoring and research coordinated through PCIMP, which is made up of a consortium of 15 industry, government and community stakeholders. PCIMP published an ‘Ecosystem Health Report Card’ for the 2005/06 period (Storey *et al*., 2007) that characterises physical (water and sediment quality) and ecosystem conditions in the main sectors of Port Curtis. In addition, Danaher *et al*., (2005) provides a detailed map of the intertidal habitats of Port Curtis, listing each intertidal wetland community and its area in hectares.

Marine and estuarine monitoring within Port Curtis has occurred over a period of much port and industrial development. The existing environment can therefore be described within the scale of the changes that have occurred over this time and the current distribution of the principal habitats. The availability of long-term data provides a sound basis for impact assessment as compared with the more typical once-off ‘baseline’ surveys that are frequently all that are available for assessments of new projects.

In the same way, populations of listed vulnerable or endangered species such as dugongs and turtles have been monitored throughout a similar period. Their continued distribution in the area provides some evidence for the value of the habitats to these species and their responses (insofar as these are detectable) to natural and development changes that have occurred over the period of industrialisation. A number of the monitoring studies, including a seagrass monitoring program (Chartrand *et al*., 2009) remarked on the continuing coexistence of seagrass beds and dugong feeding in close proximity to port activities and the need for management to continue to protect these key values.

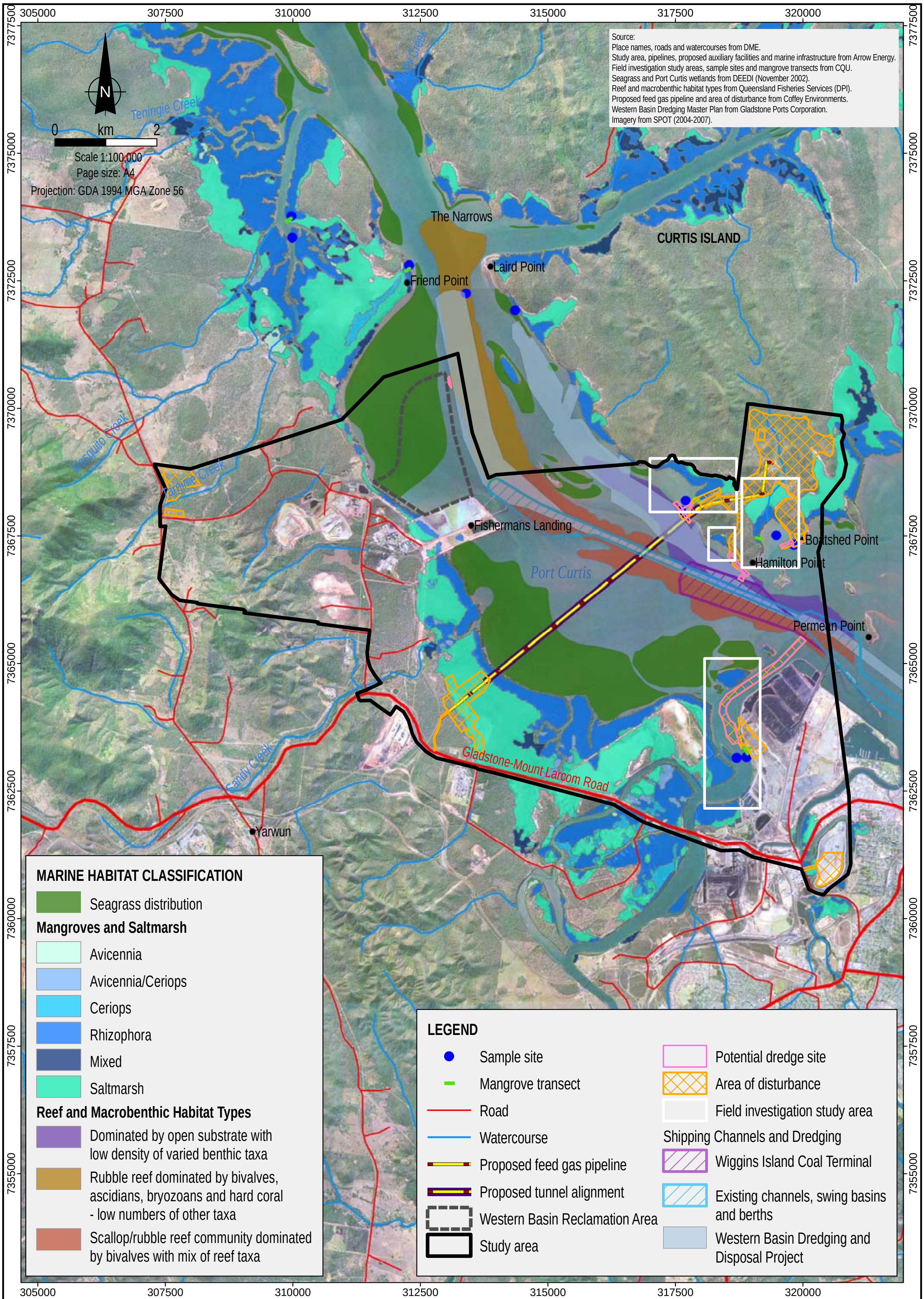
5.2 Physical Environment

A range of physical environments exists within the Port Curtis region, which support and provide habitats for significant biodiversity. These values are described in Sections 5.2.1, 5.2.2 and 5.2.3 respectively and are shown on Figure 3.

5.2.1 Benthic zone

The benthic zone encompasses the sediment substrate and sub-surface layers below a water body and supports an array of small and microscopic organisms that live both on, in and below the surface of the sediments. The benthic fauna form an important component of the food chain within the Port Curtis ecosystem and assist in sediment and nutrient recycling. The large tidal range exposes extensive intertidal areas and hydrodynamic forces such as wave action and tidal currents influence distributions of organic inputs, deposition and resuspension regimes. This in turn affects the overall carbon content and faunal composition (Meksumpun *et al*., 2005; Sakamaki and Nishimura, 2007).

As part of the Arrow LNG Plant impact assessment study, Central Queensland University (Appendix A) conducted a survey to characterise sediment properties, including carbon content and sediment particle size of six sites within Port Curtis and five sites within Calliope River(Appendix A). The study area included the sites of proposed marine infrastructure including North China Bay, Hamilton Point, Boatshed Point, Fishermans Landing and the Calliope River. In addition to proposed infrastructure sites, investigations were conducted at The Narrows, Targinie Creek and Friend Point, which will not be directly impacted by Arrow LNG Plant infrastructure but are representative of the wider Port Curtis marine ecosystem. The inclusion of these areas in the investigations provides additional context for the marine environment within the region.



coffey environments	Date: 03.10.2011 MXD: 7033CA_MNE_GIS003_v1_2 File Name: 7033CA_MNE_F003_GIS	Arrow Energy Arrow LNG Plant	arrow energy go further	Marine and estuarine habitat distribution in the Port Curtis region	Figure No: 3

The investigations determined that at Hamilton Point, Targinie Creek, The Narrows and Launch 4N, the intertidal areas had significantly higher sediment carbon content compared to subtidal areas. The opposite was observed at Boatshed Point and C1, C2 and C4 in the Calliope River. There was no significant difference in sediment carbon content of intertidal and subtidal sediment at sites C3 and C5 in the Calliope River. At most sites, the intertidal and subtidal sediments were composed of 60 to 80% silt and mud and 20 to 40% sand and gravel (i.e., there was no depth-related difference). The subtidal sites at Targinie Creek and The Narrows had significantly different sediment size distribution compared to all other sites, with significantly higher sand and gravel composition of up to 80% (see Appendix A).

Particle size fractions and organic content are key factors influencing benthic faunal composition (Currie and Small, 2005). Predominantly the intertidal and subtidal benthic substrate of Port Curtis is homogenous with only minor variations in carbon content and sediment composition at selective sites. These differences are likely to be a result of the localised hydrodynamic regimes.

The benthic zone along the coastal margins in the study area has a **high** sensitivity and can be seen as having national importance given that it contributes to wetlands under the Directory of Important Wetlands of Australia. Under the Department of Environment and Resource Management's (DERM) (formerly Environmental Protection Agency (EPA)) (2005) 'Wetland and Mapping Classification Methodology Version 1.2' the benthic zone along the coastal margins can be classified as a component of wetlands based the second and third point from the following definitions:

"Wetlands are areas of permanent or periodic/intermittent inundation, with water that is static or flowing fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6m. To be a wetland the area must have one or more of the following attributes:

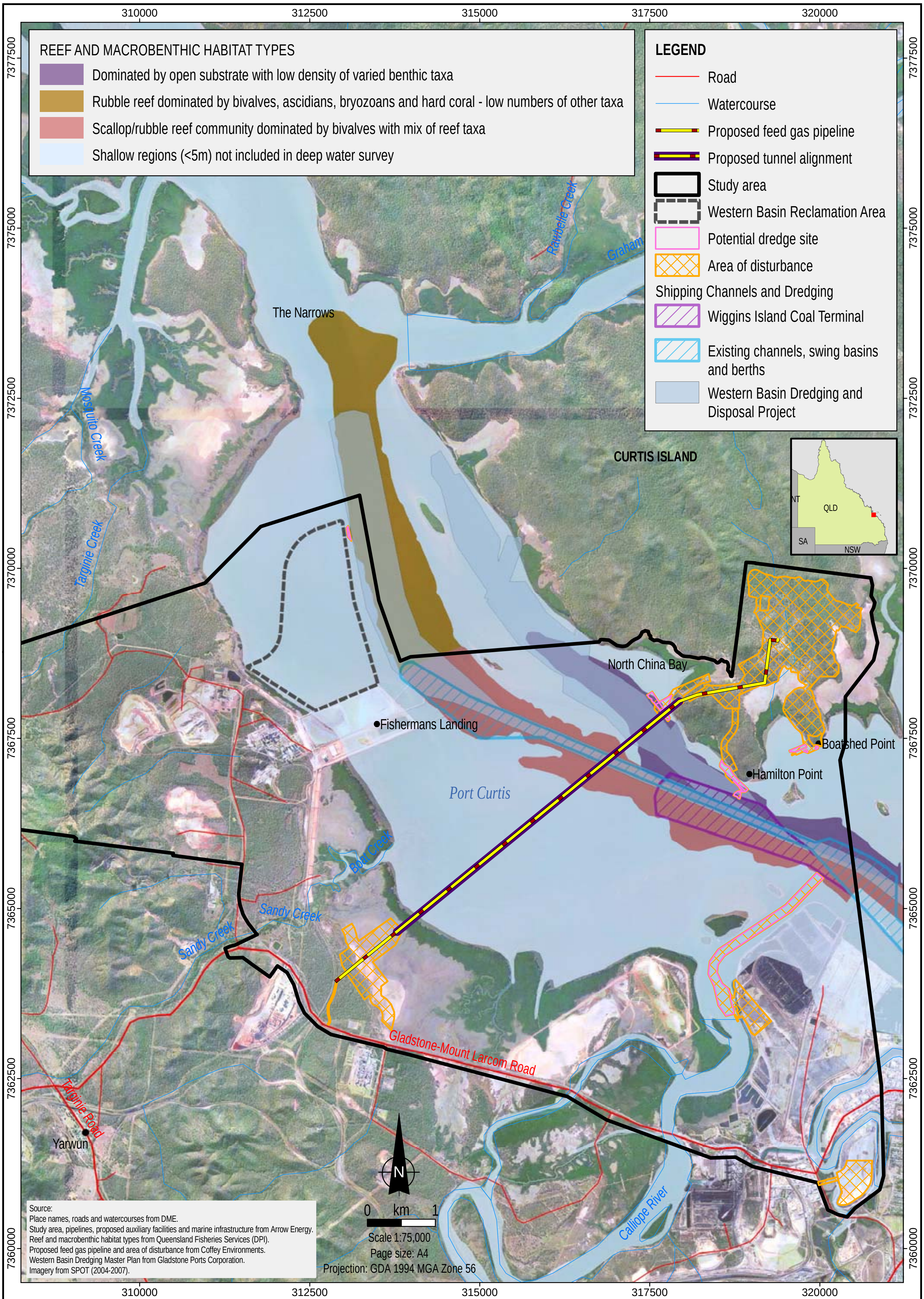
i. at least periodically the land supports plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle, or

ii. the substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers, or

iii. the substratum is not soil and is saturated with water, or covered by water at some time."

5.2.2 Reef and Rock Substrate

Many reefs form from a range of physical processes such as sand and rubble deposition and consolidation, and exposure or erosion of rock outcrops. In Port Curtis, rubble reef areas and coral bommies can be found in a deep channel at the entrance of The Narrows to the north of the study area near Graham Creek and extending south to Fishermans Landing. Rasheed *et al*. (2003) have characterised seagrass communities in a study that included all areas within the port limits and the Port of Gladstone-Rodds Bay DPA. In their study area, rubble reef and coral bommies covered approximately 15% of the study area substrate and supported a broad range of organisms including bivalves, ascidians, bryozoans and hard corals. A combined scallop and rubble reef also extends from Fishermans Landing, past Hamilton Point to South Trees Island. It covers approximately 16% of the study area substrate and is dominated by scallops, bivalves and mixed reef communities. Overall the port supports approximately 3,341.28 ha of reef (based on figure from Rasheed *et al*., 2003) (Figure 4).



coffey environments	Date: 03.10.2011 MXD: 7033CA_MNE_GIS004_v1_2 File Name: 7033CA_MNE_F004_GIS	Arrow Energy Arrow LNG Plant	arrow energy go further	Reef and macrobenthic distribution in the Port Curtis region	Figure No: 4

Adjacent and offshore to Port Curtis is the Great Barrier Reef, which spans more than 2000 km along the Queensland coastline and covers 35 million hectares (DERM, 2010). It is made up of almost 3000 individual reefs, many coral islands and 300 species of hard corals (DERM, 2010). However, the nearest outer reef at Irving Reef is over 40 km offshore from Port Curtis.

The reef habitat is not a major feature of the Port Curtis area but its sensitivity in the study area is defined as **medium** on the basis of vulnerability of reef systems to sedimentation and its contribution to the community assemblage and overall population and diversity of the GBRWHA.

Rock substrate supports an array of organisms, including algal flora, barnacles, oysters and tubeworms, by providing a solid substrate for attachment. In Port Curtis, Danaher *et al*. (2005) recorded rock substrate along the seaward edge of the intertidal zone, which is inundated during each tidal event. The precise distribution of rock substrate within the study area has not been mapped, however it is known to occur at the mid to upper intertidal zone immediately south of Laird Point and at Hamilton Point (URS, 2009) and is widespread throughout Port Curtis. This substrate is typically composed of oyster encrusted boulders and rubble (URS, 2009) (Plate 1).

The sensitivity of rock substrate along the coastal margins in the study area is **medium**, as for the coral bommie and rubble reefs described above. It also contributes to wetlands under the Directory of Important Wetlands of Australia given its intertidal distribution. The rock substrate can be classified as a component of wetlands based on the third point of the ‘Wetland and Mapping Classification Methodology Version 1.2’ (EPA, 2005) definitions (see 5.2.1 for definitions).

5.2.3 Intertidal Mudflats

Intertidal mudflats include the zone exposed at low tide and submerged at high tide. Mudflats support a high biodiversity and biomass of benthic species, support fisheries productivity and act as a feeding ground for migratory birds (Erftemeijer and Lewis, 1999), and URS (2009) conducted a survey characterising coastal zones within Port Curtis. Soft mudflats composed of fine sediment are exposed during low tide to an extent of approximately 300 m at North China Bay, Kangaroo Island and Friend Point.

The sensitivity of intertidal mudflats in the study area is **high** and can be defined as having national importance given that it is a component of the wetlands under the Directory of Important Wetlands of Australia. The intertidal mudflats can be classified as a component of wetlands based on the first and second point of the ‘Wetland and Mapping Classification Methodology Version 1.2’ (EPA, 2005) definitions (see section 5.2.1 for definitions).

5.3 Flora

With the large tidal range within Port Curtis, the coastal habitats are characterised by extensive areas of intertidal saltmarsh and mangrove communities and seagrass beds. These are described in Sections 5.3.1, 5.3.2 and 5.3.3 respectively.

5.3.1 Saltmarsh

Saltmarsh environments typically occur landward of mangroves in the extreme high tide areas, which are inundated only at the highest spring tides. The species inhabiting this zone reflects the competition and physiological ability to survive the extent of salt and frequency of submersion. Species include halophytic (salt tolerant) grasses such as salt couch, *Sporobolus virginicus*, and saltmarsh species such as the bead weed, *Sarcocornia quiniqueflora* (Plate 2). Extensive bare areas of unvegetated saltflat comprising of poorly drained clay soils are also common, occurring generally landward of saltmarsh areas and covered by bacterial or algal mats that dry out to form a leathery salty crust. Benthic organisms such as crabs and gastropods are generally sparse, except in drainage channels. Nevertheless, these areas can play an important role as feeding habitat for fish during high tides and provide a source of organic material export into coastal waters, as described in Danaher *et al.* (2005).

Typical saltmarsh areas are shown in Figure 3. They occur on the landward margins of the mangroves and are most extensive around Targinie Creek and in the inner embayments of North China Bay and Boatshed Point. There are also saltmarsh areas to the west of Kangaroo Island, in the southwest of Port Curtis and at the southeast of Curtis Island.

The combined area of saltflat and salt tolerant species in the Port Curtis study of Danaher *et al*., (2005) is 4,573.17 ha. Based on the defined area of Port Curtis (see Section 3) the 2002 data set sourced from the Department of Employment and Economic Development and Innovation (DEEDI[1]) indicates 3,105.12 ha of saltmarsh exist within the limits.

The sensitivity of saltmarsh in the study area reflects its national importance through its contribution to wetlands under the Directory of Important Wetlands of Australia. However, the Vegetation Management Regulation in accordance with the Vegetation Management Act lists *'Samphire open forbland to isolated clumps of forbs on saltpans and plains adjacent to mangroves'* to be a regional ecosystem of least concern within South Eastern Queensland Bioregion. On this basis, the saltmarsh in the study area is assessed as **medium** sensitivity.

5.3.2 Mangroves

Mangroves occupy the intertidal margins of much of Port Curtis, where they provide ecological benefit through their functions of high productivity, protection from erosion, nutrient filtering and recycling. The structurally complex habitat also provides the nursery areas for juveniles of commercially and recreationally important species of fish and crustaceans. There are extensive areas of mangroves around Port Curtis and Curtis Island; the largest areas occurring within Targinie Creek and Graham Creek, and in the southwest, between Fishermans Landing and the Calliope River (Figure 3).

Along the Queensland coast, the number of mangrove species decreases latitudinally from 36 species found in Cape York Peninsula, to 20 species in the central Queensland region and only nine species found in the Moreton Bay region (Danaher, 1995; Bruinsma *et al*., 1999). In the southeast Queensland region, from Curtis Island to the Gold Coast, 14 species of mangrove have been recorded (Duke *et al*., 2003). Of these the red mangrove (Rhizophora stylosa) is the most widespread and dominant. This species lines much of the coastline of Port Curtis, where it ranges in density and thickness from several hundreds of metres (from shore to inland) in the inlets and tidal creek systems, to a narrow band of sparse trees, or absence at rocky headlands. Inland of the red mangrove, there is often a zone of yellow mangrove (*Ceriops)* and other emergent species such as the grey or white mangrove (*Avicennia)* and black or river mangrove *(Aegiceras)*.

[1] GIS layers for mangroves, saltmarsh and seagrass received from DEEDI from the 2002 data set.

In some areas on the western shore of Curtis Island, low *Ceriops* bushes form a narrow zone just above the high tide mark and are particularly noticeable on the rocky headlands where the *Rhizophora* is sparse or absent. At the high tidal mangrove margin (particularly in the creeks and embayments), the mangroves give way to the saltmarsh zone, which include areas of bare saltflat and scattered saltmarsh species.

The extent of mangroves in Port Curtis has changed considerably since the expansion of the industries and associated port facilities and urbanisation over the past 60 years, with changing coastline and areas of wetland and intertidal habitat reclaimed. Duke *et al.,* (2003) estimated that the mangrove area has decreased from 3,842 ha in 1941 to 3,240 ha in 1988 and 2,370 ha in 1999, representing a total loss of 38% in the Port Curtis region between 1941 and 1999. Similarly, there has been a loss of 1,342 ha of saltmarsh or 34.8% over the same time period.

The Port Curtis Ecosystem Health Report Card (Storey *et al.,* 2007) conducted as part of the PCIMP monitoring program, indicated the presence of diverse mangrove communities that contain a variety of tree and seedling stages throughout Port Curtis. More specifically, the present condition of the mangroves described in the health report observed:

- Species diversity was not impacted by sediment contaminants at current concentrations.
- Indices such as tree biomass, density, foliage cover and seedling density varied over a small scale as much as between zones; hence no major differences between the zones was detected.
- Crabhole density reflected sediment particle size more than contaminant concentration.

This suggests a general resilience of the mangroves where normal tidal inundation occurs. The combined area of all mangrove species and associations in the Port Curtis study of Danaher *et al*., 2005 is 6,736 ha. Based on the defined area of Port Curtis (see Section 3) the 2002 data set sourced from DEEDI indicates 2,408 ha of mangroves exist within the limits.

Within the study areas, recorded 5 species of mangroves (Appendix A):

- *Rhizophora stylosa* (29% comprised of adults; 21% of seedlings).
- *Ceriops tagal* (38% comprised of adults; 3% of seedlings).
- *Avicennia marina* (6% comprised of adults; 1% of the seedlings).
- *Osbornia octodonta* (<1% comprised of the adults / seedlings).
- *Aegiceras corniculatum* (<1% comprised of the adults / seedlings).

Examples of these mangrove communities are shown in Plate 3 and Plate 4.

The total area of mangroves in the survey area covered approximately 814 ha, of which 41% was closed *Rhizophora*, 6.5% *Ceriops* and 5.4% mixed emergent *Avicennia*. The largest area of mangroves (306 ha) was found in Targinie Creek, followed by mainland, North China Bay, Calliope River, Wiggins Island B, Boatshed Point, Friend Point, Hamilton Point, Landing Area 1, Mud Island, Laird Point and Wiggins Island A (45 ha, 27 ha, 24 ha, 16 ha, 15 ha, 8 ha, 5 ha, 4 ha, 2 ha, 2 ha and 2 ha respectively). The extents of each of the mangrove types are shown in Figures 12 to 16 in Appendix A.

The mainland site was the only site to have a significant difference in parameter, as tree density was significantly higher compared to all other sites. Despite the differences in mangroves in each

Plate 1
Example of rock substrate at Hamilton Point

Plate 2
Example of salt couch and bead weed along the Calliope River

Plate 3
Example of *Rhizophora* along the Calliope River

Plate 4
Example of *Avicennia* at Hamilton Point

of the study areas, there was no significant difference in mangrove density (with the exception of mainland site), species richness, diversity, evenness or canopy cover between sites. This is consistent with Storey *et al*. (2007) and indicates no evidence of stress at any of the surveyed sites.

Mangroves are listed nationally under the Directory of Important Wetlands Australia, and therefore would normally be considered to have high sensitivity. However, the area to be disturbed is listed as a regional ecosystem of least concern within South Eastern Queensland Bioregion, therefore have been classified as having a **medium** sensitivity in the study area.

5.3.3 Seagrass

Seagrasses are the only flowering plants that have successfully colonised the underwater marine environment and occur in sheltered, soft bottom habitats in temperate and tropical waters around most continents. They grow like typical land plants (related to water lilies) with roots and leaves, but the stems, called rhizomes, remain buried and grow horizontally to form extensive networks below the surface. These act to increase the lateral spread of the seagrass beds and to stabilise the sediments. Seagrasses grow mainly in intertidal and shallow subtidal mudflats in coastal waters and estuaries but can grow down to depths of 60 m, where water clarity allows sufficient light penetration (Connolly *et al,* 2006). There are about 60 seagrass species worldwide, of which 30 are found in Australia and 15 along the Queensland coast.

The seagrass beds provide a number of important ecological functions. They help to stabilise sediments, trap and recycle nutrients, and provide habitat for juvenile fish and crustaceans, including the basis of commercial and recreational fisheries. They also provide feeding areas for vulnerable and endangered species such as the dugong and several species of turtles. For these reasons, seagrass areas are now protected in legislation. Large areas (as much as 40,000 km^2) of seagrass are protected within the GBRWHA and the GBRMP. Outside of the Commonwealth managed World Heritage Area and marine park, seagrasses are protected by state governments in Queensland, under the Queensland Fisheries Act 1994 and cannot be damaged without a permit. FHAs are also designated under the Fisheries Act to protect against disturbance to specific areas that are deemed critical to fisheries. The importance of seagrasses as feeding areas for dugongs has also been recognised with the establishment of a number of DPAs along the Queensland east coast, which restrict or prohibit the use of nets according to identified risk. Port Curtis is included within the Port of Gladstone-Rodds Bay DPA.

The principal threats to seagrass beds are through increased sedimentation, which can either smother the seagrasses or reduce the amount of light available. Sedimentation can be local through dredging, or can originate away from the coast in the upper catchments of rivers. Hence seagrasses most at risk are those within or closest estuaries or coastal developments. However, many healthy seagrass beds occur in busy industrial ports such as Gladstone where their continued health shows that proper management and legislative processes can maintain this coexistence and minimise disturbance.

Seagrass in Port Curtis

Seagrass beds are scattered throughout Port Curtis, although the main areas are in the western part and occur in close proximity to Gladstone and Fishermans Landing and the port activities. It has been recognised (Storey *et al*., 2007) that long-term monitoring data are necessary to make informed decisions about the planning and development of port infrastructure because seagrass beds are not necessarily stable over time. The areas of cover, species composition and biomass vary depending on factors such as sedimentation (and associated light penetration), which may be due to natural or man-made causes in Port Curtis and/or in the catchment hinterland. The Gladstone Ports Corporation (GPC) and many other port users have recognised the need for coordinated long-term monitoring. This awareness triggered baseline studies in 2002 in which thirteen seagrass beds were selected for monitoring in Port Curtis and Rodds Bay. Annual monitoring of these beds have been carried out at fixed sites since 2004 and have been managed under the auspices of PCIMP and the GPC (formerly the Gladstone Ports Authority (GPA) (Rasheed *et al*., 2008, Taylor *et al*., 2007, Chartrand *et al.,* 2009). The area coverage and species composition, in Port Curtis for the 2002 baseline surveys are shown in Figures 65, 66 and 68 (Chartrand *et al.,* 2009). The 2002 data is a complete record of all seagrass beds present in the Port Curtis – Rodds Bay region. All other monitoring surveys from 2002 onwards targets particular beds within the region and data is extrapolated from the baseline survey.

From the most recent monitoring in 2008, (Chartrand *et al*., 2009) the main observations are:

- Changes in indices of meadow area (patches versus continuous cover), biomass, and species composition.
- Generally a minimum of indices in 2004 and 2005, with higher values before and after that period, (significantly in the case of biomass in most of the beds) and maximum values in 2007.
- Healthy seagrass beds in 2008, even though slightly lower in abundance and area compared with 2007.
- Changes of species dominance; notably alternation of dominance of *Zostera capricorni* and *Halodule ovalis* at Wiggins Island beds 4 and 5; and dominance of *Halodule uninervis* at beds 7 and 9 to the south and north of Fishermans Landing.
- Consistently observed evidence of dugong feeding. In 2008, dugong feeding tracks were observed in the majority of seagrass beds, with the highest density in the light *Z. capricorni* bed at Wiggins Island.

Characteristics including indices of meadow area, biomass and species composition have varied in monitoring surveys conduct between 2002 and 2008; however, the overall location and extent of most seagrass beds remain consistent.

The Port Curtis Ecosystem Health Report Card (Storey *et al*., 2007) reported that in 2006 the seagrasses were generally healthy and had recovered from the low of 2005. They also reported the observation of dugong feeding trails in most of the beds that are monitored, particularly Wiggins Island. The combined area of all intertidal seagrass beds in the Port Curtis study of Danaher *et al.* (2005) is 4,500.89 ha. Based on the defined area of Port Curtis (see Section 3) the 2002 data set sourced from DEEDI indicates 3,442.18 ha of seagrass exist within the limits

The observations of local fluctuations are also reported in the GBRWHA. While seagrass areas are generally healthy and stable over 20 years, localised fluctuations near urbanised coasts and river discharges do occur (Coles *et al*., 2007).

The main drivers of the variation are likely to be related mainly to local climate and rainfall that cause turbid conditions and reduced light availability. Ultimately, seagrass distributional boundaries are determined by the minimum light requirements, which are considered globally to be up to 29 % of (immediate) sub-surface light levels, with extended periods below this resulting in decline of seagrass. These minimum levels have been quantified only for a few species of seagrass to date, with variations due to species-specific differences (Collier and Waycott, 2009). However, knowledge of the minimum surface light for survival (particularly if a species is at the high or low end of the minimum light requirement) is important for predicting how species distributions might be affected by water quality conditions and management. In Port Curtis, there is insufficient data to confirm minimum light requirements at present but temperature, light and turbidity loggers were established in the seagrass beds in 2007 to improve correlations in future (Chartrand *et al*., 2009).

The long-term monitoring described above demonstrates the temporal variations in the seagrass beds monitored in Port Curtis, most of which are in the western half. In the areas of potential project infrastructure, including North China Bay, Hamilton Point, Boatshed Point and the Calliope River, there was no evidence of any seagrasses either as emergent leaves or rhizomes within the sediment (Appendix A). This is consistent with the general description of seagrass distribution within Port Curtis (Rasheed *et al.,* 2008; Chartrand *et al*., 2009) and also with the results of the Gladstone Liquefied Natural Gas (GLNG) EIS supplementary survey, (URS, 2009), which did not observe any intertidal or subtidal seagrass beds from studies in adjacent areas. The location of marine project infrastructure is therefore not expected to directly affect or remove any existing seagrass beds.

The sensitivity of seagrass in the study area is defined as **high**; having state importance (given that it is recognised to support a significant population of dugongs and green turtles and is protected under Queensland legislation), and national importance given its ecological function within the GBRWHA.

5.4 Fauna

Port Curtis and surrounding waters support several listed marine species including dugongs, turtles, cetaceans, fish, sea snakes, seahorse, pipefish and is at the southern limit of habitat for saltwater crocodiles. The occurrence of these groups of organisms and others is discussed in the following section in relation to their conservation status and habitat requirements.

5.4.1 Dugongs

The dugong occurs mostly within tropical latitudes between east Africa and the western Pacific. Populations have declined over much of this range since the early 1960s, leaving isolated populations separated by large distances (Marsh *et al.,* 2002, Marsh *et al.,* 2005) and for these reasons, dugongs are considered susceptible to extinction globally. Only the Australian populations still inhabit an extensive and continuous geographical range from Western Australia to Queensland and for this reason, conservation of the Australian populations is therefore important for the species as a whole.

Dugongs are classified as a protected migratory and a marine species under the EPBC Act and are listed as vulnerable by both the International Union for the Conservation of Nature (IUCN) (IUCN, 2010) and the Nature Conservation (Wildlife) Regulation in accordance with the Nature Conservation Act. Furthermore, the species is the only surviving species in the family Dugongidae. Its presence in the Great Barrier Reef is one of the reasons for the region’s world heritage listing (Grech and Marsh, 2007).

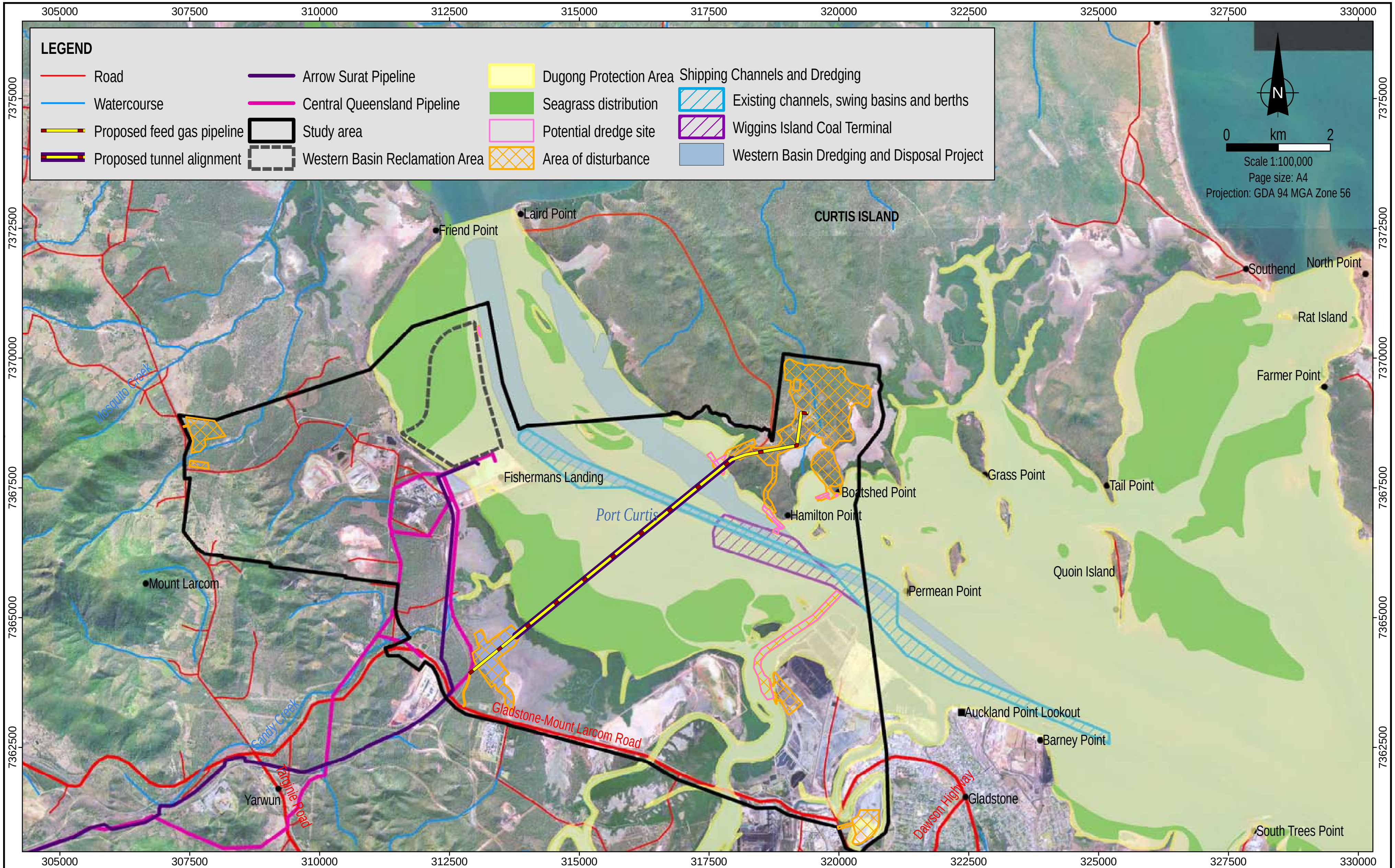
The GBRMP supports a substantial dugong population of approximately 14,000 individuals (Marsh and Lawler, 2002; Marsh and Lawler, 2001). The population in Port Curtis can be inferred from the central and southern Great Barrier Reef population due to the migratory behaviour of the species. This region has been known to accommodate an important population since estimates were first made in 1986 (Marsh and Lawler, 2006). Variability in population does occur at individual bays, potentially caused by changes in seagrass habitat (Marsh and Lawler, 2006). Nevertheless, current populations are now significantly less than were recorded previously (Marsh *et al*., 2005). The long lifespan and low reproduction rate of the dugong makes the species population recovery potential slow, and vulnerable to both natural and anthropological factors such as boat strike, Indigenous hunting, entanglement in mesh netting during commercial fishing or trawling and destruction or fragmentation of essential habitat. Such impacts can affect survival and overall population dynamics and cause displacement to potentially lower quality resources.

Dugongs can undertake large-scale movements in search of food as a result of disturbance or loss of seagrass habitat (Preen and Marsh, 1995, Marsh and Lawler, 2002; Sheppard *et al*., 2006). Climatic episodes including cyclones and floods have also been associated with such movement patterns (Preen and Marsh, 1995, Marsh and Lawler, 2002). Satellite tagging studies show that the Queensland east coast dugongs frequently undertake ranging and return movements at micro (<15 km) and macro (>100 km) scales (Sheppard *et al.,* 2006) and it seems likely that dugongs in Port Curtis are following such movements.

The distribution, abundance and conservation of the dugong has influenced the designation of protected areas in Queensland waters (Marsh and Lawler, 2002). The Port of Gladstone-Rodds Bay zone B DPA status protects the species and its habitat; allowing only restricted mesh netting (EPA, 2007). Figure 5 describes the Port of Gladstone-Rodds Bay DPA and seagrass beds within the area.

Seagrass beds in the Port Curtis region support dugong feeding activity during migrations along the Queensland coast. Consistent evidence of grazing has been recorded on the majority of intertidal seagrass beds within the vicinity of Wiggins Island, Quoin Island, Pelican Banks, South Trees and across the north and south of Fishermans Landing (Chartrand *et al*., 2009). The area surrounding Wiggins Island appears to have the highest consumption rate, based on the observations of the feeding trails that extend throughout a significant proportion of the beds in the port (Chartrand *et al.,* 2009). Dugongs have been known to feed in large herds of approximately 140 individuals and can graze in a single location up four weeks or potentially longer in Morton Bay (Preen, 1992). Such activities can cause considerable disturbance to seagrass communities, with seagrass shoot density reduced by 95% in favoured locations. A combination of dugong feeding behaviour and increasing anthropogenic impacts can severely reduce the area of seagrass available for the dugong’s survival.

Preen (1992) defined dugong seagrass feeding preferences based on the frequency of dugongs grazing on seagrass species. While dugongs are unable to selectively feed at an individual plant level due to their wide muzzle (Spain and Heinsohn, 1975), they are capable of grazing on a chosen species of seagrass at a community scale. Preen (1992) found that of the species present, *Zostera capricorni* is considered least favourable, while *Halodule ovalis* and *Halodule uninervis* is highly desired. Such preference is most likely due to their rudimentary dentition, which constrains them from grinding the food sufficiently to digest strong fibrous plant material (Lanyon, 1991). Z. capricorni is broad-leafed and fibrous in comparison to Halodule species which are thin-leafed, high in nitrogen and low in fibre (Lanyon, 1991; Preen, 1995). Figures 6 and 7 describe monitored seagrass beds in Fishermans Landing and Rodds Bay area’s respectively.



Source;
Place names, roads and watercourses from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Seagrass distribution (2002) and Dugong Protection Area from DEEDI.
Proposed feed gas pipeline and area of disturbance from Coffey Environments.
Western Basin Dredging Master Plan from Gladstone Ports Corporation. Imagery from SPOT (2004-2007).

coffey environments

Date: 03.10.2011
MXD: 7033CA_MNE_GIS005_v1_2
File Name: 7033CA_MNE_F005_GIS

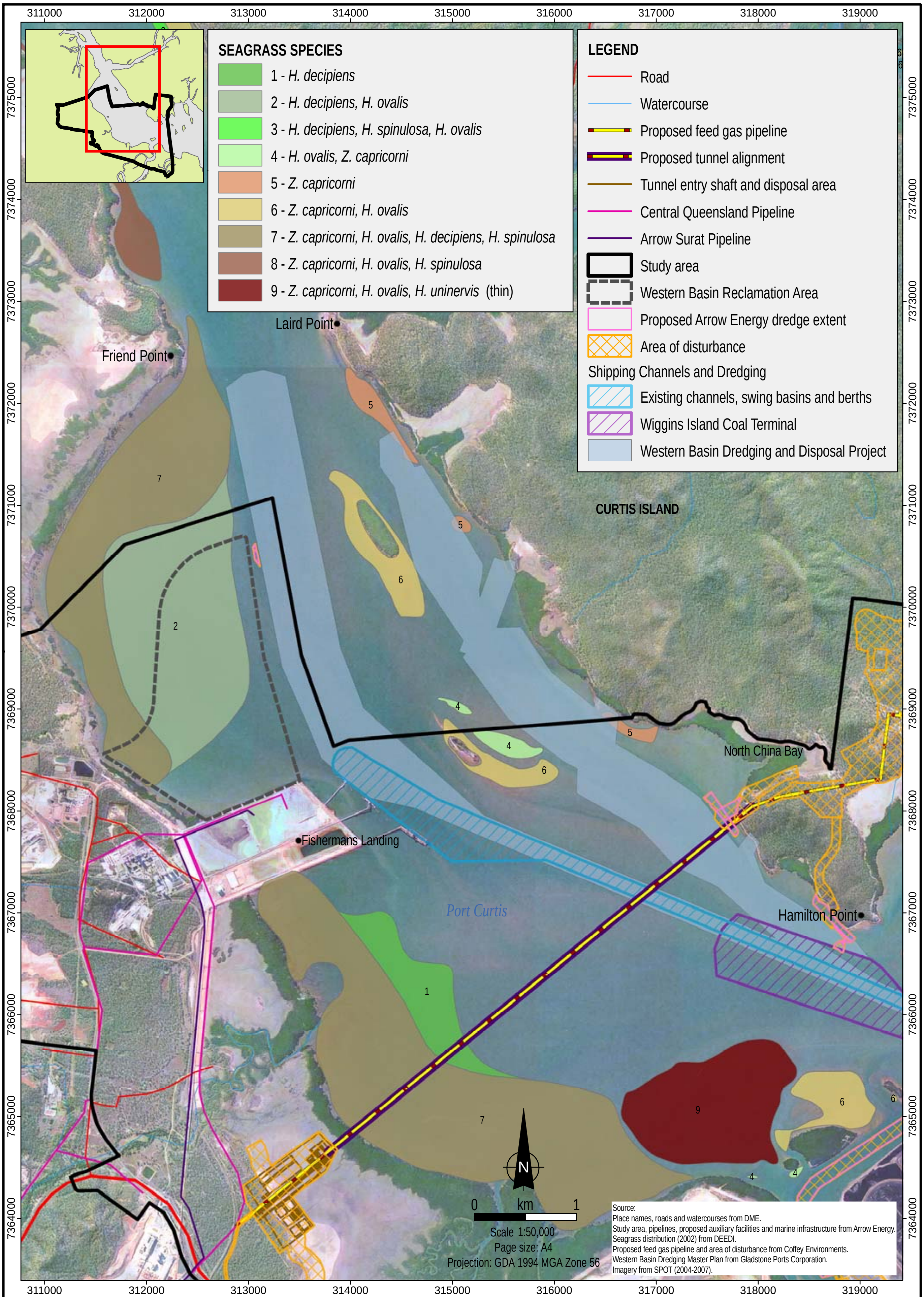
Arrow Energy

Arrow LNG Plant

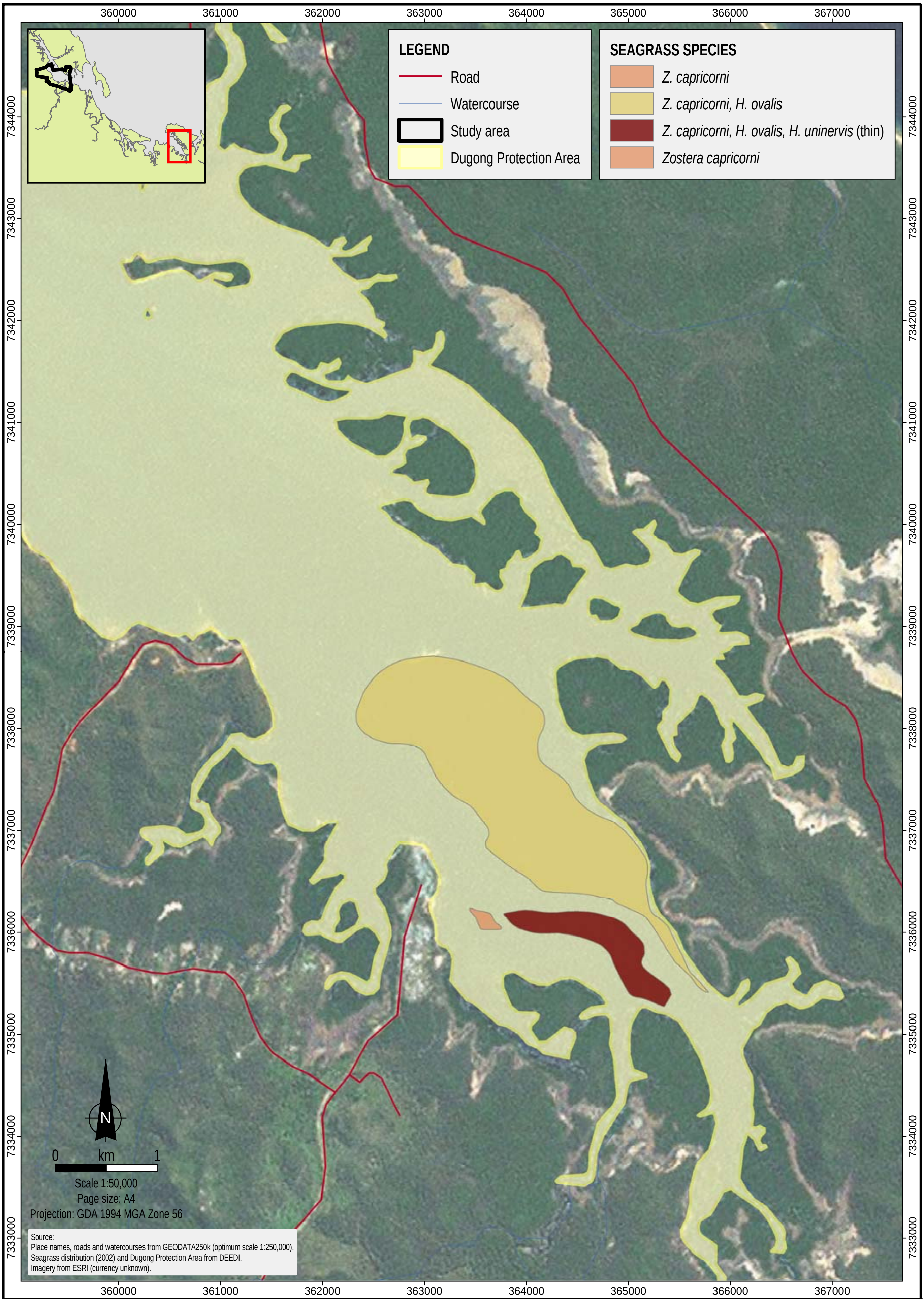
arrow energy go further

Port of Gladstone - Rodds Bay Dugong Protection Area and seagrass beds in the Port Curtis region

Figure No: 5



coffey environments	Date: 03.10.2011 MXD: 7033CA_MNE_GIS006_v1_2 File Name: 7033CA_MNE_F006_GIS	Arrow Energy Arrow LNG Plant	arrow energy go further	**Monitored seagrass beds in the Fishermans Landing area**	Figure No: **6**



coffey environments	Date: 03.10.2011 MXD: 7033CA_MNE_GIS007_v1_2 File Name: 7033CA_MNE_F007_GIS	Arrow Energy Arrow LNG Plant	arrow energy go further	Monitored seagrass beds in Rodds Bay	Figure No: 7

Notwithstanding these preferences, the main question with respect to development of the Arrow LNG Plant in Port Curtis is the importance of the different areas as intermediate feeding locations during migrations. This question was investigated by Grech and Marsh (2007), who developed a spatial population model that incorporates the abundances and frequencies of dugong utilisation of the different regions along the Queensland coast. These are then categorised into low, medium or high areas of conservation value, according to the dugong density estimates; assuming densities to be a robust index for preference and habitat conservation value. Within the central Queensland coast localities of Shoalwater Bay and Port Clinton, the assessment identified both urban and remote areas within the GBRWHA as ‘hot spots’ for dugong conservation. In comparison, the Port of Gladstone-Rodds Bay DPA is considered an area of relatively low conservation value, due the low dugong population density. This cannot be taken to mean that the feeding areas in between the ‘hot spots’ are not important for migrating dugongs, which may be using them during their migrations. However, Alquezar (Appendix A) observed that there are no seagrass beds in the area of the Arrow LNG Plant’s marine project infrastructure.

The sensitivity of the dugong in the study area is defined as **medium**, having a vulnerable conservation status under the IUCN and state governments.

5.4.2 Turtles

There are seven species of marine turtle in the world, six of which occur within Queensland waters, namely the flatback, green, loggerhead, hawksbill, olive ridley and leatherback turtles. All species are listed as marine and recognised as vulnerable or endangered under the IUCN Red List (2010), EPBC Act and the Nature Conservation (Wildlife) Regulation 2006 in accordance with the Nature Conservation Act. All six species may occur in Port Curtis, although records indicate that the flatback, green and loggerhead turtles are the species normally observed within the area. The conservation status of the marine turtles is given in Table 4.

Table 4 Conservation Status of Marine Turtles in Queensland Waters

Scientific Name	Common Name	IUCN Red List	EPBC Act	Nature Conservation (Wildlife) Regulation
Natator depressus	Flatback turtle	Data deficient	Vulnerable	Vulnerable
Chelonia mydas	Green turtle	Endangered	Vulnerable	Vulnerable
Caretta caretta	Loggerhead turtle	Endangered	Endangered	Endangered
Eretmochelys imbricate	Hawksbill turtle	Critically Endangered	Vulnerable	Vulnerable
Lepidochelys olivacea	Olive ridley turtle	Vulnerable	Endangered	Endangered
Dermochelys coriacea	Leatherback turtle	Critically Endangered	Vulnerable	Endangered

All species share similar characteristics with a long lifespan, low reproductive rate and high site fidelity. Turtles typically have an average life expectancy of approximately 55 to 60 years (Chaloupka and Limpus, 2005) and a low reproductive output due to the long maturity period, the low probability of individual survivorship to adulthood and the long interval between breeding seasons (Hamann *et al.,* 2003). The majority of females migrate to the same location to lay consecutive clutches both within and between nesting seasons (Limpus *et al*., 1984), and Limpus *et al*., (2006) considered that the display of such behaviour is thought to be a result of:

- The hatchlings being imprinted to the natal region and subsequently to the identifiable rookery as an adult during the first breeding season;
- The imprinting of the hatchlings to the natal region during the egg or hatching phase.

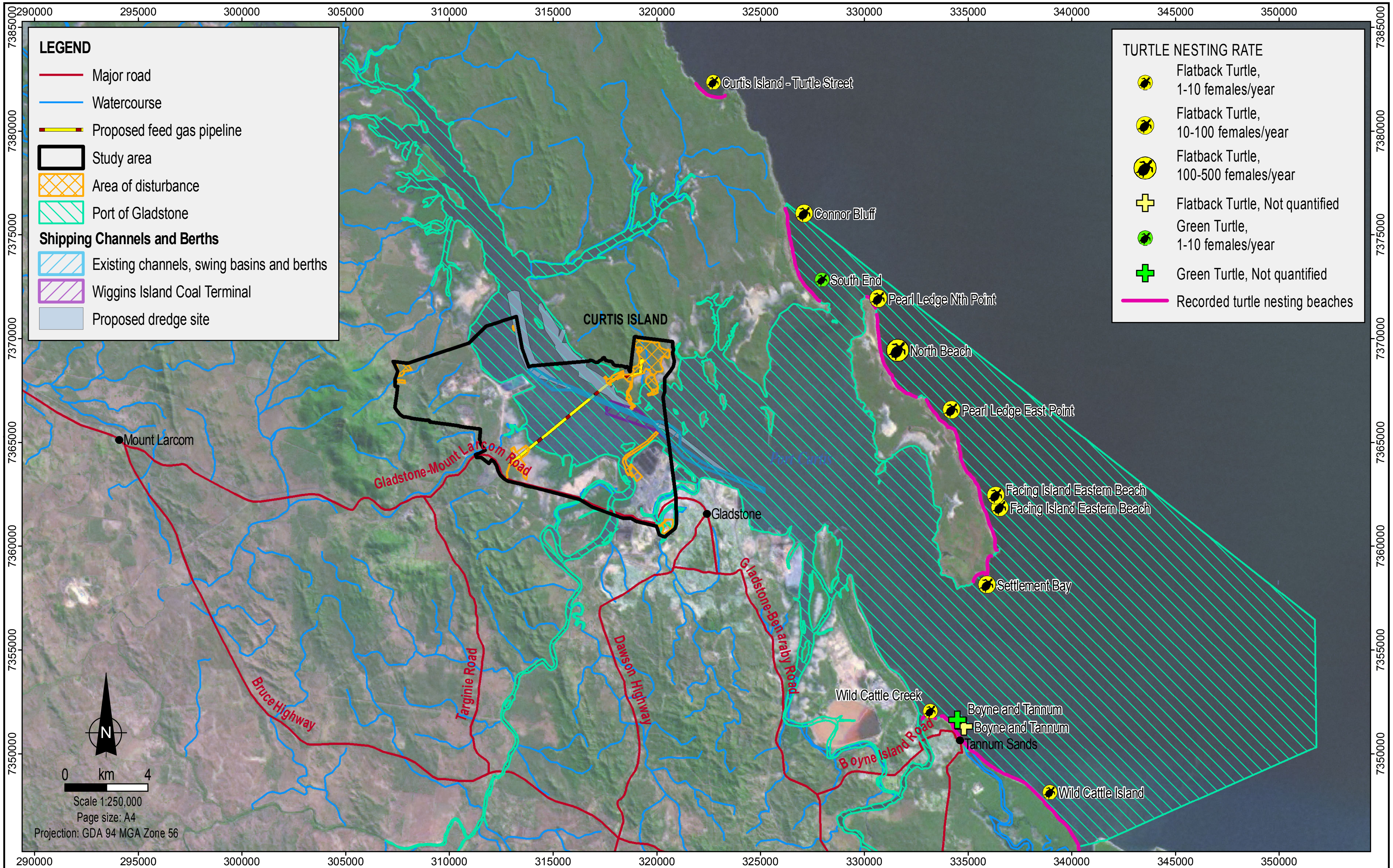
Gender determination of the developing hatchling is temperature dependent and occurs during a critical stage of incubation (Bull, 1980). Once emerged, the light of the horizon acts as a cue in directing the hatching from the nest to the sea (Limpus, 1971b). The presence of artificial light can therefore potentially impede the view of natural light from the horizon disorientating the hatchling (Limpus, 2007) and potentially increasing the risk of mortality. Individuals that reach the sea continue out to pelagic waters where they feed on macro zooplankton until reaching maturity (Walker, 1994 in Limpus, 2008a). As adults, some species of turtles are carnivorous, feeding on invertebrates (loggerhead and flatback turtle) (Limpus, 2007; Limpus, 2008b) or herbivorous targeting seagrass, algae and fruit from coastal flora (green turtle) (Limpus, 2008a).

Adult turtles migrate between feeding and breeding areas. Most individuals tend to migrate less than 1000 km between their rookery and feeding area, however, some are known to reach distances of more than 2600 km (Limpus, 2008b). There is no set migratory route followed by all turtles during their breeding migration, but they frequently return to the same feeding and rookery areas (Limpus, 2008a).

The distribution and nesting sites of the flatback turtle (*Natator depressus)* is restricted to coastlines along Australian continental shelf waters (Limpus *et al*., 2006); Limpus *et al*., 1988). There are four breeding stocks in Australia that occur from Western Australia to eastern Australia (Limpus, 2007). Currently there is no national or regional population estimate for the species. The flatback turtle is the dominant species in the Port Curtis region, with an intermediate-sized nesting population of 51 females around South End, Curtis Island (Limpus *et al*., 2006) (Figure 8). Populations of the eastern Australian stocks of flatback turtles have been monitored on the south eastern beaches of Curtis Island since 1969 (Limpus *et al.,* 2006; Limpus, 2007). The number of nesting females returning to Curtis Island over the monitoring period has remained constant, with any variability in the nesting population unlikely to be a result of nesting females relocating to other sites (Limpus *et al*., 2006). This suggests that the population has not been negatively affected or shown any overall decline in the survivorship of adults or recruitment of new adults to the population (Limpus *et al*., 2006).

Foraging resources and nesting sites for the flatback turtle are primarily located within the GBRMP and the GBRWHA. The species has rarely been associated with intertidal seagrass beds or coral reef, however, individuals captured in trawling activities suggest they utilise soft benthic habitats (Robins and Mayer, 1998).

The green turtle (*Chelonia mydas*) has a worldwide distribution predominantly within tropical and subtropical regions. Seven breeding stocks have been recognised within Australia (Limpus, 2008a) including significant populations of approximately 49,000 individuals within the Great Barrier Reef (DEWHA, 2010a). The southern Great Barrier Reef region, which encompasses Port Curtis, is known to support approximately 8000 individuals (DEWHA, 2010a). The species occasionally nests on beaches near South End, Curtis Island; however, the major breeding rookeries are concentrated within the Capricorn Bunker Group islands of the southern Great Barrier Reef (Bustard, 1972; Limpus *et al*., 1984).



Source: Place names, roads and watercourses from DME. Proposed feed gas pipeline and area of disturbance from Coffey Environments.
Port of Gladstone digitised by Coffey Environments from GPC figure 'Port of Gladstone port limits and channel and berth depths' (04/10/07).
Turtle nesting sites digitised by Coffey Environments from EPA figure 'Shorebirds and Turtles'.
Turtle nesting rates courtesy Col Limpus QPWS Senior Principal Conservation Officer Parks and Wildlife Strategy Research Coordination Unit.
Nesting rates recorded between 1968 - 1999, not all records shown.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy. Imagery from ESRI (currency unknown).

coffey environments

Date: 03.10.2011
MXD: 7033CA_MNE_GIS008_v1_2
File Name: 7033CA_MNE_F008_GIS

Arrow Energy
Arrow LNG Plant

arrow energy go further

Turtle nesting sites in the Gladstone region

Figure No: 8

Foraging resources and nesting sites for the green turtle are primarily located within the GBRMP and the GBRWHA. The herbivorous diet of the species limits individuals to shallow benthic foraging areas such as seagrass beds and coral and rocky reef, which support algal mats (Musick and Limpus, 1997).

Loggerhead turtles (*Caretta caretta*) also have a worldwide distribution predominantly within subtropical and tropical regions. The species has two key breeding stocks: one in Western Australia (Baldwin *et al*., 2003) and the other in the south Queensland-New Caledonia region (Limpus and Limpus, 2003). In eastern Australia, there are approximately 500 nesting females per year with approximately 10 to 150 females returning to the southern Great Barrier Reef per year (Limpus and Limpus, 2003). The loggerhead turtle has been recorded to nest intermittently within the Port Curtis region (see Figure 8), although the main breeding areas are located along the southeast Queensland and Mackay coast and within the islands of the Capricorn Bunker Group (Limpus, 2008b).

Foraging resources and nesting sites for the loggerhead turtle are primarily located within the GBRMP and the GBRWHA. The species is known to utilise a broad range of habitats as foraging areas including coral and rocky reefs (Limpus *et al*. 1984), sandflats, estuaries and seagrass beds (Limpus and Reimer. 1994; McCauley and Bjorndal 1999; Musick and Limpus,1997).

The leatherback turtle (*Dermochelys coriacea*) and the hawksbill turtle (*Eretmochelys imbricata*) are of worldwide distribution in tropical and subtropical oceans. The leatherback has the most widespread distribution of all turtles, which extends into northern and southern temperate regions. Both species appear to have a limited distribution within Australian waters, with no nesting evidence recorded within the coastal ranges of the Port Curtis region. The leatherback turtle is not known to have any major breeding stocks in Australia with only sporadic nesting recorded in specific coastal sites in southern Queensland and the Northern Territory (Limpus, 2009a). In Australia, the Torres Strait-northern Great Barrier Reef region, and Arnhem Land, and the Dampier Archipelago in Western Australia support the largest stocks of hawksbill turtles (Limpus, 2009b; Boderick *et al*., 1994).

The management of marine turtles is challenging because of their complex life cycles. The status, distribution and abundance of the turtle are difficult to quantify as:

- Hatchlings and adults disperse and spend a majority of their life in the marine environment.
- Migratory patterns vary based on the individual.
- Only females have high fidelity to their natal sites.
- Not all females nest each year.
- A range of habitats are utilised during different phases of the life cycle.
- A range of impacts are experiences during different phases of the life cycle.

In order to allow for this complexity the EPBC Act protects all turtles within Australian waters from three nautical miles offshore to the end of the exclusive economic zone 200 nm offshore. Turtles in coastal waters from the Queensland coast to three nautical miles offshore are protected by the Nature Conservation (Wildlife) Regulation, the Nature Conservation (Protected Areas) Regulation and the Great Barrier Reef Marine Park Zoning Plan, which declares most significant rookeries for all species as protected habitat and regulates the level of human use. At a local scale a substantial number of smaller zoned marine parks are closed seasonally for the turtle, to restrict trawling and control tourism activities. Each of the current protection and prevention measures assists in protecting the Queensland turtle population.

The distribution of the species of turtles suggests that it is likely they could occur and forage throughout Port Curtis. There are no feeding or nesting areas in direct proximity to project facilities; however nesting sites on the eastern shore of Curtis Island, near South End, may potentially be influenced by glare from lighting at the LNG processing facilities, which will require mitigation and management.

The sensitivity of turtles in the study area is species dependent and outlined below.

- The sensitivity of the flatback turtle is medium and can be defined as having a vulnerable conservation status under the Commonwealth and state governments.
- The sensitivity of the green turtle is high and has an endangered conservation status under the IUCN.
- The sensitivity of the loggerhead turtle is high and has an endangered conservation status under the IUCN, Commonwealth and state governments.

5.4.3 Cetaceans

The Species Profile and Threats database, a subordinate of the EPBC Act identifies 13 species of cetaceans listed as protected species, which have an indicative range extending into Port Curtis and the surrounding regions. These are listed in Table 5.

Table 5 Conservation Status of Whales and Dolphins (Cetaceans) in Queensland Waters

Scientific Name	Common Name	IUCN Red List
Delphinus delphis	Common dolphin	Least concern
Grampus griseus	Risso's dolphin *	Least concern
Lagenodelphis hosei	Fraser's dolphin	Least concern
Orcaella heinsohni	Australian snubfin dolphin *	Near threatened
Sousa chinensis	Indo-Pacific humpback dolphin *	Near threatened
Stenella attenuata	Spotted dolphin	Least concern
Tursiops aduncus	Indian Ocean bottlenose dolphin	Data deficient
Tursiops truncates	Bottlenose dolphin	Least concern
Balaenoptera edeni	Bryde's whale *	Data deficient
Balaenoptera musculus	Blue whale*	Endangered
Megaptera novaeangliae	Humpback whale *	Least concern
Orcinus orca	Killer whale	Data deficient
Peponocephala electra	Melon headed whale	Least concern

* Indicates species listed on the Wetland Info's Wetland Information Summary Search database operated by the Department of Environment and Resource Management (DERM) and have been sighted within the Fitzroy natural resource management region and the Gladstone local government area.

Of the cetaceans listed in Table 5, the species of most concern and likely to be in the study area are the Australian snubfin dolphin and the Indo-Pacific humpback dolphin. Both species are recognised as near threatened under the IUCN Red List. The Indo-Pacific humpback dolphin is suggested to be endemic to Australian waters and the Australian snubfin dolphin also remains restricted to similar regions with some extension into southern Papua New Guinea waters (Beasley *et al*., 2005; Parra *et al*., 2006). Both species have been known to occur in waters from north Western Australia to southeast Queensland. Population estimates in Queensland only are likely to be in the thousands rather than tens of thousands based on:

- Low numbers recorded during aerial surveys along the coastline between 1987 and 1995 (29 snubfin dolphins and 54 humpback dolphins) (Corkeron *et al*., 1997; Parra *et al*., 2002).
- Low numbers recorded during boat-based line transect surveys along the northeast coastline (22 Irrawaddy dolphins and 14 humpback dolphins) (Parra, 2005).
- Low numbers recorded between 1985 and 1987 for areas along the southeast coastline (119 humpback dolphins) (Corkeron *et al.,* 1997).

From the limited studies conducted, Parra *et al.,* (2006) quantified a population of approximately less than a hundred individuals of each species in Cleveland Bay near Townsville between 1999 and 2002.

Parra (2006) recognised that the Indo-Pacific humpback dolphin and the Australian snubfin dolphin tend to coexist in both time and space, occurring year round in similar regions. Their habitat is predominately shallow coastal waters in or adjacent to near modified environments such as dredged channels, breakwaters and river mouths. These habitats exist along a majority of the Queensland coastline and appear to support foraging and mating activities. Coastal developments continue to increase in such areas of preferred habitat, which can have implications to the species survival, including gill netting activities, pollution, vessel traffic and overfishing.

Management plans can only be effectively implemented with sufficient estimates of population numbers and information detailing migratory routes (Wilson *et al*., 1999). The discrepancy in taxonomic identification of the Australian snubfin dolphin with the Irrawaddy dolphin, (*Orcaella brevirostris*), in addition to the limited published literature on both species and their status has hindered effective conservation and management plans.

The blue whale (*Balaenoptera musculus*) is registered as endangered under the IUCN Red List (2010), and is the subject of a recovery plan (DEH, 2010). It is a migratory, wide ranging oceanic species. The current scientific view suggests that the species shows a general migration pattern of summer presence in higher latitudes and wintering in warmer tropical waters (DEH, 2010). Based on 100 aerial surveys conducted between 1998 and 2005 in the Bonney Upwelling, only 50 individuals were recorded (DEWHA, 2010b). Reliable estimates of blue whale population sizes in the Australian region are not currently available due to their large distribution, the difficulty of surveys and because many aggregation areas remain unknown (DEWHA, 2010b). Although this figure is an underestimate it is a reliable minimum estimate. There are two recognised sub species of blue whales in the southern hemisphere; the true or Antarctic blue whale (*B. m intermedia*) and the pygmy blue whale (*B. m. brevicauda*). In Australia, blue whales are found in waters, off the coast of southwestern Australia and off the coast of South Australia and western Victoria. These areas are significant feeding grounds, associated with upwelling on the edge of the continental shelf and production of krill upon which they feed on during the summer months (Gill and Morrice, 2003). Otherwise, the species is generally linked to deep coastal waters beyond the continental shelf. Blue whale sightings have been scarce within the wide continental shelf of northern Australia (Branch *et al*., 2007). This species is not likely to occur in Port Curtis.

Most of the other cetacean species listed in Table 5 have the potential to migrate through Port Curtis or reside within neighbouring regions. The species described above are those that have a higher international and national conservation status and have previously been sighted in the Port Curtis region.

Generally, adult female cetaceans have a low reproductive rate calving only every few years and the low reproductive rates and sparse distribution makes population dynamics difficult to quantify. In response, the Commonwealth government established the Australian whale sanctuary under the EPBC Act and in Queensland it is complimented by the Nature Conservation (Whales and Dolphins) Conservation Plan. The Australian whale sanctuary recognises the environmental significance of all cetaceans and the need to protect and manage species within Commonwealth marine areas and prescribed waters. The sanctuary is designed to protect all cetaceans in Australian waters three nautical miles offshore to the end of the exclusive economic zone and prosecute any persons that kill, injure or interfere with any cetacean species.

The sensitivity of cetaceans in the study area is species-dependent and outlined below.

- The sensitivity of the Australian snubfin dolphin and the Indo-Pacific humpback dolphin is **low**, given their near threatened conservation status under the IUCN and state government.
- The sensitivity of the blue whale is high and can be defined as **high** given its endangered conservation status under the IUCN and Commonwealth government; however, it is unlikely to be in the study area.
- The sensitivity of humpback whale is **medium**, on the basis of its listing status as vulnerable; however, it is also unlikely to be in the study area.

5.4.4 Saltwater Crocodiles

The saltwater crocodile is protected under the EPBC Act and is recognised as vulnerable under the Nature Conservation (Wildlife) Regulation. The species has been known to inhabit reef, coastal and inland watercourses typically north of the tropics (Taplin, 1987) and its habitat extends to the Gladstone region. The species is normally constrained to coastal areas and wetlands, however, individuals have been observed hundreds of kilometres upstream in river systems, such as the Fitzroy River (Taplin, 1987).

The east coast plain region, which encompasses Gladstone, is suggested to support a moderate density of estuarine crocodiles despite the low quality in nesting and living habitat (Read *et al.,* 2004; Taplin, 1987). Surveys conducted within the east coast plain region during 1994 and 2000 recorded 434 non-hatchling crocodiles, contributing to approximately 10% of the Queensland population. A combination of suboptimal ambient temperature conditions, extensive anthropogenic activities and habitat modification, may also contribute to the constraints in population distribution and density to areas above the Tropic of Capricorn (Taplin, 1987, Read *et al*., 2004). From this combination of influencing factors it is considered the estuarine crocodile population will only be able to sustain large numbers within the isolated regions of Cape York Peninsula and the Gulf of Carpentaria (Read *et al*., 2004). During the study conducted by Alquezar (2011) (Appendix A) no estuarine crocodiles were observed.

The sensitivity of the estuarine crocodile is **medium** and can be defined as vulnerable under the Nature Conservation (Wildlife) Regulation. However, as Port Curtis is at their southernmost limit of their range, and no recent sightings have been made, impact s have not been included in the assessed further.

5.4.5 Fish and Shellfish

High species richness and abundance of fish occur in the marine, coastal, estuarine and freshwater habitats of Port Curtis. The size and composition of these communities reflects the availability of the aquatic habitats upon which the species depend during different phases of their life history, many having freshwater estuarine and marine phases (Moore, 1982; Leis, 2002; Hagan and Able, 2003; Manson *et al*., 2005). For these species, declared FHAs and passageways are of particular importance in maintaining connectivity between different aquatic environments.

CQU conducted a survey to characterise fish and invertebrate communities in mangrove-lined shallow water habitats at five sites within Port Curtis, Targinie Creek, North China Bay and Hamilton Point, Boatshed Point and the Calliope River (see Appendix A). In total, 1262 fish and macroinvertebrates representing 29 species were collected from a variety of sites representative of soft sediment shallow habitats, mangroves and other vegetation lined banks. The species included prawns, small species of bait fish and larger species of fish. The most common species encountered were the banana prawn (*Fenneropenaeus merguiensis*) (41%); the spotty-face anchovy (*Stolephorus waitei*) (17%); the greenback mullet (*Liza subviridis*) (16%), the southern herring (*Herklotsichthys castelnaui*) (10%); and the common ponyfish (*Leiognathus equulus*) (7%).

A further 36 fish and macroinvertebrates from 124 species representing large sized assemblages in deeper water channels were recorded. The diamond scale mullet (*Liza vaigiensis*) had the highest catch number in field studies, followed by beach salmon (*Leptobrama muelleri*) blue threadfin (*Eleutheronema tetradactylum*) and the mud crab (*Scylla serrata*). In the phase II field investigations, the giant queenfish (*Scomberoides commersonnianus)* and blue catfish (*Ariopsis graeffei*) had the highest catch number. Other species collected during field investigations using gill nets included green turtles, beach salmon, and blue threadfin.

Several green turtles were seen around the gill nets, which were observed at all time to ensure none became entangled. The geographical ranges of all common fish and prawn species identified in the survey extend right around northern Australia.

It is established that mangroves play an important role in the life history of many commercially and recreationally important fisheries (e.g., Laegdsgaard and Johnson, 2001; Ikejima *et al.,* 2003; Manson *et al*., 2005; Alfaro *et al.*, 2006). The study by CQU also found that 53% of fish and nekton sampled were offshore spawners that used estuaries as nursery grounds during juvenile stages, 31% of nekton were offshore spawners typically found in estuaries throughout all life-history stages, 13% were visitors that appeared in estuaries for brief irregular visits and 3% were estuarine and freshwater spawners (Appendix A). The banana prawn and the common ponyfish were the most common organisms that used estuaries as nursery grounds during their juvenile stages. The southern herring was the most common visitor that appeared in estuaries for brief irregular visits, and estuarine glassfish (*Ambassis marianus*) made up the highest number of estuarine and freshwater spawners.

Overall, the study by CQU (see Appendix A) found no significant differences in nekton abundances, diversity or species evenness among the mangrove lined, shallow water estuary sites within Port Curtis and the Calliope River for both sampling events. However, there were significantly higher densities at Targinie Creek and Calliope River compared to the other sites. There were no significant differences in fish and nekton total abundance, diversity or species evenness among sites within Port Curtis and the Calliope River for both phases of the study. However, there were significantly higher numbers of species at Targinie Creek and Calliope River compared to the other sites. For larger fish and nekton, representative of deeper channels, the highest relative abundance and species richness was recorded at Boatshed Point, followed by Hamilton Point and The Narrows Crossing. Targinie Creek had the lowest biodiversity of the larger nekton size classes. No species of conservation importance were observed (note that pipefish are discussed in Section 5.4.7); but the overall level of sensitivity is defined as **medium** on the basis of presence of some species of recreational importance.

Recreational fishing

In the central Queensland coastal region, fishing is one of the most easily accessed recreational activities with high participation rates (Platten, 2004). Specifically, Gladstone has one of the highest boat ownership rates per capita in Australia. From 1985 to 2005, boat registrations in the Gladstone region increased from 2171 to 4581 with many of the boats intended for recreational fishing (Platten *et al*., 2007).

DEEDI's Coastal Habitat Resources and Information System (CHRIS) provides catch data for the Fitzroy division, which encompasses Port Curtis and surrounding waters. Comprehensive surveys were conducted for the years 1997, 1999, 2002 and 2005 and provided the following information:

- Most recent records (2005) indicate that the highest catch numbers were for the following species: bream (*Acanthopagrus australis*) (30,914), mullet (*Mugil cephalus*) (141,810), sweetlips (*Lethrinus miniatus*) (154,248), trevally (*Pseudocaranx dentex*) (105,483), tropical snapper (*Lutjanus lutjanus, Lutjanus rivulatus, and Lutjanus fulviflamma*) (211,564), whiting (*Sillago sihama, and Sillago analis*) (262,471) and mackerel (*Rastrelliger kanagurta*) (103,633). All common fish species identified from records extend in range beyond the Port Curtis region to areas right around northern Australia.

- During the 2002, 1999 and 1997 surveys, bream (492,608; 358,759; 389,000), cod (168,095; 102,781; 172,000), sweetlips (371,612; 254,365; 145,000), tropical snapper (233,698; 188,840; 123,000) and whiting (779,217; 643,040; 699,000) had consistently high catch numbers.

- In 2002 and 2005, the mullet had consistently high catch numbers (145,892; 141,810); however, the species is recorded as data deficient for prior surveys.

- In 2002, the grunter (*Pomadasys kaakan*) (127,629), parrot (*Oplegnathus woodwardi*) (109,772) and red throat emperor (*Lutjanus sebae, Lutjanus malabaricus, and Plectropomus maculates*) (109,772) had spikes in catch rate with numbers increasing significantly from previous surveys. However, all species catch numbers have declined since the 2005 survey, particularly with the parrot (33,323) and red throat emperor (41,778).

The status of recreational fishing is a key indicator of environmental health, productivity and sustainability. In Port Curtis, it appears recreational fishery stocks of dominant species are productive and sustainable under current management, having maintained consistently high catch numbers since 1997.

The species targeted by the recreational fishers are of regional importance in terms of listing criteria, and on that basis alone, significance would be **low** according to Table 1 in Section 4. However, the resource is of frequent recreational use and importance and is assessed as high significance, which is likely to be more consistent with its perceived significance from a social perspective.

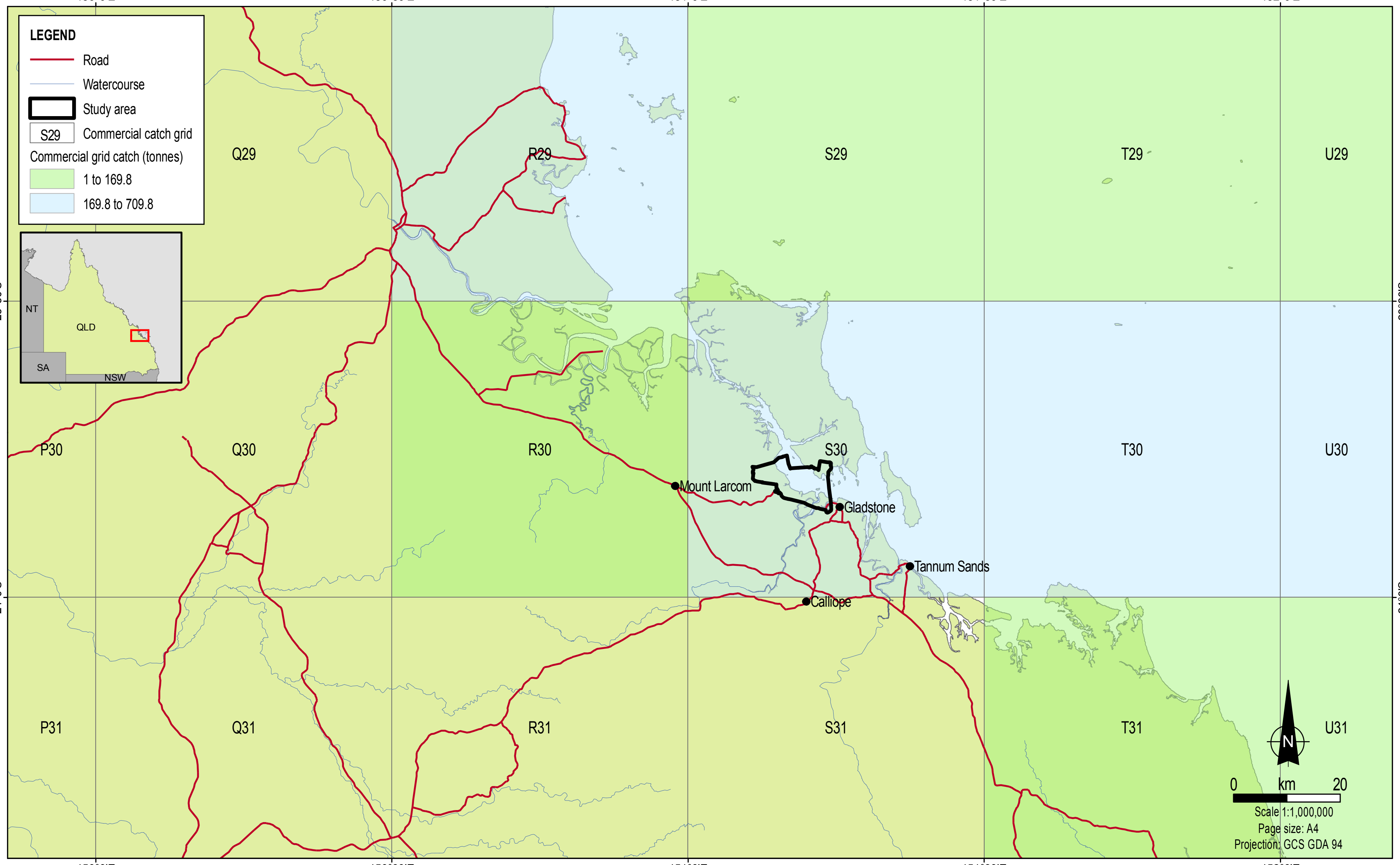
Recreational fishing in Port Curtis and surrounding waters is discussed further in the Social Impact Assessment (SKM, 2011).

Commercial fishing

Commercial fishing in Queensland is a significant contributor to state and national economies and meets Australia’s seafood demands in both quantity and value. DEEDI provides commercial catch data for Queensland waters. All common species identified from records extend in range beyond the Port Curtis region to areas right around northern Australia, and for some species, southern Australia as well. Commercial fisheries are typically classified based on the targeted species and the fishing equipment used. These include:

- Trawl fisheries: There are four main trawl fisheries operating in Queensland, including the east coast otter trawl fishery which encompasses the central Queensland coast. These fisheries primarily target prawn and scallop species and use one of two types of trawl equipment; beam trawl or otter trawl.
- Net fisheries: There are three net fisheries operating in Queensland, including the east coast inshore fin fish fishery which encompasses the central Queensland coast. The southern east coast fisheries primarily target mullet, tailor (Pomatomus saltatrix), whiting, flathead (Cymbacephalus nematophthalmus, and Platycephalus longispinis), bream, mulloway (Argyrosomus japonicus) and school mackerel (Rastrelliger kanagurta).
- Line fisheries: There are five line fisheries operating in four key areas in Queensland, including the GBRMP and south of the GBRMP to New South Wales. These fisheries primarily target coral trout (Plectropomus leopardus, Plectropomus maculates, Plectropomus laevis, and Variola louti), Spanish mackerel (Scomberomorus commerson) and red throat emperor (Lutjanus sebae, Lutjanus malabaricus, and Plectropomus maculates). The main techniques include bottom handlines for demersal species, trolling for pelagic species and droplines for deep water species.
- Pot fisheries: There are many pot fisheries along the Queensland coast with major catch sites denoted by the target crab species. The main mud crab (Scylla serrata) fisheries operate in the intertidal waters of Moreton Bay, The Narrows, Hinchinbrook Channel and Princess Charlotte Bay generally between December and June. These fisheries use wire-mesh crab pots, trawl-mesh crab pots and collapsible traps to access resources. Conversely, spanner crab (Ranina ranina) fisheries operate year round except during a one month spawning period typically in the waters south of Yeppoon. Under the Fisheries Act, fishers must use dillies a hooped frame with netting stretched across them, to catch stocks.
- Apart from the catching sector, there are also local processing and wholesale marketing outlets in Gladstone (i.e., scallop and fish processing operations), which is part of the value-adding for the commercial fishing sector. Fishing, agriculture and forestry combined currently contribute 2.7% of Queensland’s industry Gross Value Add, and 0.8% to Gladstone (AEC Group, 2011).

Since 1988, commercial trawl, pot, net and line fishers have recorded information on catch efforts in 30-minute grid squares (Figure 9). Port Curtis, The Narrows and surrounding waters (grid S30),



Source:
Place names from DME. Roads and watercourse from Geoscience Australia.
Study area from Arrow Energy.
Coastline from GBRMPA.
Commercial catch grids from DEEDI (2005).

coffey environments

Date: 03.10.2011
MXD: 7033CA_MNE_GIS009_v1_1
File Name: 7033CA_MNE_F009_GIS

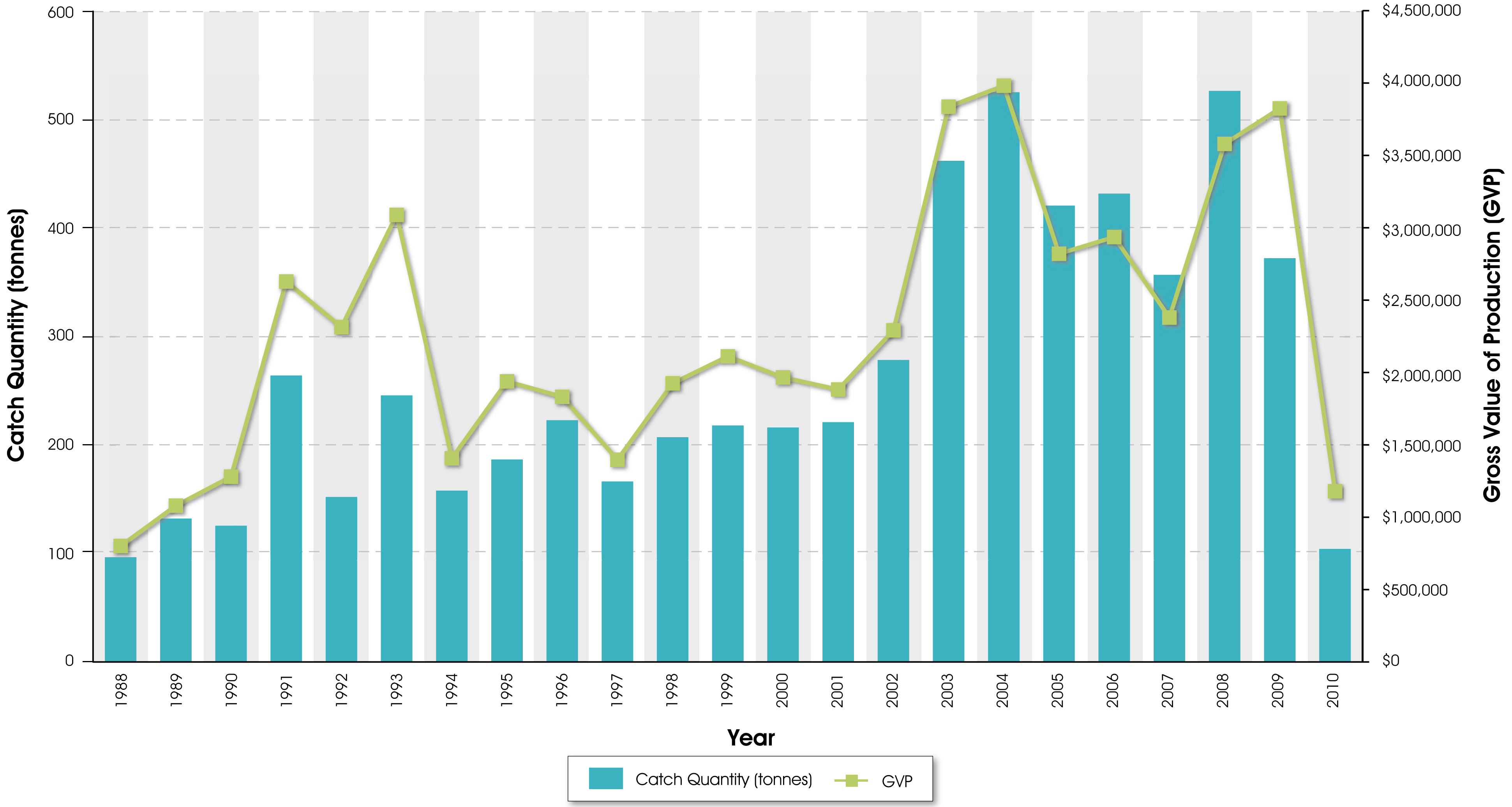
Arrow Energy

Arrow LNG Plant

arrow energy go further

Commercial catch for all species and fishery types in Central Queensland waters, 2005

Figure No: 9



Source: Commercial fisheries data is supplied by the Department of Employment and Economic Development and Innovation (DEEDI)

coffey environments	Job No: 7033	Arrow Energy	arrow energy go further	Commercial Catch Quantity and Gross Value of Production in Grid S30, 1988 - 2010
	File Name: 7033CA_MNE_F010_GL	Arrow LNG Plant		Figure No: 10

are key commercial fishing grounds and account for 104.2 tonnes of produce caught in 2010. The commercial catch for all species and fishery types between 1988 and 2010 is shown in Figure 10. During this period, catch quantity and value increased in value in grid S30, with a rapid rise after 2002. Between 2003 and 2010, commercial catch quantities remained high but variable. The catch data recorded for 2010, however, is incomplete and should not be used to infer trends. The value of the mangroves as nursery areas for many of the commercially exploited species is also important in assessing the overall significance of the commercial fishing.

The status of commercial fishing is a key indicator of environmental health, productivity and sustainability. In grid S30, it appears all commercial fishery stocks of dominant species are productive and sustainable under current management of the Fisheries Act having maintained consistent catch quantities since 1988 and increased yield from 2003 to 2010.

Commercial fishing in Port Curtis and surrounding waters is discussed further in the Social Impact Assessment (SKM, 2011).

The species targeted by the commercial and recreational fishers are of regional importance in terms of listing criteria, and on that basis alone, significance would be low according to Table 1 in Section 4. However, the resource is of frequent commercial use and importance and is assessed as high significance, taking into account is importance to the local community from an economic and social perspective.

5.4.6 Sea Snakes

Information on the abundance, population dynamics and distribution of sea snake species is limited in the published literature (Lukoschek *et al*., 2007). In Australia, 33 of the world's 54 described species occur, almost exclusively within Australia's exclusive economic zone (Cogger, 2000).

A number of sea snake species are listed under the EPBC Act. The Species Profile and Threats database, a subordinate of the EPBC Act identifies 12 sea snakes listed as protected species, which have an indicative range extending into Port Curtis and the surrounding regions, although none of the species is recognised on the IUCN Red List. These are listed in Table 6.

Table 6 Conservation Status of Marine Sea Snakes in Queensland Waters

Scientific Name	Common Name	IUCN Red List
Acalyptophis peronei	Horned sea snake	Not evaluated#
Aipysurus duboisii	Dubois' sea snake*	Not evaluated#
Aipysurus eydouxii	Spine-tailed sea snake*	Not evaluated#
Aipyaurus laevis	Olive sea snake*	Not evaluated#
Astrotia stokesii	Stokes' sea snake	Not evaluated#
Disteria kingie	Spectacled sea snake*	Not evaluated#
Disteria major	Olive-headed sea snake	Not evaluated#
Emdocephalus annulatus	Turtle-headed sea snake	Not evaluated#
Hydrophis elegans	Elegant sea snake	Not evaluated#
Hydrophis mcdowell	Small headed sea snake	Not evaluated#
Lapemis hardwickii	Spine-bellied sea snake	Not evaluated#
Pelamis platurus	Yellow-bellied sea snake	Not evaluated#

* Indicates species listed on the Wetland Info's Wetland Information Summary Search database operated by DERM and have been sighted within the Fitzroy natural resource management region and the Gladstone local government area.

Most sea snakes forage near the seabed but must come to the surface to breathe and so are restricted to relatively shallow waters. Some species have an affiliation to coral reefs, estuarine or soft sediment habitats (Lukoschek *et al.,* 2007). Any of the species listed in Table 6 may potentially occur within the study area where these habitats occur. Estuarine and soft-sediment habitats exist along much of the Queensland coast, including Friend Point, Laird Point and Targinie Creek within Port Curtis. Those species affiliated with coral reefs are likely to reside within the GBRMP located adjacent to the study area, where coral colonies are abundant but outside Port Curtis.

Sea snakes have been recorded to aggregate in high densities within some areas throughout their spatial ranges but not in other similar ecological areas (Heatwole, 1997). This distribution along with unknown population estimates can have implications on conservation and management of the species. Ultimately, the baseline information necessary to determine the benefits of marine protected areas for sea snakes is not available (Lukoschek *et al*., 2007). Currently the only protected areas that encompass the range of selected species of sea snakes are those within the GBRMP. The state government and research organisations are working with members of industry to encourage the use of TEDs on trawlers to minimise the rate of sea snake by-catch. However, further research is required to assist in developing effective conservation and management plans.

The sensitivity of seasnakes is assessed as **medium**. Although listed under the EPBC Act, the species potentially present do not have any conservation status and are not on the IUCN Red List.

5.4.7 Seahorses and Pipefish

Seahorses and pipefish, known as syngnathid fishes, occupy a diverse range of habitats including seagrass, tidepools and sheltered inshore areas (Heck, 1980; Gomon *et al*., 1994). The preferred habitat selection may reflect functional morphology or avoidance of predation (Heck, 1980; Motta *et al*., 1995). Despite this generalised association, there is limited information about the specific habitats of the individual species.

Selected species of syngnathid fish have been recognised to hold significant environmental value and are listed under the EPBC Act. The Species Profile and Threats database, a subordinate of the EPBC Act identifies syngnathid fishes listed as protected species, which have an indicative range extending into Port Curtis and the surrounding regions. All of the species listed with exception to *Solegnathus hardwickii* (data deficient) are not recognised on the IUCN Red List (2010). These are listed in Table 7.

Table 7 Conservation Status of Marine Seahorse and Pipefish in Queensland Waters

Scientific Name	Common Name	IUCN Red List
Acentronura tentaculata	Short-pouch pygmy pipehorse	Not evaluated
Campichthys tryoni	Tryon's pipefish	Not evaluated
Choeroichthys brachysoma	Pacific short-bodied pipefish	Not evaluated
Corythoichthys amplexus	Brown-banded pipefish	Not evaluated
Corythoichthys flavofasciatus	Yellow-banded pipefish	Not evaluated
Corythoichthys haematopterus	Reef-top pipefish	Not evaluated
Corythoichthys intestinalis	Banded pipefish	Not evaluated

Table 7 Conservation Status of Marine Seahorse and Pipefish in Queensland Waters (Cont'd)

Scientific Name	Common Name	IUCN Red List
Corythoichthys ocellatus	Ocellated pipefish	Not evaluated
Corythoichthys paxtoni	Paxton's pipefish	Not evaluated
Corythoichthys schultzi	Schultz's pipefish	Not evaluated
Doryrhamphus excises	Blue-stripe pipefish	Not evaluated
Festucalex cinctus	Girdled pipefish	Not evaluated
Filicampus tigris	Tiger pipefish	Not evaluated
Halicampus dunckeri	Duncker's pipefish	Not evaluated
Halicampus grayi	Mud pipefish	Not evaluated
Halicampus nitidus	Glittering pipefish	Not evaluated
Halicampus spinirostris	Spiny-snout pipefish	Not evaluated
Hippichthys cyanospilos	Blue-spotted pipefish	Not evaluated
Hippichthys heptagonus	Madura pipefish	Not evaluated
Hippichthys penicillus	Beady pipefish	Not evaluated
Hippocampus bargibanti	Pygmy seahorse	Not evaluated
Hippocampus kuda	Spotted seahorse	Not evaluated
Hippocampus planifrons	Flat-face seahorse	Not evaluated
Hippocampus zebra	Zebra seahorse	Not evaluated
Lissocampus runa	Javelin pipefish	Not evaluated
Micrognathus andersonii	Short-nose pipefish	Not evaluated
Micrognathus brevirostris	Thorn-tailed pipefish	Not evaluated
Nannocampus pictus	Painted pipefish	Not evaluated
Solegnathus hardwickii	Pipehorse	Data deficient
Solenostomus paradoxus	Ornate ghost pipefish	Not evaluated
Solenostomus cyanopterus	Robust ghost pipefish	Not evaluated
Syngnathoides biaculeatus	Double-ended pipehorse	Not evaluated
Trachyrhamphus bicoarctatus	short-tailed pipefish	Not evaluated

Seagrass and coral reef habitats are present within Port Curtis and the surrounding regions, including the GBRMP and coastal areas along the central and southeast Queensland coastline. With only limited published information on the habitat preferences of individual species, any of the syngnathid fishes listed in Table 7 could occur in the Port Curtis region. With such variability in habitat utilisation and distribution, and unknown population estimates, limited management plans have been implemented apart from protection of selected reef and seagrass habitats. Currently the only protected areas that encompass the range of selected species of sea horses and pipefish are those within the GBRMP. Under the Fisheries Act, areas along the Queensland coast undergo seasonal trawling closure. This management approach allows breeding stocks, including syngnathid fishes, to increase and be conserved.

The sensitivity of pipefishes and seahorses is assessed as **medium** due to their reliance on threatened habitats. Although listed under the EPBC Act, the species do not have any conservation status and are not on the IUCN Red List.

5.4.8 Macrobenthic Communities

Macrobenthic communities include macroinvertebrate species, which live within and on the seabed sediments. They play an important role in maintaining water quality and recycling nutrients (Harris, 1999; Peterson and Heck, 1999) and form the basis of the food chain for higher trophic levels. These communities show strong links with environmental and sediment characteristics and provide a valuable indicator for ecosystem health as the dynamics of benthic fauna reflect impacts of abiotic, biotic and anthropogenic influences (Currie and Small, 2005; Currie and Small, 2006)

CQU (Appendix A) conducted a baseline survey to characterise the intertidal and subtidal macrobenthic communities of 11 sites within Port Curtis including, Hamilton Point, Launch 4N,Calliope River and sites C1, C2, C3, C4 and C5 which are also in the Calliope River, Boatshed Point, The Narrows and Targinie Creek. A total of 551 macroinvertebrate organisms from 124 species and seven different phyla were collected. The most common phyla included polychaete worms 38%, molluscs 31%, and crustaceans 28% with nemerteans and pycnogonids being the least common (< 1%). At each site, molluscs (*Mactra abbreviate*), crustaceans (*Corophium cf. Acutum,* and *Ogyrides delli*) and annelid worms (*Glycera* sp. and *Eunice vittata)* were the most abundant of the species.

From the results, Alquezar (2011) (Appendix A), found no significant differences in macroinvertebrate total abundance or species evenness among sites in the studies, with macroinvertebrate species showing widespread distribution within Port Curtis. The Narrows had the highest species richness and diversity, however, these characteristics were significantly lower at Hamilton Point and Targinie Creek. At a site-specific scale there were no significant differences in biodiversity between intertidal and subtidal sites, as was the case for sediment organic content and particle size.

For the field investigations, significant differences were observed among sites, with significantly lower macroinvertebrate abundance, species richness and diversity. At a site-specific scale there was a significant difference of biodiversity between intertidal and subtidal sites, with higher biodiversity being present at intertidal sites.

Overall macroinvertebrate community assemblages were dissimilar among sites across both phases of field sampling and to a lower extent depth and sampling times.

A previous study (Alquezar, 2008) in 2008 within the same sites and during the same season showed similar biodiversity (total abundance, species richness, diversity and evenness) to the results of those shown in Appendix A. However, there were some differences, particularly for the subtidal area at Hamilton Point where a significant decline in macroinvertebrate numbers occurred from 2008 to 2010. In contrast, intertidal abundance and richness were higher at Boatshed Point and Laird Point in 2010 than in 2008. There are many factors, such as changes to hydrology, currents, water quality and sediment and organic input that might influence macrobenthic communities, sometimes giving rise to long-term fluctuations or trends. Over a six-year period from 1995 to 2001 Currie and Small (2005) found a progressive decline and subsequent recovery of indices of benthic species abundance and richness in Port Curtis, correlated with turbidity, which promoted recruitment and growth of benthic communities. Strong correlations with rainfall, freshwater inflow, nutrients and chlorophyll levels also supported the hypothesis that benthic changes were related to long term climatic cycles including El Niño southern oscillation events. The importance of the study is to understand pre-construction ranges of benthic populations. The benthic species themselves, while not all described (Currie and Small, 2005) are representative of overlapping east coast temperate and tropical Australian biogeographic regions (Wilson and Allen, 1983) and hence widespread in distribution and not localised or endemic to Port Curtis.

The sensitivity of macrobenthic communities in the study area is **very low** as they can be defined as having local importance, given that community total abundance and species evenness is similar within the project and wider port area.

5.4.9 Plankton

Collectively, plankton include of a range of small or microscopic organisms that float or drift in the water column (Appendix A). Plankton includes both phytoplankton, which are plants and zooplankton, which include fauna ranging from larval forms of fish and many invertebrates to animals permanently in the plankton.

Phytoplankton such as dinoflagellates and diatoms contribute to a large proportion of the ocean's productivity through photosynthesis; the conversion of solar energy and nutrients into chemical energy. Typically most species of phytoplankton retain chlorophyll, a photosynthetic pigment that enables the use of solar energy to convert carbon dioxide into complex organic molecules, such as sugar or protein. The density of phytoplankton in the water column can provide an indication to the health of the ecosystem and how it is influenced by a number of environmental or anthropogenic impacts such as sediment or nutrient loading.

Small crustaceans such as copepods, shrimps and their larvae represent a large proportion of organisms that make up zooplankton. Such organisms graze on phytoplankton and form a vital pathway for the transfer of organic carbon from phytoplankton to organisms higher in the food chain.

These planktonic communities have not been studied specifically, as once-off sampling would not be meaningful, but are included for consideration where impacts could potentially affect larval life cycle processes and integrity of the ecosystems in Port Curtis.

The sensitivity of plankton in the study area is **very low** and can be defined as having local importance given that many organisms undergo larval life cycle processes and support ecosystems in Port Curtis.

5.4.10 Introduced Species and Pest Species

Within Australian waters, over 200 marine species have been introduced unintentionally through mariculture and shipping activities (DEEDI, 2010). In 2001, Lewis *et al* (2001) conducted a survey within Port Curtis to ascertain baseline information on native, introduced and pest species. Ten introduced species were described in Port Curtis, including the ascidian *Styela plicata* and *Botrylloides leachi*, the bryozoan *Amathia distans, Bugula neritina, Cryptosula pallasiana, Watersipora subtorquata* and *Zoobotryon verticillatum*, the hydrozoan *Obelia dichotoma*, the isopod *Paracerceis sculpta* and the dinoflagellate *Alexandrium* sp. The species listed are not recognised as pests and are established in ports throughout Australia and the world. Despite their widespread distribution they are not known to pose a significant threat to native communities within the port.

As of the 01 July 2001, the Australian Quarantine and Inspection Service (AQIS) enforced a mandatory ballast water management system to reduce the risks of introduction of pest species into Australian waters. At a regional scale, the GPC has integrated monitoring as part of the port's sampling program. This aims to target those areas that are exposed to significant shipping activities and ballasting (Lewis *et al*., 2001).

The sensitivity of introduced or pest species becoming established in the study area is potentially **very high** and can be defined as having international importance given that many organisms in foreign ports could be known to invade and be transported into Port Curtis and into the GBRWHA.

6. ISSUES AND POTENTIAL IMPACTS

This section describes the issues and potential impacts on marine and estuarine ecology values that may be attributable to the construction, operation or decommission phases of the Arrow LNG Plant. This section considers the magnitude of the impacts, as described in Table 2 (in Section 4) prior to the application of any mitigation measures. The following issues and potential impacts are assessed:

- Direct loss and disturbance of marine and estuarine habitat from construction of the marine facilities.
- Indirect loss and disturbance (e.g., from sediment plumes).
- Impacts on marine and estuarine fauna.
  - Boat strike.
  - Underwater noise.
  - Lighting.
- Loss of commercial and recreational fishing access.
- Introduced species and pest species.
- Shipping activities and accidents.

Hydrotest water will be used for integrity testing of pipeline and tanks and will be sourced from the sea or from freshwater generated through the reverse osmosis plant and discharged to the sea. If biocides and/or oxygen scavengers are used, the hydrotest water will be tested and treated as necessary before discharge to minimise impacts to the marine and estuarine environment[2].

6.1 Loss and Disturbance of Marine and Estuarine Habitat

6.1.1 Direct Construction Impacts

The areas that will be occupied or otherwise affected by the project infrastructure (such as the LNG jetty, MOF and launch site) include intertidal mudflats, reefs and rock substrate, benthic sediments, mangrove and saltmarsh communities. These habitats support an array of marine and estuarine fauna during some or all stages of their lifecycle (including fish spawning habitat for recreationally and commercially important fishing species) , which will be directly removed or buried where they are replaced by project infrastructure. The areas of each habitat directly affected are calculated on the basis of the footprint area of each particular facility and a buffer of 5 m surrounding each to allow for construction equipment. Areas adjacent to those directly impacted may also be indirectly affected by the lateral spread of construction-induced increases in turbidity plumes and sedimentation from land and offshore disturbances (WBM BMT, 2011). This will mainly affect marine and estuarine habitats in the local vicinity of the marine infrastructure.

The Vegetation Management Regulation in accordance with the Vegetation Management Act lists regional ecosystems (REs) of 'least concern' for the South Eastern Queensland bioregion, which

[2] This will be determined by hydrodynamic modelling (based on WBM BMT, 2011) once volumes and concentrations are known

encompasses the Gladstone region (namely REs 12.1.2 and 12.1.3 (saltpan and mangroves). The following assessment identifies the quantity and listing of any regional ecosystem that may potentially be lost or disturbed.

Marine habitat types and the area that may potentially be impacted are provided in Table 8. In instances where there are options for the location of marine infrastructure, each option is assessed, and the most conservative or worst case scenario of habitat loss is considered in the impact assessment. Whilst this approach provides an upper estimate of impact for the Arrow LNG Plant, it ensures that the assessment of impact is not underestimated for whichever combination of infrastructure locations is selected. An exception is the marine habitats directly impacted by construction at launch sites 1 and 4N, which are so small that they have not been included in Table 8.

Table 8 Estimated Schedule of Disturbance on Habitat Types for the Arrow LNG Plant

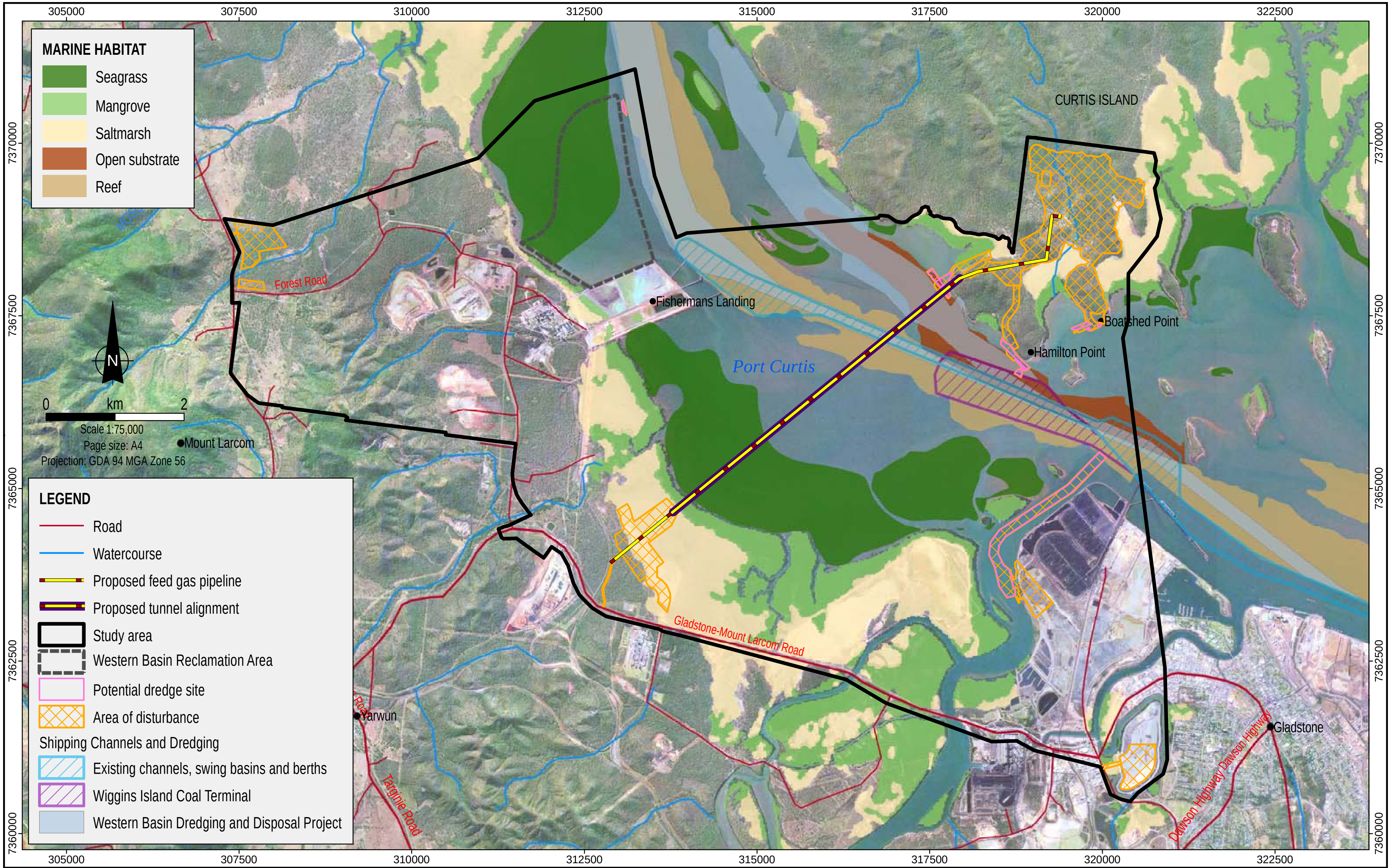
Habitat Type	Infrastructure Component	Case	Potential Area of Disturbance (ha)	Worst Case (i.e., for impact assessment)
Mangroves*	Boatshed Point MOF and associated haul road	Base	<0.1	Yes
	South Hamilton Point MOF and associated haul road	Alternative	0	No
	TWAF 7	Base	<0.1	Yes
	TWAF 8	Alternative	0	No
	LNG Facility and associated infrastructure	Base	5.78	Yes
Saltmarsh*	Mainland tunnel entry area and disposal area	Base	55.2	Yes
	TWAF 7	Base	1.3	Yes
	TWAF 8	Alternative	0	No
	LNG Facility and associated infrastructure	Base	1.7	Yes
Seagrass†	No direct impacts	Base	0	Yes
Benthic zone and intertidal mudflat	Construction of Boatshed Point MOF and associated dredging	Base	0	No
	Construction of Hamilton Point South MOF and associated dredging	Alternative	2.02	Yes
	Dredging associated with LNG jetty	Base	3.29	Yes
Reef	Dredging associated with Launch 1	Base	0.13	No
	Dredging associated with Launch 4N	Alternative	0.14	Yes

* Areas calculated for mangroves and saltmarsh are based on the 1997-2003 data set sourced from DEEDI.

† Areas calculated for seagrass are based on the full 2002 data set sourced from the DEEDI.

Mangroves

The Vegetation Management Act lists *'Mangrove vegetation of marine clay plains and estuaries.'* to be a regional ecosystem of least concern within bioregion 11 and 12 (RE 12.1.3), which encompass the study area. During construction activities, the maximum area is approximately 5.78 ha of mangroves to be cleared (mostly from the LNG plant and associated infrastructure; (see Table 8 and Figures 11 and 12). This accounts for approximately 0.03% of the mangroves in the Port Curtis region based on the total regional boundaries of mangroves calculated by methods



Source: Place names, roads and watercourses from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Proposed feed gas pipeline and area of disturbance from Coffey Environments.
Seagrass (November 2002), mangroves and saltmarsh from DEEDI. Open substrate and reef from Queensland Fisheries Services (DPI).
Western Basin Dredging Master Plan from Gladstone Ports Corporation.
Imagery from SPOT (2004-2007).

coffey environments

Date:	04.10.2011
MXD:	7033CA_MNE_GIS011_v1_2
File Name:	7033CA_MNE_F011_GIS

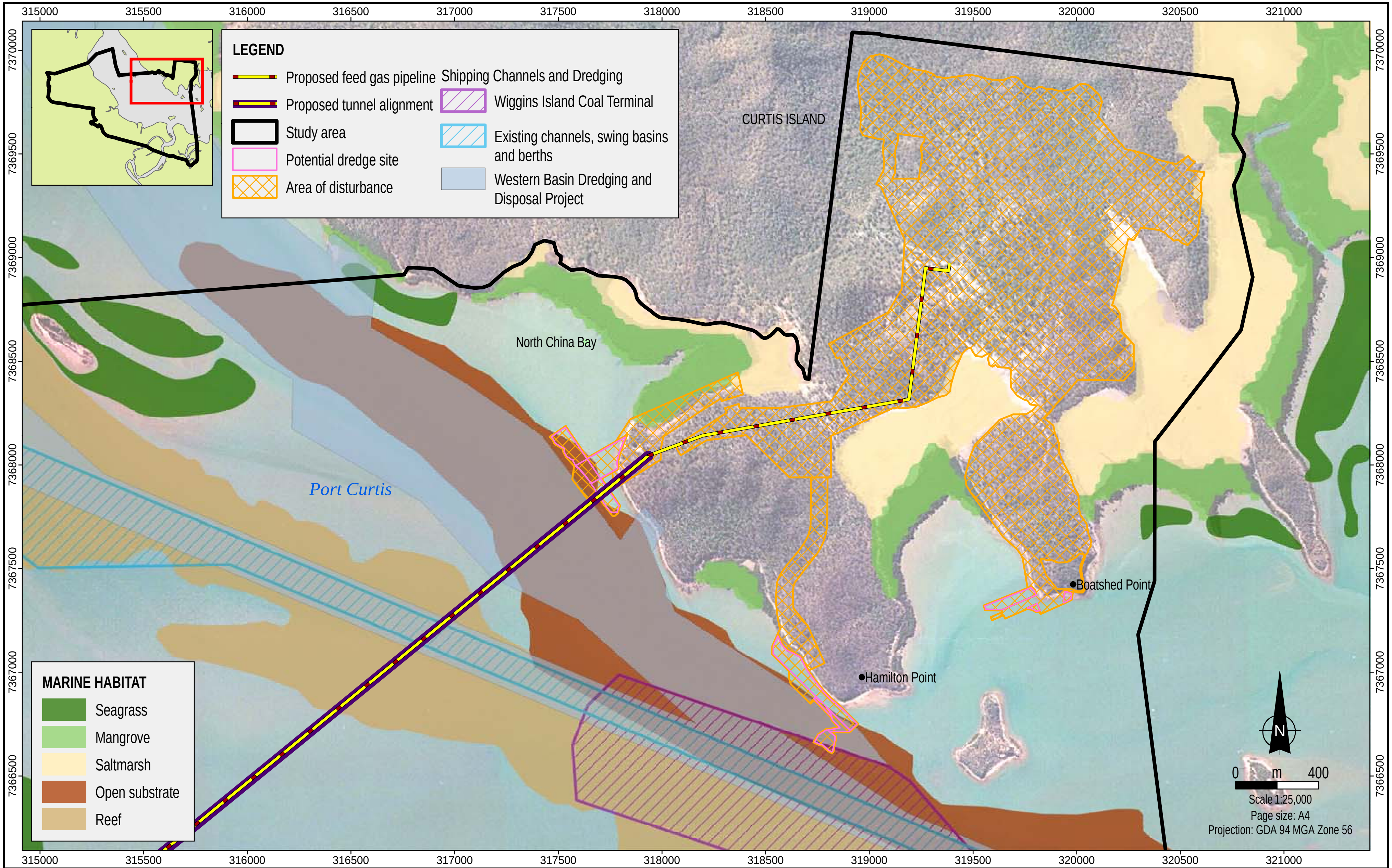
Arrow Energy

Arrow LNG Plant

arrow energy go further

Marine habitat impact areas

Figure No: 11



Source:
Place names from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Proposed feed gas pipeline and area of disturbance from Coffey Environments.
Seagrass (November 2002), mangroves and saltmarsh from DEEDI. Open substrate and reef from Queensland Fisheries Services (DPI).
Imagery from SPOT (2004-2007).

coffey environments

Date:	04.10.2011
MXD:	7033CA_MNE_GIS012_v1_2
File Name:	7033CA_MNE_F012_GIS

Arrow Energy

Arrow LNG Plant

arrow energy go further

Curtis Island potential marine habitat impact areas

Figure No: 12

described in Danaher *et al*., (2005). In comparison with the data set for the Port Curtis region sourced from DEEDI, the area to be disturbed or cleared accounts for approximately 0.1% of the area available. Table 8 outlines the area of disturbance for each of the infrastructure components. It is likely that the closed *Rhizophora* community will be subjected to the greatest clearing, as it is the primary species inhabiting the fringe of the coast. Clearing of mangroves could potentially affect the breeding, feeding and migration of species such as seahorses, pipefish, sea snakes, fish, nekton and macroinvertebrates; some of which are listed under the EPBC Act. On a regional basis, the loss of mangrove from project construction is considerably less than 1 percent of the areas calculated by Danaher *et al*., (2005) and DEEDI. The magnitude of impact of direct loss of mangroves by clearing for marine infrastructure and the pipeline is assessed as low, because of the small area of impact in absolute and percentage terms, and the consequent localised area of effects.

Saltmarsh

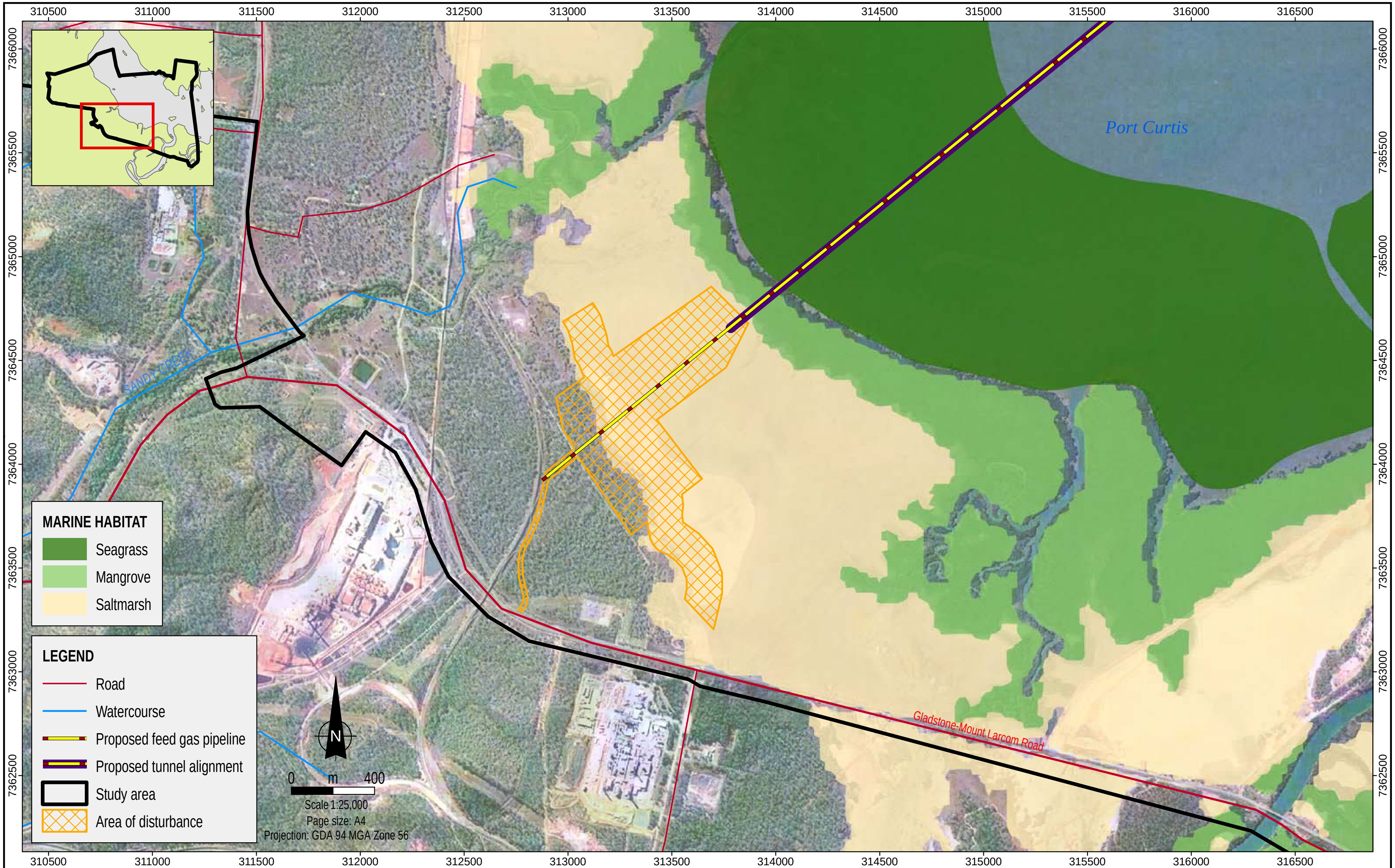
The Vegetation Management Regulation in accordance with the Vegetation Management Act lists *'Samphire open forbland to isolated clumps of forbs on saltpans and plains adjacent to mangroves'* to be a regional ecosystem of least concern within South Eastern Queensland Bioregion (RE 12.1.2), and is assessed as medium sensitivity on this basis (Section 5.3.1). The worst case scenario is for approximately 59 ha of saltmarsh to be impacted at the mainland tunnel entry area (and small areas at TWAF 7 and the LNG plant associated infrastructure) during the construction phase (see Table 8 and Figures 12 and 13). This represents approximately 1.3% of the saltmarsh present in the Port Curtis region based on the investigation conducted by Danaher *et al*. (2005). In comparison with the data set for the Port Curtis region sourced from DEEDI, the area to be disturbed or cleared represents approximately 1.7% of the total area. Table 8 outlines the area of disturbance for each of the infrastructure components. Clearing of saltmarsh could indirectly affect the breeding, feeding and migration of fish, nekton and macroinvertebrates.

On a regional basis, the loss of saltmarsh from project construction is considerably less than 2% of the areas calculated by Danaher *et al*., (2005) and Rasheed *et al.,* (2002).

The magnitude of impact of direct loss of saltmarsh by clearing for the tunnel construction is assessed regionally as medium. Although the overall area of impact is low in percentage terms, the 59 ha of impacted saltmarsh is mainly located in the one area and such impacts may have a greater habitat fragmentation effect.

Seagrass

No seagrass removal is planned during construction of the LNG jetty, MOF infrastructure, vessel terminals or pipeline construction to Curtis Island (Table 8 and see Figure 11). This calculation of zero seagrass area loss is based on observations (Appendix A), which found no evidence of seagrass within the project footprint. This observation is consistent with the full 2002 data set sourced from DEEDI, and with the general description of more recent seagrass distribution within Port Curtis (Rasheed *et al*., 2008; Chartrand *et al*., 2009). It is also consistent with the results of the Gladstone Liquefied Natural Gas (GLNG) EIS supplementary survey, (URS, 2009). It is therefore not expected that construction of the infrastructure will directly impact or remove any existing seagrass beds. The magnitude of impact is therefore very low.



Source:
Roads and watercourses from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Proposed feed gas pipeline and area of disturbance from Coffey Environments.
Seagrass (November 2002), mangroves and saltmarsh from DEEDI.
Imagery from SPOT (2004-2007).

coffey environments

Date:	03.10.2011
MXD:	7033CA_MNE_GIS013_v1_1
File Name:	7033CA_MNE_F013_GIS

Arrow Energy

Arrow LNG Plant

arrow energy go further

Marine habitat impact areas tunnel entry shaft and tunnel spoil disposal area

Figure No: 13

Benthic Zone and Intertidal Mudflat

The worst case calculation of area of impact to mudflat from construction of the marine infrastructure, dredging, piling and other construction activities is that it will disturb approximately 5.31 ha of intertidal mudflat and benthic sediments (Figures 12, 14 and 15). Table 8 outlines the area of disturbance for each of the infrastructure components. This could potentially displace or cause mortality to fish, shellfish, seahorse, pipefish, sea snakes and macroinvertebrates. Further impacts associated with construction may potentially constrain the route of migrations for dugongs, turtles and cetaceans. Many of the organisms in the benthic zone and intertidal mudflat potentially affected by the Arrow LNG Plant are listed as matters protected by the EPBC Act.

The magnitude of impact of direct loss of intertidal and subtidal mudflats by construction (including dredging) for marine infrastructure is assessed as low, because of the small area of impact in absolute and percentage terms, and the otherwise extensive nature of this habitat in Port Curtis.

Reef and Rocky Substrate

The worst case scenario is for approximately 0.14 ha of reef dominated typically by bivalves, ascidians, bryozoans and hard coral to be impacted (Table 8; see Figures 12, 14 and 15). Table 8 outlines the area of disturbance for each of the infrastructure components. This represents approximately 0.004% of the reef present in the Port Curtis region based on the investigation conducted by Rasheed *et al*. (2003). As a result, such activities could affect the breeding, feeding and migration of seahorses, pipefish, sea snakes, fish, nekton and macroinvertebrates; some of which are EPBC Act listed.

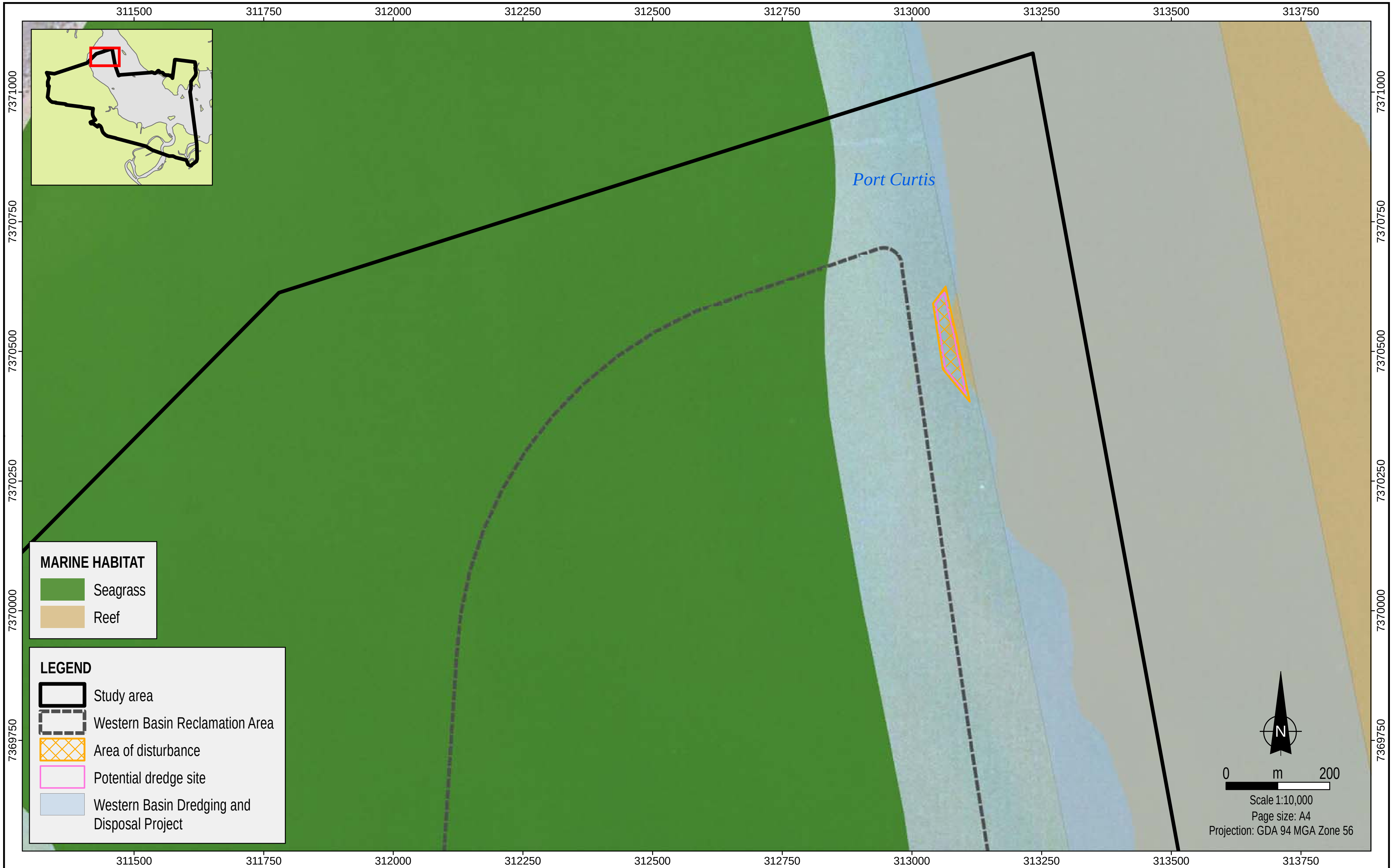
Precise distribution of rocky substrate in Port Curtis is unknown, however is expected to occur in the mid to upper intertidal zone immediately south of Laird Point and at Hamilton Point (URS, 2009), therefore the worst case scenario is for impacts to rocky substrate to occur composed of oyster encrusted boulders and rubble to occur at the mid to upper intertidal zone at the Hamilton Point South MOF option (alternative case).

To some extent, the new hard structures, such as rock armour (if any) and jetty piles, will provide some mitigation by replacement hard surface habitats for colonisation by organisms such as algae, corals, macroinvertebrates, fish and oysters.

The magnitude of impact of direct loss of reef habitat by construction for marine infrastructure is assessed as **low**, because of the small area of impact in absolute and percentage terms.

6.1.2 Indirect impacts

Dredging within Port Curtis is required for LNG shipping access and is to occur in areas of central Port Curtis and along the west coast of Curtis Island. The affects of these dredging activities are assessed within the Western Basin Dredging and Disposal project. Additional dredging for the Arrow LNG Plant includes dredging at five sites within Port Curtis, including the footprints for launch sites 1 and 4N, Boatshed Point MOF 1, Hamilton Point South MOF 2, and the LNG jetty). The indirect impacts to marine habitat during construction will arise mainly from the dispersion of dredging induced plumes (Figure 16 and 17), which has been assessed for each area and dredging plan by WBM BMT, (2011). Other impacts resulting from the operating constraints of machinery (i.e., the ability of plant operators to stay within the designated worksite) have been included as a buffer surrounding the actual work areas in the areas of disturbance as shown in Figure 3 and therefore have already been assessed in Section 6.1.1.



Source:
Study area and marine infrastructure from Arrow Energy.
Proposed area of disturbance from Coffey Environments.
Seagrass (November 2002) from DEEDI. Reef from Queensland Fisheries Services (DPI).
Western Basin Dredging Master Plan from Gladstone Ports Corporation.
Imagery from SPOT (2004-2007).

coffey environments

Date: 04.10.2011
MXD: 7033CA_MNE_GIS014_v1_2
File Name: 7033CA_MNE_F014_GIS

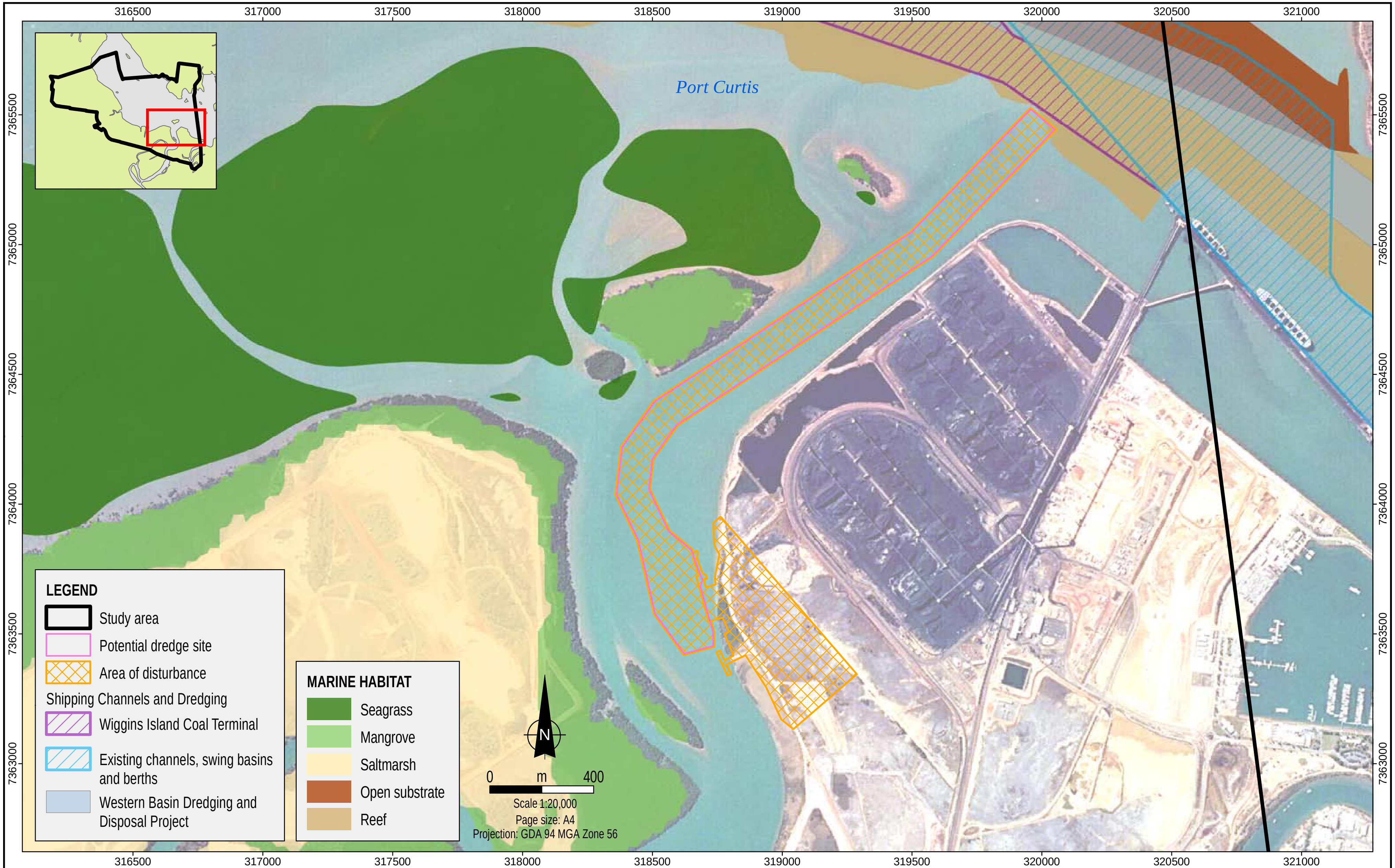
Arrow Energy

Arrow LNG Plant

arrow energy go further

Marine habitat impact areas
Launch Site 4N

Figure No: 14



Source:
Area of disturbance from Coffey Environments.
Study area, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Seagrass (November 2002), mangroves and saltmarsh from DEEDI.
Open substrate and reef from Queensland Fisheries Services (DPI).
Imagery from SPOT (2004-2007).

coffey environments

Date: 04.10.2011
MXD: 7033CA_MNE_GIS015_v1_3
File Name: 7033CA_MNE_F015_GIS

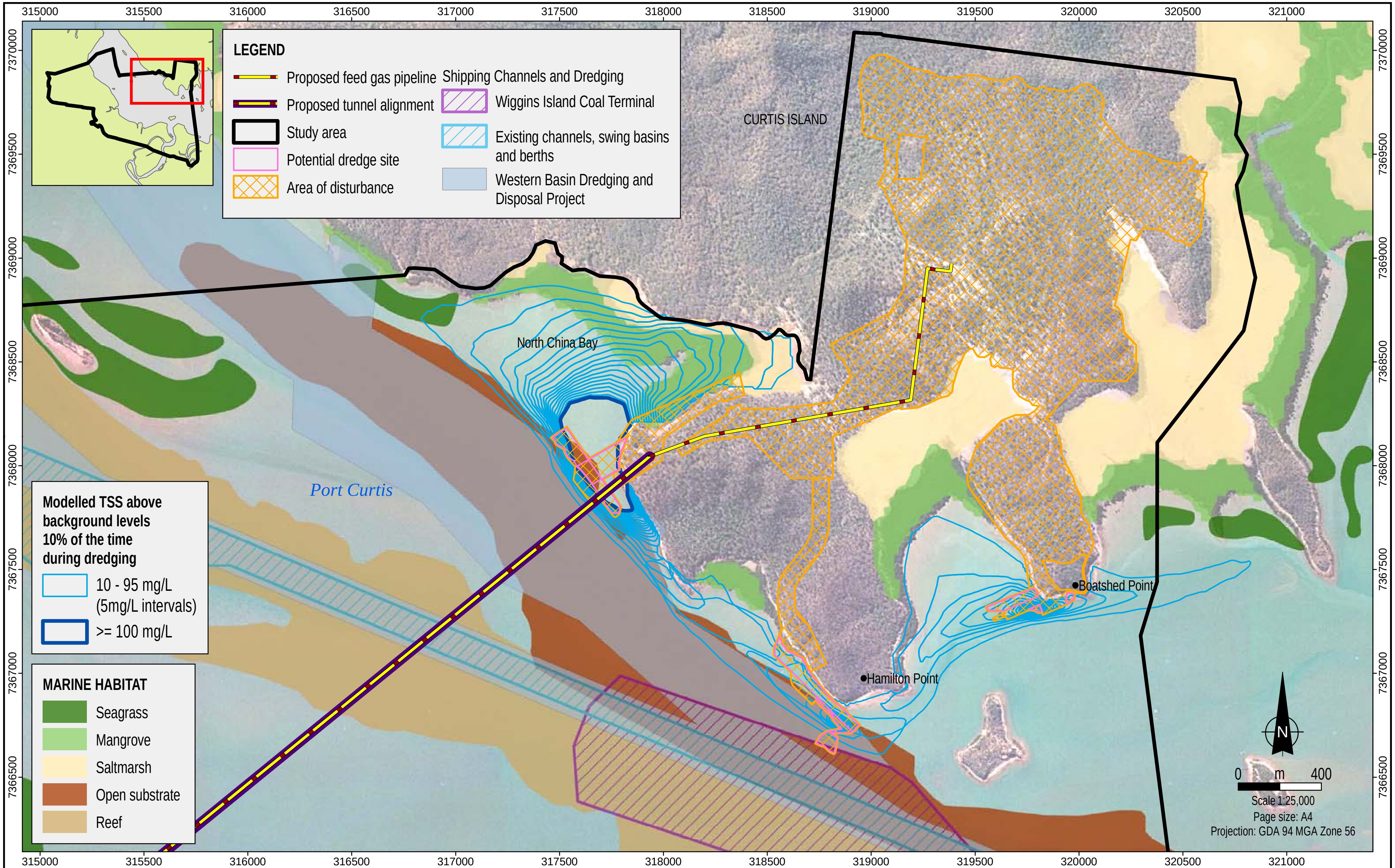
Arrow Energy

Arrow LNG Plant

arrow energy go further

Marine habitat impact areas Launch Site 1 and Calliope River dredging

Figure No: 15



Source: Place names from DME.
Study area, pipelines, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Proposed feed gas pipeline and area of disturbance from Coffey Environments.
Seagrass (November 2002), mangroves and saltmarsh from DEEDI. Open substrate and reef from Queensland Fisheries Services (DPI).
Modelled TSS from BMT WBM.
Imagery from SPOT (2004-2007).

coffey environments

Date: 04.10.2011
MXD: 7033CA_MNE_GIS016_v1_1
File Name: 7033CA_MNE_F016_GIS

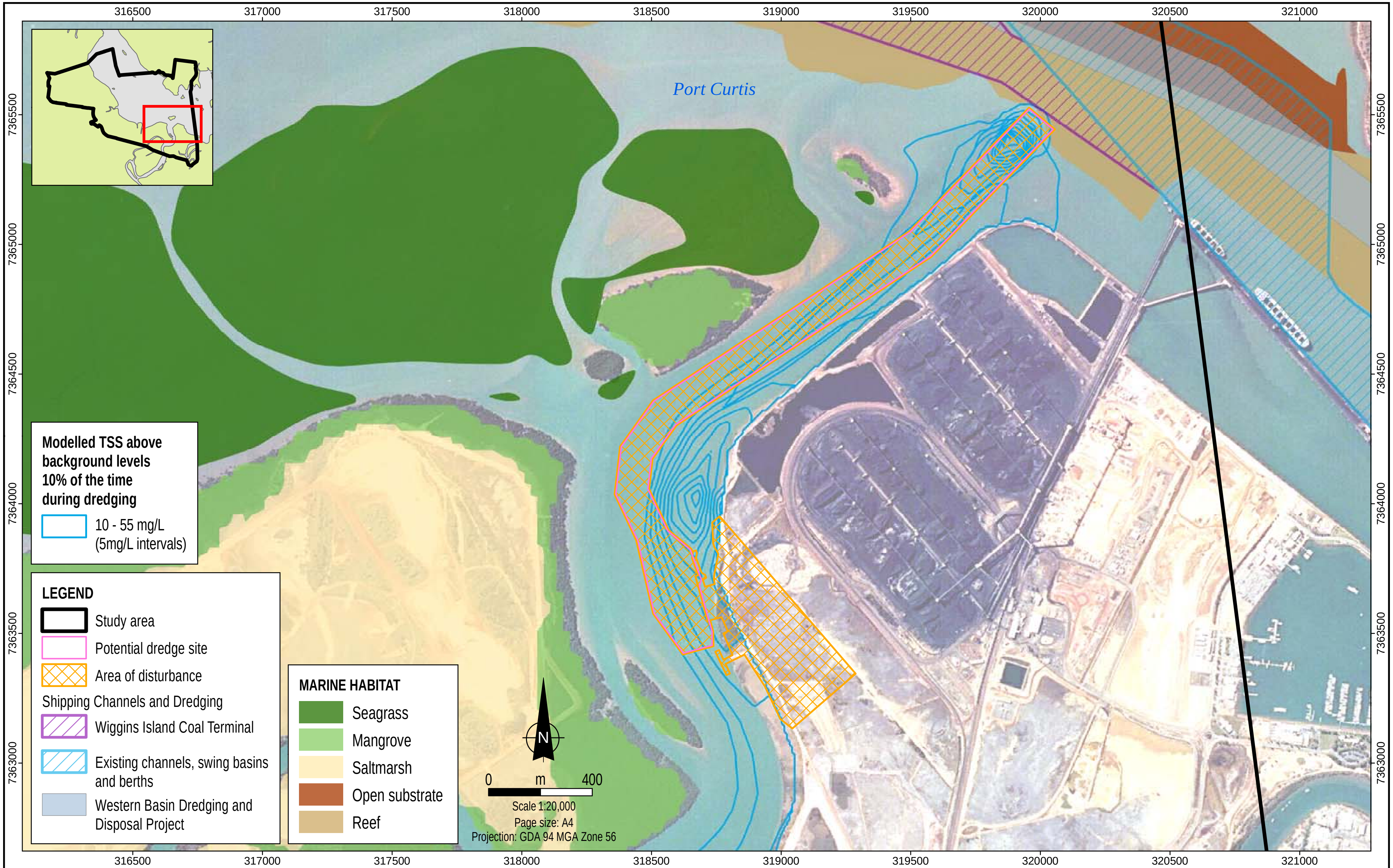
Arrow Energy

Arrow LNG Plant

arrow energy go further

Potential marine habitat indirect impact areas near Curtis Island

Figure No: 16



Source:
Area of disturbance from Coffey Environments.
Study area, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Seagrass (November 2002), mangroves and saltmarsh from DEEDI. Open substrate and reef from Queensland Fisheries Services (DPI).
Modelled TSS from BMT WBM.
Imagery from SPOT (2004-2007).

coffey environments

Date: 04.10.2011
MXD: 7033CA_MNE_GIS017_v1_1
File Name: 7033CA_MNE_F017_GIS

Arrow Energy

Arrow LNG Plant

arrow energy go further

Potential marine habitat indirect impact areas in Calliope River

Figure No: 17

Dredging will impact marine habitat indirectly through increased turbidity and sedimentation on habitat adjacent to dredging activities. The indirect impact of dredging through increased turbidity and disposition of sediments is examined in this section. Impact assessment is based on the predicted spatial extent of plume formation from each of the locations of dredging operations (WBM BMT, 2011), where contours of TSS concentration of 5 mg/L represent the threshold above ambient, and TSS concentration of 100 mg/L was the maximum TSS contour to represent small to moderate impacts. Plume TSS concentrations in excess of 100 mg/L are approximately double the natural background during spring tide conditions and more than ten times the natural background during neap tides and double during spring tide conditions, and are therefore considered to represent a moderate indirect impact.

Mangroves

Modelling of turbidity plumes resulting from dredging show that mangrove communities at Wiggins Island A and B, Mud Island, the Calliope River and Curtis Island (mainly in North China Bay) are expected to experience elevated levels of turbidity exceeding ambient for 10% of the time during dredging (see Figures 16 and 17). However, maximum plume concentrations (>100 mg/L) occur within North China Bay and adjacent to the LNG jetty but these would decrease below 100 mg/L in before reaching mangrove communities.

The magnitude for impact due to increased levels of turbidity and sedimentation is therefore assessed as **low**.

Saltmarsh

Modelling of turbidity plumes resulting from dredging show the contours where saltmarsh in North China Bay will experience levels of turbidity exceeding background levels for 10% of the time during dredging (see Figure 16). However, plume concentrations (>100 mg/L) do not affect saltmarsh.

The magnitude for impact due to increased levels of turbidity and sedimentation is **low**.

Seagrass

Modelling of turbidity plumes resulting from dredging show that seagrass communities at Curtis Island within North China Bay will experience elevated levels of turbidity exceeding ambient levels for 10% of the time during dredging (see Figure 16). However, maximum plume concentrations (>100 mg/L) do not impact seagrass communities.

The magnitude for indirect impact of dredging on seagrass is **low**.

Benthic zone and intertidal mudflat

The total area of intertidal and subtidal mudflats affected by plumes from dredging by increased turbidity in excess of 100 mg/L above background levels exceeding 10% of the time is less than 0.1 ha (see Figure 16). Benthic zone and intertidal mudflat will also experience elevated levels of turbidity above background levels exceeding background levels for 10% of the time during dredging in the Calliope River, at Boatshed Point, Hamilton Point and in North China Bay (see Figure 17).

The magnitude for indirect impact of dredging on benthic environments (muddy seafloor) is **medium** given that all of the plumes above ambient TSS values affects benthic habitat, (i.e., not otherwise covered by seagrass), including areas within the 100 mg/L contour.

Reef and Rock Substrate

Modelling of turbidity plumes resulting from dredging show that reef and rock substrate within Port Curtis will experience levels of turbidity elevated above background levels for 10% of the time during dredging (see Figure 16). However, maximum plume concentrations (>100 mg/L) do not impact reef and rock substrate.

The magnitude for indirect impact of dredging on reef environments is therefore **low** given the low extent of area exposed to plumes above ambient TSS values and there are no areas within the 100 mg/L contour.

6.2 Impact on Marine and Estuarine Fauna and Flora

6.2.1 Boat Strike

Industry and recreational marine vessel activities continue to expand along the Queensland coast, including Port Curtis. Marine vessel activities present an increasing risk of impact on large marine organisms such as dugongs, marine turtles and cetaceans through injury or mortality caused by boat strike.

Most marine vessel activities will take place in sheltered and shallow coastal waters where dugongs, marine turtles and cetaceans commonly reside or graze. Displacement from habitat or feeding grounds due to marine vessel disturbance can be energetically expensive for individuals and in extreme situations, could affect the survival of individuals if feeding grounds cannot be accessed elsewhere (Hodgson and Marsh, 2007). If movement to another resource is possible, individuals are likely to be less affected than those forced to remain in the area and tolerate the disturbance (Gill *et al*., 2001). Deep waters can act as a refuge providing individuals with the opportunity to dive and avoid the vessels. This is a behavioural strategy that has been adopted by dugongs and a range of cetaceans (Nowacek *et al*., 2001a, Baker and Herman, 1989, Finley *et al*., 1990; Hodgson and Marsh, 2007). However, the rate of response of each species or individual to marine vessels is dependent on a number of other factors such as visual cues and hearing ranges.

Marine vessels, ranging from small boats to supertankers all produce underwater noise. Large vessels generate strong and low frequency sounds of up to approximately 50 Hz, medium vessels have an output typically between 100 Hz and 1000 Hz and small vessels generate high frequency sounds generally greater than 1000 Hz (Richardson *et al*., 1995). The reaction rate for marine organisms is partly dependent on their ability to hear within the range of oncoming vessel. If the organism is unable to detect a vessel then there is a greater risk of boat strike.

The increasing trend in recreational boating and modified vessels with low drafts and greater speeds in shallow waters place these organisms at greater risk to boat strike (Wright *et al*., 1995). However, the frequency of high-speed marine vessel using the port will pose the greatest risk of boat strike to large marine organisms. For the Arrow LNG Plant, low speed, low frequency output marine vessels (LNG ships, LPG vessels, LNG escort tugs and barges) and high speed, high frequency output marine vessels (passenger ferries) will be operated during the construction and operation phases. The type, number and frequency of vessels expected to be commissioned are outlined in Table 9. Despite the uncertainty in the number of marine vessels, it is the frequency which if of greater value to determine the magnitude of boat strike.

The marine vessels with low speed, low frequency sound output will generally be restricted to deep water channels during construction and operation phases by virtue of their size, outside shallow water areas where dugongs, turtles and cetaceans typically occur. Based on these constraints such vessels are unlikely to result in boat strike. In addition the frequency of these vessels entering the port is typically separated by a one or two day interval allowing organisms to reside or move freely between areas in the port with minimal disturbance. In comparison, high speed, high frequency output marine vessels will pose a greater risk of boat strike to these organisms as vessels will be making regular transfers (typically 10 return trips per day) between the mainland (Fishermans Landing or Calliope River) and Curtis Island (Boatshed Point) and will operate outside the main shipping channel.

Table 9 Estimated Type, Number and Frequency of Marine Vessels for the Arrow LNG Plant

Type	Number	Frequency [2]
Ferry	2	28 return trips per day
Barge	1	120 return trips per year
LNG carrier	1	576 return trips per year
LPG vessel	1	1 return trip in the first year
LNG escort tug	4	960[1] per year
Cutter suction dredging vessel	1	To be confirmed[3]
Support vessel	1	To be confirmed[3]
Backhoe dredging barge	1	To be confirmed[3]
Backhoe support tugs	2	To be confirmed[3]

[1] Based on four tugs (two active and two on standby) per LNG carrier per one way journey.
[2] Based on four LNG Trains
[3] Frequency of dredge vessels (including tugs and support vessels) will be outlined in the dredge management plan.

The marine vessels with low speed, low frequency sound output will generally be restricted to deep water channels during construction and operation phases by virtue of their size, outside shallow water areas where dugongs, turtles and cetaceans typically occur. Based on these constraints such vessels are unlikely to result in boat strike. In addition the frequency of these vessels entering the port is typically separated by a one or two day interval allowing organisms to reside or move freely between areas in the port with minimal disturbance. In comparison, high speed, high frequency output marine vessels will pose a greater risk of boat strike to these organisms as vessels will be making regular transfers (typically 28 return trips per day) between the mainland (Fishermans Landing or Calliope River) and Curtis Island (Boatshed Point) and will operate outside the main shipping channel.

Dugongs

In 2005, the dugong population for Port Curtis was estimated at approximately 2,580 individuals as inferred from the central and southern Great Barrier Reef population. This record accounts for approximately 18% of the estimated population in the GBRMP.

Dugongs rely on sound and visual cues to detect and avoid marine vessels. The West Indian manatee (a closely related species) can detect sounds between 0.4 Hz to 46 kHz, with highest sensitivity between 6 to 20 kHz (Gerstein *et al*., 1999). Although specifics for dugong hearing have not yet been determined, Ketten *et al*. (1992) theorized that the species' hearing sensitivity is greater than manatees. However, Hodgson (2004) proposed that despite such capabilities dugongs delay fleeing until the probability of imminent boat strike is greater than the energetic cost of fleeing, which puts them at greater risk of injury. Dugongs have a high energy requirement and when disturbed from feeding or displaced to another seagrass bed in response to marine vessels their energy intake is sacrificed. Hodgson (2004) observed that dugongs were significantly less likely to continue feeding if boats were within 50 m of the individual.

The navigation route for high speed, high frequency output vessels is anticipated to avoid key seagrass beds north and south of Fishermans Landing and Wiggins Island where dugongs typically feed. However, due to evidence of feeding trails throughout all seagrass beds in the port it can be assumed that individuals move frequently among and between seagrass beds. Therefore boat strike is a potential impact for the localised dugong population along navigation routes.

Prior to mitigation, the potential magnitude of boat strike is **high**, on the basis that over the life of the project, any dugongs injured or killed as a result of boat strike could impact local populations. Any injuries or deaths of dugongs will also result in public concern.

Turtles

The turtle population for Port Curtis can be determined from direct monitoring on Curtis Island or inferred from the southern Great Barrier Reef population (Limpus *et al*., 2006; DEWHA, 2010a; Limpus and Limpus, 2003). Records indicate:

- 51 flatback nesting females have been observed at South End, Curtis Island.
- Approximately 10 to 150 nesting turtle females (varying species) utilise the southern Great Barrier Reef each year accounting for 2% to 30% of the estimated population along eastern Australia.
- Approximately 8000 individuals (varying species) utilise the southern Great Barrier Reef each year accounting for 16% of the estimated population in the Great Barrier Reef. Many of these nesting areas are on the outer reefs, such as at Heron Island, which lies some 50 km offshore from Port Curtis.

The sensitivity of hearing in marine turtles varies among species. Most species including the green turtle and the loggerhead turtle are able to hear between 100 Hz and 800 Hz (Ketten and Bartol, 2006). This suggests that high speed, high frequency small marine vessels may be difficult for marine turtles to detect until in close range. Marine turtles also have efficient vision (Moein, Bartol and Musick, 2003) and rely on timely visual cues to detect a marine vessel. The rate of visual detection is dependent on water clarity and the attenuation of light through particulate matter in the water column (Preisendorfer, 1986, Hazel *et al*., 2007). Together these factors influence the turtles response to oncoming marine vessels.

The navigation route for high speed, high frequency output vessels is anticipated to avoid key seagrass beds north and south of Fishermans Landing and Wiggins Island, and coral reef habitat at the northwest extremity of Port Gladstone extending south to Fishermans Landing where turtles feed and reside in between breeding seasons. However, due to the migratory behaviour of marine turtles and the broad range of habitats present and potentially used, it can be assumed that individuals move frequently within the port. Therefore boat strike is a potential impact for the turtles that occur along navigation routes.

Prior to mitigation, the magnitude of boat strike is **high** on the basis that any turtles injured or killed as a result of boat strike could impact local populations. Any injuries or deaths of turtles will also result in public concern.

Dolphins

The populations of Indo-Pacific humpback dolphin and the Australian snubfin dolphin in Port Curtis can only be inferred from the population identified in Cleveland Bay near Townsville. Currently no other population estimates are available at any other local or regional scale.

Cetaceans have a broad hearing frequency range with variability among species. Most odontocete species, which include toothed whales, porpoises and dolphins, can typically hear sound between 1 kHz and 100 KHz (Au Whitlow, 1993). This suggests that the Indo-Pacific humpback dolphin and the Australian snubfin dolphin are also likely to be capable of detecting high speed, high frequency marine vessels and have the ability for rapid avoidance actions.

The navigation route for high speed, high frequency output vessels is anticipated to cross directly over shallow coastal waters in or adjacent to near modified environments where the Indo-Pacific humpback dolphin and the Australian snubfin dolphin may potentially forage, breed and reside. Therefore boat strike is a potential impact for the localised dolphin population along navigation routes.

Prior to mitigation, the magnitude of boat strike can be defined as **high** on the basis that any injured or dead animals as a result of boat strike could impact local populations and will also result in public concern.

6.2.2 Underwater Noise

The ocean is not a silent environment. Sounds from both natural (physical and biological) and man-made sources contribute to the overall ambient underwater noise. Physical sources of underwater noise are from air ocean interaction, wind, waves, rainfall and other oceanic processes. The dominant source of naturally occurring noise across the band frequencies from 1 to 100 Hz is associated with ocean surface waves generated by wind, from which ambient noise levels can be up to 98 dB re 1 µPa, 20 to 1,000 Hz (Richardson *et al*., 1990).

Marine animals such as whales, dolphins, fish and invertebrates are responsible for generating noise, which is associated with communication, navigation, echolocation and/or feeding strategies (NRC, 2003). For whales, sound levels can be very high and cover a wide range of frequencies. The highest biological noise source levels have been calculated to be up to 232 dB re1µPa for toothed whales (e.g. killer whales, dolphins and sperm whales). These noise levels are produced as broadband clicks that range from less than 10 Hz to more than 200 kHz (NRC, 2003; Richardson *et al*., 1995). The vocalisation of baleen whales (e.g. blue whales, humpback whales) is significantly lower in frequency and are broadly categorised as low-frequency moans. Such vocalisations can be detected over long distances, but nevertheless, can be very loud.

Many species of marine fish and invertebrates also produce sound, used primarily for communication (NRC, 2003). Fish produce sounds by striking internal bony structures against one another, or by muscle movement amplified by the gas-filled swim bladder (NRC, 2003). Many species also participate in regular chorusing behaviour (multiple individuals calling simultaneously), often at dawn or sunset, producing a characteristic peak frequency of 1 KHz at broadband levels of 86 dB re 1 µPa (APPEA, 2005). Invertebrates such as snapping shrimps are also capable of generating distinct broad peaks within the 2,000 to 15,000 Hz frequency bands by snapping closed their large front claw (McCarthy, 2004).

Commercial shipping is the major contributor to anthropogenic underwater noise, especially at low frequencies between 5 to 500 Hz (NRC, 2003). This is mainly from propeller noise (cavitation, blade frequency, and passage forces), hydrodynamic hull flow, engines and other machinery. The noise of merchant shipping falls into two categories. First, the noise of distant traffic that is not audible as a ship but contributes to elevated sea noise levels across a defined frequency range and affects large geographic areas (hundreds of kilometres). Second, and applicable to Port Curtis, is noise from nearby traffic that is identifiable, with sound level and frequency characteristics that are roughly related to ship size and speed. Noise levels measured for the larger class vessels (e.g., supertankers), can be up to 180 dB re 1 µPa but smaller vessels typically have a range of 180 dB re 1 µPa (at the lower frequency band of 20 Hz), (Richardson *et al*., 1995). The loudest source of noise is usually dominated by propeller cavitation noise, particularly the use of bow thrusters for dynamic positioning (McCauley 1998).

In recent years, there has been increasing concern that intense, human-generated underwater sounds from activities such as seismic surveys and pile driving, may have the potential to interfere with the behaviour of marine fauna, particularly marine mammals that communicate and/or navigate using sound (Richardson *et al.,* 1995; McCauley *et al*., 2003a, Bailey *et al*., 2010). As the effects of different levels and frequencies of noise on marine fauna are not fully understood, it may be necessary for the project to consider mitigation measures for some of these sources. This will be decided along with the EMP. The Environment Protection (noise) Policy 2008 (Noise EPP) considers the health and biodiversity of ecosystems and has an acoustic quality objective to preserve the amenity of the marine areas. Policy Statement 2.1 Interactions between offshore seismic exploration and whales, 2008 under the EPBC Act refers to seismic surveys. The policy is considered as some of the mitigation measures discussed is relevant to the present activities.

The main sources of underwater noise arising from project construction will include pile driving, movements of vessels carrying equipment and personnel, and dredging activities in the Calliope River. During operations, the main source of noise will be from the movements of Arrow Energy LNG carriers and associated tugs manoeuvring them alongside the LNG jetty.

Pile driving

The characteristics of sound from impact pile driving (as distinct from vibratory piling) include the main pressure pulse propagated at the hammer impact on the pile, followed by pile and sediment vibrations. These characteristics change with increasing pile depth along with the received sound, which will change with distance from source as higher frequencies are attenuated in shallow water. The hammer frequency and duration of pile driving determine the cumulative underwater receiving levels.

Impulsive hammering can be loud and levels measured in various projects are summarized in Table 10.

There is much variance in acoustic propagation characteristics depending on depth, bottom type and topography and piling equipment specifications. The sediment particle sizes for Boatshed Point and Hamilton Point, where pile driving is anticipated were similar, regardless of depth (intertidal and subtidal). These areas had an average composition of 60 to 80% silts and muds and 20 to 40% sands and gravels. Assessment of underwater noise from the Arrow LNG Plant is discussed below.

The potential impacts of the underwater sounds from activities can be first informed by review of other analogues and is summarised below.

SVT Engineering Consultants (2010) engaged by Queensland Curtis Liquefied Natural Gas (QCLNG) Project modelled underwater noise from piling at the LNG jetty and MOF locations using specifications of steel sheet and circular piles and hammer power that are similar to those proposed for the Arrow LNG Plant. The location of the modelling conducted for the QCLNG Project is also in the near vicinity of the proposed Arrow LNG Plant's LNG jetty location in North China Bay, hence key features of sediment type and bottom topography will be broadly similar.

Table 10 Pile Driving Noise Levels during Various Projects

Project	Recorded levels/distance from source	Source
Pipe installation	135db re 1 µPa at 100m	Richardson *et al*., 1995
Various sources	177 to 217 dB re 1 µPa at 10 m (peak)	McCauley and Salgado-Kent, 2008
Various sources	152 to 180 dB re 1 µPa at 10 m (SEL)	McCauley and Salgado Kent, 2008
Offshore wind farm installation	205 dB re 1 µPa at 100 m (peak)	Bailey *et al*., 2010
Offshore wind farm installation	Background (80 km)	Bailey *et al*., 2010
Port of Melbourne: piling of channel markers	173 dB re 1 µPa at 53 m	Salgado-Kent *et al*., 2008
Port of Melbourne: piling of channel markers	150 dB re 1 µPa at 350 m	Salgado-Kent *et al*.,2008
Port of Melbourne: piling of channel markers	184 dB re 1 µPa at 89 m	Salgado-Kent and Parnum, 2009
Port of Melbourne: piling of channel markers	148 dB re 1 µPa at 293 m	Salgado-Kent and Parnum, 2009

* SEL = sound exposure level

SVT Engineering Consultants (2010) engaged by Queensland Curtis Liquefied Natural Gas (QCLNG) Project modelled underwater noise from piling at the LNG jetty and MOF locations using specifications of steel sheet and circular piles and hammer power that are similar to those proposed for the Arrow LNG Plant. The location of the modelling conducted for the QCLNG Project is also in the near vicinity of the proposed Arrow LNG Plant's LNG jetty location in North China Bay, hence key features of sediment type and bottom topography will be broadly similar.

Table 11 shows the avoidance noise levels for turtles and dugongs and cetaceans based on the sound level criteria sourced from literature.

Table 11 Avoidance and Injury Noise Levels for Turtles, Dugongs and Cetaceans

Effect	Possible Avoidance	Possible Injury
Peak (Turtles)	175 dB re 1 µPa	220db re 1 µPa
SEL (Turtles)	No data	198 dB re 1 µPa
Peak (Dugongs and cetaceans)	224 dB re 1 µPa	230 dB re 1 µPa
SEL (Dugongs and cetaceans)	160 dB re 1 µPa	198 dB re 1 µPa

Based on these criteria, the peak and sound exposure level (SEL) contours indicated that the zone of physical injury from jetty piling could extend 55 m from the source for turtles and 22 m for dugongs. Respective distances for potential avoidance were 205 m for dugongs and 1,500 m for turtles.

These distances are relatively low in comparison to some offshore examples (David, 2006; Bailey *et al*., 2010) where levels of sound sufficient to elicit avoidance by dolphins could extend up to 40 or 50 km from the source. This is because the pile driving activities for the LNG jetty and MOF construction will take place in very shallow water (5 m), meaning that only a short portion of the pile is in the water and most of the acoustic energy is transferred to the seabed. This will also apply to the pile driving for the Arrow LNG Plant.

Noise estimates for the extent of zones of injury or avoidance in the Gladstone Liquefied Natural Gas (GLNG) Project (L Huson and Associates Pty Ltd, 2009), the WBDD Project (GHD, 2009) and the Wiggins Island Coal Terminal (Connell Hatch, 2006), are somewhat variable, depending on the assessment before or after mitigation. Connell Hatch (2006) estimated that distances to prevent death or injury to marine mammals, turtles and fish from a 14 t pile driving hammer was less than 5 m (i.e., distance from source where peak pressures fall below 216 dB re 1 µPa. Based on this, GHD (2009) assessed the impacts of the pile driving for 19 channel markers to a depth of six to eight metres to be negligible, as the noise would be detected well before animals encroached within this distance, particularly if soft start procedures are used. Likely avoidance distances are not given.

Based on a literature review of Savery and Associates Pty Ltd report (2010) prepared for the Australia Pacific Liquefied Natural Gas (APLNG) Project, percussive piling required for the construction of the MOF and LNG jetty is most likely to be of a frequency to cause disturbance to dolphins. On this basis, the pre-mitigation magnitude was estimated to be high to very high, reducing to medium with mitigation, and requiring validation monitoring.

The underwater noise characteristics for pile driving during construction of the GLNG Project (L Huson and Associates Pty Ltd, 2009) were estimated to be similar to those measured for trial piling operations by McCauley and Salgado-Kent (2008) for the Channel Deepening Project in Port Phillip Bay, Victoria for which sound levels measured at 350 m were 150 dB re 1 µPa mean squared pressure. These distances are consistent with subsequent monitoring of channel marker installation by the Port of Melbourne (Table 10). For the GLNG Project, L Huson and Associates Pty Ltd (2009) estimated that prior to mitigation, short term avoidance by marine fauna (humpback whales, dolphins and turtles) would be expected inside this 350 m range. As no seagrass feeding beds occurred within this distance, avoidance would only affect migration across a small part of Port Curtis.

The major uncertainties around these threshold response distances relate to the shortage of empirical data, particularly for dugongs, and the extent to which observed responses of cetaceans can be assumed to apply. Even for cetaceans, threshold distances for avoidance vary according to circumstances, particularly familiarisation, and instances where inquisitive males approach seismic surveys well within distances of expected behavioural change. Conversely, cow and calf pairs may standoff further than critical distances, even at much lower received sound levels (APPEA, 2005). The shallow areas where piling is proposed will substantially attenuate sounds within the ranges of the above examples. Furthermore, no seagrass feeding areas are expected to be within the range of sound levels necessary to cause behavioural changes.

A distance of around 350 m from the source for sound levels to drop below 150 dB re 1 µPa has been applied in Port Curtis for the GLNG Project (L Huson and Associates Pty Ltd, 2009). This is below the level (160 dB re 1 µPa^2) considered for lowest precaution zone under the Policy Statement 2.1 Interactions between offshore seismic exploration and whales 2008, but not necessarily below levels where behavioural responses may be expected from marine animals exposed.

The literature is generally consistent in describing a relatively narrow zone of potential injury risk (if suddenly exposed) but a much wider range for sounds that would be intense enough to cause disturbance or some form of behavioural shift. Nevertheless, the underwater sound characteristics of pile driving indicate that sound levels may exceed thresholds of physiological damage to marine fauna if very close to the source, or cause behavioural changes out to distances of several hundreds of metres. Most pile driving will be nearshore and shallow water but could potentially be deeper and might affect most of the water column.

The magnitude of the impact of underwater noise from pile driving is therefore assessed as **high**.

Assessments of underwater noise impacts typically involve predicting the source levels (estimated or measured at 1 m from the source) and using models to estimate transmission loss with distance until received levels are below thresholds for possible physical injury, avoidance, or potential for masking of sounds. Responses of marine fauna to pile driving are discussed below.

Invertebrates

Marine invertebrates lack body cavity air spaces or sensory organs to perceive sound pressure, and for these reasons, are generally less susceptible to physiological damage (Swan *et al*., 1994). The comparative robustness of rock lobsters to withstand exposure to ammonium nitrate explosive charge (as was used for seismic exploration prior to air gun arrays; (see Anon 1966), compared to the fish present in the vicinity demonstrates this resilience. Responses of marine invertebrates to the airgun arrays may be an alarm response such as ‘tail flip’ in crustaceans (McCauley, 1994), but risk of injury is restricted to the organisms being within very close range to the source.

Pelagic invertebrates, such as squid and cuttlefish are capable of detecting vibrations. At received sound levels of 174 dB re1 µPa mean squared pressure (as a sudden exposure), squid showed a startle response by firing their ink sacs and jetting away from the air-gun source (McCauley *et al*., 2003a).

While the diversity of benthic species may be high and may include important components of the ecosystem within Port Curtis, as described in Appendix A, the overall sensitivity to underwater noise impacts is **low**, requiring no specific need for mitigation in the case of invertebrates.

Plankton

A scientific review by Swan *et al*. (1994) concluded that for planktonic organisms, including fish eggs and larval stages, lethal or pathological impacts could only occur to those organisms within about five to 10 m of an airgun, depending on the size of the source. They also concluded that impacts to populations of lobsters, fish and prawns (assuming planktonic larvae are killed within 5 m of the seismic airguns) would be negligible compared with the size of natural mortality rates. This has been supported in a study correlating the timing of seismic surveys with subsequent recruitment (catch rate) of rock lobsters in western Victoria. No evidence was found to suggest that recruitment declined as a result of the effects of seismic energy on rock lobster larvae (Parry and Gason, 2006).

While the array of planktonic and larval species may be high and may include important components of the ecosystem within Port Curtis, overall risk to populations from underwater noise impacts to plankton and larvae is **low**, requiring no specific need for mitigation in the case of planktonic organisms.

Fish (including seahorses and pipefish)

The most important factor determining hearing sensitivity in fish is the presence of the swim bladder and its proximity to the inner ear. It acts as a pressure transducer, converting sound pressure to particle velocity. Thus fish without a swim bladder, or ones in which the swim bladder has no close connection with the inner ear are less vulnerable to injury from sound pressure than those with swim bladders of resonant frequencies near 100 Hz being most sensitive (Swan *et al*., 1994; Turnpenny and Nedwell 1994). Not all fish have swim bladders. Sharks, rays, tuna, mackerel and many of the flatfishes such as flounders do not possess a swim bladder and in turn are not susceptible to swim bladder-induced trauma. However, seahorses and pipefish do have swim bladders or rudimentary swim bladders. During the fish survey conducted in Port Curtis by Alquezar (2011) (Appendix A), no pipefishes or seahorses were observed (Appendix 1); however, they are difficult to sample and individuals may be using certain habitats, particularly in areas of seagrass.

Fish can show startle and alarm responses at received air-gun levels above 156 to 161 dB re 1 µPa mean square level (McCauley *et al*., 2003b). Physiological damage to fish ears has been reported in cage-held fish exposed to prolonged high intensity sound (e.g. up to 180 dB re 1 µPa) where avoidance was prevented (McCauley *et al*., 2003b).

McCauley and Salgado-Kent (2008) modelled impacts of pile driving on fish for the wharf construction in the Tamar River as part of the Gunns Paper Mill Project in Tasmania. Three zones of impact from the piling were identified:

- Serious physiological impact zone: within 10 to 20 m of impact, within which fish may suffer serious internal injuries.
- Physiological impact zone: extending from 20 to 300 m, within which fish could suffer temporary hearing loss or a temporary threshold shift, lessening with increasing distance from the source.
- Behavioural change zone: extending out to 500 m from source, where behavioural change such as avoidance or startle response and increased alertness may be expected.

Fish are more susceptible to underwater noise than invertebrates, particularly those with swim bladders. Fish, such as listed pipefish could occur in the immediate vicinity of pile driving, where organisms could be exposed to levels sufficient to cause injury and a startle response out to several hundred metres from the source. Impact magnitude of underwater noise from piling is considered to be **high** in the absence of mitigation measures.

Turtles

Risks of encounters with turtles may be quite high, as they move throughout Port Curtis. Studies by McCauley *et al*. (2003a) observed behavioural responses of turtles to air guns that started when received levels reached 166 dB re 1 µPa and avoidance behaviour occurred at levels around 175 dB re 1 µPa. Although this is based only on responses of two animals, it suggests turtles would be able to avoid risk of injury from close contact. There is no equivalent information for other marine reptiles such as sea snakes although these may be similarly vulnerable.

Turtles may be exposed to levels of underwater noise sufficient to cause disturbance to behaviour out to 1,500 m (SVT Engineering Consultants, 2010) for the QCLNG Project) or injury if migrating in close proximity and with sudden exposure to pile driving. Some mitigation is therefore warranted.

Cetaceans and dugongs

In an open sea situation, Bailey *et al.,* (2010) applied noise criteria for marine mammals (based on the measurements given in Table 11) and concluded that while risk of auditory injury would only occur within 100 m of the source, behavioral change could occur up to 50 km away.

Pile driving has been shown to affect marine mammals, such as dolphins: for example to their directional hearing or by masking vocalisation frequencies and amplitude (David, 2006). While audible up to 40 km, at the 9 kHz frequency, pile driving noise is capable of masking dolphin vocalisations within 10 to 15 km; dropping to 6 km at 50kHz and 1.2 km at 115kHz. Observed behavioural modifications may be in response to these underwater sounds but could also reflect redistribution of prey (David, 2006). This and the study by Bailey *et al*. (2010), indicate that there are circumstances where sound intensities from pile driving is sufficient enough to result in avoidance behaviour that can extend over many kilometres.

Whale stand-off distances from seismic surveys) vary according to factors such as location and species, previous familiarisation, sex (e.g., cow calf pairs stay further away than inquisitive males) (see APPEA, 2005). This has enabled thresholds of possible injury and thresholds of possible avoidance to be determined under various circumstances. Even so, there are generally recognised sound intensity levels that could give rise to possible injury, and levels above which avoidance or other behavioural change is expected. Inferred auditory damage risk criteria for marine mammals exposed to seismic pulses underwater, whether single or multiple, are given at sound pressures of 230db re 1 µPa and sound exposure levels of 198db re 1 µPa (Southall *et al*., 2007).

There is little direct information on responses of dugongs but auditory thresholds of related manatees were reported from 0.4 to 46 kHz, and detection thresholds of possible vibrotactile origin measured at 0.015-0.2 kHz (Gerstein *et al*., 1999), with an upper limit of functional hearing at 46 kHz and peak frequency sensitivity at 16 and 18 kHz (50 dB re: 1 microPa). Manatees are described as making high pitched squeaks (Nedwell *et al*., 2004), and Gerstein *et al*. (1999) which suggests that high frequency sensitivity may be an adaptation to shallow water, where the propagation of low frequency sound is limited by physical boundary effects. Inadequate hearing sensitivity at low frequencies may be a contributing factor to the manatees' inability to effectively detect boat noise and avoid collisions with boats.

Estimates based on modelling (SVT Engineering Consultants, 2010) for the QCLNG Project; and L Huson and Associates Pty Ltd, 2009 (for the GLNG Project) of the potential impact and avoidance distances, beyond which cetaceans and dugongs would not be significantly disturbed may be best estimates available for the circumstances in Port Curtis. These distances do not reach the seagrass beds on which the dugongs feed (Figure 18). It is assumed that if applied to the Arrow LNG Plant, similar results would be found. However, uncertainties remain on actual responses of species such as the dugong, the Australian snubfin dolphin and the Indo-Pacific humpback dolphin, which are listed as vulnerable and near-threatened respectively. There is the possibility that these organisms could move closer to the pile driving activities when moving between feeding areas within Port Curtis. Impact magnitude is therefore assessed as **medium** and therefore mitigation is required.

Shipping Activities and Accidents

In Port Curtis, the existing sources of anthropogenic underwater noise mainly come from vessel activities. The vessel traffic associated with the construction of the project will be similar to that operating elsewhere in Port Curtis and changes in underwater noise compared with existing levels is unlikely to be great. Ambient sound levels have not been measured in Port Curtis. On average, the typical sound emission levels for the range of commercial shipping using Port Curtis is expected to be around 150 dB at a distance of 100 m (L Huson and Associates Pty Ltd, 2009 for the GLNG Project). In this assessment, barge and ferry movements were considered negligible in relation to overall shipping within the port.

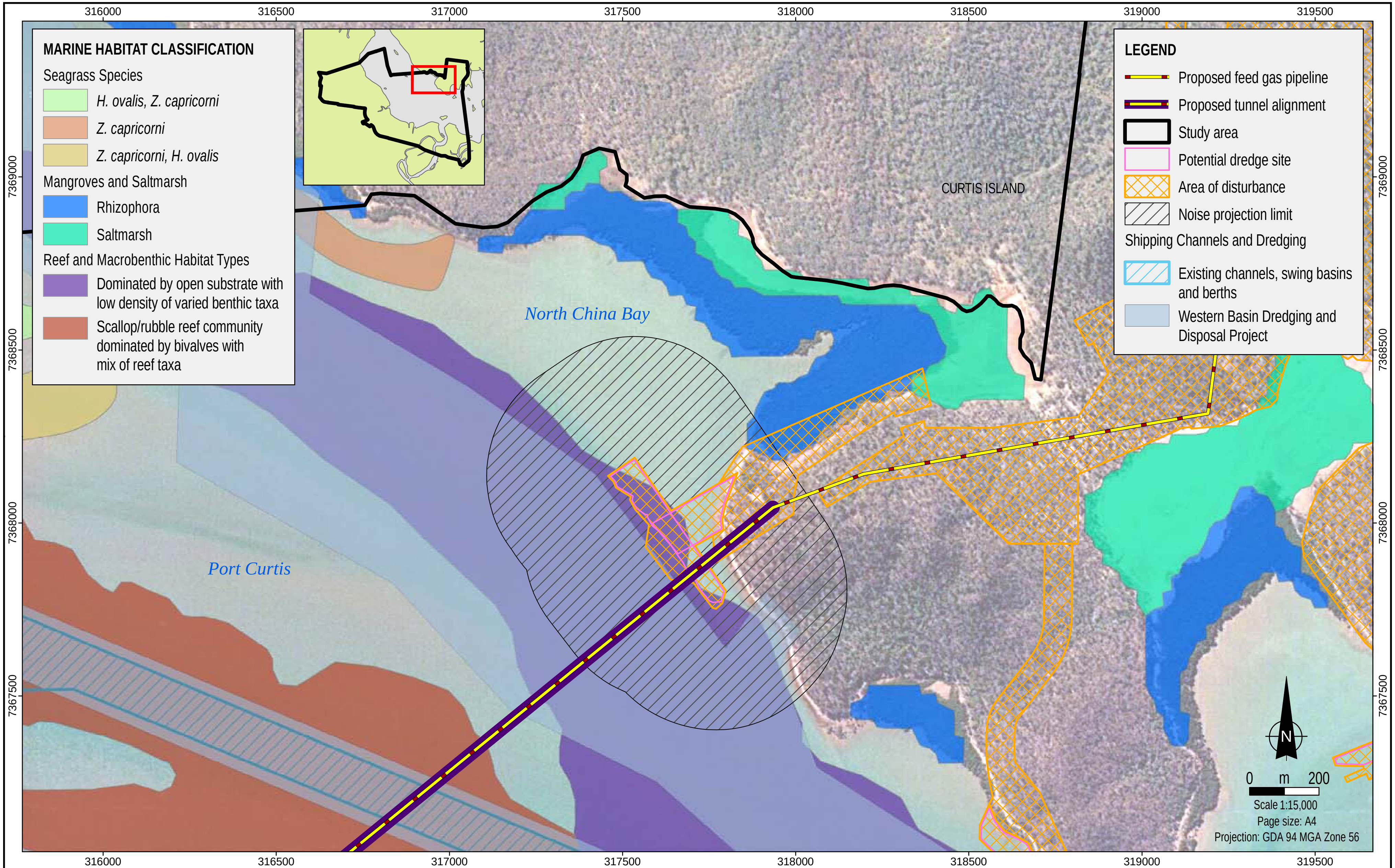
The additional vessel movements associated with the project are not expected to increase sound intensities in Port Curtis substantially above those already present from port activities but will increase the area in which they operate, particularly during construction. Therefore the magnitude of this impact is assessed as **medium**.

Dredging

Dredging activities in the Calliope River and Port Curtis will create underwater noise from the type of equipment used; potentially, engines, thrusters and suction or cutting equipment. Nedwell *et al*. have inferred in the absence of published noise levels for backhoe dredging operations that source noise levels are likely to be between 170 and 180 dB. Data is available for cutter suction dredging which typically has source level noise of between 180 and 188 dB (Nedwell *et al*., 2008).

Most operations will be in shallow water and will attenuate rapidly therefore creating an overall medium magnitude. Mitigation may be required in the case of species of high sensitivity for both backhoe and cutter suction dredging.

A summary of the assessment of the magnitude of impact from underwater noise in the absence of mitigation is given in Table 12.



Source: Place names from DME.
Study area, proposed auxiliary facilities and marine infrastructure from Arrow Energy.
Seagrass and Port Curtis wetlands from DEEDI (November 2002).
Reef and macrobenthic habitat types from Queensland Fisheries Services (DPI).
Sound tenuation zone, area of disturbance and proposed feed gas pipeline from Coffey Environments.
Imagery from SPOT (2004-2007).

coffey environments

Date: 04.10.2011
MXD: 7033CA_MNE_GIS018_v1_2
File Name: 7033CA_MNE_F018_GIS

Arrow Energy
Arrow LNG Project

arrow energy go further

Underwater noise projection at Hamilton Point

Figure No: 18

Table 12 Significance and Magnitude of Underwater Noise on Environmental Values in the Port Curtis Region

Source	Receptor	Sensitivity	Magnitude
Pile Driving	Invertebrates	Very Low	High
	Plankton	Very Low	High
	Fish	Low	High
	Turtles	High/Medium	High
	Cetaceans / dugong	Medium	High
Shipping	Turtles	High/Medium	Medium
	Cetaceans / Dugong	Medium	Medium
Cutter Suction Dredging	Turtles	High/Medium	Medium/Low
	Cetaceans/Dugong	Medium	Medium/Low
Backhoe Dredging	Turtles	High/Medium	Medium
	Cetaceans/Dugong	Medium	Medium

6.2.3 Lighting

Artificial light can modify natural illumination and cause disruption to visual cues of marine organisms, particularly marine turtles (Witherington, 1992). Most species of marine turtles nest at night and the impact of brightly lit industrial precincts along coastal margins can disorientate turtles and affect their behaviour (Limpus, 1971a). The Queensland Alumina Limited alumina refinery on Boyne Island emits a glow that is visible at the Hummock Hill turtle nesting beaches, 18 km to the north (Limpus, 1971a). The glow from the facility has been known to alter light horizons and disorientate female turtles and hatchlings returning to the ocean from this nesting beach causing them to proceed towards the artificial light (Limpus, 1971a). Light experiments on flatback hatchlings emerging from nests have shown that they are attracted to short wavelength light (blues) over longer wavelength light (oranges/yellows). Furthermore, the species has difficulty in discriminating between long wavelength lights (reds/oranges) and a dark background. In some instances such disorientation can lead to turtle mortality, particularly in hatchlings during the swim away from the coastal waters (Limpus, 1971a, Witherington, 1992).

The main reproductive periods for those species that utilise South End and adjacent beaches are outlined in Table 13. However, not all of these species nest specifically at South End.

Table 13 Seasonal Reproductive Periods for Marine Turtles in the Port Curtis Region

Scientific Name	Common Name	Breeding Period	Nesting Period	Hatching Period or Birth
Natator depressus	Flatback turtle	Mid-October (Limpus, 2007)	Late-November to early-December (Limpus, 2007)	Early-December to late-March (Limpus, 2007)
Chelonia mydas	Green turtle	Mid-September to mid November (Limpus, 1993)	Mid to late-October to late-March or early-April (Bustard, 1972)	Late-December to May (Limpus, 2008a)
Caretta caretta	Loggerhead turtle	Late-October to early-December (Limpus, 2008b)	Late-October to early-March (Limpus, 2008b)	Late-December to May (Limpus, 2008b)

Although the closest turtle nesting beach is situated around South End, 8.13 km from the centre of the LNG site in a straight line, light glow generated by the Arrow LNG Plant could potentially affect the behaviour of turtles approaching or leaving the nesting beach. The LNG jetty, MOF, marine facilities and the facility will be lit for safety and security purposes during construction, operation and decommissioning. Light generated by large ships at anchor outside the Port of Gladstone entrance could also be a potential impact on nesting beaches at night (Limpus, 1971a), although glow from ships would not be much different from current port activity.

The LNG facility will also generate light from elevated flares at a potential height of 110 m. The elevated flare will be pilot lit but there will not be continuous flaring under normal operating conditions. Flaring at the start up of the LNG facility will be over a period of approximately 28 days, with subsequent LNG facility start up involving flaring for less than 12 hours. Maintenance flaring will be over 24-hour duration to make the LNG plant gas free and this will occur every three years. Emergency flaring will include all that is not planned including safety shutdown, blow down and depressurising. The duration of flaring under an emergency scenario is expected to be for a maximum of 24 hours.

The visual assessment for the Arrow LNG Plant has identified that a substantial level of light caused by the venting flare could be directly viewed from the South End community along with general facility lighting (AECOM, 2010).

Nesting females of all turtle species demonstrate site fidelity to their natal beach. This is suggested to be a result of imprinting on hatchlings as part of their physiology. Based on such behaviour, offsets cannot compensate for the illumination of the facility on the nesting beaches at South End or the direct impact it may have on the local turtle population. Rather mitigation measures need to be implemented to avoid or reduce the magnitude of the impact.

Prior to mitigation, the magnitude of impact of stray light can be defined as medium on the basis that it is some distance away (8 km), and the LNG facility is not the first or only source of industrial light. Nevertheless there are potential adverse changes to species life cycle, which could result in public concern if breeding success is adversely affected.

Impacts of lighting on other marine species are not likely to be greater than for turtles and therefore have not been assessed separately.

6.2.4 Sedimentation from Propwash

The movement of the Arrow Energy LNG carriers into and out of Port Curtis and the associated operation of manoeuvring tugs may cause resuspension of bottom sediments into the water column and potential remobilisation to sensitive areas such as seagrass.

However, as the nearest seagrass beds are 1 to 2 km from the LNG jetty (Figure 3) and turning areas for the Arrow Energy LNG carriers, and the frequency of visits (as listed in Table 9) will not result in cumulative effects, impacts are likely to be low and not considered further.

6.3 Loss of Commercial and Recreational Fishing Access

The Port Curtis region supports significant recreational and commercial fishing. The importance of the area as spawning habitat for many of the species is also evident from the observations of the surveys carried conducted (Appendix A). Numbers of Gladstone residents is expected to increase during the construction and operation of the Arrow LNG Plant, and participation in fishing activities could also potentially rise. Construction staff (2,500-3,500) will be fly in – fly out. There will be no fishing allowed on Curtis Island (around Arrow LNG Plant) or whilst on shift, with the only fishing activities conducted may be by staff living in and around Gladstone.

During the operation of the Arrow LNG Plant, an exclusion zone of 250 m will be enforced at all times around the LNG jetty on Hamilton Point for the safety and security of employees and the community, as well as for overall security of the project. As a result, there will be a small loss of recreational and commercial fishing access in this area. Once marine components of the Arrow LNG Plant are constructed, commercial fishers will be prohibited under the Fisheries Regulation from setting nets within 200 m of a jetty or wharf and recreational fishers will no longer be able to access areas proposed for the LNG jetty for security reasons. A 250 m (radius around the centre of the LNG carrier manifold) exclusion zone will apply. Such effects will also occur at the equivalent facilities at the other LNG projects, giving rise to a cumulative restricted fishing effect. This could result in the redirection of effort to other areas, which may offset any conservation effect of the no-take areas surrounding the various projects' facilities. The net effect of this on fish resources would be very low, unless the areas receiving higher fishing effort were of greater habitat value than the ones where fishing can no longer take place. The field investigations (Appendix A) showed generally similar results for fish and invertebrate catches in each of the areas sampled.

Based on loss of area or interruption to access to fishing areas, the magnitude is characterised as low in terms of overall commercial and recreational fishing interests. However, locally, effects to individuals and businesses may be felt more keenly. Given the complexity and importance of recreational and commercial fishing to the local community, this issue is addressed in more detail in the Arrow LNG Plant Social Impact Assessment (SKM, 2011).

6.4 Introduced Species and Pest Species

Introduced and pest species have the potential to cause significant economic, environmental and social impacts in Port Curtis and at a state level. Most marine and estuarine introductions occur when organisms are transported in the ballast water of ships. The Arrow Energy LNG carriers will travel between various destinations around the world and Port Curtis in order to load and export LNG. During such exchanges at different ports, there is the possibility that organisms will be acquired as part of the ballast water or hull fouling and then released into the waters of Port Curtis or the Great Barrier Reef. If the species is invasive and rapidly increases in population, native and endemic communities could be compromised.

The greatest risk of introducing invasive species is the frequency of LNG vessels moving in between Port Curtis and foreign ports. Currently Port Curtis accommodates over 1,200 vessels per annum (GPC, 2010), which make hundreds of trips to and from foreign ports. Since the operation of the port in 1914, few introduced species have established a population. Today ten introduced species exist in the port and none are considered pest species (Lewis *et al*., 2001). For the Arrow LNG Plant, Arrow Energy LNG carriers will move in and out of the port approximately 40 times per month and there is the potential to bring in introduced or pest species. However, the likelihood that invasion of exotic species would change from its past rates as a result of the LNG vessels is unlikely with correct avoidance and mitigation measures.

The magnitude of an introduced species or pest species establishing a population in the port can be defined as **low**, as the risk of an introduced species or pest species establishing a population in the port and affecting survival of local marine communities is low.

6.5 Shipping Activities and Accidents

Over 3,500 ships export commodities such as coal, oil, alumina, bauxite and general container freight make over 9,700 voyages through and anchor in designated areas of the marine park each year (GBRMPA, 2006). Shipping exports contribute significantly to the state and national economies, however, these operations have the potential to cause environmental harm during general operations or accidents. Although outside the study area, LNG carriers associated with the Arrow LNG Plant will need to navigate through the marine park and surrounding waters and have the potential to:

- Create oil, chemical, sewage, grey water and ballast spills.
- Litter.
- Ground, anchor or sink in the GBRWHA.

These impacts could potentially displace, smother or lead to the mortality of flora and fauna and alter or damage physical habitats. Further details of potential impacts will be addressed in the shipping and hazard and risk technical reports.

The greatest risks of adverse shipping activities and accidents are the frequency of LNG vessels moving in between Port Curtis and foreign ports and the lack of compliance with operational procedures or pilotage. Currently Port Curtis accommodates over 1,200 vessels, which make hundreds of trips to and from foreign ports (GPC, 2010). Between 1987 and 2004, only 33 of the 700 incidents recorded in the GBRWHA, including 11 collisions and 22 groundings, were considered significant (Aston, 2006). Table 14 outlines the number of incidents recorded during each year from 2000 to 2004. However, in 2006 and 2010 the MV Global Peace collision in the Gladstone Harbour and the Shen Neng 1 grounding in the GBRMP resulted in serious oil spills. Since 2006 only five major incidents have been recorded (GBRMPA, 2006). Given past and recent trends it can be suggested that it is likely that adverse shipping activities and accidents can occur and can potentially be severe depending on the type of incident. For spills, in particular, significance is dependent on the type and nature of the material released, the sensitivity of the receiving environment, the prevailing conditions at the time and emergency response plans.

Table 14 Shipping and Pollution Incidents in the Great Barrier Reef World Heritage Area for 2000 to 2004*

Incident Type	2000	2001	2002	2003	2004
Confirmed spill – vessel	17	16	12	13	18
Unconfirmed spill origin and type	12	13	16	8	12
Ballast or sewage spills	0	0	1	2	1
Groundings	4	11	9	12	15
Sinkings	10	7	9	14	19
Land sourced spills	2	0	2	3	1
Other	3	8	2	3	6
Total	48	55	51	55	72

Source: Aston, 2006

*These figures include commercial, recreational, and merchant vessels.

For the Arrow LNG Plant, Arrow Energy LNG carriers will move in and out of the port approximately 20 return trips per month. Given past trends and with correct procedures for the movements of carriers to and from Port Curtis, it is unlikely such events will occur.

Table 15 outlines the magnitude of each adverse shipping activity (prior to any mitigation) and accident.

Table 15 Magnitude of Shipping Activities and Accidents on Environmental Values in the Port Curtis Region

Incident Type	Magnitude
Large volume oil, hydrocarbon and chemical spills	High
Small volume oil, hydrocarbon and chemical spill	Medium
Sewage, greywater and ballast spills	Low
Litter	Low
Grounding	Medium
Anchoring	Low
Sinking	Medium

7. AVOIDANCE, MITIGATION AND MANAGEMENT MEASURES

Where feasible, engineering design measures have been included in this section to avoid or reduce impacts. Where these are unavoidable, mitigation and management measures for each impact are proposed to reduce the magnitude of the impacts as far as practicable. In the event that environmentally sensitive areas are severely impacted by the project and mitigation and management measures provide only minimal protection, offset strategies are suggested to compensate for the loss.

7.1 Loss and Disturbance of Marine and Estuarine Habitat

7.1.1 Construction

The direct loss of marine and estuarine habitat will occur to the extent of the areas that will be occupied by the marine infrastructure and buffer area for construction equipment. The extent of loss is already reduced through design to the smallest practicable project footprint in the marine environment, and this loss from construction activities is unavoidable, for both the base case and the alternative cases. The proposed installation of the pipeline beneath Port Curtis to Curtis Island by the use of a tunnel boring machine minimises any loss and disturbance of marine habitats, which might otherwise have occurred.

To minimise the impacts of marine infrastructure construction, boundaries and access tracks for equipment and personnel will be established to confine the activities within these designated areas. Routes for construction vessels in Port Curtis will be established to avoid sensitive areas. Methods to mitigate the impacts from sedimentation and turbidity in the habitats adjacent to construction are described further in the coastal processes and hydrodynamics study.

Offsets

The preferable hierarchy of impact management involves avoidance techniques then mitigation measures. However, if avoidance and mitigation measures cannot be implemented, it is suggested that offsets be considered. Under Commonwealth and Queensland government, the following offset policies apply:

- Draft Policy Statement: Use of environmental offsets under the Environment Protection and Biodiversity Conservation Act 1999 (Cwlth) 2007.
- Queensland Government Environmental Offsets Policy (Qld) 2008.
- Fish Habitat Management Operational Policy FHMOP 005 (Qld) 2004 (Dixon and Beumer, 2002).
  - Marine Fish Habitat - Mitigation and Compensation for Works or Activities Causing Marine Fish Habitat Loss, 2002 Department of Primary Industries and Fisheries.

The Commonwealth government has the authority and position on the use of environmental offsets under the EPBC Act. Under the policy, matters protected by the EPBC Act that will be impacted, are likely to trigger Commonwealth interest and involvement. Some mangroves, saltmarsh, intertidal mudflats, reef and benthic and rock substrate will be cleared, removed or disturbed. As a result, mortality, displacement or impacts to the breeding and feeding habitats of EPBC listed organisms such as seahorses, pipefish, and sea snakes could occur. There are no marine or estuarine plants or vegetation communities listed under the EPBC Act that will be directly or indirectly affected by the project. However environmentally sensitive areas such as Ramsar wetlands, and GBRWHA do occur within and adjacent to the area of disturbance. To compensate for the loss of marine and estuarine habitat, offsets should follow the eight principles outlined under the Commonwealth offsets policy. Offsets for consideration include:

- Rehabilitation of ‘like for like’ habitats that demonstrate ecological equivalence in the Gladstone region.
- Creation of artificial habitats that provide as similar as possible ecological functions as the area that is to be lost in the Gladstone region.
- Facilitate, or otherwise manage under agreement, unprotected habitat and actively manage and protect the habitat as a conservation area. The habitat must demonstrate ecological equivalence to the area that is to be lost. Habitat should be located in the Gladstone region if possible, however, if this is not feasible greater conservation value may come from locating offsets elsewhere[3].

Given the impacts of the marine infrastructure, Arrow Energy will also need to comply with environmental and legal criteria of the Queensland government environmental offsets policy. This is the overarching framework for specific-issue offset policies, the Fish Habitat Management Operational Policy FHMOP 005, specifically addressing the Departmental procedure: Mitigation and Compensation for Works or Activities Causing Marine Fish Habitat Loss.

The Fish Habitat Management Operational Policy is designed to ensure no net loss of marine fish habitat so that fisheries resources can be maintained in the future. Construction activities associated with the project will disturb or destroy some fish habitat (none of which are declared fish habitat areas) including mangroves, saltmarsh, intertidal mudflats, reef and benthic and rock substrate that are inundated by the tides, with potentially adverse effects on fish. In order to compensate for the loss, the following offsets as listed under the policy could be considered:

- Rehabilitation or enhancement of degraded habitats that can demonstrate ecological equivalence in the Gladstone region.
- Propose land exchange or land acquisition or management that allows the inclusion of tenured land to be managed as a declared FHA.
- In-kind or financial support of:
  - Research projects.
  - Community based initiatives (e.g., Seagrass Watch).
  - Restoration or rehabilitation projects.
  - Signage or educational materials for marine fish habitat information or management.
  - Enhance fishing access for the community (e.g., fishing platforms).

[3] As per the Vegetation Management Offsets Policy (Qld) 2006, offsets which are established a large distance from the impact area should be many times larger than the original impact areas in order to establish ecological equivalence.

- Other alternatives might consider projects, such as:
  - Undertaking or funding restoration projects across the state.
  - Initiating community awareness projects.
  - Contributing credits before debits are used (i.e., mitigation banking concept).

As such, Arrow Energy has committed to the 'Brighter futures' program, which provides financial support for locally events, projects and initiatives by working with local businesses and service providers.

For approval, requirements as stated under the Commonwealth and Queensland offset policies must be met. Locations for offsets have not yet been identified and will require further assessment based on environmental suitability for ecological equivalence, legal feasibility and stakeholder engagement responses. The specific details of the offsets for the project will be provided in the marine offsets plan.

7.1.2 Operations

During operation activities, no further loss or disturbance of marine and estuarine habitat is expected and therefore mitigation is not required.

7.2 Impact on Marine and Estuarine Fauna

7.2.1 Boat Strike

It is essential to provide large marine organisms the opportunity to avoid marine vessels, given the significance of displacement and boat strike in Port Curtis (e.g., its status within Rodds Bay Zone B DPA and presence of other listed or endangered species such as turtles). The first measure is to where possible enforce speed limits for marine vessels, which is said by Hodgson (2004) to:

- Provide a greater period for marine organisms to react and avoid marine vessels.
- Allow marine vessel operators to identify the potential for collision with a marine organism.
- Reduce the probability of serious injury or mortality of a marine organism.

Port Curtis currently has no speed limit restrictions for waters outside boat harbours, marinas and populated areas of operation. Marine vessels operating under the Arrow LNG Plant must demonstrate compliance with existing port speed limits when in designated areas, which will include the Rodds Bay DPA.

Operators of marine vessels should also:

- Manoeuvre within navigation channels to reduce the area of disturbance and to marine fauna.
- Consider installing propeller guards on high speed vessels to reduce the impact of injury in the event of a boat strike.
- Consider operating marine vessels which are powered by jet propulsion and have shallow drafts.

Given implementation of the above measures, it is not practical to conduct marine mammal observation procedures on the construction and operations activities within Port Curtis other than for pile driving activities (see Section 7.2.2).

Mitigating the impact of displacement and boat strike for the Arrow LNG Plant can have implications as many other marine vessels operate under other existing and proposed industry in Port Curtis. Arrow Energy will discuss and coordinate marine vessel activities with relevant port authorities and other industries to control the operation of their marine vessels, particularly high speed vessels within the port.

7.2.2 Underwater Noise

The proposed mitigation measures for pile driving draw heavily from the research and improved understanding over the past ten years of responses of cetaceans and other marine fauna to seismic airgun signals (APPEA, 2005). A number of mitigation measures are proposed for pile driving activities, as described below.

- Implementing soft start procedures, where a sequential build-up of warning pulses will be carried out prior to full power pile driving activities. This will enable mobile marine fauna in the vicinity the opportunity to move away without being suddenly exposed to dangerous levels of sound before sound levels reach maximum. Soft start described in Bailey *et al*. (2010) consisted of five strokes of the hammer separated by 5, 3, 2 and 1 minute followed by slow increase to full power over a 20-minute period.
- Prior to soft start, observations should be made of the surrounding area for the presence of turtles, dugongs and dolphins.

As waters of Port Curtis are very turbid, observation of the presence of turtles, dugongs and dolphins may not always be reliable. As such, soft-start procedures for pile driving and dredging is the most important mitigation measure as this initial noise should ensure that any fauna in the area will have moved off prior to full power driving activities, however observations of the area should be made to ensure this is occurring (where possible).

Noise characteristics from project-related vessels such as tugs, supply boats and LNG carriers are likely to be similar to other port shipping. However, there are no practical ways to reduce the noise characteristics from these vessels. They are slow moving and the noise generated from such vessels can be detected and avoided by animals before any physical injury from sound occurs. Furthermore, it is not practical or necessary for an observation program to be implemented other than that proposed to mitigate impacts from pile driving.

7.2.3 Lighting

Night time deck lighting on ships and onshore LNG facilities must meet minimum safety and security requirements. Beyond that, it is important that the Arrow LNG Plant plans to reduce the external spill of light as far as practicable, particularly to reduce the impact of lighting on the South End turtle nesting beaches, as there is a direct line of sight from the plant. While the distance to source in this case is 8 km, and some distant background glow from port and industrial facilities is likely (AECOM, 2011), additional measures will also help to reduce glow. Hick and Caccetta (1997) and Pendoley (2005) recognised that light generated from industrial facilities could be minimised by implementing a range of in-principle means that Arrow Energy will apply as practicable such as:

- Using long wavelength lights, including red, orange or yellow lights.
- Filtering the light source to reduce short wavelength light, including white lights.
- Redirection and shielding of the light source onto work areas, away from wider marine areas.
- Lowering the height of light source as far as practicable.
- Reducing reflective surfaces (where possible).

The effects of light spillage from ships can be reduced by implementing management practices such as zoning anchorage areas and investigating appropriate light technology for marine vessels (Environment Australia, 2003). Such mitigation measures will also be beneficial for other fauna and residents of South End, Tide Island and Witt Island.

7.2.4 Dredging

Control strategies for minimising the impacts from dredging will be managed under a Dredge Management Plan, primarily aimed at controlling overflows and sedimentation, thereby minimising impacts to water quality. In relation to protection of marine habitats and species, protection measures will include the following.

- Keep within identified dredge footprint area.
- Maintain a fauna spotting function (where possible). No commencement of dredging if marine mammals, turtles or crocodiles are spotted within area of dredging, and stopped if spotted within the area of dredge head. In both cases, resumption of dredging must wait until fauna have moved away.
- Operate during safe weather conditions.

7.3 Reduction of Commercial and Recreational Fishing Access

Where the loss of commercial and recreational fishing access to resources through exclusion zones cannot be avoided, Arrow LNG Plant will need to cooperate with local stakeholders to minimise the impacts or to develop offset areas and strategies. These plans are recommendations only and are provide assistance in community consultation. The extent of inconvenience will vary from person to person and given the complexity and importance of recreational and commercial fishing to the local community, this issue is addressed in more detail in the Arrow LNG Plant Social Impact Assessment (SKM, 2011). There will be no fishing permitted by employees or contractors from any project infrastructure during shift work for construction or operation of the LNG facilities.

7.4 Introduced Species and Pest Species

In order to reduce the risk of introduced and pest species entering the waters of Port Curtis, Arrow Energy LNG carriers and other vessels coming from overseas ports will comply with ballast water management requirements and implement hull hygiene measures such as the maintenance of appropriate hull anti-fouling, cleaning and inspection. Commonwealth and local government have provided mandatory guidelines for the disposal of ballast water. This is to be achieved through processes of re-ballasting at sea, ballasting in deep water, non-discharge in Australian ports, participation in compliance arrangements, taking on ballast in agreed clean overseas ports and monitoring areas that are exposed to significant shipping activities and ballasting. Documentation of compliance with hull cleaning and ballast management will be required.

Management of shipping waste such as wastewater discharges from shipping ballast will be regulated by the International Convention of Pollution from Ships (MARPOL) as established by International Maritime Organisation.

The regulation of shipping waste is undertaken by Gladstone Ports Corporation under a certified agreement with the Australian Quarantine Inspection Service. The Australian Quarantine Inspection Service deems all salt water from ports and coastal waters outside Australia's territorial sea to present a high-risk of introducing exotic marine pests into Australia. The discharge of high-risk ballast water from ships is prohibited anywhere inside Australia's territorial sea.

Therefore, ballast water must be exchanged in deep sea, away from coastal areas, prior to entering the Great Barrier Reef Marine Park and the project area. Other wastes will be collected from the ships by an authorised collector vessel as per international regulations.

All Arrow Energy LNG carriers loading at the LNG jetty will be subject to strict criteria checks:

- Suitability: Upon Nomination each vessel will be positively vetted, under the Oil Companies International Marine Forum – Ship Inspection Report Programme (OCIMF SIRE) system. This includes reviews of Ship inspections, safety records, and operator audits.
- Compatibility: The vessel details and layout are compared to the Terminals facilities, to check that the vessel will fit and be moored safely with the correct configuration for safely loading at the Terminal.
- Acceptability: When the vessel arrives a further inspection is carried out to ensure the previous checks were correct and still valid.

These checks are made under international standards and developed from guidelines laid down by industry bodies such as Oil Companies International Marine Forum (OCIMF) and Society of International Gas Tanker and Terminal Operators (SIGTTO), the vetting procedure and compatibility checks are recognised requirements by all major Tanker operators.

7.5 Shipping Activities and Accidents

Management will take into account existing legislation, safety measures required by law and track record for Arrow Shipping.

The risk of general shipping activities and accidents impacting on Port Curtis, the GBRMP and the GBRWHA must be avoided or minimised under state, Commonwealth and international legislation and conventions. These are as follows:

International

- United Nations Convention on the Law of the Sea 1982.
- International Convention for the Prevention of Pollution from Ships 1973 and the 1978 Protocol (MARPOL 73/78).
- International Regulations for Preventing Collisions at Sea 1972 (COLREGS).

- International Convention for the Safety of Life at Sea 1974 (SOLAS).

Commonwealth

- *Navigation Act 1912.*
- *Protection of the Sea (Prevention of Pollution) from Ships Act 1983.*
- *Protection of the Sea (Powers of Intervention) Act 1981.*
- *Protection of the Sea (Civil Liability) Act 1981.*
- *Environment Protection and Biodiversity Conservation Act 1999.*
- *Environment Protection (Sea Dumping) Act 1981.*
- *Historic Shipwrecks Act 1976.*
- *Sea Installations Act 1981.*
- *Maritime Transport Security Act 2003.*
- *Transport Safety Investigation Act 2003.*
- *Great Barrier Reef Marine Park Act 1975.*
- Great Barrier Reef Marine Park Regulations 1983.
- Great Barrier Reef Marine Park Zoning Plan 2003.
- Great Barrier Reef Area Plans of Management.

State

- *Transport Operations (Marine Safety) Act 1994.*
- *Transport Operations (Marine Pollution) Act 1995.*

Details of legislation and conventions will be addressed further in the shipping and hazard and risk technical reports. The LNG carriers associated with the Arrow LNG Plant must comply with all listed legislation and conventions, especially when passing through the GBRMP. To avoid sinkings, groundings and anchor damage, project vessels will only traverse the GBRMP via designated navigation routes with pilotage where this is required.

For spills, discharges, groundings and sinkings in Port Curtis, the GBRMP, the GBRWHA and surrounding waters, Arrow Energy LNG carriers must ensure emergency response plans and maintenance inspections are implemented and that staff are trained in the carrying out correct procedures. Appropriate hazard and risk equipment should also be available on board all vessels and onsite at the facility. In the event an incident occurs within the port and the incident is cannot be adequately contained by personnel of the vessel, then response plans governed by port and other authorities will be initiated.

Emissions from Arrow Energy LNG carriers is unlikely as they are strictly governed and monitored in respect of discharge of engine room waste, disposal of domestic and other associated waste, sewage, and ballast management.

All non-putrescible waste generated on the Arrow Energy LNG carriers will be stored in facilities provided onboard and then safely removed and transported to approved mainland disposal facilities or contractors. Domestic galley waste and sewage will be treated by maceration, according to international maritime conventions and discharged below surface (to aid dispersal) outside 3 nautical miles from the coast. In all instances any discharges must meet the requirements of MARPOL.

Further details of avoidance, mitigation and management measures will be addressed in the shipping and hazard and risk technical reports and environmental management plans.

8. ASSESSMENT OF RESIDUAL EFFECTS

The following section discusses the assessment of significance of the residual impacts assuming successful implementation of all avoidance and mitigation measures. It considers the magnitude of the impacts (after mitigation) on the sensitivities of the environmental values, as described in Tables 1 and 2, in order to determine the residual significance (Table 3).

8.1 Loss and Disturbance of Marine and Estuarine Habitat

8.1.1 Construction

Construction of marine infrastructure will cause some unavoidable loss of marine and estuarine habitat in those areas where habitat is replaced by infrastructure, and mitigation does not change this. The areas are small and represent only a very low percentage of the habitats within the study area such that the magnitude of impact is low in all cases except for saltmarsh, which has a medium magnitude of impact (Section 6.1.1). The significance of the impact will not vary. However, to compensate for the loss of the area that is to be disturbed or destroyed, offsets will be established, which will provide ecological equivalence or greater. Given that such offsets will replace the use of mitigation measures, the magnitude of the impact will then be reduced as ecological equivalence will have been met, therefore lowering the significance of the impact.

8.1.2 Operations

During operations, no further loss or disturbance of marine and estuarine habitat is expected. To some extent, the hard surfaces of the LNG jetty and wharf structures will mimic reefs and provide settlement surfaces for encrusting marine fauna and corals, which in turn will attract populations of fish during operations. Subject to requirements at the time, this artificial habitat will be removed at decommissioning.

8.2 Impacts to Marine and Estuarine Fauna

8.2.1 Boat Strike

Avoidance and mitigation measures such as speed limits, set navigation routes and propeller guards are considered, as practicable, for each vessel. This will reduce the magnitude of the impact to low. In turn, boat strikes to dugongs, turtles and dolphins would be considered unlikely and the impacts threatening a community’s survival are unlikely to occur. Assuming all avoidance and mitigation measures are successful the residual significance of the effect on dugongs, turtles and dolphins will be reduced to minor.

8.2.2 Underwater Noise

Levels of underwater noise from project-related vessels are not easily mitigated but are not expected to be different from existing shipping activities in terms of sound frequency and intensity. Although large LNG carriers are likely to be audible for many kilometres, particularly in the open ocean, they are detectable and avoidable by marine mammals. It is not likely that animals will suddenly become exposed to levels of underwater noise that cause physiological injury.

Attenuation of sound is much greater in shallow areas where there are muddy (absorptive) seabeds, compared with deep areas or hard, reflective bottoms Impacts are therefore localised and will not reduce the extent of communities or cause disturbance threatening their survival.

Application of measures proposed to mitigate underwater noise from pile driving will reduce the magnitude of the impact from high, as assessed in Section 6 to medium. The magnitude of the impact as a result of shipping and dredging is assessed as low. The sensitivities of the marine fauna remain unchanged but the residual impacts from these sources of underwater noise after mitigation are assessed and outlined in Table 16.

Table 16 Residual Significance of Underwater Noise on Environmental Values in the Port Curtis Region

Source	Value	Sensitivity	Magnitude	Significance
Pile driving	Invertebrates	Very low	Medium	Negligible
	Plankton	Very low	Medium	Negligible
	Fish	Low	Medium	Minor
	Turtles	High/medium	Medium	Moderate
	Cetaceans / dugong	Medium	Medium	Minor
Shipping	Turtles	High/medium	Low	Minor
	Cetaceans / dugong	Medium	Low	Minor
Dredging (backhoe and cutter suction)	Turtles	High/medium	Low	Minor
	Cetaceans	Medium	Low	Minor

8.2.3 Lighting

The LNG facility and associated infrastructure will be illuminated at night during the construction and operation phase. By implementing mitigation measures suggested by Hick and Caccetta (1997) and Pendoley (2005) to reduce all visible light at South End turtle nesting beaches and where practical scheduling maintenance flaring to periods outside turtle reproductive seasons, the magnitude of the impact will be reduced from minor or moderate (depending on species), as described in Section 6, to **very low**. In turn, adverse lighting effects such as disorientation or mortality is unlikely to occur and threats to the lifecycle and habitat necessary for an ecological community's survival are unlikely to occur. Assuming mitigation measures are successfully implemented the residual effect of lighting is likely to be reduced to **negligible** for all species.

If implementation of all mitigation measures is not feasible the magnitude of the impact will remain the same and light will still be visible to the South End community. Restricting flaring may not be possible given certain processes required for the operation and maintenance of the LNG plant. Given the distance from source, intermediate frequency and short term effects of flaring on South End nesting beaches, the magnitude of adverse changes to the breeding of the turtle population would be low. Assuming adequate mitigation measures are implemented, the residual effect of lighting on marine turtles under these circumstances is likely to be **minor**.

8.3 Loss of Commercial and Recreational Fishing Access

Loss of habitat is minimal, as shown for mangroves, seagrass areas. There is also minimal loss, or redirection of due to exclusion zones around the facilities. Given the importance of recreational and commercial fishing to the local community, residual effects have not been addressed in this assessment and are discussed in the Social Impact Assessment (SKM, 2011).

8.4 Introduced Species and Pest Species

Introduced species and pest species are considered to be a **negligible** impact and are unlikely to invade or establish a population in Port Curtis, the GBRMP, GBRWHA or surrounding waters. Given Arrow LNG Plant's shipping compliance with Commonwealth and local government mandatory guidelines and enforcing antifouling measures the residual effect will remain **negligible**.

8.5 Shipping Accidents and Activities

Shipping accidents in Port Curtis, the GBRMP, the GBRWHA and surrounding waters are considered to have a moderate to major significance (Section 6) where large volume spills could potentially cause widespread, severe and long lasting impacts on ecological communities and their life cycles. Given that LNG carriers servicing the Arrow LNG Plant will comply with MOSAG in conjunction with international, Commonwealth and state government legislation and guidelines during navigation through the GBRWHA, the risk of an impact occurring from spills is extremely small. Notwithstanding that consequences of spills from accidents can be high, particularly considering the sensitivity of Port Curtis, the GBRMP and the GBRWHA, implementation of the range mitigation and precautionary measures described in Section 7, together with greater supervision and monitoring will prevent the occurrence of accidents and spills to the maximum practically feasibility, such that the residual impacts during normal operations are **very low** (Table 17).

Table 17 Significance of Shipping Activities and Accidents on Environmental Values in the Port Curtis Region

Incident Type	Sensitivity	Magnitude	Significance
Large volume oil, hydrocarbon and chemical spills	Very high	Very low	Negligible
Small volume oil, hydrocarbon and chemical spill	Very high	Very low	Negligible
Sewage, greywater and ballast spills	Very high	Very low	Negligible
Litter	Very high	Very low	Negligible
Grounding	Very high	Very low	Negligible
Anchoring	Very high	Very low	Negligible
Sinking	Very high	Medium	Moderate

9. CUMULATIVE IMPACT

A number of existing industries, bulk handling and port facilities currently operate in Port Curtis with further submissions for projects in the area awaiting approval. The objective of this assessment is to consider the cumulative impacts of the proposed Arrow LNG Plant in the context of the pre-existing and other proposed industries.

The baseline scenario for cumulative impact includes all existing industry currently constructed and operating in the port and any project submitted for approval in the timeframe between the initial submission of the Arrow LNG Plant and the start up of the project. Projects considered for this assessment include the following:

- Wiggins Island Coal Terminal (WICT) Project.
- Western Basin Strategic Dredging and Disposal (WBDD) Project.
- Australia Pacific LNG (APLNG) Project.
- Queensland Curtis LNG (QCLNG) Project.
- Hummock Hill Island Development.
- Gladstone LNG (GLNG) Project.
- Fishermans Landing Northern Expansion (FLNE) Project.
- Arrow LNG Plant.

The assessment has been based on the assumption that all projects will occur and that the WBDD Project and the FLNE Project will be constructed prior to the establishment of any of the LNG proponent projects.

A range of potential impacts associated with each of the projects has been considered and includes:

- Loss and disturbance of marine and estuarine habitat.
- Impacts on marine and estuarine fauna.
  - Boat strike.
  - Underwater noise.
  - Lighting.
  - Dredging.
- Loss of commercial and recreational fishing access and resources.
- Introduced species and pest species.
- Shipping activities and accidents.

9.1 Loss and Disturbance of Marine and Estuarine Habitat

In the event that all of the proposed projects are approved, the associated marine infrastructure will result in unavoidable and direct loss or disturbance of marine and estuarine habitat, which will add to any previous loss or disturbance caused from currently established industry. The project-related, cumulative area of marine and estuarine habitat that will be impacted is outlined in Table 18. Please note that the timing for construction for each project does not affect impacts to marine habitats, as disturbance (including clearing) accumulates, regardless of time, as more projects disrupt the marine environments within the Port Curtis. All data in Table 18 have been sourced from the individual projects environmental impact statement or supplementary environmental impact statement. The cumulative impact of clearing regulated vegetation, in regards to Regional Ecosystems, can be found in the terrestrial ecology impact assessment (Ecosure, 2011).

Table 18 Estimated Cumulative Direct and Indirect Impact on Environmental Values

Project	**Area of Environmental Habitat to be Directly or Indirectly Impacted (ha)**												
	Mangroves*		**Saltmarsh***		**Seagrass**		**Reef and Rock Substrate**		**Benthic Zone and Intertidal Mudflat**		**Fish and Intertidal Habitat†**		**Total Habitat Impacted**
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	
WICT Project	–	–	–	–	–	–	–	–	–	–	398		**398**
WBDD Project and Supplementary	–	–	–	–	258.8	1406	–	–	643.2	4010	–	–	**6318**
FLNE Project and Supplementary	1.45	–	0.45	–	89.18	–	–	–	84.35	461.51	395	3728	**4759.94**
APLNG Project	2.4	–	31.7	–	–	–	–	–	–	–	–	–	**34.1**
GLNG Project and Supplementary	4.42	28.09	25.26	18.44	–	34	–	–	–	–	–	–	**110.21**
QCLNG Project and Supplementary	–	9.4	–	–	2.004	–	–	–	–	–	–	–	**11.404**
Gladstone LNG Project				–	–	–	–	–	–	–	–	–	3.3
Hummock Hill	0.86	–	0.04	–	–	–	–	–	–	–	–	–	0.9
Subtotal	9.13	37.49	57.45	18.44	349.984	1440	0	0	727.55	4471.51	793	3728	11635.85
Arrow LNG Plant	2.36	0	59	0	0	0	0.14	<0.1	5.31	0	–	–	66.81
Cumulative Area of Impact (Total)	**11.49**	**37.49**	**116.45**	**18.44**	**349.98**	**1440**	**0.14**	**<0.1**	**732.86**	**4471.51**	**793**	**3728**	11702.66
Arrow Representative Percentage (% of total impact area)	**20.54**	**0.00**	**50.67**	**0.00**	**0.00**	**0.00**	**100.00**	**0.00**	**0.72**	**0.00**	**0.00**	**0.00**	**0.57**

* Components of or regional ecosystems listed under the Vegetation Management Regulation. (Regional Ecosystems determined by DERM)

† Fish and intertidal habitats sourced from proponent documents are not separated into individual environmental values. Areas provided are assumed to be inclusive of mangroves, saltmarsh and seagrass.

The WBDD Project and the FLNE Project generate some of the highest potential loss or disturbance of marine and estuarine habitat in Port Curtis, accounting for 53.99% cumulative area of impact. The WBDD Project accommodates the long term dredging and disposal of material required to provide for the development of the harbour and access to the port. The FLNE Project is an intended reclamation area near existing industry for the development of additional wharves to support the future marine infrastructure demands.

While the Vegetation Management Act 1999 does not apply to mangroves (section 8, VMA), regional ecosystem categories, comprising the bioregion, are specified in the Vegetation Management Regulation 2000 (Qld) and include descriptions of vegetation communities comprising mangroves, marine plants and inter-tidal areas. For those environmental values for which there is no attached conservation status, the cumulative impacts have been represented as a percentage in Table 19. This demonstrates the extent of the impacts on the total area of each value in Port Curtis. Similarly, where clearing thresholds have not been established for other habitats such as the seagrass or benthic these are represented in Table 19 in percentage terms.

It is clear from Table 18 that the Arrow LNG Plant's contribution to cumulative loss of these other values is low in absolute or percentage terms.

9.2 Impacts to Marine and Estuarine Fauna

9.2.1 Boat Strike

The risk of boat strike can be assumed to be related the frequency of marine vessels operating in the port, where greater movements across the port increases the chance of boat strike to organisms such as dugongs, turtles and cetaceans; all of which occur in Port Curtis. Table 19 outlines the frequency of movements of marine vessels for all projects.

Although the frequency of marine vessel movement across the port has not been established for all projects in detail, there will be a substantial increase in marine vessel movements, along the different navigation routes of each project, which could interfere with movements of species within Port Curtis, particularly the dugong.

The Port of Gladstone-Rodds Bay DPA is considered an area of relatively low conservation value due to the low dugong population density (Grech and Marsh 2007). Notwithstanding, dugong feeding trails have been observed throughout all seagrass beds in Port Curtis (Chartrand *et al*., 2009) indicating frequent movement of individuals between beds and widespread utilisation of the habitat. Increased movements of vessels increases the risk of boat strike where routes pass directly across seagrass beds. Dugongs are capable of adopting avoidance strategies such as diving (Hodgson and Marsh, 2007), but their behavioural habit of delaying fleeing based on comparative energetic requirements of relocating (as discussed in Section 6) can increase the probability of boat strike. Given the variability in marine infrastructure locations and navigational routes of each LNG proponent project, seagrass beds north and south of Fishermans Landing and at Wiggins Island is likely to experience higher frequencies of marine vessel movement.

In comparison, marine vessels commissioned during the operation phase such as Arrow Energy LNG carriers, LPG vessels and escort tugs will be restricted to deep water channels outside shallow water areas where dugongs, turtles and cetaceans typically feed, breed and reside. For this reason and despite the increased frequency of movements, it is unlikely that the magnitude of the impact will increase from the numbers assessed in the construction phase.

Table 19 Estimated Cumulative Frequency of Marine Vessels

Project	Construction			Operation	
	Duration	**Timing (year)**	**Frequency (per month)**	**Duration**	**Frequency (per month)**
WICT Project	–		–	–	–
WBDD Project	–		–	–	–
FLNE Project	–		–	–	–
APLNG Project	2 – 4 years	2011 – 1014	70 one way barge trips 140 one way ferry trips	Ongoing	24 one way LNG carrier trips 3 one way LPG vessel trips
GLNG Project	3 years	2010 – 2013	30 one way ferry trips	Ongoing	15 one way LNG carrier trips
QCLNG Project	4 years	2010 – 2015	70 one way barge trips 135 one way ferry trips	Ongoing	24 one way LNG carrier trips 2 one way LPG vessel trips 144 one way LNG escort tug trips
Subtotal			**445 trips**		**212 trips**
Arrow LNG Project	3 – 4 years	2014 – 2018#	5 one way barge trips 1680 one way ferry trips 2 one way LPG vessel trips (once off occurrence)	Ongoing	3.33 one way LNG carrier trips 13.32 one way LNG escort tug trips
Subtotal			**1687 trips**		**Approximately 17 trips**
Cumulative Impact (Total)			**2132 trips**		**229 trips**
Arrow Representative Percentage (%)			**79.1%**		**7.42%**

*Table based on the assumption that vessels will undergo a single return trip to and from Curtis Island and construction and operation will occur over a seven day week. Frequencies based on the information provided in public documents.

Construction timing for phase one only.

The Arrow LNG Plant is predicted to constitute 79.1% of the total vessel movement expected within Port Curtis during construction and 7.42% of total vessel movement expected during operation. However it must be noted that these percentages are based on incomplete information, and as such the actual percentages may be lower. As there are no seagrass areas in the LNG jetty, MOF and wharf infrastructure areas, construction vessels for the Arrow LNG Plant are unlikely to add significantly to the cumulative risk of boat strike to feeding dugongs. Similarly, the Arrow Energy LNG carriers will use the main deep shipping channels and cumulative risks of boat strike from sudden encounters are low. However, there is uncertainty about the importance of seagrass feeding beds in Port Curtis to the dugong population, particularly for animals migrating through the area. Overall, the projects' contribution to the (potential) cumulative impacts on dugongs is low, considering that:

- The area of disturbance is not a main area for dugong populations.
- No seagrass feeding areas in the areas occupied by project facilities.

- The importance of feeding habitat for migrating dugongs is thought to be higher in the Rodds Bay than the Port Curtis area.
- There is some residual exposure to animals migrating to or between seagrass areas.

9.2.2 Underwater Noise

The cumulative impact of underwater noise from vessel movements and pile driving activities will depend to a large extent on the schedule of construction activities of the contributing projects. There is a potential prolonged effect if all operations happen sequentially and an intensity effect if all take place simultaneously. The timing of construction activities for each project is expected to be staggered, and as such, a sequential build-up of pile driving noise is not likely.

Assessing the cumulative impacts needs to consider overlapping boundaries of distances to threshold sound levels for behavioural responses to pile driving from each of the LNG projects. Since these are estimated at up to 1.5 km (worst case) SVT Engineering Consultants (2010), it is unlikely that avoidance of sound from one operation could result in fauna entering within the threshold from the nearest operation, assuming simultaneous pile driving activities. Whether pile driving is simultaneous or consecutive, effects are therefore primarily temporary and localised to each operation. For vessels, impacts of underwater sound are likely to be similar to boat strike insofar as the detection of underwater sound is the primary means for avoidance. Although avoidance of one vessel will not increase the probability of collision with another, during the construction period of the LNG facilities, the cumulative effect will be a greater area of shallow water within which fauna may need to avoid vessels. During operations, risks will reduce, as the majority of traffic (from all projects) will be confined to the deeper shipping channels.

9.2.3 Lighting

Light generated by all proposed projects, if approved, could potentially affect the behaviour of turtles at the closest nesting beach at South End. Much of the infrastructure required for each project requires lighting facilities for safety and security purposes during construction and operation phases. The LNG facilities in particular will also generate light from elevated flares with a potential height of greater than 100 m. During start-up, maintenance operations or in times of emergency, flaring may be required to burn hydrocarbon releases. In most circumstances flaring will only occur intermittently and for a short duration each time.

Arrow LNG Plant is the only proponent with direct impact (i.e., Arrow LNG Plant is within direct line of sight at South End (back beach only)). However, all LNG projects are expected to cause an indirect glow from light emissions during the construction and operation of each facility and this is likely to be visible from South End (AECOM, 2011), as will distant glare from industrial and port facilities.

The assessment of cumulative impacts is based upon the distance from source (at least 8 km) and each project adopting its own mitigation measures to minimise light spill in the area of South End. The cumulative effect will reflect the combined efforts of each project to achieve **low** impact.

9.3 Loss of Commercial and Recreational Fishing Access

The Port Curtis region supports significant recreational and commercial fishing. With employees numbers expected to increase substantially with the construction and operation of the proposed proponent projects, participation in recreational fishing activities could also potentially rise. Note that fishing will not be permitted from any of the Arrow LNG Plant's jetty or wharf facilities. However, there is uncertainty surrounding the off-duty participation levels of new employees for each of the projects and the period of time potential increases could occur for.

Given the complexity and importance of recreational and commercial fishing to the local community, cumulative impacts cannot be assessed and will be discussed further in the social and stakeholder consultation study.

9.4 Introduction of Invasive Species, Shipping Activities and Accidents

The risk of introducing invasive species or the occurrence of shipping accidents is related to the frequency of LNG vessels moving in between Port Curtis and foreign ports. Over 3, 500 ships exporting commodities make over 9, 700 voyages through the marine park and world heritage area each year (GBRMPA, 2006). Of those over 1, 200 vessels enter Port Curtis (GPC, 2010). If all proposed projects are approved, an additional 1344 one way LNG carrier trips will be expected per year through Port Curtis, the GBRMP, the GBRWHA and surrounding waters, which potentially increases the frequency of shipping and the risk of the impacts by 20%. This emphasizes the importance of adherence to all protocols and management plans to avoid pollution from large or small spills and introduction of exotic species, and adopting proper navigational procedures through the GBRWHA during all transits.

10. INSPECTION AND MONITORING

Table 20 outlines in-principle inspection and monitoring measures that relate to the marine environmental values impacted by the project activities, as identified in Section 6.

Table 20 Inspection and monitoring for impacted environmental values

Environmental Value Impacted	Objective	Mitigation	Inspection / Monitoring
Unavoidable, direct loss of mangrove/ seagrass/ saltmarsh vegetation.	Replacement of like habitat.	Offset/ equivalent initiative.	Periodic monitoring of outcome (subject to offset strategy).
Indirect loss of mangrove/ seagrass/ saltmarsh vegetation during construction.	Minimise lateral extent of vegetation disturbance.	Keep activities within designated boundaries (access tracks for equipment / personnel etc). Erosion control measures. Rehabilitation.	Routine inspection and audit.
Impacts to listed fauna from boat strike.	Reduce risks of collision.	Speed limits. Remain within designated channels. Prop guards/ jet boat hulls. Observation procedures.	Adherence to company procedures. Records of observations.
Impacts to listed fauna from underwater noise during construction (especially pile driving).	Avoid or limit exposure of listed fauna to underwater noise levels that could cause physiological harm.	Observation of area prior to start-up – allow any listed fauna to move away before start-up. Maximise activities during low tide (minimum transfer of noise to marine environment). Low energy start-up as practicable.	Records of observations.
Impacts to listed fauna (turtles) from project lighting.	Avoid disturbance to turtle nesting at South End.	Shielding (as practicable). Light filtering (as practicable).	Contribute to existing long term monitoring of turtle nesting (and additional monitoring where required).
Impacts to water quality from dredging.	Meet required water quality standards.	Dredge Management Plan for typical controls such as managing overflows. Keep within dredge footprint. Stop or move to alternative areas if approaching or exceeding relevant turbidity conditions. Fauna observation function.	Statutory water quality monitoring of turbidity thresholds. Collaboration with Port Curtis-wide monitoring of seagrass habitats (e.g., PCIMP).
Impacts to marine ecosystems from introductions of pest species.	Avoid pathways for marine pest introduction.	Adherence to quarantine protocols for ballast exchange and anti-fouling protocols.	Records of compliance.

11. CONCLUSIONS

Components of the Arrow LNG Plant are situated within Port Curtis and the GBRWHA; an area that provides many ecological functions and represents significant environmental values. A range of potential issues and impacts associated with the construction and operation of the project has been identified to affect marine and estuarine ecology values. Mitigation measures to reduce the magnitude of each impact were applied and an assessment of the residual effects was conducted.

The impacts identified as having the most significant impact on marine and estuarine ecology values include:

- Loss and disturbance of marine and estuarine habitat.
- Impacts on marine and estuarine fauna.
  - Underwater noise.
  - Lighting.
  - Dredging.
- Shipping activities and accidents.

One of the main impacts that will occur during the construction phase of the project is dredging of seabed habitat and clearing of marine and estuarine vegetation for the construction of facilities. Such impacts will directly affect values including mangroves, saltmarsh, the benthic zone and rock substrate, where these lie directly within the project footprint. These and other values such as marine and estuarine fauna are also likely to be temporarily disturbed by turbidity, noise and effects of light. The effects of the construction activities will be unavoidable, regardless of locations of the marine infrastructure, however, actual extent of habitat loss is low in both absolute and percentage terms. The use of a tunnel boring machine to construct a tunnel under the port to Curtis Island will avoid direct impacts to the marine environment of Port Curtis from the installation of the gas feed pipeline. However, the construction of the tunnel entry shaft on the mainland will impact saltmarsh and mudflats. Dredging will directly and indirectly impact seagrass, reef, benthic zone and rock substrate, and construction of jetties, MOFs will impact mangroves and saltmarsh. In the event dredging and clearing of habitat is unavoidable, offsets will be designated to compensate for the loss of marine and estuarine habitat.

The project has the potential to increase the level of underwater noise arising through pile driving. During such operations, underwater noise could significantly impact marine and estuarine ecology values, particularly marine fauna. As the effects of different levels and frequencies of noise on marine fauna are not fully understood, the level of underwater noise generated by the project can be reduced as a precautionary measure through soft starts.

Lighting has been assessed as having a significant impact on EPBC listed marine and estuarine fauna, particularly marine turtles. Artificial light can modify natural illumination and cause disruption to visual cues of marine turtles (Witherington, 1992). Most species of marine turtles nest at night and the impact of brightly lit industrial precincts along coastal margins can disorientate turtles and affect their behaviour (Limpus, 1971a). However, light generated from industrial facilities can be reduced, shielded or where practical scheduled outside nesting periods in order to protect local turtle populations.

Increased shipping movements will increase the potential for collision and injury to large marine fauna such as turtles, dugongs, whales and dolphins, with the potential for community concern in the event of any project-related injury. Personnel ferries will be operated at speeds over shallow areas within Port Curtis that will minimise risks of collisions with marine fauna

Adverse shipping activities and accidents have the potential to occur during the life of the project and can cause significant damage to marine and estuarine ecology values in Port Curtis, the GBRMP, the GBRWHA and surrounding waters. With high numbers and frequencies of marine vessels expected to be operating in the port at any one particular time, there is an increased risk of an incident occurring. The significance of a spill is dependent on the type and nature of the material released, the sensitivity of the receiving environment, the prevailing conditions at the time and emergency response plans. All vessels commissioned under the Arrow LNG Plant during both the construction and operation phase should follow approved incident and emergency protocols in conjunction with international, national and state law. In the event an incident occurs within the port and the incident is cannot be adequately contained by personnel of the vessel; then response plans governed by port and other authorities will be initiated.

In most circumstances and with successful mitigation, the magnitude of the impact is reduced and can be managed, with no residual impacts greater than ‘moderate’. However, despite implementing a range of mitigation and precautionary measures some impacts such as spills can still occur with the significance ranging from minor to major and the consequences potentially catastrophic. Although the residual significance remains major for shipping (large volume oil, hydrocarbon and chemical spills), it does not suggest further mitigation measures are required, rather greater supervision and monitoring should be put into practice. In these cases, strict implementation of environmental management plans will need to be undertaken and enforced.

The Arrow LNG Plant in association with other industry and proposed projects will contribute to both temporary and permanent impacts on of marine and estuarine ecological values within the Port Curtis region. Habitat loss and disturbance, boat strike to marine fauna, underwater noise, and shipping incidents all have the potential to accumulate in line with increased projects in the area. The impacts of project lighting are of particular importance and have the potential to affect the behaviour of turtles at South End. All LNG projects are expected to cause an indirect glow from light emissions at each facility. Impacts are expected to remain very low given the distances involved and other background sources of glow. The effects of these cumulative impacts can be reduced with the implementation of the proposed mitigation measures to eliminate any major residual impact levels.

Table 21 details the significance of the key impacts identified in the impact assessment before and after successful implementation of mitigation measures.

Table 21 Significance Impacts on Environmental Values for the Arrow LNG Plant

Value	Sensitivity	Impact	Magnitude	Significance	Mitigation	Residual Magnitude	Residual Significance
Mangrove	Medium	Direct: Loss and disturbance of marine and estuarine habitat (clearing).	Low	Minor	Not applicable. Offset.	Very low	Negligible
		Indirect: Turbidity plumes from dredging.	Low	Minor	Operate under safe weather conditions. Keep within dredging footprint. Offset.	Very low	Negligible
Saltmarsh	Medium	Direct: Loss and disturbance of marine and estuarine habitat (clearing).	Medium	Minor	Not applicable. Offset.	Very low	Negligible
Seagrass	High	Direct: Loss and disturbance of marine and estuarine habitat (clearing)	Very low	Negligible	N/A	Very low	Negligible
		Indirect: Turbidity and sedimentation from dredging.	Low	Minor	Operate under safe weather conditions. Keep within dredging footprint. Offset.	Low	Minor
Benthic zone and Intertidal mudflat	High	Direct: Loss and disturbance of marine and estuarine habitat (clearing or dredging).	Low	Minor	Not applicable. Offset.	Low	Minor
		Indirect: Turbidity and sedimentation from dredging.	Medium	Moderate	Operate under safe weather conditions. Keep within dredging footprint. Offset.	Very low	Negligible

Table 21 Significance Impacts on Environmental Values for the Arrow LNG Plant (Cont'd)

Value	Sensitivity	Impact	Magnitude	Significance	Mitigation	Residual Magnitude	Residual Significance
Reef and Rock substrate	Medium	Direct: Loss and disturbance of marine and estuarine habitat (clearing or dredging).	Low	Minor	Not applicable. Offset.	Very low	Negligible
		Indirect: Turbidity and sedimentation from dredging.	Low	Minor	Operate under safe weather conditions. Keep within dredging footprint. Offset.	Very low	Negligible
Dugongs	Medium	Direct: Boat strike.	High	Moderate	Enforce speed limit. Stay in navigational channels. Consider installing propeller guards. Consider jet propulsion marine vessels.	Low	Minor
		Direct: Underwater noise (pile driving).	High	Moderate	Soft start. Maintain fauna spotting function (at start of piling and for short period post start up).	Medium	Minor
		Direct: Underwater noise (shipping)	Medium	Minor	No practical ways to reduce the noise characteristics.	Low	Minor
		Direct: Underwater noise (dredging)	Medium	Minor	Keep within dredging footprint. Maintain fauna spotting function (at start up and for short period post start up). Operate under safe weather conditions.	Low	Minor

Table 21 Significance Impacts on Environmental Values for the Arrow LNG Plant (Cont'd)

Value	Sensitivity	Impact	Magnitude	Significance	Mitigation	Residual Magnitude	Residual Significance
Turtles (species dependent)	High/Medium	Direct: Boat strike.	High	Moderate	Enforce speed limit. Stay in navigational channels. Consider installing propeller guards. Consider jet propulsion marine vessels.	Low	Minor
		Direct: Underwater noise (pile driving).	High	Moderate	Soft start. Maintain fauna spotting function (at start of piling and for short period post start up).	Medium	Moderate
		Direct: Underwater noise (shipping)	Medium	Moderate/Minor	No practical ways to reduce the noise characteristics.	Low	Minor
		Direct: Underwater noise (dredging)	Medium	Moderate/Minor	Keep within dredging footprint. Maintain fauna spotting function. Operate under safe weather conditions.	Low	Minor
		Direct: Lighting.	Medium	Moderate/Minor	Shielding/ redirection. Filtering. Long wavelength lights. Reduced height of lights. Lowering height of light source as far as practicable. Reducing reflective surfaces (where possible).	Low	Minor

Table 21 Significance Impacts on Environmental Values for the Arrow LNG Plant (Cont'd)

Value	Sensitivity	Impact	Magnitude	Significance	Mitigation	Residual Magnitude	Residual Significance
Cetaceans	Medium	Direct: Boat strike.	High	Moderate	Enforce speed limit. Stay in navigational channels. Consider installing propeller guards. Consider jet propulsion marine vessels.	Low	Minor
		Direct: Underwater noise (shipping)	Medium	Minor	No practical ways to reduce the noise characteristics.	Low	Minor
Macro-invertebrates	Low	Direct: Underwater noise (pile driving).	High	Minor	As for other fauna	Medium	Negligible
Plankton	Very low	Direct: Underwater noise (pile driving).	High	Negligible	As for other fauna	Medium	Negligible
Fish and shellfish	Medium	Direct: Underwater noise (pile driving).	High	Moderate	Soft start. Observation of area for presence of larger species prior to start up.	Medium	Minor
GBRWHA	Very High	Direct: Introduced species and pest species	Low	Minor	Company protocols; AQIS requirements for ballast; Hull hygiene	Very low	Negligible
		Direct: Shipping (large volume oil, hydrocarbon and chemical spills).	High	Major	Emergency response plan. Hazard and risk equipment.	Very low	Negligible
		Direct: Shipping (small volume oil, hydrocarbon and chemical spill).	Medium	Moderate	Emergency response plan. Hazard and risk equipment.	Very low	Negligible

Table 21 Significance Impacts on Environmental Values for the Arrow LNG Plant (Cont'd)

Value	Sensitivity	Impact	Magnitude	Significance	Mitigation	Residual Magnitude	Residual Significance
GBRWHA (Cont'd)		Direct: Shipping (sewage, greywater and ballast spills).	Low	Moderate	Emergency response plan. Hazard and risk equipment.	Very low	Negligible
		Direct: Shipping (litter).	Low	Moderate	Disposal unit.	Very low	Negligible
		Direct: Shipping (grounding).	Medium	Moderate	Set navigation routes. Pilotage.	Very low	Negligible
		Direct: Shipping (anchoring).	Low	Moderate	Designated navigation routes. Pilotage.	Very low	Negligible
		Direct: Shipping (sinking).	Medium	Moderate	Designated navigation routes. Pilotage.	Very low	Negligible

For summary of impacts to commercial and recreational fishing access, please refer to Arrow LNG Plant's Social Impact Assessment (SKM, 2011)

12. REFERENCES

AECOM, 2011. Landscape and visual impact of lighting. Report prepared by AECOM, Brisbane, for the Arrow Energy, Brisbane.

AEC Group, 2011. Economic Impact Assessment. Report prepared by AEC Group Ltd, Brisbane, for the Arrow Energy, Brisbane.

Alfaro, A., Thomas, F., Sergent, L., and Duxbury, M., 2006. Identification of trophic interactions within an estuarine food web (northern New Zealand) using fatty acid biomarkers and stable isotopes. *Estuarine, Coastal and Shelf Science* 70:271–286.

Alquezar, R., 2011. Arrow LNG Plant: Estuarine and marine field investigations (Phase I & II). Report Prepared by CQ University, Gladstone, Australia.

Alquezar, R., 2008. Macroinvertebrate and sediment assessment for the Curtis Island gas pipeline EIS. Report prepared by CQ University, Gladstone, Australia.

Anon, 1966. Effect of underwater explosions on fish. *Australian Fisheries Newsletter* (March): 8–9.

APPEA, 2005. *A compilation of recent research into the marine environment*. Australian Petroleum Production and Exploration Association, Canberra.

Aston, J., 2006. 'Shipping and oil spills' in The State of the Great Barrier Reef. A WWW publication accessed on 10 August, 2011 at http://www.gbrmpa.gov.au/__data/assets/pdf_file/0003/3963/Shipping_FINAL_APPROVED_for_publication_June2006_pdf. Great Barrier Reef Marine Park Authority, Townsville.

Au Whitlow, W.L., 1993. *The sonar of dolphins*. Springer-Verlag New York Inc., New York.

Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G. and Thompson, P., 2010. Assessing underwater noise levels during pile driving at an offshore windfarm and its potential effects on marine mammals. *Marine Pollution Bulletin* 60:888–897.

Baker, C.S., and Herman, L.M., 1989. Behavioural responses of summering humpback whales to vessel traffic: Experimental and opportunistic observations. Report prepared for U.S. Department of the Interior National Park Service, Alaska.

Baldwin, R., Hughes, G. and Prince, R., 2003. 'Loggerhead turtles in the Indian Ocean'. In *Loggerhead sea turtles*. Edited by A. Bolten and B. Witherington. Smithsonian Institution, U.S.A. 199–209.

Beasley, I., Robertson, K., and Arnold, P., 2005. Description of a new dolphin: the Australian snubfin dolphin Oracella heinsohni sp. n. (Cetacea, Delphinidae). *Marine Mammal Science* 21:365–400.

Bradley, J., 2009. Policy for vegetation management offsets. Report prepared by Department of Environment and Resource Management, Queensland Government, Brisbane.

Branch, T., Stafford, K., Palacios, D., Allison, C., Bannister, J., Burton, C., Cabrera, E., Carlson, C., Galletti Vernazzani, B., Gill, P., Hucke-Gaete, R., Jenner, K., Jenner, M., Matsuoka, K., Mikhalev, Y., Miyashita, T., Morrice, M., Nishiwaki, S., Sturrock, V., Tormosov, D., Anderson, R., Baker, A., Best, P., Borsa, P., Brownell (Jr), R., Schilderhouse, S., Findlay, K., Gerrodette, T., Ilangakoon, A., Joergensen, M., Kahn, B., Ljungblad, D., Maughan, B., McCauley, R., McKay , S., Norris, T., Oman Whale and Dolphin Research Group, Rankin, S., Samaran, F., Thiele, D., Van Waerebeek, K. and Warneke, R., 2007. Past and present distribution, densities and movements of blue whales Balaenoptera musculus in the Southern Hemisphere and Northern

Indian Ocean. *Mammal Review* 2:116–175.

Bruinsma, C., Danaher, K., Treloar, P., and Sheppard, R., 1999. Queensland coastal wetland resource investigation of the Bowen region: Cape Upstart to Gloucester Island, Report prepared by Department of Primary Industries Fisheries, Queensland Government, Brisbane.

Bull, J., 1980. Sex determination in reptiles. *The Quarterly Review of Biology* 55:3–21.

Bustard, R., 1972. *Sea turtles: Natural history and conservation*. William Collins Sons & Co Ltd, Glasgow, UK.

Chaloupka, M., and Limpus, C., 2005. Estimates of sex- and age-class-specific survival probabilities of a southern Great Barrier Reef green sea turtle population. *Marine Biology* 146:1251–1261.

Chartrand, K., Rasheed, M. and Unsworth, R., 2009. Long term seagrass monitoring in Port Curtis and Rodds Bay. November. Report prepared by Marine Ecology Group, Cairns, Queensland for the Department of Employment, Economic Development and Innovation, Brisbane.

Coastal Protection and Management Act 1995

Coastal Protection and Management (Coastal Management Districts) Regulation 2003

Cogger, H.G., 2000. *Reptiles and Amphibians of Australia.* Reed New Holland, Sydney, Australia.

Coles, R., McKenzie, L., Rasheed, M., Mellors, J., Taylor, H., Dew, K., McKenna, S., Sankey, T., Carter, A. and Grech, A., 2007. Status and trends of seagrass habitats in the Great Barrier Reef World Heritage Area. Report prepared by Reef and Rainforest Research Centre Limited, Cairns, Queensland.

Collier, C., and Waycott, M., 2009. Drivers of change to seagrass distributions and communities on the Great Barrier Reef: Literature review and gap analysis. Report prepared by Reef and Rainforest Research Centre Limited, Cairns, Queensland.

Connell Hatch. 2006. Wiggins Island Coal Terminal Environmental Impact Statement. Consultancy report for Central Queensland Ports Association and Queensland Resources.

Connolly, R., Currie, D., Danaher, K., Dunning, M., Melzer, A., Platten, J., Shearer, D., Stratford, P., Teasdale, P. and Vandergragt, M., 2006. Intertidal wetlands of Port Cutis: Ecological patterns and processes, and their implications. Technical Report No. 43. Report prepared by Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, Brisbane, Queensland.

Corkeron, P., Morissette, N., Porter, L. and Marsh, H., 1997. Distribution and status of hump-backed dolphins, Sousa chinensis, in Australian waters. *Asian Marine Biology* 14:49–59.

Currie, D., and Small, K., 2005. Macrobenthic community responses to long-term environmental change in an east Australian sub-tropical estuary. *Estuarine, Coastal and Shelf Science* 63:315–331.

Currie, D., and Small, K., 2006. The influence of dry-season conditions on the bottom dwelling fauna of an east Australian sub-tropical estuary. *Hydrobiologia* 560:345–361.

Danaher, K., 1995. Marine vegetation of Cape York Peninsula. Report prepared by the Department of Primary Industries, Queensland.

Danaher, K., Rasheed, M. and Thomas, R., 2005. The intertidal wetlands of Port Curtis. Report prepared by the

Department of Primary Industries and Fisheries, Queensland.

David, J., 2006. Likely sensitivity of bottle nosed dolphins to pile driving noise. *Water and Environment Journal* 20:48–54.

DEEDI, 2010. Marine pests. A WWW publication accessed on 28 July 2010 at http://www.dpi.qld.gov.au/4790_8515.

htm. Department of Primary Industries, Queensland Government, Brisbane.

DEH, 2010. Blue, fin and sei whale recovery plan 2005 – 2010. Report prepared by the Department of the Environment and Heritage, Australia.

DERM, 2010.The Great Barrier Reef. A WWW publication accessed on 8 August 2010 at http://www.derm.qld.gov.au/ parks_and_forests/ world_heritage_areas /great_barrier_reef.html. Queensland Government, Brisbane.

DEWHA, 2008. EPBC Act policy statement 2.1. Interaction between offshore seismic exploration and whales. Report prepared by Department of Environment, Water, Heritage and the Arts, Australia.

DEWHA, 2010a. Chelonia mydas in Species Profile and Threats Database. A WWW publication accessed on 18 August, 2010 at http://www.environment.gov.au/ sprat. Department of the Environment, Water, Heritage and the Arts, Canberra.

DEWHA. 2010b. Balaenoptera musculus in Species Profile and Threats Database. A WWW publication accessed on 18 August 2010 at http://www.environment.gov.au/sprat. Department of the Environment, Water, Heritage and the Arts, Canberra.

Dixon, M., and Beumer, J., 2002. Mitigation and Compensation for Works or Activities Causing Marine Fish Habitat Loss: Departmental Procedures, Fish Habitat Management Operational Policy FHMOP 005. Report prepared by Queensland Department of Primary Industries.

Draft Policy Statement: Use of environmental offsets under the Environment Protection and Biodiversity Conservation Act 1999 2007 (Cwlth).

Duke, N., Lawn, P., Roelfsma, C., Zahmel, K., Pedersen, D., Harris, C., Steggles, N. and Tack, C., 2003. Assessing historical change in coastal environments: Port Curtis, Fitzroy River estuary and Moreton Bay regions, Report to the CRC for Coastal Zone Estuary and Waterway Management. Report prepared by the University of Queensland, Brisbane.

Ecosure, 2011. Terrestrial Ecology Impact Assessment. Report prepared by Ecosure Pty Ltd, West Burleigh, Queensland for Arrow Energy, Brisbane.

Environment Australia. 2001. *A directory of important wetlands in Australia*, Third Edition. Environment Australia. Canberra.

Environment Australia, 2003. Recovery plan for marine turtles in Australia (Cwlth). Environment Australia. Canberra.

Environmental Protection Act 1994.

EPA, 2005. Wetland mapping and classification methodology – Overall framework: A method to provide baseline mapping and classification for wetlands in Queensland. Version 1.2. Report prepared by Environmental Protection Agency, Queensland.

Environment Protection and Biodiversity Conservation Act 1999.

Environment Protection (noise) Policy 2008 (Noise EPP)

Environmental Protection Regulation 2008.

EPA, 2007. Operational Policy: Conservation and management of dugongs in Queensland 2007

Erftmeijer P., and Lewis, R., 1999. ‘Planting mangroves on intertidal mudflats: Habitat restoration or habitat conversion?’ In *Proceedings of the ECOTONE VIII Seminar: Enhancing coastal ecosystems restoration for the 21st century, Ranong,* *Thailand*. Royal Forest Department of Thailand, Thailand, 156–165.

Finley, K., Miller, G., Davis, R., Greene, C., 1990. Reactions of belugas, Delphinapterus leucas, and narwhals, Monodon monoceros, to icebreaking ships in the Canadian High Arctic. *Canadian Bulletin of Fisheries and Aquatic Sciences* 224:97–117.

Fisheries Act 1994.

Fisheries Regulation 2008.

GBRMPA, 1998. Great Barrier Reef Marine Park - Mackay Capricorn Section zoning information. A WWW publication accessed at http://www.gbrmpa.gov.au/data/assets/pdf_file/0005/10679/mpz_32.pdf. Great Barrier Reef Marine Park Authority, Townsville.

GBRMPA. 2006. Management status: Shipping and oil spills. A WWW publication accessed on 17 August 2010 at http://www.gbrmpa.gov.au/corp_site/info_services/publications/sotr/latest_updates/shipping. Great Barrier Reef Marine Park Authority, Townsville.

Gerstein, E., Gerstein, L., Forsythe, S. and Blue, J., 1999. The underwater audiogram of the west Indian manatee (Trichechus manatus). *Journal of Acoustical Society of America* 105:3575–3583.

GHD. 2009. Western Basin Dredging and Disposal Project EIS. Report prepared by GHD Pty Ltd for Gladstone Ports Corporation, Gladstone, Queensland.

Gill, P., and Morrice, M., 2003. Blue whales in the Bonney upwelling – current information, Technical Paper 2003/1. Report prepared by Deakin University, Melbourne.

Gill, J., Norris, K. and Sutherland, W., 2001. Why behavioural responses may not reflect the population consequences of human disturbance. *Biological Conservation* 97:265–268.

Gomon, M., Glover, J., and Kuiter, R., 1994. *The fishes of Australia's south coast*. State Print, Adelaide.

GPC, 2010. Shipping. A WWW publication accessed on 28 September 2010 at http://www.gpcl.com.au/shipping.html. Gladstone Ports Corporation, Gladstone, Queensland.

Great Barrier Reef Marine Park Act 1975.

Great Barrier Reef Marine Park Regulation 1983.

Great Barrier Reef Marine Park Zoning Plan (Cwlth) 2003.

Grech, A., and Marsh, H., 2007. Prioritising areas for dugong conservation in a marine protected area using a spatially explicit population model. *Applied GIS* 3:1–14.

Hagan, S., and Able, K., 2003. Seasonal changes of the pelagic fish assemblage in a temperate estuary. *Estuarine, Coastal and Shelf Science.* 56:15–29.

Hamann, M., Limpus, C., and Owens D., 2003. 'Reproductive cycles of males and females'. In *The Biology of Sea Turtles Volume II*. Edited by P. Lutz, J. Musick and J. Wyneken. CRC Press, U.S.A.

Harris, G., 1999. Comparison of the biogeochemistry of lakes and estuaries: ecosystem processes, functional groups, hysteresis effects and interactions between macro- and microbiology. *Marine and Freshwater Research*, 50:791–811.

Hazel, J., Lawler, I., Marsh, H., and Robson, S., 2007. Vessel speed increases collision risk for the green turtle Chelonia mydas. *Endangered Species Research* 3:105–113.

Heatwole, H., 1997. Marine snakes: Are they a sustainable resource? *Wildlife Society Bulletin* 4:766–772.

Heck, K., 1980. 'Seagrass habitats: The roles of habitat complexity, competition and predation in structuring associated fish and motile macroinvertebrate assemblages'. In *Estuarine Perspectives*. Edited by V. Kennedy. Academic Press, New York.

Hick, P., and Caccetta, M., 1997. Spectral measurement of illumination sources at Varanus Island: A study of the possible effects of the East Spar Facility lights on turtles - Minesite

Hodgson, A. 2004. Dugong behaviour and responses to human influences. PhD. Thesis for the School of Tropical Environment Studies and Geography. James Cook University. Townsville, Australia.

Hodgson, A., and Marsh, H., 2007. Response of dugongs to boat traffic: The risk of disturbance and displacement. *Journal of Experimental Marine Biology and Ecology* 340:50–61.

Ikejima, K., Tongnunui, P., Medej, T., and Taniuchi, T., 2003. Juvenile and small fishes in a mangrove estuary in Trang province, Thailand: seasonal and habitat differences. *Estuarine, Coastal and Shelf Science* 56:447–457.

IUCN, 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission, IUCN, Gland, Switzerland and Cambridge, United Kingdom.

IUCN, 2010. IUCN Red List of Threatened Species. A WWW publication accessed on 13 April 2010 at www.iucnredlist.org. International Union for Conservation of Nature, Gland, Switzerland and Cambridge, United Kingdom.

Ketten, D., and Bartol, S., 2006. Functional measures of sea turtle hearing. Report prepared by Woods Hole Oceanographic Institution. Woods Hole, Massachusetts.

Ketten, D., Odell, D., and Domning, D., 1992. 'Structure, function, and adaptation of the manatee ear.' In *Marine Mammal Sensory Systems*. Edited by J. Thomas, R. Kastelein and A. Supin. Plenum Press, New York.

Land Act 1994

Land Protection Pest and Stock Route Management Act 2002

L. Huson and Associates Pty Ltd., 2009. Underwater Noise Impact assessment: Gladstone LNG Project. Report prepared by L. Huson and Associates Pty Ltd, Woodend, Queensland.

Laegdsgaard, P. And Johnson, C. 2001. Why do juvenile fish utilise mangrove habitats? *Journal of Experimental Marine Biology and Ecology* 257:229–253.

Lanyon, J., 1991. The nutritional ecology of the dugong (Dugong dugon) in tropical north Queensland. PhD. Thesis prepared for Monash University, Australia.

Leis, J., 2002. Pacific coral-reef fishes: the implications of behaviour and ecology of larvae for biodiversity and conservation, and a reassessment of the open population paradigm. *Environmental Biology of Fishes* 65:199–208.

Lewis, S., Hewitt, C., and Melzer A., 2001. Port survey for introduced marine species - Port Curtis. Report prepared by CQ University, Gladstone, Queensland.

Limpus, C., and Limpus, D., 2003. 'Loggerhead turtles in the equatorial and southern Pacific Ocean - A species in decline'. In *Loggerhead sea turtles*. Edited by A. Bolten and B. Witherington. Smithsonian Institution, U.S.A., 199–209.

Limpus, C., Fleay, A. and Baker, V. 1984. The flatback turtle, Chelonia depressa, in Queensland: Reproductive periodicity, philopatry and recruitment. *Australian Wildlife Research*. 11: 579-87.

Limpus, C.J., and Reimer, D., 1994. 'The Loggerhead Turtle, Caretta caretta, in Queensland: a population in decline'. In *Proceedings of the Australian Marine Turtle Conservation: Proceedings of the Australian Marine Turtle Conservation Workshop, Gold Coast, 14-17 November 1990*. Edited by R. James. Queensland Department Envivonment and Heritage, Canberra, ANCA.

Limpus, C., McLaren, M., McLaren, G., and Knuckey, B., 2006. Queensland Turtle Conservation Project: Curtis Island and Woongarra coast flatback turtle studies, 2005-2006. Report prepared by Environmental Protection Agency, Queensland.

Limpus, C., Gyuris, E., and Miller, J., 1988. Reassessment of the taxanomic status of the sea turtle genus, Natator, McCulloch, 1908 with a redescription of the genus and species. *Transactions of the Royal Society of South Australia* 112:1–9.

Limpus, C., 1971a. The flatback turtle Chelonia depressa (Garman) in southeast Queensland, Australia. *Herpetologica* 27:431–446.

Limpus, C., 1971b. Sea turtle ocean finding behaviour. *Search* 2:385–387.

Limpus, C., 2007. A biological review of Australian marine turtle species. 5. Flatback turtle, Natator depressus (Garman). Report prepared by Environmental Protection Agency, Queensland.

Limpus, C., 2008a. A biological review of Australian marine turtle species. 2. Green turtle, Chelonia mydas (Linneaus). Report prepared Environmental Protection Agency, Queensland.

Limpus, C., 2008b. A biological review of Australian marine turtle species. 1. Loggerhead turtle, Caretta caretta (Linneaus). Report prepared Environmental Protection Agency, Queensland.

Limpus, C., 2009a. A biological review of Australian marine turtles. 6. Leatherback turtle, Dermochelys coriacea (Vandelli). Report prepared by Environmental Protection Agency, Queensland.

Limpus, C. 2009b. A biological review of Australian marine turtle species. 3. Hawksbill turtle, Eretmochelys imbricata (Linneaus). Report prepared by Environmental Protection Agency, Queensland.

Local Government Act 2009 (Qld)

Lukoschek, V., Heatwole, H., Grech, A., Burns, G., and Marsh, H., 2007. Distribution of two species of sea snakes, Aipysurus laevis and Emydocephalus annulatus, in the southern Great Barrier Reef: metapopulation dynamics, marine protected areas and conservation. *Coral Reefs* 26:291–307.

Manson, F., Loneragan, N., Harch, B., Skilleter, G., and Williams, L., 2005. A broad-scale analysis of links between coastal fisheries production and mangrove extent: A case-study for northeastern Australia. *Fisheries Research* 74: 69–85.

Marine Parks (Great Barrier Reef Coast) Zoning Plan (Qld) 2004

Marine Parks Act 2004

Marine Parks Regulation 2006

Marsh, H., and Lawler, I., 2001. Dugong distribution and abundance in the southern Great Barrier Reef Marine Park and Hervey Bay: Results of an aerial survey in October–December 1999. Report prepared by Great Barrier Reef Marine Park Authority, Townsville.

Marsh, H., and Lawler, I., 2002. Dugong distribution and abundance in the northern Great Barrier Reef Marine Park - November 2000. Report prepared by Great Barrier Reef Marine Park Authority, Townsville.

Marsh, H., and Lawler, I., 2006. Dugong distribution and abundance on the urban coast of Queensland: A basis for management. Report prepared by Marine and Tropical Sciences Research Facility, Queensland.

Marsh, H., Penrose, H., Eros, C., and Hugues, J., 2002. The dugong (Dugong dugon) status reports and action plans for countries and territories, United Nations environment programme, early warning and assessment report series, 1. Report prepared by United Nations Environment Programme, Cambridge, UK.

Marsh, H., De'ath, G., Gribble, N., and Lane, B., 2005. Historical marine population estimates: Triggers or targets for conservation? The dugong case study. *Ecological Applications* 15:481–492.

Matters of National Environmental Significance, Significant Impact guidelines 1.1 Environment Protection and Biodiversity Conservation Act 1999, Department of the Environment, Water, Heritage and the Arts, Australia.

McCarthy, E., 2004. *International regulation of underwater sound: Establishing rules and standards to address ocean noise pollution*. Springer Publishing, Dordrecht.

McCauley, R., 1994. 'Seismic Surveys'. In *Environmental implications of offshore oil and gas development in Australia - The findings of an independent scientific review*. Edited by. J. Swan, J. Neff and P. Young. Australian Petroleum Production and Exploration Association. Sydney, 19–121.

McCauley, R., 1998. Radiated underwater noise measured from the drilling rig Ocean General; Rig Tenders Pacific Ariki and Pacific Frontier, and Fishing Vessel Reef Venture, and natural sources in the Timor Sea, Northern Australia. Report prepared by Curtin University, Perth.

McCauley.S. J., and Bjorndal, K. A. 1999. Conservation Implications of Dietary Dilution from Debris Ingestion: Sublethal Effects in Post-Hatchling Loggerhead Sea Turtles. Conservation Biology 13(4):925–929

McCauley, R., Fewtrell, J., Duncan, A., Jenner, C., Jenner, M., Penrose, J., Prince, R., Adhitya, A., Murdoch, J., and McCabe, K., 2003a. 'Marine seismic surveys: Analysis and propagation of air-gun signals and effects of air-gun exposure on humpback whales, sea turtles, fish and squid', In *APPEA environmental implications of offshore oil and gas development in Australia: Further research*. Australian Petroleum Production and Exploration Association, Canberra.

McCauley, R., Fewtrell, J., and Popper, A., 2003b. High intensity anthropogenic sound damages fish ears. *Journal of Acoustical Society of America* 113:638–642.

McCauley, R., and Salgado-Kent, C., 2008. Underwater acoustics impact study report. Appendix C. Module D. Document prepared to meet obligations under EPBC Act , 1999. Report prepared by Centre for Marine Science and Technology, Curtin University, Perth for Gunns Limited, Launceston, Australia.

Meksumpun, S., Meksumpun, C., Hoshika, A., Mishima, Y., and Tanimoto, T., 2005. Stable carbon and nitrogen isotope ratios of sediment in the gulf of Thailand: Evidence for understanding of marine environment. *Continental Shelf Research* 25:1905–1915.

Moein Bartol, S., and Musick, J., 2003. 'Sensory biology of sea turtles'. In *Biology of sea turtles Vol II*. Edited by P. Lutz, J. Musick and J. Wyneken. CRC Press, Florida, 79–102.

Moore, R., 1982. Spawning and early life history of barramundi, Lates calcarifer (Bloch), in Papua New Guinea. *Australian Journal of Marine and Freshwater Research* 33:647–661.

Motta, P., Clifton, K., Hernandez, P., and Eggold, B., 1995. Ecomorphological correlates in ten species of subtropical seagrass fishes: diet and microhabitat utilization. *Environmental Biology of Fishes* 44:37–60.

Musick, J., and Limpus, C., 1997. 'Habitat utilization and migration in juvenile sea turtles'. In *The Biology of Sea Turtles.* Edited by P. Lutz and J. Musick. CRC Press, Florida, 137–163.

Nature Conservation Act 1992

Nature Conservation (Dugong) Conservation Plan 1999

Nature Conservation (Estuarine Crocodile) Conservation Plan 2007

Nature Conservaion (Protected Areas) Regulation 1994

Nature Conservation (Whales and Dolphins) Conservation Plan 1997

Nature Conservation (Wildlife) Regulation 2006

Nedwell, J., Edwards, B., Turnpenny, A., and Gordon, D., 2004. Fish and marine mammal audiograms: A summary of available information. Report prepared by Subacoustech Ltd, Hampshire, UK, for ChevronTexaco Ltd.

Nedwell, J.R., Ward, P.D., Lambert, D., Watson, D., Goold, J., Englund, A., Bendell, A., and Barlow, K. 2008. 'Assessment of potential for significant disturbance/disruption to cetaceans present in and around Broudhaven Bay Co. Mayo from Pipeline Construction Operations'. Report prepared by Subacoustech.

Nowacek, S., Wells, R., and Solow, A., 2001. Short-term effects of boat traffic on bottlenose dolphins, Tursiops truncatus, in Sarasota Bay Florida. *Marine Mammal Science* 17:673–688.

NRC, 2003. *Ocean noise and marine mammals*. The National Academic Press. Washington, D.C.

Parra, G., 2005. Behavioural ecology of Irrawaddy, Orcaella brevirostris (Owen in Gray, 1866), and Indo-Pacific humpback dolphins, Sousa chinensis (Osbeck, 1975), in northeast Queensland, Australia: A comparative study. PhD. Thesis prepared by James Cook University, Townsville.

Parra, G., 2006. Resource partitioning in sympatric delphinids: Space use and habitat preferences of Australian snubfin and Indo-Pacific humpback dolphins. *Journal of Animal Ecology* 75:862–874.

Parra, G., Azuma, C., Preen, A., Corkeron, P., and Marsh, H., 2002. Distribution of Irrawaddy dolphins, Orcaella brevirostris, in Australian waters. *Raffles Bulletin of Zoology, Supplement* 10:141–154.

Parra, G., Corkeron, P., and Marsh, H., 2006. Population sizes, site fidelity and residence patterns of Australian snubfin and Indo-Pacific humpback dolphins: Implications for conservation. *Biological Conservation* 129:167–180.

Parry, G., and Gason, A., 2006. The effect of seismic surveys on catch rates of rock lobsters in western Victoria, Australia. *Fisheries Research* 79:272–284.

Pendoley, K., 2005. Sea turtles and the environmental management of industrial activities in North West Western Australia. PhD. Thesis prepared by Murdoch University, Perth.

Peterson, B., and Heck, K., 1999. The potential for suspension feeding bivalves to increase seagrass productivity. *Journal of Experimental Marine Biology and Ecology* 240:37–52.

Platten J., Sawynok B., and Parsons W., 2007. How much fishing effort is there 2005-07? Pattern of Fishing Effort of Recreational Fishers offshore from Central Queensland. Report prepared by CapReef, Rockhampton.

Platten, J., 2004. Historical trends in recreational fishing catches in the Gladstone region. Report prepared by Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, Indooroopilly.

Preen, A. 1992. Interactions between dugongs and seagrasses in a subtropical environment. PhD. Thesis for the Department of Zoology. James Cook University. Townsville, Australia.

Preen, A., and Marsh, H., 1995. Response of dugongs to large-scale loss of seagrass from Hervey Bay, Queensland, Australia. *Wildlife Research* 22:507–519.

Preen, A., 1995. Impacts of dugong foraging on seagrass habitats: observational and experimental evidence for cultivation grazing. *Marine Ecology Progress Series* 124:201–213.

Preisendorfer, R., 1986. Secchi disk science: visual optics of natural waters. *Limnology and Oceanography* 31:909–926.

Queensland Government Environmental Offsets Policy (Qld) 2008

Rasheed, M., McKenna, S., Taylor, H., and Sankey, T., 2008. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - October 2007. Report prepared by Department of Primary Industries and Fisheries, Queensland.

Rasheed, M., Thomas, R., Roelofs, A., Neil, K., And Kerville, S., 2003. Port Curtis and Rodds Bay seagrass and benthic macro-invertebrate community baseline survey, November/December 2002. Report prepared by Department of Primary Industries and Fisheries, Queensland.

Read, M., Miller, J., Bell, I., and Felton, A., 2004. The distribution and abundance of the estuarine crocodile, Crocodylus porosus, in Queensland. *Wildlife Research* 31:527–534.

Richardson, W., Greene, C., Malme, C., and Thomson, D., 1995. *Marine mammals and noise*. Academic Press. London.

Richardson, W., Wursig, B., and Greene, C. Jnr., 1990. Reactions of bowhead whales (Balaena mysticetus), to drilling and dredging noise in the Canadian Beaufort Sea. *Marine Environmental Research* 29:135–160.

Robins, J., and Mayer, D., 1998. Monitoring the impact of trawling on sea turtle populations of the Queensland East Coast. Report prepared by Department of Primary Industries, Queensland.

Sakamaki, T., and Nishimura, O., 2007. Physical control of sediment carbon content in an estuarine tidal flat system (Nanakita River, Japan): A mechanistic case study. *Estuarine, Coastal and Shelf Science* 73:781–791.

Salgado-Kent, C., McCauley, R., and Duncan, A., 2008. Port Melbourne East Dawson Dock impact pile driving underwater noise. July, 2008. Field Measurements summary. Prepared by Centre of Marine Science and Technology, Curtin University.

Salgado-Kent, C., and Parnum, I., 2009. Port Melbourne Channel Impact pile driving underwater noise. September. Report prepared by Curtin University, Perth.

Savery and Associates Pty Ltd, 2010. Noise and vibration impact study, Downstream LNG plant. Report prepared by Savery and Associates Pty Ltd, The Gap for Australia Pacific LNG Curtis

Sheppard, J.K. , Preen, A. P., Marsh, H., Lawler, I. R., Whiting, S. D., and Jones, R. E., 2006. Movement heterogeneity of dugongs, *Dugong dugon* (Müller), over large spatial scales. *Journal of Experimental Marine Biology and Ecology* 334:64–83.

SKM, 2011. Arrow LNG Plant Social impact assessment. Report prepared by Sinclair Knight Mertz 2011, for Coffey Environments Australia Pty Ltd and Arrow Energy Holdings Pty Ltd. Brisbane, Queensland.

Southall, B., Bowles, A., Ellison, W., Finneran, J., Gentry, R., Greene, Jr. C., Kastak, D., Ketten, D., Miller, J., Nachtigall, P., Richardson, W., Thomas, J., and Tyack, P., 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals* 33:411–521.

Spain, A., and Heinsohn, G., 1975. Size and weight allometry in a north Queensland population of Dugong dugon (Miller) (Mammalia: Sirenia). *Australian Journal of Zoology* 23:159–168.

Storey, A., Andersen, L., Lynas, J., and Melville, F., 2007. Port Curtis ecosystem health report card, Port Curtis Integrated

Monitoring Program. Report prepared by CQ University, Gladstone.

Sustainable Planning Act 2009 (Qld)

SVT Engineering Consultants, 2010. QCLNG Gladstone Channel underwater noise assessment. Report prepared by SVT Engineering Consultants, Perth.

Swan, J., Neff, J., and Young, P., 1994. Environmental implications of offshore oil and gas development in Australia: The findings of an independent scientific review. Report prepared by Australia Petroleum Exploration Association and Energy Research and Development Corporation, Sydney.

Taplin, L. 1987. 'The management of crocodiles in Queensland, Australia'. In Wildlife Management: Crocodiles and Alligators. Webb, G., Manolis, C. and Whitehead, P. 129 - 140. Surrey Beatty and Sons Pty Limited. New South Wales.

Taylor, H., Rasheed, M., Dew, K., and Sankey, T., 2007. Long term seagrass monitoring in Port Curtis and Rodds Bay, Gladstone - November 2006. Report prepared by Department of Primary Industry and Fisheries, Queensland.

Turnpenny A., and Nedwell J., 1994. The effects on marine fish, diving mammals and birds of underwater sound generated by seismic surveys. Consultancy report to UKOOA. Report prepared by Fawley Aquatic Research Laboratories Ltd., Hampshire, UK.

URS, 2009. Gladstone Liquefied Natural Gas Project Marine Ecology Technical Report. Report prepared by URS, Brisbane for Gladstone Liquefied Natural Gas Project, Gladstone, Queensland.

Vegetation Management Act 1999

Vegetation Management Regulation 2000

WBM BMT 2011. Coastal Processes, Hydrodynamics and Marine Quality Impact Assessment, by WBM BMT 2011 for the Arrow LNG Plant.

Wilson, B., and Allen, G., 1987. ‘Major components and distribution of marine fauna’. In *Fauna of Australia: General Articles*. Edited by. G. Dyne and D. Walton. Australian Government Publishing Service. Canberra, 43–68.

Wilson, B., Hammond, P., and Thompson, P., 1999. Estimating size and assessing trends in a bottlenose dolphin population. *Ecological Applications* 9:288–300.

Witherington, B., 1992. Behavioural responses of nesting sea turtles to artificial lighting. *Herpetologica* 48:31–39.

Wright, S., Ackerman, B., Bonde, R., Beck, C., and Banowtz, D., 1995. ‘Analysis of watercraft-related mortality of manatees in Florida, 1979 – 1991’. In *Population Biology of the Florida Manatee*. Edited by T. O'Shea, B. Ackerman and H. Percival. U.S. Department of the Interior National Biological Service, Washington.

13. ACRONYMS AND GLOSSARY

Units

% *abbr*. per cent.

> *abbr.* greater than.

< *abbr.* less than.

dB *abbr.* decibel.

Re 1 µ Pa *abbr.* reference level to 1 micropascal.

ha *abbr.* hectare.

Hz *abbr.* hertz.

kHz *abbr.* kilohertz.

km *abbr.* kilometre.

m *abbr.* metre.

m^3 *abbr.* cubic metre.

Mtpa *abbr.* million tonnes per annum.

A

APLNG Project *abbr.* Australian Pacific Liquefied Natural Gas Project.

AQIS *abbr.* Australian Quarantine and Inspection Service.

Arrow *abbr.* Arrow Energy Ltd.

Arrow LNG Plant *abbr.* Arrow Energy LNG Plant.

C

CHRIS *abbr.* coastal habitat resources information system.

Coral bommies *n* are outcrops of rock and coral.

COLREGS *abbr.* International Regulations for Preventing Collisions at Sea 1972

D

DEEDI *abbr.* Department of Employment, Economic Development and Innovation.

demersal *adj.* found at or near the sea bottom.

diadromous *adj.* migratory between fresh and salt waters.

DPA *abbr.* dugong protection areas.

E

EIS *abbr.* environmental impact statement.

Environmental Management Charge *n*. a charge payable by most commercial operators granted permits by the Great Barrier Reef Marine Park Authority.

EPA *abbr.* Environmental Protection Agency.

EPBC Act *abbr. Environment Protection and Biodiversity Conservation Act 1999*.

EPC *abbr engineering, procurement and construction (EPC) management* **ESA** *abbr.* environmentally sensitive area.

F

FHA *abbr.* fish habitat areas.

FLNE Project *abbr.* Fishermans Landing Northern Expansion Project.

G

GBR Coast MP *abbr.* Great Barrier Reef Coast Marine Park.

GBRMP *abbr.* Great Barrier Reef Marine Park.

GBRMPA *abbr.* Great Barrier Reef Marine Park Authority.

GBRWHA *abbr.* Great Barrier Reef World Heritage Area.

GLNG Project *abbr.* Gladstone Liquefied Natural Gas Project.

GPA *abbr.* Gladstone Ports Authority.

GPC *abbr.* Gladstone Ports Corporation.

GSDA *abbr.* Gladstone State Development Area.

H

HDD *abbr.* horizontal directional drilling.

I

IPIECA *abbr.* International Petroleum Industry Environmental Conservation Association

IUCN *abbr.* International Union for the Conservation of Nature.

L

LNG *abbr.* liquefied natural gas.

M

MOF *abbr.* materials offloading facility.

MOSAG *abbr.* Multi-business Oil (and Chemical) Spill Advisory Group.

N

National Environmental Significance (Protected Matters) *n*. Commonwealth marine areas, listed threatened species, listed migratory species, listed marine species, world heritage areas.

O

OCIMF *abbr.* Oil Companies International Marine Forum.

OCIMF-SIRE *abbr.* Oil Companies International Marine Forum- Ship Inspection Monitoring Programme

P

PCCC *abbr.* Port Curtis Coral Coast.

PCIMP *abbr.* Port Curtis Integrated Monitoring Program.

pelagic *adj.* living at or near the surface of the ocean, far from land, as certain animals or plants.

pilotage *n.* the act of piloting.

Q

QCLNG Project *abbr.* Queensland Curtis Liquefied Natural Gas Project.

R

right of way *n.* a path or route which may lawfully be used.

S

SEL *abbr .*sound level exposure.

Shell *abbr.* Royal Dutch Shell plc.

Shell CSG (Australia) *abbr.* Shell CSG (Australia) Pty Ltd

SIGTTO *abbr.* Society of International Gas Tanker Owners and Terminal Operators.

SOLAS *abbr* International Convention for the Safety of Life at Sea 1974

T

TED *abbr.* turtle excluder devices.

terrigenous *adj.* denoting or relating to sediments on the sea bottom derived directly from the neighbouring land, or to the rocks formed primarily by the consolidation of such sediments.

W

WBDD Project *abbr.* Port of Gladstone Western Basin Dredging and Disposal Project.

WICT Project *abbr.* Wiggins Island Coal Terminal Project.

Attachment A - Terms of Reference cross reference table

Table A.1 Terms of Reference cross reference

No.	Terms of Reference Requirement	Section
3.3.5.1	Marine flora and fauna occurring in the areas affected by the proposal should be described noting the patterns and distribution in Port Curtis. The description of the fauna and flora present in the areas should include: • Fish species, mammals, reptiles and crustaceans occurring in marine waters, including pest species.	• Section 5.4. Fauna(Pest species in section 5.4.10)
	• Marine plants, including seagrass, saltmarsh and mangroves.	• Section 5.3. Flora (seagrass – 5.3.3, saltmarsh – 5.3.1 and mangroves 5.3.2)
	• Benthic, rocky shore and reefal habitats.	• Section 5.2. Physical Environment. (Benthic – 5.2.1, reef and rocky substrate – 5.2.2, and Figure 3)
	• Habitat for commercial and recreational fisheries.	• Section 5.4.3. Fish and Shellfish.
	• Particular reference habitat of any rare or threatened species.	• Section 5.4. Fauna (inc. 5.4.1 – Dugongs, 5.4.2 –Turtles, 5.4.4 – Cetaceans.)
	• Proximity to declared Fish Habitat Areas.	• Section 3.2 – State Legislation (specifically Fisheries Act 1994)
	• Presence of marine mammals and marine turtle foraging areas and nesting areas in vicinity of the proposed port.	• Section 5.4. Fauna (inc. Dugongs - 5.4.1, Turtles - 5.4.2
	• Sea floor habitat and benthic macro invertebrate communities in the vicinity of the spoil ground.	• Section 52 and 5.3 and figure 3.
	• Where relevant, MNES identified under the EPBC Act.	• Section 3.1 – Commonwealth Legislation (specifically EPBC Act)
3.3.5.2	The potential impacts of the project on benthic habitat and marine fauna and flora, including sea grass beds, marine plants, other fish habitats and other rare or threatened species should be assessed. The EIS should also discuss the potential for damage to these ecosystems (including dependent faunal species).	• Section 6 – Issues and Potential Impacts (specifically 6.1 – marine habitat, 6.2 – impact on marine fauna)
	Mitigation methods to reduce impacts on identified environmental values should be outlined. Restoration of the disturbed area (especially where marine plants have been removed) should also be outlined.	• Section 7– Avoidance, Mitigation and Management Measures
	Vectors for an introduction of a marine pest, possible impacts of a marine pest incursion and proposed mitigation measures should be discussed together with on-going monitoring for marine pests in the port and proposed response arrangements if a marine pest incursion occurs.	• Vectors in Section 5.4.10, possible impacts in Section 6.4, proposed mitigation and response arrangements in Section 7.5, and on-going monitoring in table 21.
	Assessments should include, where relevant, Matters of National Environmental Significance (MNES) identified under the EPBC Act. The MNES are to be discussed in section 8.	• MNES relevant to the project outlined in Section 3.1. Commonwealth Legislation.

Table A.1 Terms of Reference cross reference (Cont'd)

No.	Terms of Reference Requirement	Section
8.1	The EIS should provide: • A description of the values of the Great Barrier Reef World Heritage Area (GBRWHA) and National Heritage places that are likely to be impacted by the project, including but not restricted to the significant regional habitat for listed threatened and migratory marine species.	• Section 3.4. Internationally Protected Areas (including GBRWHA and Ramsar Wetlands) and Section 5.1. Introduction.
	• A description of the potential direct and indirect impacts on the values of each area, place, site or reserve, resulting from: - Modification, destruction, fragmentation, isolation or disturbance of an important, sensitive or substantial area of habitat	• Section 6.1 Loss and Disturbance of Marine and Estuarine Habitat. 6.1.1. Direct Construction Impacts, and 6.1.2. Indirect Impacts.
	- A substantial change in water quality (including temperature) and hydrological regime which may adversely impact on biodiversity, ecological integrity, social amenity or human health	• Not applicable – See Marine water quality, Health, Social.
	- Persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the marine environment such that biodiversity, ecological integrity, social amenity or human health may be adversely affected.	• Not applicable – see Marine water quality, Health, Social
	• A description of the impacts on other users of the area.	• Not applicable – see Social.
	• A discussion of the extent to which identified impacts can be forecast or predicted and managed.	• Section 6. Issues and Potential Impacts
	• A description of any mitigation measures proposed to reduce the impact on the values and environments of each area, place, site or reserve.	•Section 7. Avoidance, Mitigation and Management Measures
8.2	The EIS should provide a description of EPBC Act listed threatened species and ecological communities likely to occur in the project study area.	•Section 5.4. Fauna
	The EIS should consider and assess the impacts to identified listed threatened species and communities that may be impacted by the project. The EIS should identify which component of the project is of relevance to each species or community or if the threat of impact relates to consequential actions. Impacts may result from: • A decrease in the size of a population or a long term adverse affect on an ecological community	• Section 6.2. Impact on Marine and Estuarine Fauna and Flora
	• A reduction in the area of occupancy of the species or extent of occurrence of the ecological community	• Section 6.2. Impact on Marine and Estuarine Fauna and Flora
	• Fragmentation an existing population or ecological community	• Section 6.2. Impact on Marine and Estuarine Fauna and Flora

Table A.1 Terms of Reference cross reference (Cont'd)

No.	Terms of Reference Requirement	Section
	• Disturbance or destruction of habitat critical to the survival of the species or ecological community	• Section 6.1. Loss and Disturbance of Marine and Estuarine Habitat
	• Disruption of the breeding cycle of a population	• Section 6.2.3. Lighting
	• Modification, destruction, removal, isolate or reduction of the availability or quality of habitat to the extent that the species is likely to decline	• Section 6.1.1. Direct Construction Impacts
	• Modification or destruction of abiotic (non-living) factors (such as water, nutrients, or soil) necessary for the ecological community's survival	• Not applicable
	• The introduction of invasive species that are harmful to the species or ecological community becoming established	• Section 6.4. Introduced Species and Pest Species
	• Interference with the recovery of the species or ecological community	• Section 5.4.1. Dugongs, 5.4.2. Turtles,
	• Actions which may be inconsistent with a recovery plan.	• Section 6.2. Impact on Marine and Estuarine Fauna and Flora
	• Any positive impacts should also be identified and evaluated.	• 8.1.2. Operations.
	A description of any mitigation measures proposed to reduce the impact on the listed threatened species and ecological communities should be discussed.	Section 7.1. Loss and Disturbance of Marine and Estuarine Habitat, and Section 7.2 Impact on Marine and Estuarine Fauna
8.3	The EIS should provide a description of the EPBC Act listed migratory species, distribution, life history, habitats etc likely to occur in the project study area.	• Section 5.4. Fauna.
	The EIS should consider and assess the impacts to the identified listed migratory species that may be impacted by the project. The EIS should identify which component of the project is of relevance to each species or if the threat of impact relates to consequential actions. Impacts may result from: • The destruction, isolation or modification of habitat important to a migratory species.	• Section 6.1 Loss and Disturbance of Marine and Estuarine Habitat.
	• The introduction of invasive species in an important habitat that would be harmful to a migratory species.	• Section 6.4. Introduced Species and Pest Species
	• The disruption of the lifecycle (breeding, feeding, migration, or resting behaviour) of an ecologically important proportion of the population of a migratory species.	• Section 6.2 Impact on Marine and Estuarine Fauna and Flora.

Table A.1 Terms of Reference cross reference (Cont'd)

No.	Terms of Reference Requirement	Section
	• Interference with the recovery of the species or ecological community.	• Section 5.4.1. Dugongs, 5.4.2. Turtles,
	• Actions which may be inconsistent with a recovery plan.	• Section 5.4. Fauna.
	Any positive impacts should also be identified and evaluated.	• Section 6.1.1 Direct Construction Impacts (Reef and Rocky Substrate)
	A description of any mitigation measures proposed to reduce the impact on migratory species should be discussed.	• Section 7.2 Impact on Marine and Estuarine Fauna

Appendix A

Arrow Energy LNG Plant Estuarine and Marine Ecology Field Investigations 2010-2011 (Phase I & II)

BE WHAT YOU WANT TO BE.

CQUniversity AUSTRALIA

Arrow LNG Plant
Estuarine and Marine Ecology Field Investigations 2010-2011 (Phase I & II)

Ralph Alquezar
May 2011

Prepared for

Arrow CSG (Australia) Pty Ltd and Coffey Environments Pty Ltd

Centre for Environmental MANAGEMENT
GLADSTONE

Arrow LNG Plant

Estuarine and Marine Ecology Field Investigations

2010-2011 (Phase I & II)

Prepared for

Arrow CSG (Australia) Pty Ltd and Coffey Environments Pty Ltd

2011

Centre for Environmental Management
MANAGEMENT
GLADSTONE

Centre for Environmental Management
Faculty of Sciences, Engineering & Health
CQUniversity Australia
Gladstone Queensland 4680

Acknowledgements

I wish to thank Coffey Environments for funding this study. Thanks to the field team for sample collection, Anne-Maree Frost, David Gwyther, Chelsea Kavanagh, Dylan Charlesworth, Chris Armour, Brett Buckle and Adam Balkin. I would like to thank the laboratory team at CQU, Dylan Charlesworth, and Kirsty Small for macroinvertebrate sorting and identification, and Wayne Boyd for map production. This study was conducted under the GBRMPA permit G10/05-018, animal ethics permit A08/07-234 and fisheries permit number 138966.

Document citation: Alquezar, R. (2011). Arrow Energy LNG Plant: Estuarine and Marine Ecology Field Investigations (Phase I & II). A report to Arrow CSG (Australia) Pty Ltd and Coffey Environments Pty Ltd. Centre for Environmental Management, CQUniversity Australia, Gladstone Queensland.

Table of contents

List of figures

List of tables

Executive Summary

Water quality management is an essential resource management priority for sustainable coastal processes and the protection of freshwater, estuarine and marine organisms. Coastal habitats host important nursery grounds for resident and transient organisms providing connectivity to the Great Barrier Reef. Changes to water quality due to increased land-based pressures such as urban and industrial development can have detrimental effects on fragile habitats surrounding coastal zones. Curtis Island is part of a number of coastal fringing islands, which provide food, shelter and connectivity for a vast number of species to the southern Great Barrier Reef. Curtis Island is located in Port Curtis, between Gladstone and Rockhampton on Queensland's central coast, covering an area of 57,000 ha.

As part of the Gladstone State Development Area Development Scheme administered and prepared by the Coordinator-General of the State of Queensland (hereafter Coordinator-General), Curtis Island has been selected for significant development from the liquefied natural gas (LNG) industry, with a number of LNG processing facilities to be developed within the next two to five years. Arrow CSG (Australia) Pty Ltd (hereafter Arrow Energy) has been given rights to investigate the development of an LNG facility (Arrow LNG Plant) on the southwestern end of Curtis Island. Part of the marine infrastructure of the development includes a material offloading facility (MOF), LNG and personnel jetties and a marine terminal facility (Launch Site).

In May 2010, Coffey Environments commissioned the Centre for Environmental Management (CEM) at CQUniversity Australia (CQUni) to conduct estuarine and marine ecology field investigations along strategically targeted areas potentially used for the construction of the LNG facility, which will include options for MOFs, jetties and loading facilities (Phase I). A follow-up study was further commissioned to investigate an extra site around a marine terminal facility that was subsequently proposed near the mouth of the Calliope River in February 2011 (Phase II).

Water quality, sediment physico-chemical parameters, mangrove, macroinvertebrate and fish community assemblages were investigated to determine potential construction and long term effects posed to resident biota and the surrounding environment from the project. For the Phase I survey, seven intertidal and subtidal sites were located at the sites of proposed facilities and also for more general comparison and characterisation (North China Bay/Hamilton Point, Boatshed Point, Calliope River, The Narrows, Targinie Creek, Friend Point and Laird Point). For Phase II, additional sites were added in the Calliope River to cover the area of the proposed Launch Site 1, for which some dredging will be required. The Phase II sites included C1-5 for macroinvertebrate analysis and sediment quality. Pesticides and polynuclear aromatic hydrocarbons (PAH's) were investigated at Launch Site 4N during Phase II, and the Wiggins Mainland site, Wiggins Islands, Mud Island and Launch Site 1 were investigated for nekton and mangrove community assessments.

There were no seagrass beds present in any of the study sites during both sampling trips (Phase I and II). Sediment carbon content and particle size distribution was similar at most subtidal and intertidal sites along Boatshed Point, Calliope River and Hamilton Point, consisting mainly of 60 to 80% muds and silts and 1 to 2% carbon content. Conversely, Targinie Creek, The Narrows (Phase I) and sites along Calliope River (Phase II C1-5) had significantly higher course sand and gravel sediment fractions (> 80%) and significantly lower carbon content (0.5%-1.5%), potentially attributed to higher flow events from rainfall runoff and bank morphology. Sediment metal concentrations were generally higher at intertidal sites compared to subtidal sites during the Phase II monitoring program, and generally higher along the northern section of the Fishermans Landing Northern Expansion Project, at the Launch Site 4N location. Sediment metal concentrations did not exceed any national sediment quality guidelines. Polynuclear aromatic hydrocarbons (PAH's), organochlorine (OC) and organophosphate (OP) pesticides were below instrument detection limits for all sites.

A total of 551 macroinvertebrates were collected from all sites representing 124 species and 7 different phyla during both sampling trips (Phase I & II). There were no significant differences in macroinvertebrate total abundance or species evenness among study sites during Phase I. However, species richness and diversity was significantly lower at Hamilton Point and Targinie Creek. Site C1, closest to the Calliope River mouth, had significantly lower macroinvertebrate biodiversity, compared to all other sites within the river. The Narrows had significantly dissimilar macroinvertebrate community assemblages compared to all other sites during Phase I. Highest assemblage similarity was observed at C3 and C4, and C2, C5 and Targinie Creek.

Approximately 814 hectares of mangrove forests and saltpans were mapped within strategic study sites, with dense *Rhizophora stylosa, Avicennia marina* and *Ceriops tagal* being the dominant species. The Targinie Creek study site had the largest mangrove areas within the first sampling trip (Phase I), followed by Hamilton Point and Calliope River, with Laird Point hosting the smallest area. During the Phase II study, the Wiggins Mainland site had the largest mangrove areas, followed by Wiggins Island, and Launch Site 1, with Mud Island containing the smallest area of mangroves. There were no significant differences in mangrove biodiversity or canopy cover among sample sites for both sampling trips, except for tree density at the mainland site. In general, study area plots consisted of between 10 to 20 mangroves representing 1 to 2 species per 25 m^2. Canopy cover was dense with an average of 50 to 90% cover among 25 m^2 plots.

A total of 1,262 fish and larger macroinvertebrates (nekton) representing 29 species, were collected from soft sediment shallow habitats, mangrove and other vegetation lined banks during both sampling events (Phase I & II). The most common species were the banana prawn (*Fenneropenaeus merguiensis*), the spotty-face anchovy (*Stolephorus waitei*), the greenback mullet (*Liza subviridus*), the southern herring, (*Herklotsichthys castelnaui*) and the common ponyfish (*Leiognathus equulus*). There were no significant differences in nekton biodiversity among sampling sites during Phase II, however, there were significantly higher numbers of species at Targinie Creek and the Calliope River compared to other sites during the Phase I monitoring program. Nekton community assemblages were significantly dissimilar among sites for both sampling trips, with Friend Point showing the biggest difference in community structure compared to other sites. Mud Island, Wiggins Mainland and Targinie Creek had the highest similarity. Boatshed Point and Hamilton Point had the highest relative abundance and species richness in nekton representing deeper water channel habitats, with Targinie Creek and Launch Site 1 representing the lowest biodiversity of larger nekton size classes.

Unsustainable inappropriate industrial practices can result to changes in existing hydrology, disturbance and/or removal of sensitive habitat and species assemblages and a decline in water quality. To minimise the impact of port developments on adjacent marine and estuarine habitats, it is suggested that infrastructure development be engineered in the best practical way to reduce changes in hydrology, such as waves and currents, to adjacent areas.

1.0 INTRODUCTION

1.1 Background

Arrow CSG (Australia) Pty Ltd (hereafter Arrow Energy) is investigating the construction and operation of a liquefied natural gas (LNG) facility on the southwestern end of Curtis Island. The project may potentially affect fragile marine habitats within the study area due to factors such as tunnel construction for the pipeline under Port Curtis, construction of the plant, dredging, increased shipping movements and general plant emissions, such as storm water management and reverse osmosis discharge. This study has addressed the current ecological status (baseline) of marine and estuarine habitats within the proposed study area. The study has included the investigation of sediment properties, macroinvertebrate and fish assemblages and mangrove communities within strategic areas of interest where material offloading facilities, jetties and landing areas are proposed. Baseline data gathered from this study can be used to measure relative changes over time, once the plant is constructed and operational. The following marine facilities are proposed as part of the Arrow LNG Plant.

LNG Jetty

LNG will be transferred from the storage tanks on the site to the LNG jetty via above ground cryogenic pipelines. Loading arms on the LNG jetty will deliver the product to an LNG carrier. The LNG jetty will be located in North China Bay, adjacent to the northwest corner of Hamilton Point.

MOF

Delivery of materials to the site on Curtis Island during the construction and operations phases will be facilitated by a MOF where roll-on, roll-off or lift-on, lift-off vessels will dock to unload preassembled modules, equipment, supplies and construction aggregate. The MOF will be connected to the LNG plant site via a heavy-haul road.

Boatshed Point (MOF 1) is the base-case MOF option and would be located at the southern tip of Boatshed Point. The haul road would be routed along the western coastline of Boatshed Point (abutting the construction camp to the east) and enters the

LNG Plant site at the southern boundary. A quarantine area will be located south of the LNG plant and will be accessed via the northern end of the haul road.

Two alternative options are being assessed, should the Boatshed Point option be determined to be not technically feasible:

South Hamilton Point (MOF 2): This MOF option would be located at the southern tip of Hamilton Point. The haul road from this site would traverse the saddle between the hills of Hamilton Point to the southwest boundary of the LNG plant site. The quarantine area for this option will be located southwest of the LNG plant near the LNG storage tanks.

North Hamilton Point (MOF 3): This option involves shared use of the MOF being constructed for the Santos Gladstone LNG Project (GLNG Project) on the northwest side of Hamilton Point (south of Arrow Energy's proposed LNG jetty). The GLNG Project is also constructing a passenger terminal at this site, but it will not be available to Arrow Energy contractors and staff. The quarantine area for this option would be located to the north of the MOF. The impacts of construction and operation of this MOF option and its associated haul road were assessed as part of the GLNG Project and will not be assessed in this EIS.

Personnel Jetty

During the peak of construction, base case of up to 1,100 people may require transport to Curtis Island from the mainland on a daily basis. A personnel jetty will be constructed at the southern tip of Boatshed Point to enable the transfer of workers from the mainland launch site to Curtis Island by high-speed vehicle catamarans (Fastcats) and vehicle or passenger ferries (ROPAX). This facility will be adjacent to the MOF constructed at Boatshed Point. The haul road will be used to transport workers to and from the personnel jetty to the construction camp and LNG plant site. A secondary access for pedestrians will be provided between the personnel jetty and the construction camp.

Mainland Launch Site

Materials and workers will be transported to Curtis Island via the mainland launch site. The mainland launch site will contain both a passenger terminal and a roll-on, roll-off facility. The passenger terminal will include a jetty and transit infrastructure, such as amenities, waiting areas and car parking. The barge or roll-on, roll-off facility will have a jetty, associated laydown areas, workshops and storage sheds.

The two location options for the mainland launch site are:

Launch Site 1: This site is located north of Gladstone city near the mouth of the Calliope River, adjacent to the existing RG Tanna coal export terminal.

Launch Site 4N: This site is located at the northern end of the proposed reclamation area for the Fishermans Landing Northern Expansion Project, which is part of the Port of Gladstone Western Basin Master Plan. The availability of this site will depend on how far progressed the Western Basin Dredging and Disposal Project is at the time of construction.

Marine and estuarine biological communities are susceptible to fluctuations in abundance and biodiversity due to changes in physical, chemical and biological stressors. Water quality management is an essential resources management priority for sustainable coastal processes and the protection of freshwater, estuarine and marine organisms. Coastal habitats host important nursery grounds for resident and transient organisms providing connectivity to the Great Barrier Reef (Able, 2005; Ray, 2005; Secor and Rooker, 2005). Changes to water quality due to increased land-based pressures such as urban and industrial development, agriculture and sewage treatment works can have detrimental effects on fragile habitats surrounding coastal zones.

The introduction of LNG marine infrastructure may affect natural patterns of hydrology, sediment deposition and water quality, thus indirectly affecting various biological communities. Macrobenthic community assemblages have been used in the past as indicators of ecosystem stability due to particular attributes. These include limited mobility, which allows these assemblages to be studied at a local population level, relative ease of identification and sensitivity to changes in the environment (Warwick, 1993; Roberts, 1996a; Roberts, 1996b; Terlizzi *et al*., 2002). Fish assemblages have also been used in environmental studies as an ecosystem stability indicator (Krogh and Scanes, 1996; Smith *et al*., 1999; Smith and Suthers, 1999). Fish are more mobile than macroinvertebrate organisms, which allow them to cover greater regional areas, as opposed to local areas. However some fish, such as reef damselfish and baitfish have restricted homing ranges. Fish are also relatively easy to identify *in situ*, and have commercial and public value (Warwick, 1993).

Curtis Island is located in Port Curtis, between Gladstone and Rockhampton on Queensland's central coast, covering an area of 57,000 ha and is one of a number of coastal fringing islands, which provide food, shelter and connectivity to the southern Great Barrier Reef. Port Curtis is a shallow, semi-enclosed estuarine system situated on the central coast of Queensland approximately 600 km north of Brisbane. The two large offshore islands (Curtis Island and Facing Island) that surround the waters of Port Curtis form a narrow coastal embayment approximately 200 km^2 in area. Freshwater enters the harbour from two major rivers (Boyne and Calliope) and numerous minor creeks and tributaries. Strong tidal currents and a 5 m tidal range also have major influences on the area's marine and intertidal ecosystems. The area supports a wide range of marine habitats including mangroves, seagrass beds, saltmarshes, coral reefs, extensive mudflats and subtidal soft sediments (Connolly *et al*., 2006).

Many of the Port Curtis coastal environments are considered significant in terms of conservation value. The Great Barrier Reef World Heritage Area commences at the low water mark on the mainland side of The Narrows and includes Curtis Island, and marine sections of the study area while the offshore areas east of Curtis Island are included within the Mackay/Capricorn Section of the Great Barrier Reef Marine Park (GBRMPA, 1998). Areas in and around Port Curtis also provide important feeding grounds for the endangered species, the dugong *Dugong dugon* and have been declared part of the Rodd's Bay Dugong Sanctuary (GBRMPA, 1998).

Industrial growth in the Port Curtis region over the last 40 years has resulted in the development of several foreshore manufacturing, processing and bulk handling facilities. These include major alumina and aluminum processing plants, a coal-fired power station, a cement works, several chemical refineries, and an extensive network of shipping wharves and storage facilities. Other significant industries within the region include mining, agriculture, fishing and tourism. Due to major industry in the Port Curtis region, there are a number of commercial wharves promoting international shipping to the area, which are managed by the Gladstone Ports Corporation (GPC).

As part of the Gladstone State Development Area Development Scheme prepared by the Coordinator-General of the State of Queensland (hereafter Coordinator-General), Curtis Island, has been selected for significant development from the liquefied natural gas (LNG) industry, with a number of LNG processing facilities to be developed within the next two to five years, ultimately increasing the amount of infrastructure and shipping traffic to the area. Arrow Energy has been given rights to investigate the construction and operation of a liquefied natural gas (LNG) facility on the southwestern end of Curtis Island. The facility will utilise gas supplied from coal seam gas (CSG) developments within the Surat and Bowen Basins. The gas will be transported via pipeline across central Queensland, which will then be installed beneath Port Curtis directly to the proposed Arrow LNG plant where it will be processed, stored and subsequently loaded to international LNG carriers via an offloading facility and jetty.

Given the extent of the marine infrastructure, located on Curtis Island and the mainland, there will be a number of dredge locations required for the construction of the project.

Dredging required for LNG shipping access and swing basins has been assessed under the Gladstone Ports Corporation’s Port of Gladstone Western Basin Dredging and Disposal Project. Additional dredging within the marine environment of Port Curtis may be required to accommodate the construction and operation of the marine facilities. Up to five sites may require dredging:

Dredge site 1 (dredge footprint for Launch Site 1): The dredging of this site would facilitate the construction and operation of Launch Site 1. This dredge site is located in the Calliope River and extends from the intertidal area abutting Launch Site 1, past Mud Island to the main shipping channel. The maximum estimated dredge volume at this site is approximately 900,000 m^3.

Dredge site 2 (dredge footprint for Launch Site 4N): The dredging of this site would facilitate the construction and operation of Launch Site 4N. This dredge site would abut Launch Site 4N and extend east from the Launch Site to the shipping channel. The maximum estimated dredge volume identified at this site is approximately 2,500 m^3.

Dredge site 3 (dredge footprint for Boatshed Point MOF 1): The dredging of this site would facilitate the construction and operation of the personnel jetty and MOF at Boatshed Point. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The maximum estimated dredge volume identified at this site is approximately 50,000 m^3.

Dredge site 4 (dredge footprint for Hamilton Point South MOF 2): The dredging of this site would facilitate the construction and operation of the MOF at Hamilton Point South. This dredge site would encompass the area around the marine facilities, providing adequate depth for docking and navigation. The maximum estimated dredge volume identified at this site is approximately 50,000 m^3.

Dredge site 5 (dredge footprint for LNG jetty): The dredging of this site will facilitate the construction of the LNG jetty at Hamilton Point. This dredge site extends from the berth pocket to be dredged as part of the Western Basin Strategic Dredging and Disposal Project to the shoreline and is required to enable a work barge to assist with construction of the jetty. The maximum estimated dredge volume identified is approximately 120,000 m^3.

1.2 Objectives

The objectives of this study were to determine estuarine and marine baseline information at the specific sites that are intended for infrastructure and dredge operations as part of the Arrow LNG plant. The conceptual infrastructure includes options for MOFs, jetties and landing sites. Some additional sites were included in Targinie Creek and around The Narrows to provide more general characterization and comparison of habitats.

The aims of the study were to:

- Determine sediment particle sizes and organic content at sites within the project.
- Investigate spatial intertidal and subtidal macroinvertebrate community assemblages within proposed areas of infrastructure development and dredge operations for the project.
- Determine mangrove habitat distribution and seagrass meadow community composition within targeted sites.
- Investigate fish assemblages within mangrove, seagrass and soft sediment habitats of targeted sites intended for infrastructure and dredge operations.

2.0 MATERIALS AND METHODS

2.1 Sampling

Two sampling programs were commissioned within Port Curtis and the Calliope River during 2010-2011 to characterise habitats and to determine marine and estuarine baseline data for the Arrow LNG plant. Phase I of the program was conducted in May 2010 and Phase II in February 2011.

During the Phase I monitoring program, a total of seven sites - Calliope River, Targinie Creek, The Narrows, North China Bay/Hamilton Point, Boatshed Point, Friend Point and Laird Point were selected within Port Curtis based on intended project infrastructure or broader characterisation and comparison (Table 1).

A further five sites were established along the Calliope River for Phase II of the characterization and baseline program during February 2011 (Table 2) to cover marine terminal facilities proposed subsequent to the Phase I study. Water quality and macroinvertebrate sites included C1-5 and a further site at the Fishermans Landing Northern Expansion Project (Launch Site 4N). Launch Site 4N was only used for sediment chemical analysis. Mangrove and fish assemblage sites included Wiggins Island A & B, Mud Island, Wiggins Mainland and Launch Site 1. See Figure 1 and 2 and Table 2 and 3 for site localities.

At each site, five replicate intertidal and subtidal sediment samples were collected for particle size analysis, carbon content and macroinvertebrate assemblages. Sediments were also taken for analyses of any existing contamination from organochloride (OC) organophosphate pesticides (OP) and polynuclear aromatic hydrocarbon (PAH's) at all Phase II sites. Mangrove/seagrass communities and fish assemblages were also investigated along adjacent water, sediment and macroinvertebrate sites.

Table 1. Phase I GPS coordinates of sediment, macroinvertebrate and fish subtidal and intertidal sites along Port Curtis.

Location	Intertidal	Subtidal
Boatshed Point	S23.79345, E151.22802	S23.79510, E151.23134
Calliope River	S23.83272, E151.21988	S23.83258, E151.22177
Hamilton Point	S23.78711, E151.21071	S23.78892, E151.20977
Targinie Creek	S23.735858, E151.13565	S23.73964, E151.13576
The Narrows	-	S23.74997, E151.16899
Friend Point	S23.74480, E151.15817	-
Laird Point	S23.75303, E151.17836	-

Table 2. Phase II GPS coordinates of water, sediment, and macroinvertebrate subtidal and intertidal sites. Note, 4N site was located at the Fishermans Landing Northern Expansion Project.

Water/sediment Location	Intertidal	Subtidal
C1	S23 49.790 E151 13.039	S23 49.810 E151 13.202
C2	S23 49.563 E151 12.918	S23 49.561 E151 13.077
C3	S23 49.246 E151 13.015	S23 49.290 E151 13.176
C4	S23 48.991 E151 13.379	S23 49.085 E151 13.483
C5	S23 48.853 E151 13.574	S23 48.682 E151 13.670
4N	S23 45.946 E151 09.779	S23 45.915 E151 09.913

Table 3. Phase II GPS coordinates of fish and mangrove community sites.

Mangrove/fish locations	Coordinates
Wiggins Mainland	S23 49.391 E151 12.901 S23 49.756 E151 12.915
Wiggins Island A	S23 49.193 E151 13.023
Wiggins Island B	S23 49.192 E151 13.128
Mud Island	S23 48.816 E151 13.581
Launch Site 1	S23 49.836 E151 13.266

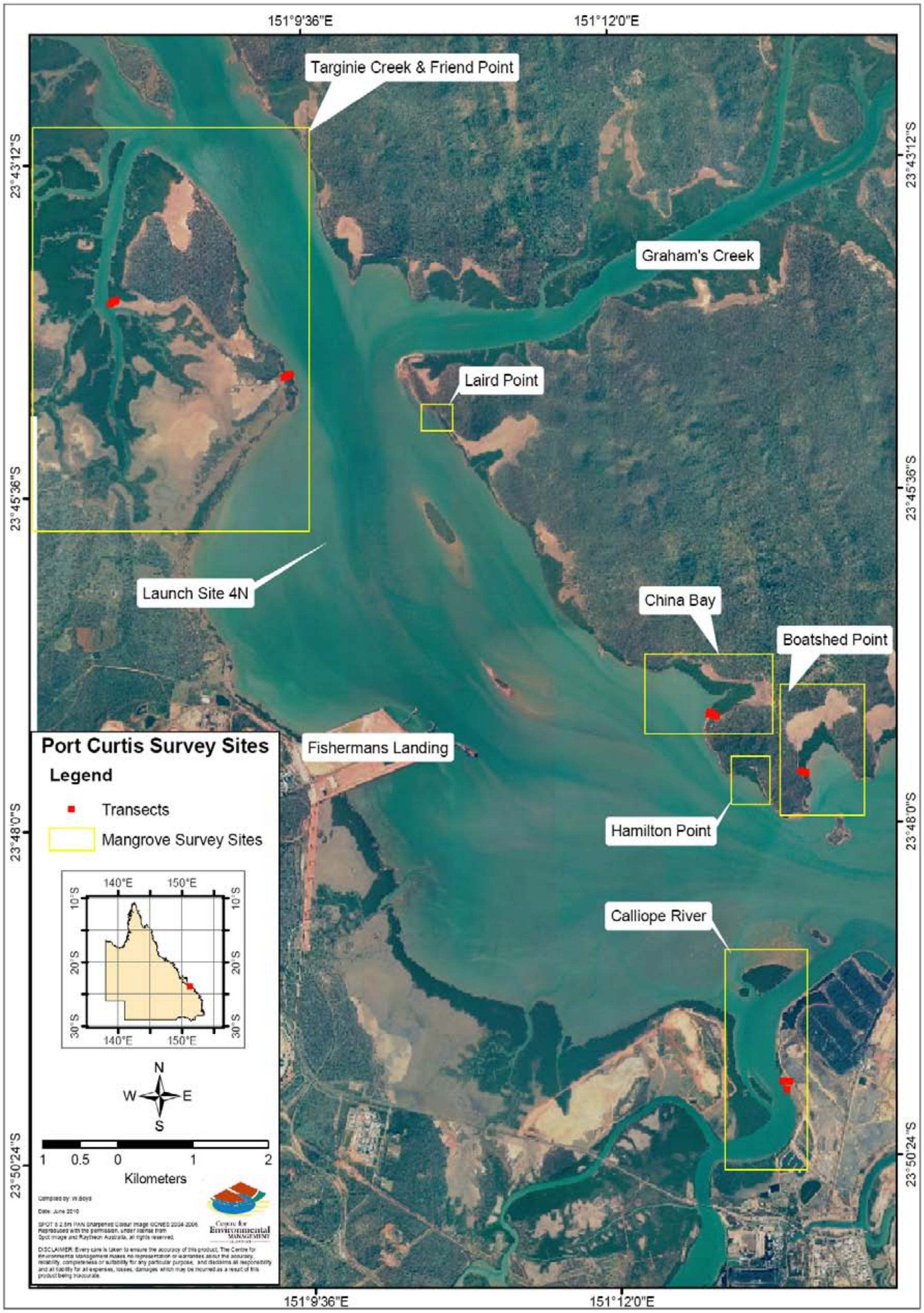


Figure 1. Map of sample sites and mangrove survey plots around Port Curtis during Phase I.

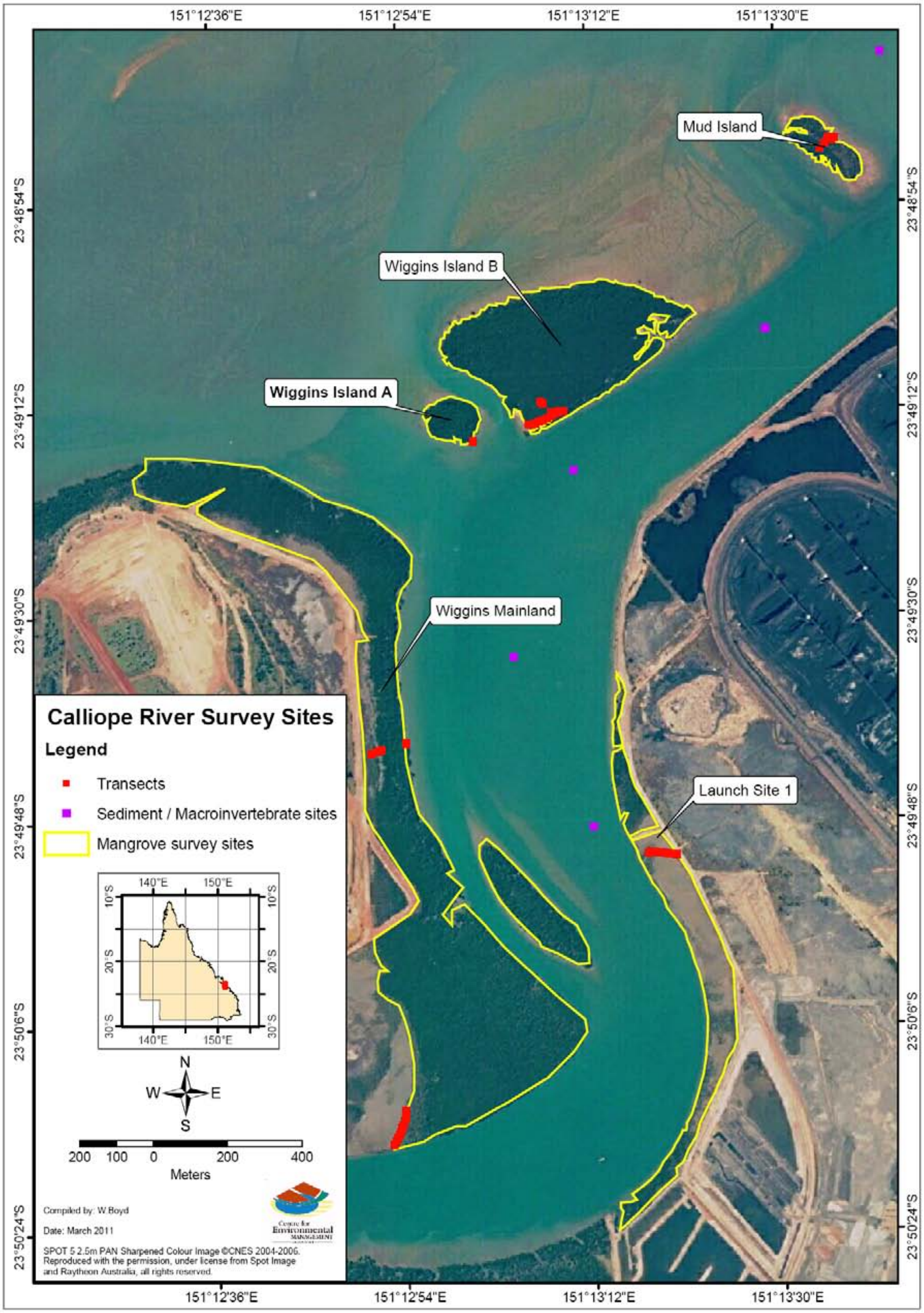


Figure 2. Map of sampling sites and mangrove survey plots along Calliope River during Phase II.

2.2 Sediment Analysis

Replicate intertidal (n = 5) and subtidal (n = 5) surface sediments were collected at each site using a van-Veen grab sampler. Sub-samples were analysed for carbon content and particle size distribution for both sampling periods and metals, OC, and OP pesticides and PAH's for the Phase II monitoring program.

Sediment samples were oven dried to a constant temperature of 50^{o}C. Sediments were sieved to less than 2 mm particle size to remove large shell grit and gravel. Sediment organic content was measured as percent loss on ignition (%LOI) using a muffle furnace at 550ºC for three hours. Sediment particle sizes were determined gravimetrically by wet sieving sediments on an agitated stack of Endecott test sieves with apertures of 2 mm, 1 mm, 500 μm, 250 μm, 125 μm and 63 μm and expressed as a percent of the total sample weight. During Phase II of the monitoring program, sediment samples were collected at sites for the determination of OC and OP pesticides and PAH's Sediment samples were digested using a hot mixture (2:1) of concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) of metal analysis, as described by the method by (Krishnamurty *et al*., 1976). Sediment digested elutriates were analysed for the following metals; aluminium (Al), arsenic (As), chromium (Cr), cadmium (Cd), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se) and zinc (Zn) using an Inductive Coupled Plasma Mass Spectrometer (ICPMS; Varian 820-MS, Melbourne Australia) and an Inductive Coupled Plasma Atomic Emission Spectrometer (ICP-AES; Varian Liberty Series II, Melbourne Australia). Blanks and spiked samples were run throughout the digestion and analysis protocols with minimal variation among samples (CV < 7%).

2.3 Macroinvertebrate Assemblages

Replicate intertidal (*n* = 5) and subtidal (*n* = 5) soft sediment macroinvertebrate assemblages and seagrass composition were investigated using a van-Veen grab sampler (0.005 m^3). Sediments and associated macroinvertebrates and seagrass were bagged and sent to the laboratory for analysis. Samples were sieved through a 1 mm mesh and the retained organisms were preserved, sorted and identified to the species level or lowest taxonomic level.

2.4 Mangrove Communities

Mangrove communities were assessed at Calliope River, Targinie Creek, Friend Point, Laird Point, North China Bay/Hamilton Point, and Boatshed Point during Phase I, and at Wiggins Island A & B, Wiggins Mainland, Mud Island and Launch Site 1 for Phase II of the monitoring program. A minimum of one 100 m transect was laid out perpendicular to the water's edge along each site. At every 10 m interval along each transect line, dominant mangrove species composition and canopy densities were determined by visual analysis.

Five by 5 m (25 m^2) plots were also laid at 0 m, 50 m and 100 m of each transect line. All trees and seedlings were counted in each 25 m^2 plot. The following mangrove parameters were measured in each plot:

- Tree and seedling density calculated as the number of trees and seedlings per plot area.
- Projective foliage cover (PFC) calculated as the percentage covered by foliage (canopy density).

Community density was determined by estimates of PFC. Four basic PFC classes were established; open (0-5%), sparse (5-25%), moderate (25- 50%) and closed (> 50%). Data were then classified into mangrove community classes on the basis of dominant genus present and relative densities of the whole community for mapping purposes (Danaher *et al*., 2005).

Ortho-rectified Spot 5 Pan-sharpened (2.5 m pixel) natural colour images covering the study area were supplied by Coffey Environments. Image processing and classification was carried out using ERDAS Imagine® 2010 software. Final map compilation was carried out using ESRI® ArcMap™ 8.3 geographical information system (GIS) software.

Study area outlines, (or polygons), reflecting the areas of interest and the selected sampling sites were created. All mangrove community areas were calculated based on these set polygons. These polygons were used to extract raster cell values from the imagery. The raster data was classified using iterative self organising data analysis (ISODATA) unsupervised classification method (ERDAS, 2009). Sixteen arbitrary classes with 98% convergence were selected. The ISODATA clustering method uses the minimum spectral distance formula to form clusters of shading related classes derived from the original red, green and blue pixel values.

The 16 classes were then manually rationalised into seven mangrove communities, identified from the field survey data, and suitably colour coded. The seven dominant communities included:

- Dense *Rhizophora stylosa* (> 50%) (Plate 1);
- Emergent *Avicennia marina* (Plate 2);
- Dense *Ceriops tagal* forests (> 50%) (Plate 3);
- Dense *Aegiceras corniculatum* (> 50%);
- Moderate *Rhizophora* and *Osbornia* mix (25-50%);
- Samphire; and
- Saltpan.

Mangrove community areas were then calculated using this data (pixel number per class by pixel size). Study area outlines, transect localities and mangrove community classifications were reproduced as high quality maps.

Plate 1. Example of a dense *Rhizophora* canopy.

Plate 2. Example of *Avicennia marina* emergents and *Ceriops tagal* canopy.

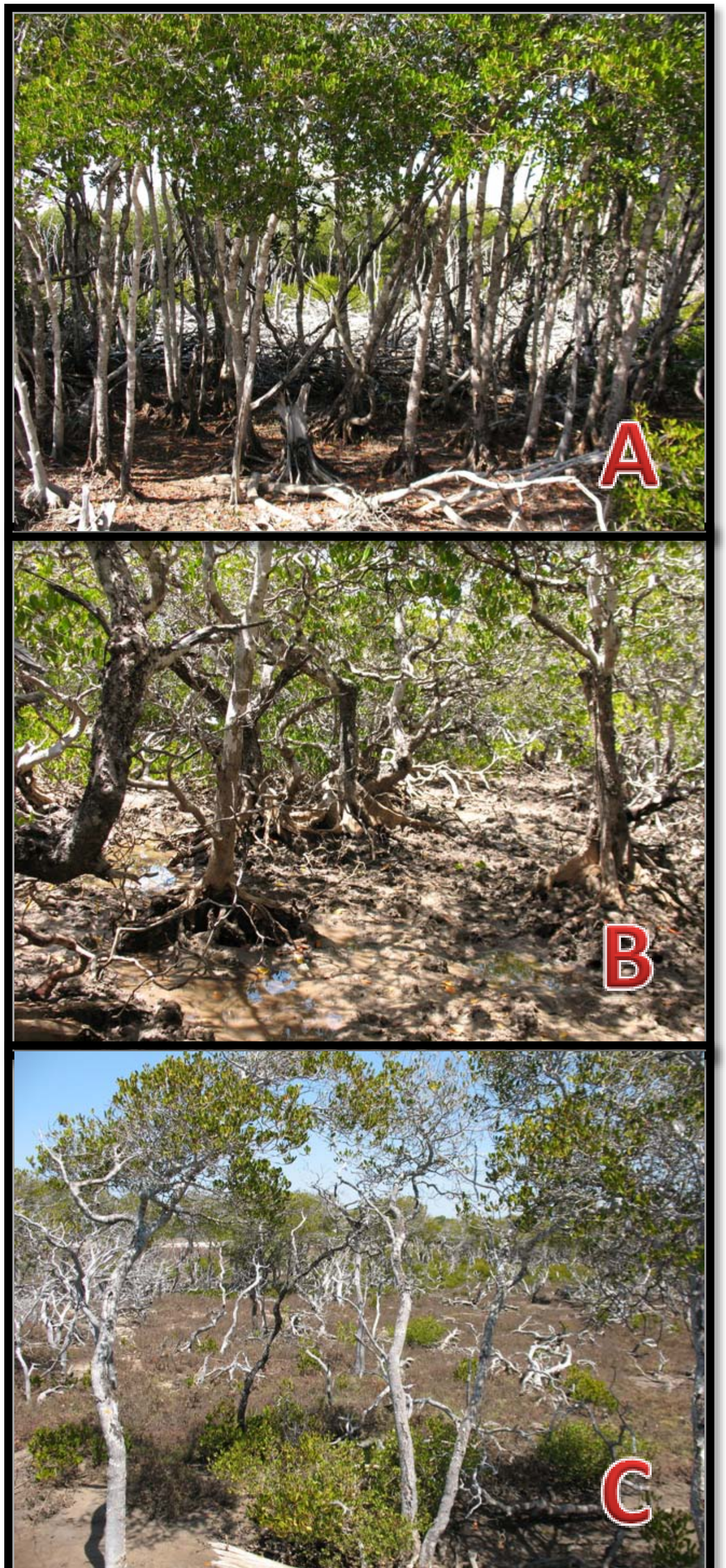


Plate 3. Example of a (a) dense, (b) moderate and (c) sparse *Ceriops tagal* canopy.

2.5 Nekton Assemblages

Nekton assemblages, which include fish and mobile invertebrates, were investigated using two netting techniques. A cast net (Ø3 m x 2.0 m drop x 6 mm mesh size) and a gill net (60 m x 1.5 m x 2', 3' and 4' panel mesh size) was used at each site, all of which were representative of different nekton habitats, including shallow soft sediments, deep water channels, mangrove, seagrass and other vegetation lined banks .

Cast nets were used to sample small, juvenile fish and other marine and estuarine fauna at diverse small-scale habitats that can be difficult to survey with other netting techniques. Cast nets allow rapid collection of a large number of spatially independent samples representing a number of microhabitats. Gill nets, in comparison, are used to sample larger mobile species that may be under represented using other netting techniques.

Nekton assemblages were sampled by conducting a minimum of 6 random replicate casts at each site (Plate 4). A 60 m gill net was deployed for approximately 2 h at each site (Plate 4). The net was regularly checked for nekton to reduce mortality. All nekton caught using both netting techniques were counted, identified, photographed and measured before they were released back to their habitat.

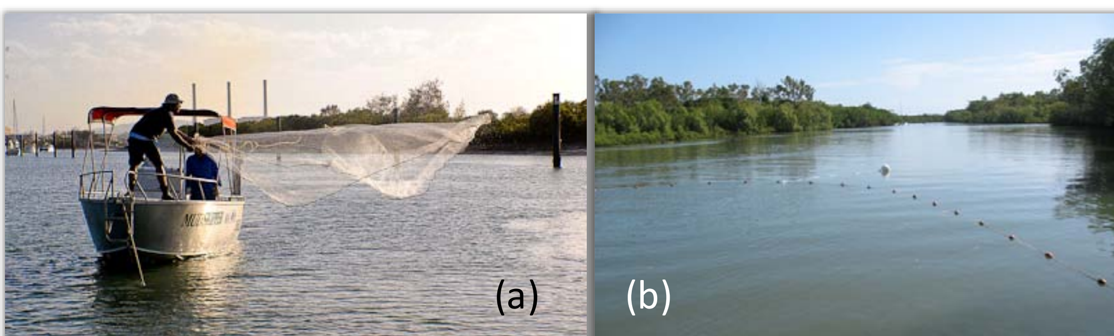


Plate 4. Examples of (a) cast net sampling and (b) gill net sampling.

2.6 Data Analysis

Differences ($P < 0.05$, 95% confidence intervals) in (a) sediment carbon content, (b) macroinvertebrate and (c) nekton and mangrove biodiversity among sites were determined using one-way analysis of variance (ANOVA). Sites were compared for PAH's and OC pesticides during Phase II. Data were tested for homogeneity of variance and normality. Significance levels were increased ($P < 0.01$, 99% confidence intervals) where data did not meet that criterion (Underwood, 1997; O'Neill, 2000). Given that Phase I and II of the programs were conducted during different times of the year (dry season – May 2010, wet season – February 2011), sites were not compared directly, however, numbers were discussed between the two sampling periods.

Macroinvertebrate and fish biodiversity were measured as total abundance (total number of organisms), species richness (total number of taxa), div ersity (Shannon-Weiner the proportion of macroinvertebrates per species) and species evenness (how evenly abundance is spread among the various taxa that make up an assemblage). Diversity values ranged from 0, indicating low community complexity, to 4, indicating high community complexity. Species evenness values were between 0 (few species make up the majority of the abundance) and 1 (even number of species making up the total abundance) (Hill, 1973; Zar, 1996; McClatchie *et al*., 1997; Nero and Sealey, 2005; Cai *et al*., 2006).

Macroinvertebrate and fish community assemblages were plotted using *non-metric* Multi Dimensional Scaling (*n*-MDS). Sample points close to each other signify they are similar in community composition. The further the sample points are away from each other, the more dissimilar their communities. Analysis of similarity (ANOSIM) was used to statistically determine dissimilarities in community structure among sites (PRIMER Ver. 6.1; Clarke, 1993). Similarity percentages (SIMPER) were used to determine what organisms best described changes in community assemblages among sampling sites (PRIMER; Clarke, 1993). Macroinvertebrate and fish community structure was examined using Bray-Curtis (B-C) similarity measures (Clarke, 1993). Bray Curtis was chosen as the preferred similarity matrix because it performed well in preserving 'ecological distance' in a variety of simulations on different types of data sets. Data were dispersion weight corrected and standardised to maintain equal weight among common and rare species. Mangrove communities were analysed using cluster analysis to determine similarities among sites (PRIMER; Clarke, 1993).

3.0 RESULTS AND DISCUSSION

3.1 Water Quality

There were no significant ($P < 0.05$) differences in water quality parameters including temperature, conductivity, salinity, dissolved oxygen or pH among sites (Table 4-5). All parameters were within national water quality guidelines (ANZECC/ARMCANZ, 2000b).

Table 4. Phase I mean physico-chemical water parameters at different sites within Port Curtis.

Site	Temp (^oC)	Conductivity mS/cm	DO (%)	pH	Turbidity (NTU)
Boatshed Point Subtidal	22.1	56.1	91.0	8.1	12.6
Boatshed Point Intertidal	22.8	55.8	91.2	8.2	10.8
Calliope River Subtidal	25.9	54.8	85.2	7.8	4.7
Calliope River Intertidal	25.2	56.0	107.6	8.2	5.1
Hamilton Point Subtidal	22.3	55.5	89.7	7.9	14.5
Hamilton Point Intertidal	22.4	55.9	96.7	8.2	7.8
The Narrows Subtidal	25.4	55.7	89.5	8.1	4.2
Friend Point Intertidal	23.0	55.1	106.0	8.2	6.6
Targinie Creek Subtidal	22.1	56.4	82.1	7.6	7.0
Targinie Creek-Intertidal	23.6	56.3	91.0	7.9	11.5
*Guideline levels	-	-	>90%	7.0 - 8.4	1 - 200

*Guideline levels are based from inshore marine National Water Quality Guidelines (ANZECC/ARMCANZ, 2000b).

Table 5. Phase II mean physico-chemical water parameters at different sites within Port Curtis. .

Site	Temp (^oC)	Conductivity mS/cm	DO (%)	pH	Turbidity (NTU)
C1 - Subtidal	29.0	34.0	88.0	7.7	34.5
C1 - Intertidal	28.9	34.0	88.0	7.7	37.3
C2 - Subtidal	29.1	34.1	87.2	7.7	35.9
C2 - Intertidal	28.9	34.1	86.6	7.7	53.6
C3 - Subtidal	29.1	34.2	87.2	7.7	36.1
C3 - Intertidal	29.0	34.0	87.5	7.7	54.4
C4 - Subtidal	29.0	34.4	87.7	7.8	31.6
C4 - Intertidal	29.1	34.3	87.0	7.7	38.9
C5 - Subtidal	29.0	34.6	87.8	7.8	39.5
C5 - intertidal	29.0	34.3	87.5	7.8	40.4
4N - Subtidal	28.7	32.6	87.7	7.6	32.2
4N - Intertidal	29.0	33.8	86.3	7.6	14.9
*Guideline levels	-	-	>90%	7.0 - 8.4	1 - 200

*Guideline levels are based from inshore marine and wetlands National Water Quality Guidelines (ANZECC/ARMCANZ, 2000b).

3.2 Sediment Analysis

3.2.1 Carbon content and particle size

Percent carbon content varied from approximately 0.2 to 11% among sites for both phases (Figure 3), with significantly higher carbon content reported at the Phase II sampling sites (Figure 3). The subtidal sites at Boatshed Point, C1, C2 and C4 had significantly higher ($P < 0.05$) sediment carbon content compared to the intertidal sites. Conversely, the intertidal sites at Hamilton Point, Targinie Creek, The Narrows and Launch Site 4N had significantly ($P < 0.05$) higher carbon content at their intertidal sites, with no significant differences ($P = 0.959$; $F = 0.003$, df 1) in carbon content between intertidal and subtidal sites at the Calliope River (C3 and C5).

Sediment particle sizes among sites were similar for Boatshed Point, Calliope River and Hamilton Point, regardless of depth (intertidal and subtidal), with an average composition of 60 to 80% silts and muds and 20 to 40% sands and gravels (Figure 4). However, the subtidal sites at Targinie Creek and The Narrows had significantly different sediment size distribution compared to all other sites, with significantly higher sand and gravel composition (up to 80%) (Figure 4).

Lower mud silt fractions (20-40%) were reported at intertidal sites within Calliope River during the Phase II monitoring program compared to the Phase I program, with significantly higher fine and coarse sands reported among subtidal sites (Figure 5). Moreover, up to 20% gravel was reported at some subtidal sites.

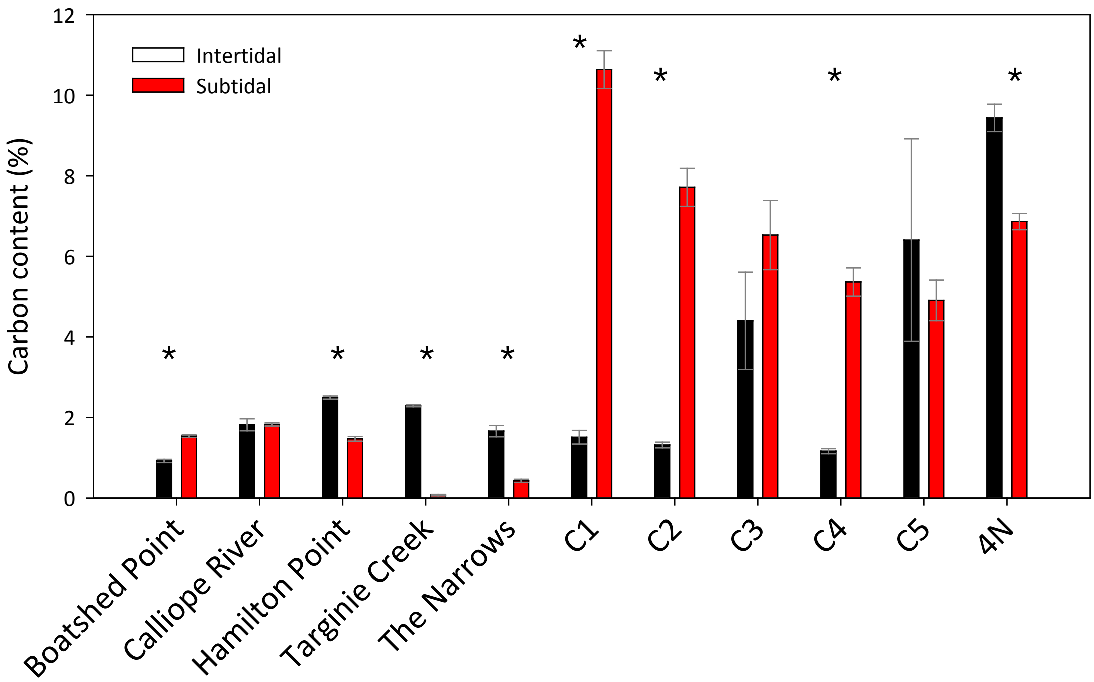


Figure 3. Mean (±se) Phase I and II sediment organic content among sites. * Denotes significant difference (P < 0.05) between subtidal and intertidal sites, *n* = 5.

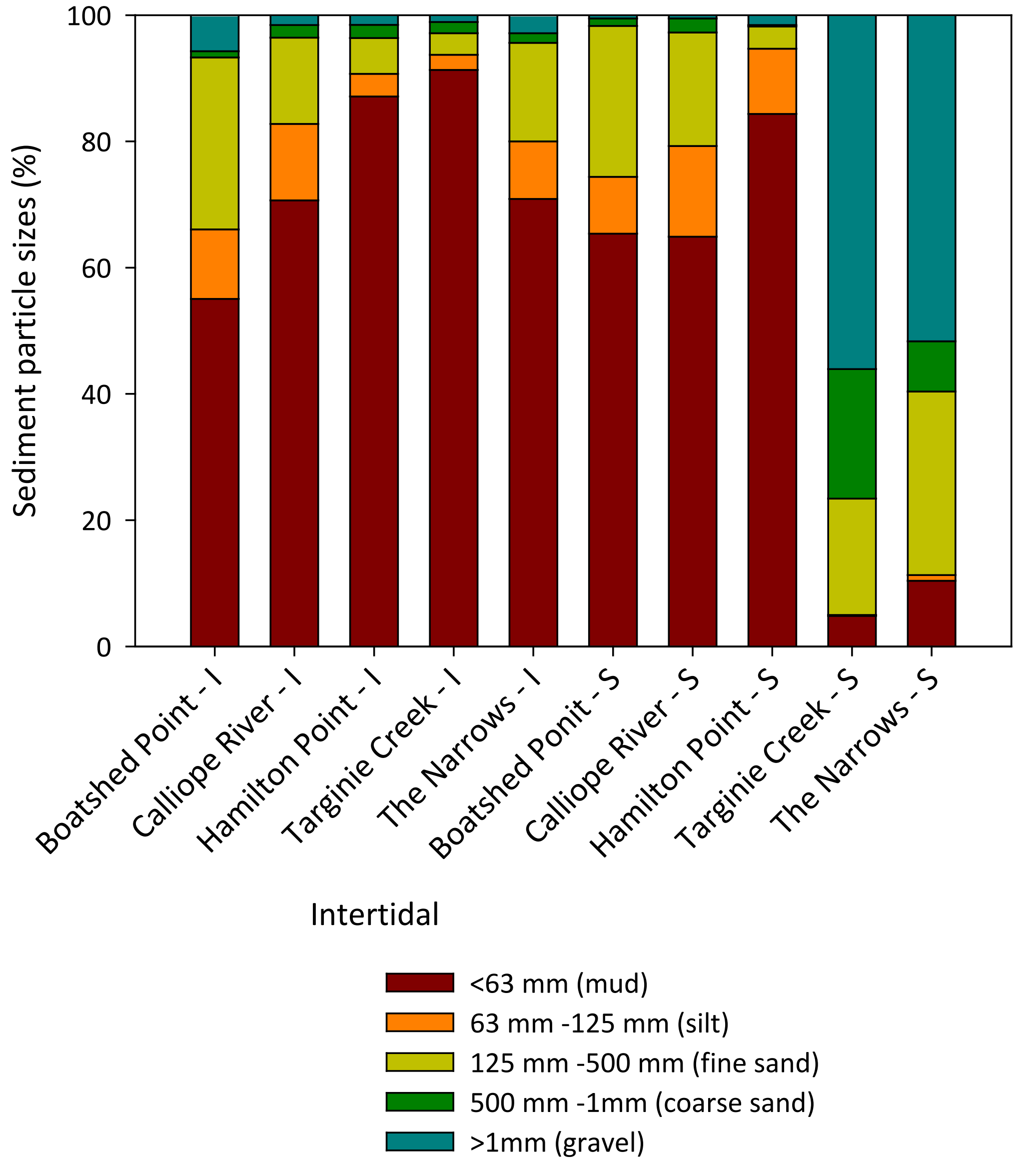


Figure 4. Percent mean sediment particle size classes at different sites within Port Curtis during Phase I monitoring. (I) denotes intertidal sites and (S) denotes subtidal sites, *n* = 5.

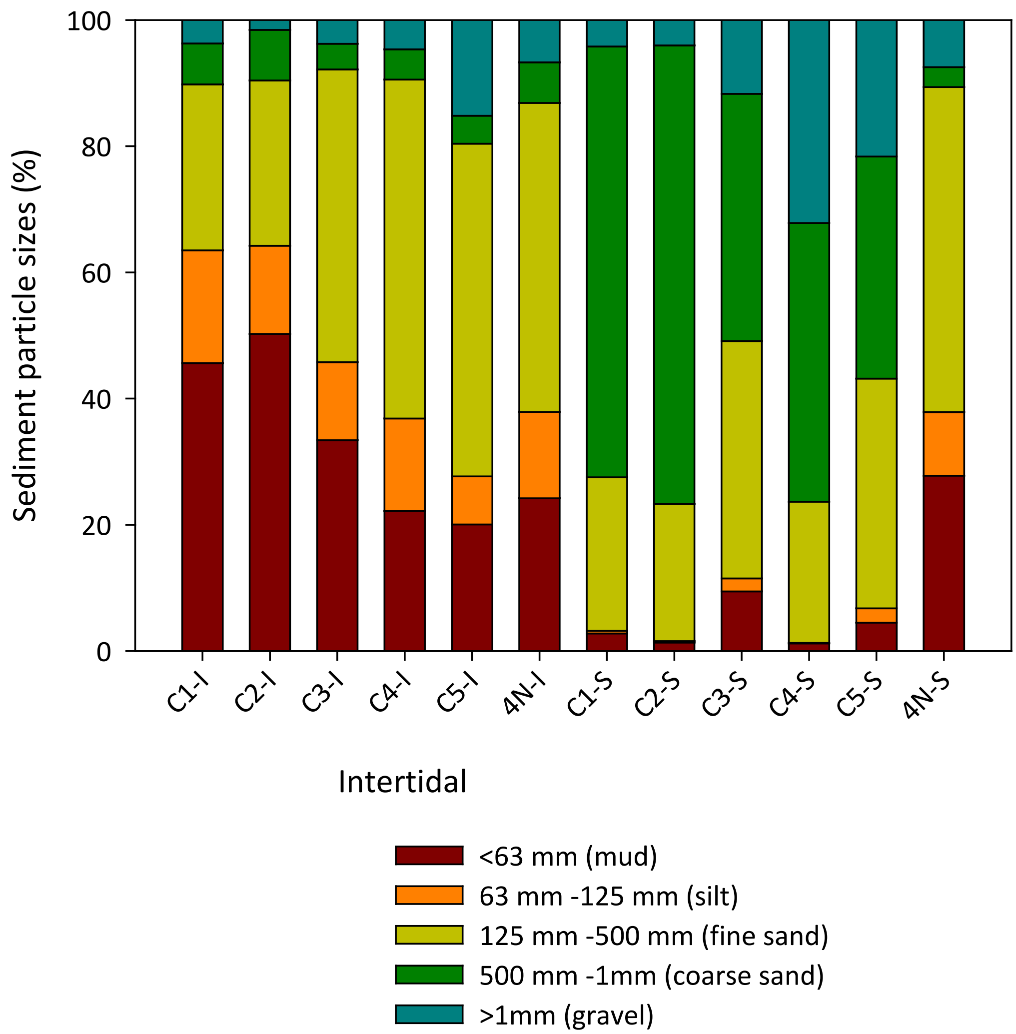


Figure 5. Percent mean sediment particle size classes at different sites within Calliope River and the Fishermans Landing Northern Expansion Project (4N) during Phase II monitoring. (I) denotes intertidal sites and (S) denotes subtidal sites, *n* = 5.

3.2.2 Sediment metal concentrations

Sediment metal concentrations did not exceed the national sediment quality guidelines at any sites (ANZECC/ARMCANZ, 2000a). Sediment concentrations were generally significantly ($P < 0.05$) higher at intertidal sites compared to subtidal sites at the Calliope River. Highest concentrations were reported next to the Launch Site 1 site (C1) and a general trend in lower concentrations towards the mouth of Calliope River (C4 and C5) (Figure 6 - 9). Sediment concentrations at the Launch Site 4N, located at the western basin, were consistently higher ($P < 0.05$) in metals compared to sites located at Calliope River (C1-C5) (Figure 6-9). See Appendix 1 for sediment quality values.

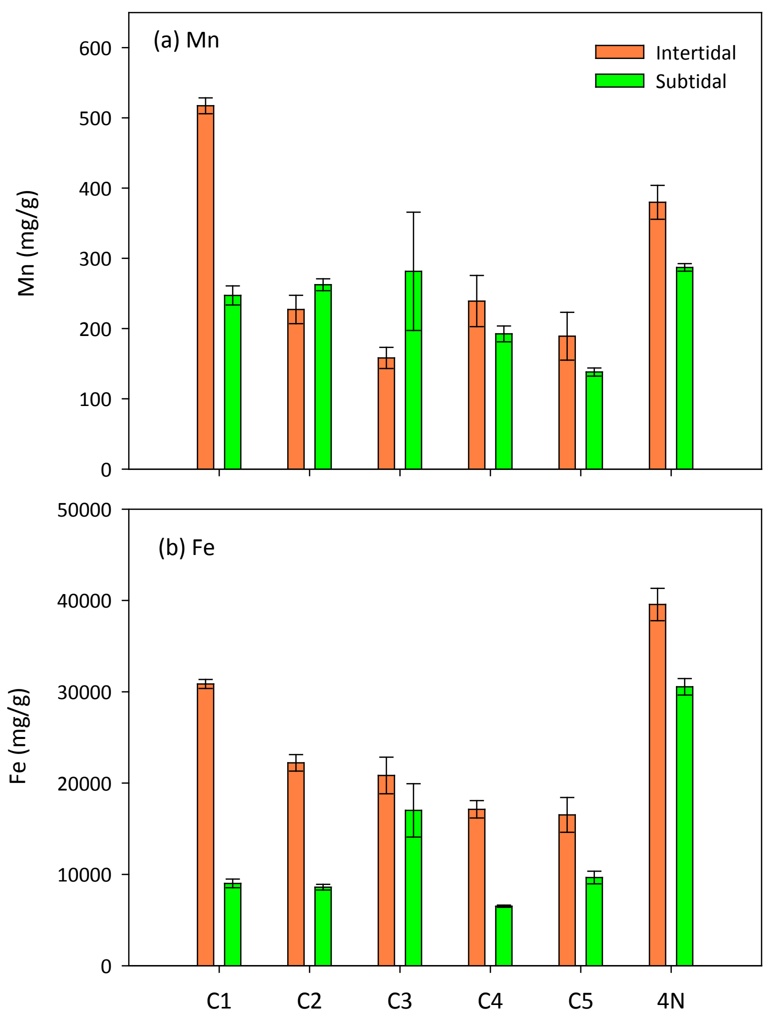


Figure 6. Mean (±se) (a) manganese, and (b) iron concentrations in sediments among sites at Calliope River and Fishermans Landing Northern Expansion Project (4N) in February 2011. Metal concentrations are in $\mu g.g^{-1}$ dry sediment weight.

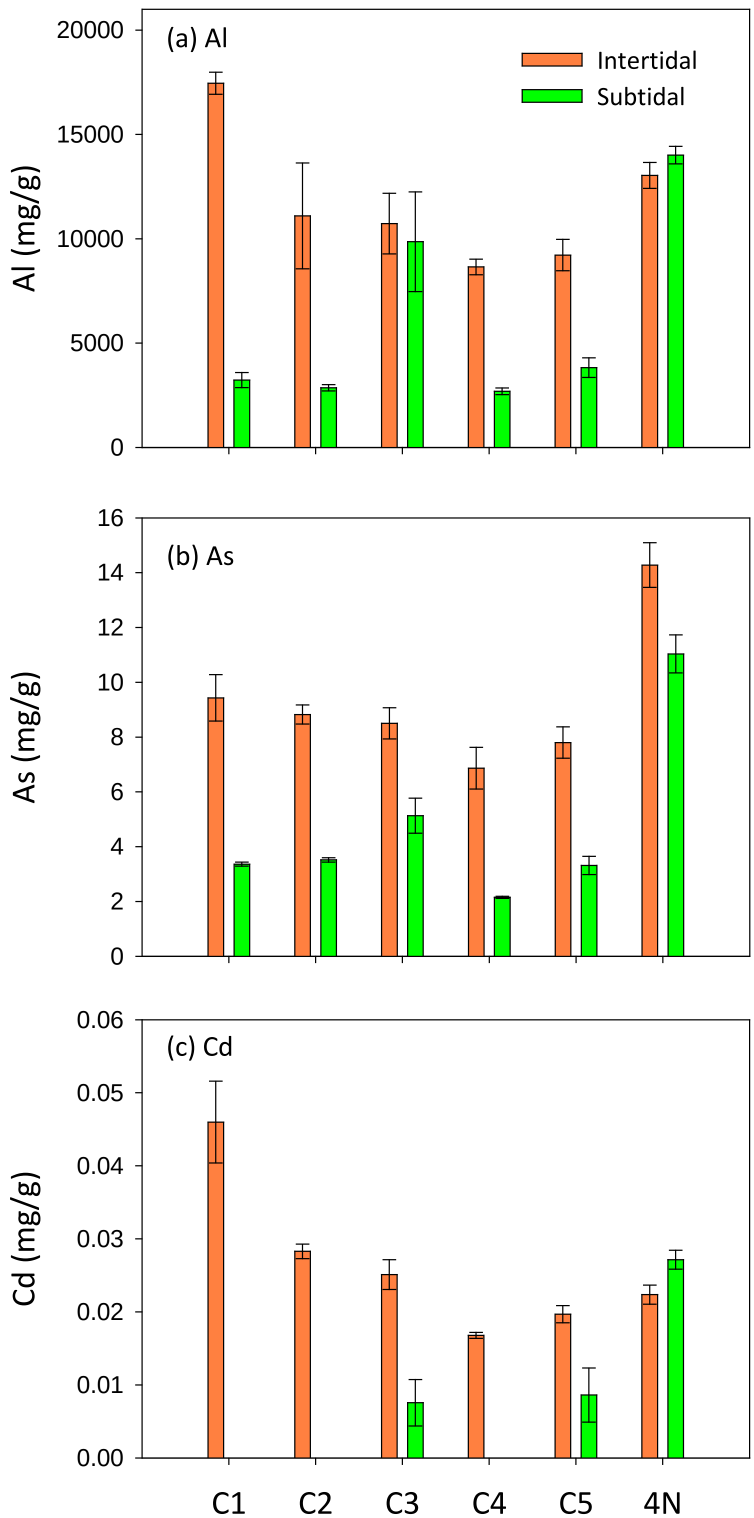


Figure 7. Mean (±se) (a) aluminium, (b) arsenic and (c) chromium concentrations in sediments among sites at Calliope River and Fishermans Landing Northern Expansion Project (4N) in February 2011. Metal concentrations are in μg.g-[1] dry sediment weight.

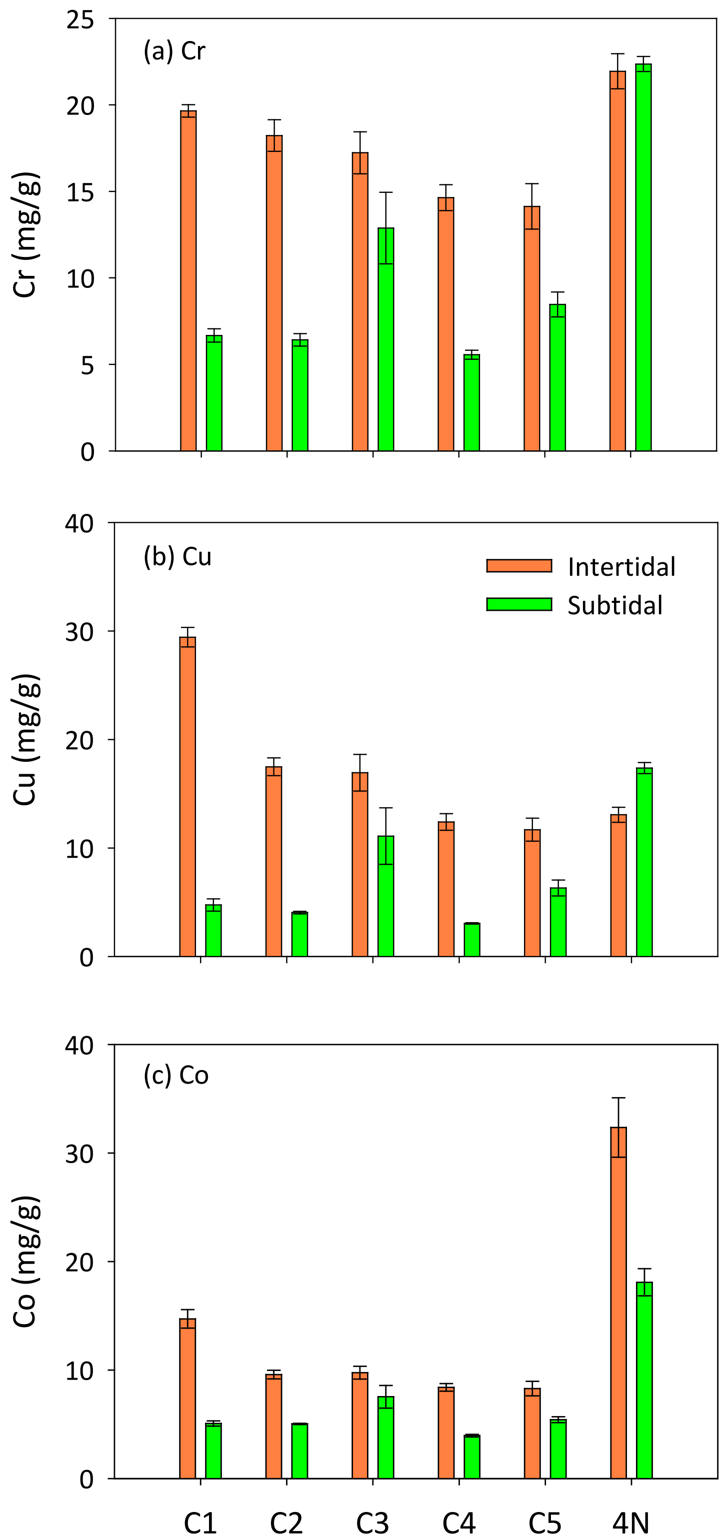


Figure 8. Mean (±se) (a) chromium, (b) copper and (c) cobalt concentrations in sediments among sites at Calliope River and Fishermans Landing Northern Expansion Project (4N) in February 2011. Metal concentrations are in μg.g-^{1} dry sediment weight.

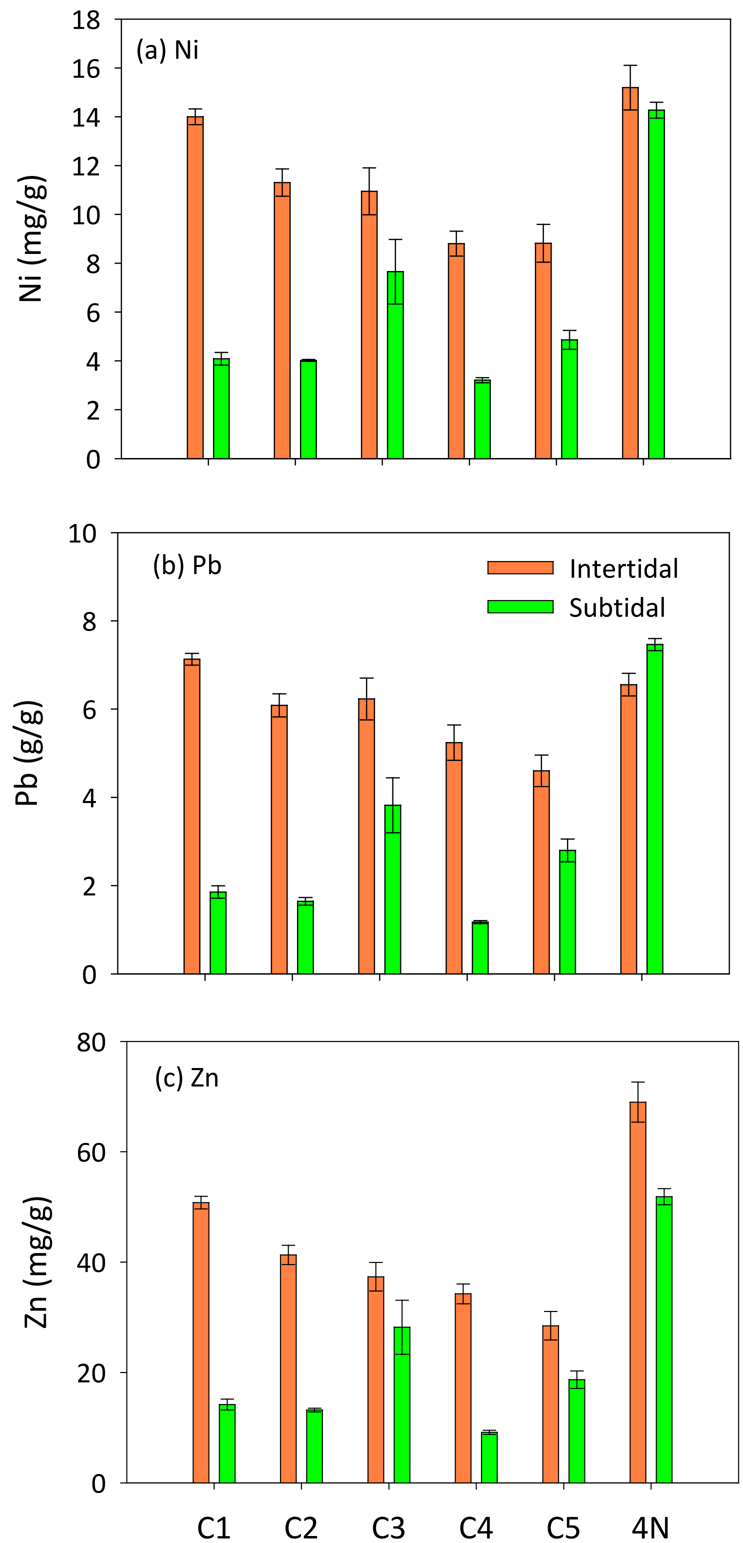


Figure 9. Mean (±se) (a) nickel, (b) lead and (c) zinc concentrations in sediments among sites at Calliope River and Fishermans Landing Northern Expansion Project (4N) in February 2011. Metal concentrations are in $\mu g.g^{-1}$ dry sediment weight.

3.2.3 PAHs and OC/OP pesticides in sediments

PAH's, OC and OP pesticides were below instrument detection limits for all sites along the Calliope River and the Fishermans Landing Northern Expansion Project Launch Site (4N) and did not breach any national water quality guidelines. See Appendix 2-4 for results on detection limits.

3.3 Macroinvertebrate Assemblages

There were no seagrass leaves or rhizomes recorded in any of the sediment/macroinvertebrate samples from study sites within Port Curtis or the Calliope River during either of the Phase I or Phase II sampling trips

A total of 551 macroinvertebrate organisms from 124 species and 7 different phyla were collected in May 2010 and February 2011 from all sites. Overall, the most common organisms recorded throughout sites included the bivalve *Mactra abbreviate* (7%), the bloodworm *Glycera* sp. (6.5%), the amphipod *Corophium cf. acutum* (5%), and the marine crabs *Cleistostoma mcneilli* (4%), and *Ilyoplax strigicarpus* (3.8%) (Appendix 5-7). The most common phyla included polychaetes (38%), molluscs (31%), and crustaceans (28%), with nermeteans and pycnogonids being the least common phyla (< 1%). Table 6 provides a list of species recorded within all study sites.

There were no significant differences in macroinvertebrate total abundance ($P = 0.05$; $F = 2.565$; *df* 4) or species evenness ($P = 0.547$; $F = 0.774$; *df* 4) among sites for the May 2010 sampling event (Figure 10). However, species richness and diversity was significantly ($P < 0.05$) lower at Hamilton Point and Targinie Creek compared to the other sites (Figure 10). Highest species richness and diversity was observed in The Narrows. Conversely, significant differences were observed in the February 2011 sampling event among sites, with significantly lower total abundance ($P = 0.047$; $F = 2.452$; *df* 5), species richness ($P = 0.008$; $F = 3.559$; *df* 5), and diversity ($P = 0.002$; $F = 4.471$; *df* 5) (Figure 10). In general, there were no significant ($P > 0.05$) differences in biodiversity between intertidal and subtidal sites during the Phase I sampling trip. The only difference observed was at The Narrows, with significantly higher numbers of organisms, species richness and diversity at the subtidal sites (Figure 10). Depth differences (intertidal/subtidal) were observed during Phase II (February 2011), with higher biodiversity at the intertidal sites, compared to the subtidal sites. Organisms that best contributed to site similarities (SIMPER) included the snapping shrimp *Alpheus pacifica* and the polychaete *Ophelina* sp.

Table 6. List of macroinvertebrate organisms encountered at all sites within Port Curtis.

Crustaceans	Molluscs	Molluscs cont
Alpheus pacifica	Anodontia omissa	Paphia undulata
Amphipoda 42	Arcidae 1	Placamen tiara
Aoridae 1	Arcidae 2	Potamididae 5
Australoplax tridentata	Arcidae 3	Rissoidae 1
Cirolana sp. 1	Azorinus sp. 2	Scintilla sp. 2
Cleistostoma mcneilli	Barbatia sp.	Tellina sp. 14
Corophium cf. acutum	Bivalvia 45	Tellina sp. 15
Cyclaspis sp. 1	Bivalvia 79	Tellina sp. 3
Diogenes guttatus	Bivalvia 92	Tellina sp. 7
Gammaridae sp. 1	Brachidontes subramosa	Turritellidae 1
Grandidierella sp. 1	Carditella (Carditellona) torresi	
Grandidierella sp. 2	Collumbellidae 1	
Ilyoplax strigicarpus	Collumbellidae 2	
Macrophthalmus latreillei	Corbula (Notocorbula) tunicata	
Macrophthalmus telescopicus	Cuspidaria sp. 1	
Megalopa 1	Cyclostremiscus sp. 4	
Ogyrides delli	Epitonium sp. 3	
Oratosquillina stephensoni	Gafrium transversarium	
Paleomonidae 1	Gari sp. 2	
Penaeus marginatus	Gastropoda 184	
Porcellanidae 2	Laternula rostrata	
Speocarcinus luteus	Leionuculana superba	
Speocarcinus sp.1	Lucinidae 3	
Tanaidacea 10	Mactra (Mactra) queenslandica	
Tanaidacea 11	Mactra abbreviata	
Tanaidacea 2	Mimachlamys gloriosa	
Echinoderms	Modiolus sp. 1	
Ophiuroidea 1	Nassarius sp. 4	
Ophiuroidea 15	Neritina ovalaniensis	
Ophiuroidea 18	Nuclana (Scaededa) crassa	
Ophiuroidea 27	Nuculana (Nuculana) novaeguiensis	
	Nuculana darwini	
	Nuculanidae 1	

Polychaetes	Polychaetes cont…	Chordates	Nermeteans
Ampharete sp.1	Marphysa 4	Gobiidae 1	Nemertea 1
Amphinomidae 4	Nephtys sp. 1	Trypauchen microcephalus	**Pycgnogonids**
Armandia sp. 1	Nereididae 7		Phoxichilidiidae 1
Cossuridae 1	Nereis sp. 1		
Cossuridae 2	Nereis sp. 2		
Diopatra dentata	Nothria sp. 1		
Dorvilleidae 3	Notomastus sp. 2		
Eunice sp. 1	Ophelina sp. 1		
Eunice sp. 2	Pectinaria (Pectinaria) Papillosa		
Eunice vittata	Pilargiidae 1		
Glycera sp. 1	Polyodontes australiensis.		
Haploscloplos sp. 1	Progoniada sp. 1		
Hesionidae 1	Sabellidae 2		
Isolda pulchella	Sabellidae 8		
Leanira sp. 1	Spionidae 2		
Litocorsa sp. 1	Spionidae 3		
Lumbrineris sp. 2	Sternapis scutata		
Lumbrineris sp. 3	Streblosoma sp. 1		
Magelona sp. 1	Syllidae 1		
Magelonidae 1	Syllidae 2		
Maldanidae 10	Terebellidae 1		
Maldanidae 2	Trichobranchidae 2		
Maldanidae 6	Trichochaetidae 2		
Maldanidae 9			

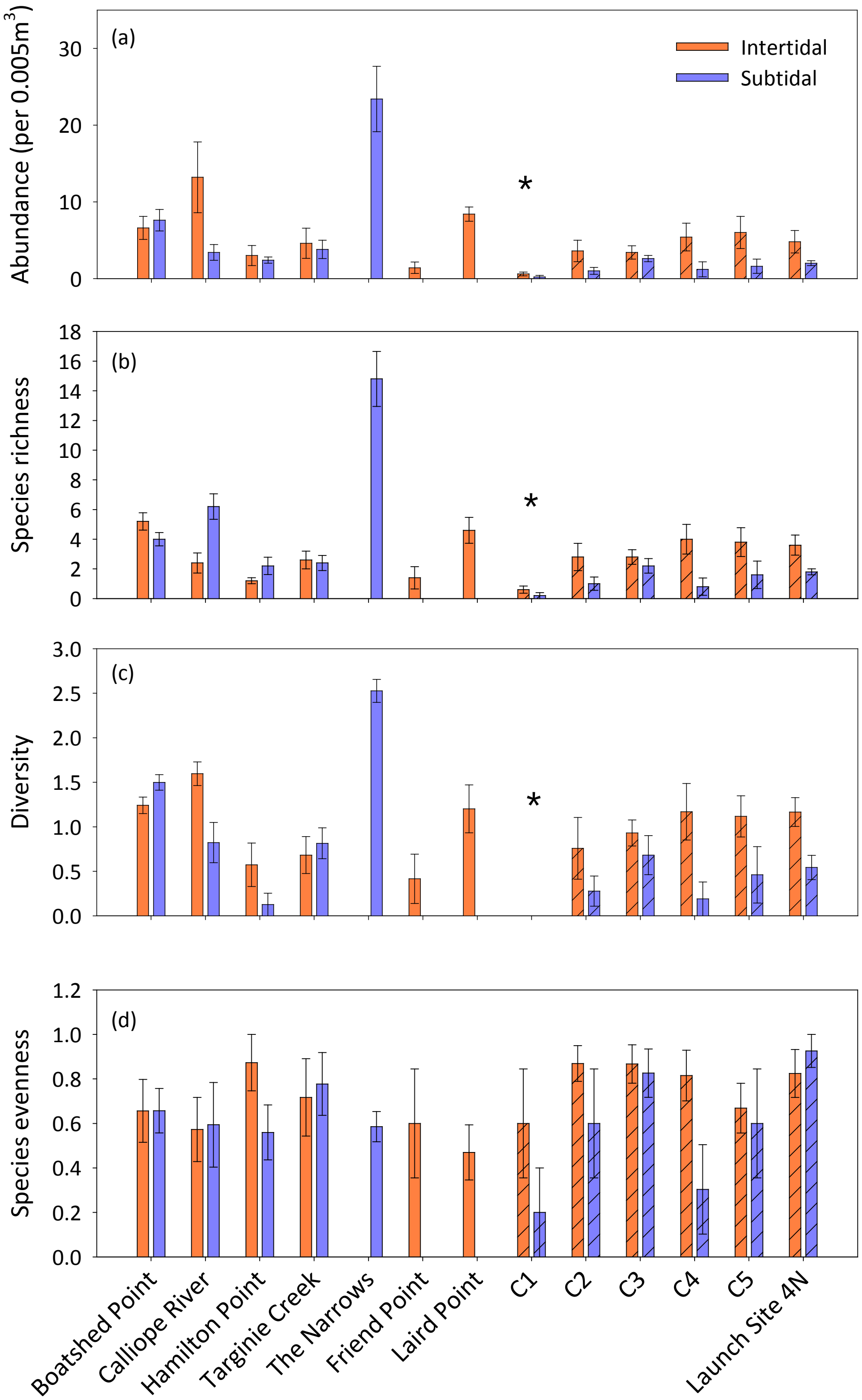


Figure 10. Mean (±se) macroinvertebrate (a) abundance, (b) species richness, (c) diversity and (d) species evenness (per 0.005 m^3) among intertidal and subtidal sites within Port Curtis for both monitoring events, n = 5. *Denotes significant ($P < 0.05$) differences among sites for February 2011 only, hatched lines denote the February 2011 survey.

Macroinvertebrate community assemblages were dissimilar among sites (ANOSIM Global R-statistic 0.212; P < 0.01; Figure 11) and to a lower extent depth (ANOSIM Global R-statistic 0.138; P < 0.01) and sampling times (ANOSIM Global R-statistic 0.112; P < 0.01). Highest assemblage similarity was between C3 and C4, and C2, C5 and Targinie Creek (Figure 11). The organisms that mostly contributed to assemblage dissimilarity among sites included *Corophium acutum, Tellina* sp., and *Ilyoplax strigicarpus* (SIMPER analysis).

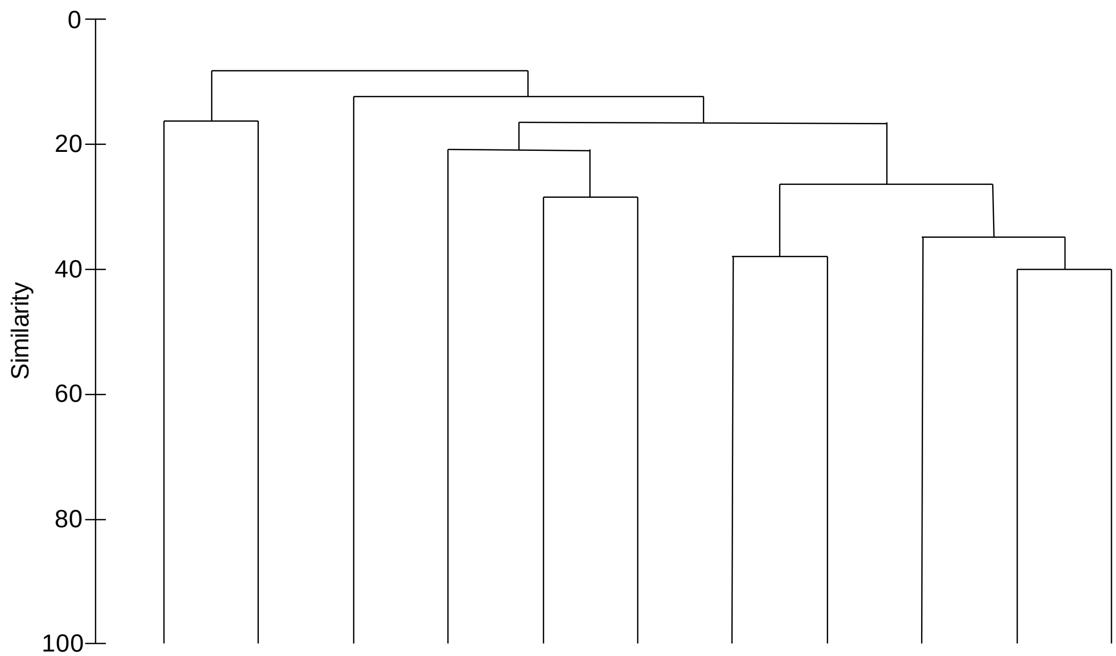


Figure 11. Cluster analysis of macroinvertebrate community assemblages (per 0.005 m^3) at each site during Phase I & II monitoring. Data were standardised and weight dispersion corrected, based on Bray-Curtis similarity matrices.

3.4 Mangrove Communities

Five mangrove species were encountered in the study plots (25 m^2) (Table 7), with a total of 353 adult and juvenile individuals encountered during Phase I and II monitoring programs. Overall, the most common mangrove species recorded in most plots were the yellow mangrove, *Ceriops tagal,* (38% adults and 3% seedlings), and the red mangrove, *Rhizophora stylosa,* (29% adults and 21% seedlings). The grey mangrove, *Avicennia marina*, was also common throughout the plots with 6% comprised of adults and 1% seedlings. The least common mangrove species recorded in the study plots were the myrtle mangrove, *Osbornia octodonta*, and the river mangrove, *Aegiceras corniculatum* (Plate 5), with less than 1% recorded for both species in all the study plots. Other local studies in the Port Curtis region have shown similar results in community structure, with *Rhizophora* being the most dominant mangrove type, followed by *Ceriops* and *Avicennia* (Danaher *et al*., 2005).

Saltmarsh communities were also recorded in many study plot areas. Based on visual observations, the main species comprising the samphire saltpan communities (Plate 6a) included bead weed, *Sarcocornia quinqueflora* (Plate 6b), and saltcouch, *Sporobolus virginicus* (Plate 6c).

Plate 5. Example of a fringing river mangrove, *Aegiceras corniculatum*, mangal community.

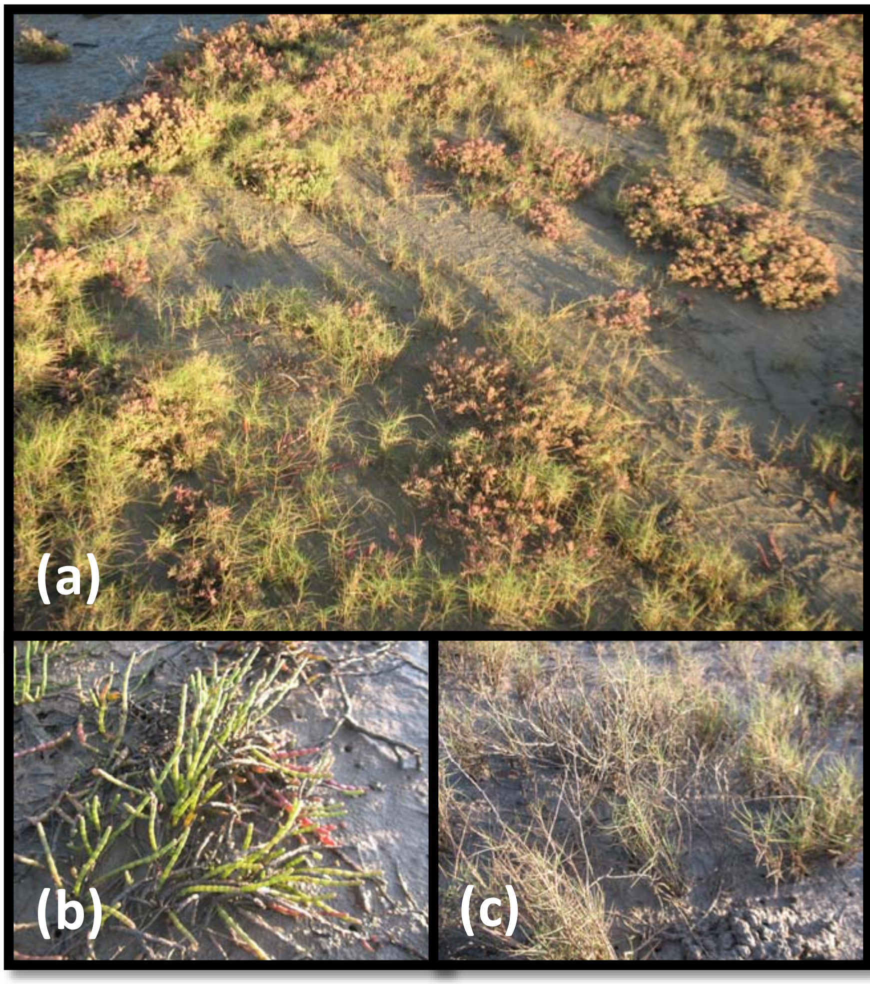


Plate 6. Example of (a) samphire saltmarsh, (b) bead weed and (c) saltcouch communities found in study plots.

Table 7. Mangrove species encountered in the mangrove study plots (25 m^2).

Species name	Common name
Aegiceras corniculatum	River mangrove
Avicennia marina	Grey mangrove
Ceriops tagal	Yellow mangrove
Osbornia octodonta	Myrtle mangrove
Rhizophora stylosa	Red mangrove

Based on the study plots, the Wiggins Mainland site was the only site to have significantly higher tree densities compared to all other sites (Table 8). There were no other significant ($P < 0.05$) differences in mangrove densities, species richness, diversity, species evenness or canopy cover among sites for both monitoring programs (Phase I and II) (Table 8). Average mangrove density was between 10 to 20 adult and juvenile mangroves per 25 m^2 for all sites except the Wiggins Mainland site, which had approximately 50 trees per 25 m^2, with an average of one to two species per plot area. Canopy cover was dense at most sites with an average of 50 to 90% cover among plot areas (Table 8). Mangrove community composition was most similar in plots among Wiggins Island A and B, followed by Boatshed Point and Hamilton Point (~90% similarity) (Figure 12). The Wiggins Mainland, Calliope River and Launch Site 1, although similar in composition to each other (60-90%), were the most dissimilar group compared to all other sites, with approximately 25% similarity (Figure 12).

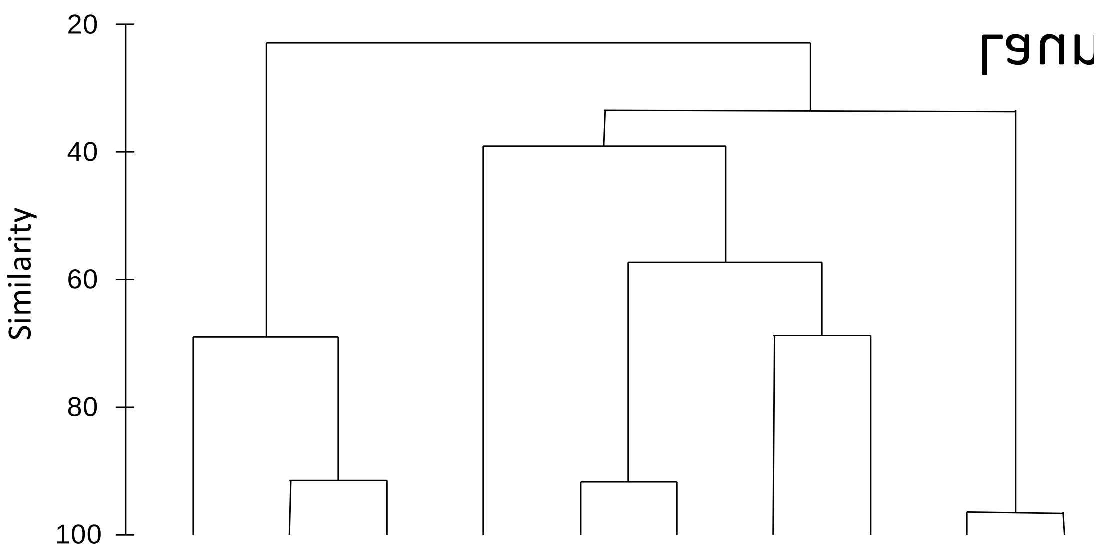


Figure 12. Cluster analysis of mangrove community assemblages (Bray-Curtis similarity) at different sites throughout Port Curtis and Calliope River during the Phase I and II monitoring programs. Data were standardised (n = 3).

Table 8. Mean (±se) mangrove density, species richness, diversity, species evenness, and percentage (%) projective foliage cover (PFC) per 25 m^2 plots, (n = 3) at all study locations during Phase I and II. Bold values denote significantly ($P < 0.05$) different from other sites.

Means	Density	Species richness	Diversity	Species evenness	% PFC
Boatshed Point	19.7 ± 7.7	2.3 ± 0.3	0.6 ± 0.1	0.1 ± 0.02	70 ± 15
Calliope River	10.7 ± 7.9	0.7 ± 0.3	0	0.1 ± 0.05	65 ± 10
Hamilton Point	14.0 ± 4.5	2.7 ± 0.7	0.9 ± 0.2	0.2 ± 0.1	45 ± 18
The Narrows	8.0 ± 2.5	1.7 ± 0.3	0.4 ± 0.2	0.2 ± 0.04	48 ± 24
Targinie Creek	9.0 ± 4.5	1.7 ± 0.9	0.6 ± 0.6	0.1 ± 0.06	45 ± 18
Wiggins Mainland	**49.7 ± 11.4**	2.3 ± 0.7	0.6 ± 0.3	0.04 ± 0.01	88.3 ± 1.7
Wiggins Is A	7.0 ± 3.0	1.0 ± 0	0.0	0.2 ± 0.1	90.0 ± 0.0
Wiggins Is B	11.2 ± 3.0	1.2 ± 0.2	0.1 ± 0.1	0.1 ± 0.03	84.0 ± 2.9
Mud Island	16.0 ± 12.0	2.5 ± 1.5	0.6 ± 0.5	0.2 ± 0.1	77.5 ± 12.5
Launch Site 1	34.0 ± 10.0	2.0 ± 1.0	0.3 ± 0.2	0.05 ± 0.02	62.5 ± 7.5

Table 9. Total dominant mangrove community areas (excluding saltmarsh/mudflat communities) calculated from polygons within the mapping/GIS component (see Figure 13 - 27).

Community	Area (ha)	% Area
Rhizophora sp.	334.1	41
Ceriops sp.	52.7	6.5
Avicennia emergents	43.9	5.4
Rhizophora/Osbornia mix	0.1	0.05
Aegiceras sp.	0.1	0.05
Samphire/saltpan	383.1	47
Total Area (ha)	*814.0*	

The mangrove survey area extents are shown in Figure 13 to 21. The total mangrove survey area, created as polygons, covered approximately 814 hectares (Table 9). Although other species were found in the study area, the following mangrove communities were dominant; closed *Rhizophora* forests made up the highest percentage of the area (< 41%) as well as *Ceriops* (approximately 6.5%) and emergent *Avicennia* (5.4%), with closed fringing *Aegiceras* shrubs and *Osbornia* sp. being the least dominant community types (< 1%) (Table 9). Saltpan/Samphire communities also formed a significant proportion of the area (47%). Targinie Creek had the largest mangrove area (633 ha) followed by Boatshed Point, North China Bay, Calliope River, Friend Point, and Hamilton Point (48 ha, 40 ha, 31 ha, 8 ha and 5 ha, respectively). The smallest mangrove area was at Laird Point (approximately 2.1 ha). Closed *Rhizophora* and moderate *Avicennia* and *Ceriops* communities were generally the more dominant mangrove community types at all sites during the Phase I study (Table 10). During the Phase II study, the Wiggins Mainland site had the highest mangrove area (41 ha) with *Rhizophora* forest making up the majority of the community (86%), followed by Wiggins Island B, Launch Site 1 and Mud Island (16 ha, 10 ha, and 2 ha, respectively). Wiggins Island A made up the smallest mangrove community (1.5 ha), made up of mainly *Rhizophora* forest (93%) (Table 11).

Table 10. Dominant mangrove community areas in hectares (ha) and as a percentage of total area at the seven locations during the Phase I monitoring program, calculated from the mapping/GIS component. Note that saltmarsh/mudflat areas were excluded from the analysis.

	Targinie Creek		**North China Bay**		**Calliope River**		**Boatshed Point**		**Friend Point**		**Hamilton Point**		**Laird Point**	
	Area	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
Rhizophora	222.9	35.3	23.5	58.0	23.0	74	14.5	30.4	5.0	62.4	4.4	93.6	1.4	66.7
Avicennia	39.1	6.2	1.9	4.7	0.5	1.7	0.0	0	1.7	21.3	0.0	0	0.1	4.8
Ceriops	44.2	6.9	1.3	3.3	0.5	1.7	0.6	1.3	1.3	16.3	0.1	2.1	0.0	0
Aegiceras	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.1	4.8
Samphire/saltpan	327	51.6	13.7	34.0	7.0	22.6	32.6	68.3	0	0	0.2	4.3	0.5	23.7
Totals (ha)	*633.2*		*40.3*		*31.0*		*47.7*		*8.0*		*4.7*		*2.1*	

Table 11. Dominant mangrove community areas in hectares (ha) and as a percentage of total area at the five locations during the Phase II monitoring program, calculated from the mapping/GIS component. Note that saltmarsh/mudflat areas were excluded from the analysis.

	Wiggins Mainland		**Wiggins Island A**		**Wiggins Island B**		**Mud Island**		**Launch Site 1**	
	Area	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**	**Area**	**%**
Rhizophora	41.2	85.8	1.4	93.3	15.7	97.5	1.6	88.8	2.5	25.5
Avicennia	0	0	0.1	6.7	0.4	2.5	0.1	5.6	0.4	4.1
Ceriops	3.8	7.9	0	0	0	0	0	0	1.5	15.3
Osbornia	0	0	0	0	0	0	0.1	5.6	0	0
Samphire/saltpan	3.0	6.3	0	0	0	0	0	0	5.4	55.1
Totals (ha)	*48.0*		*1.5*		*16.1*		*1.8*		*9.8*	

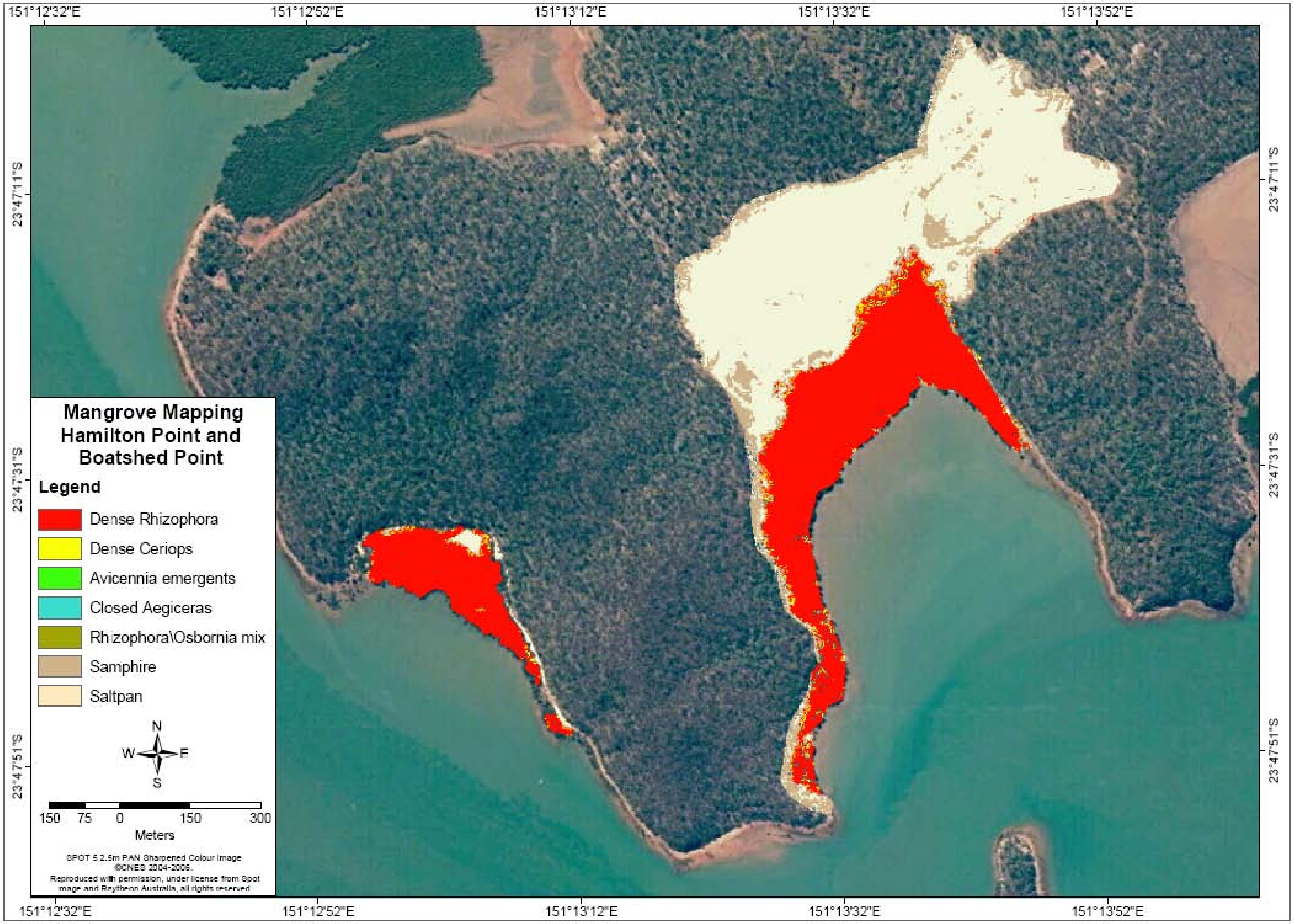


Figure 13. Dominant mangrove communities at Hamilton Point and Boatshed Point (Phase I).

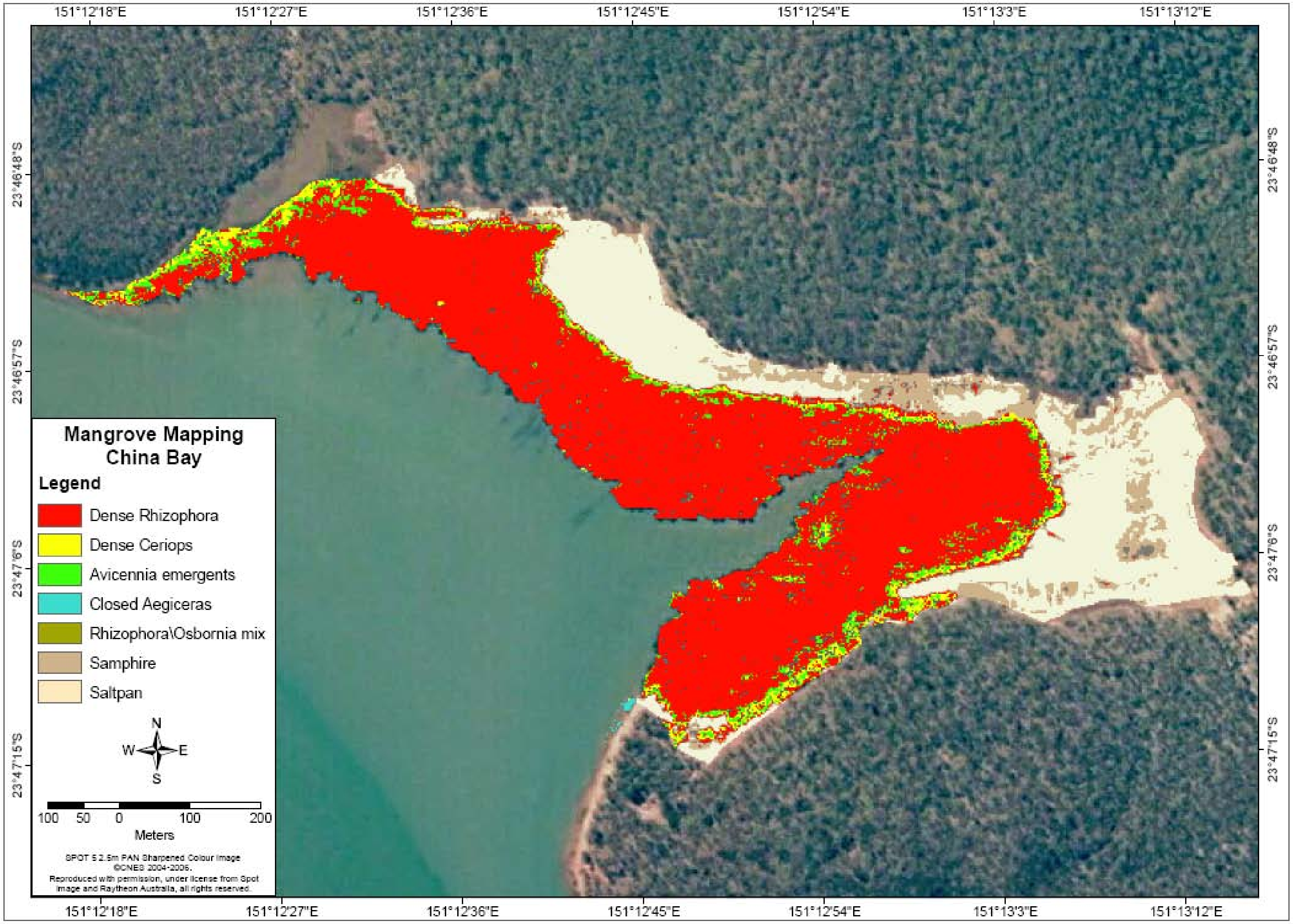


Figure 14. Dominant mangrove communities at North China Bay (Phase I).

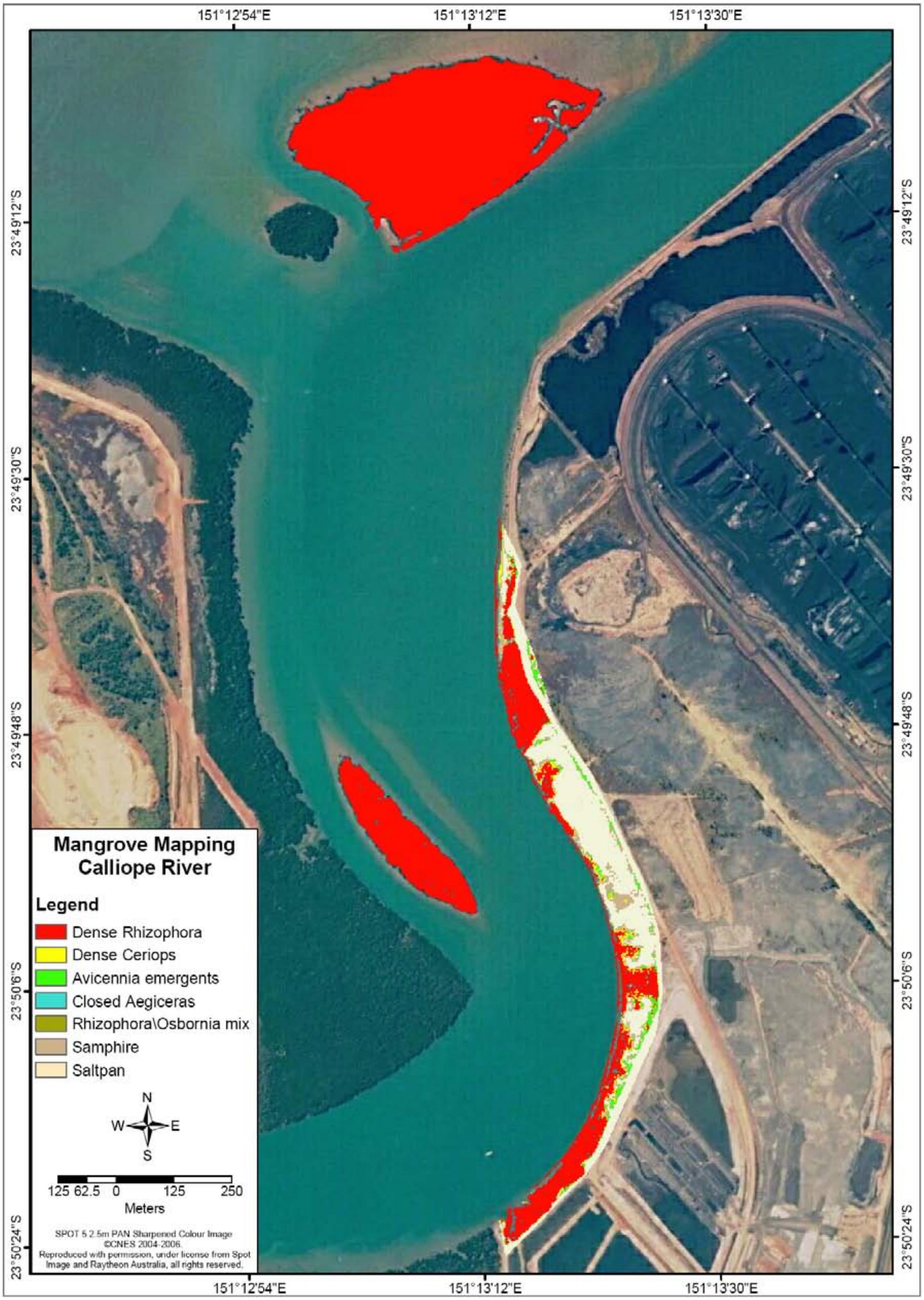


Figure 15. Dominant mangrove communities at Calliope River (Phase I).

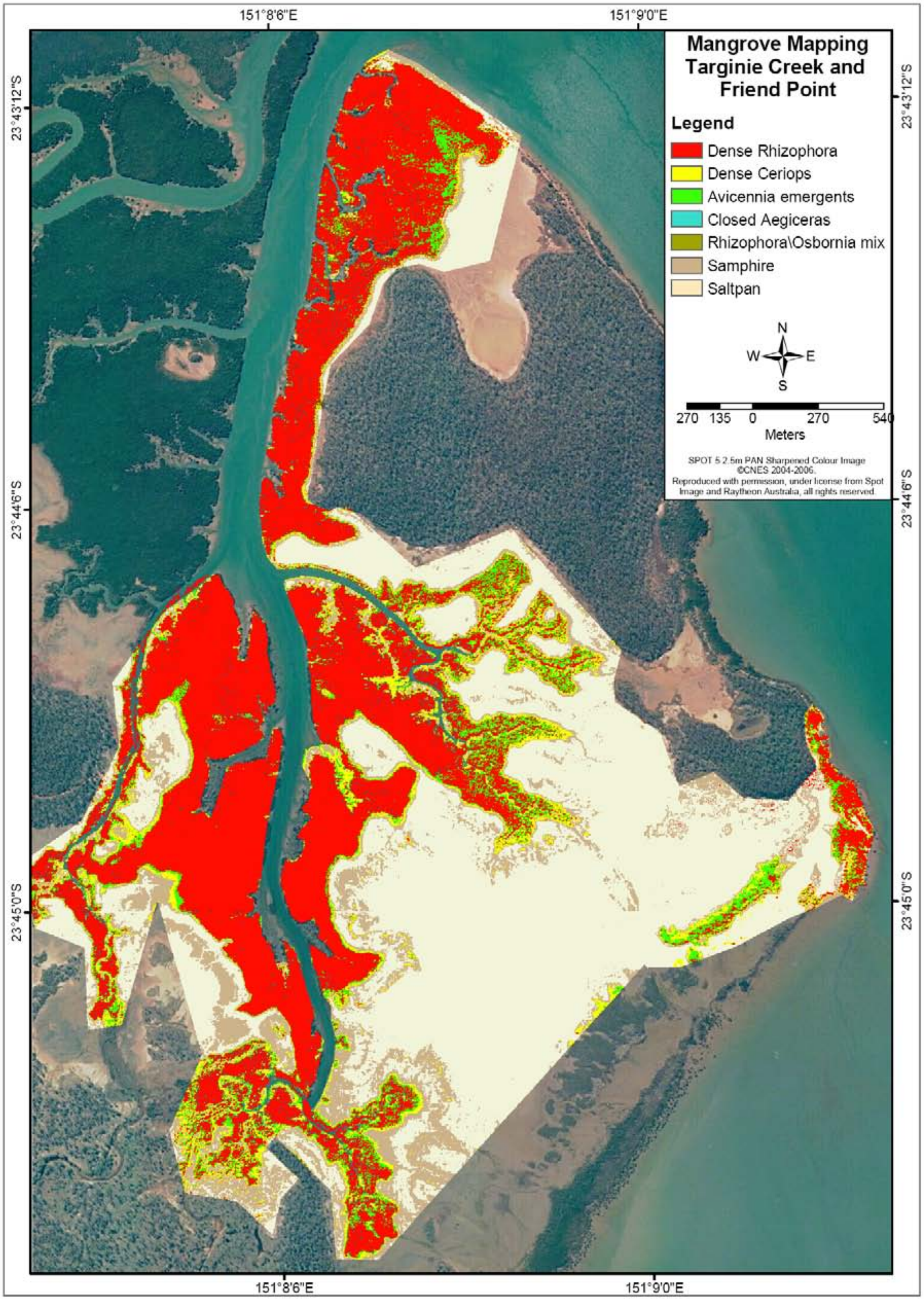


Figure 16. Dominant mangrove communities at Targinie Creek and Friend Point (Phase I).

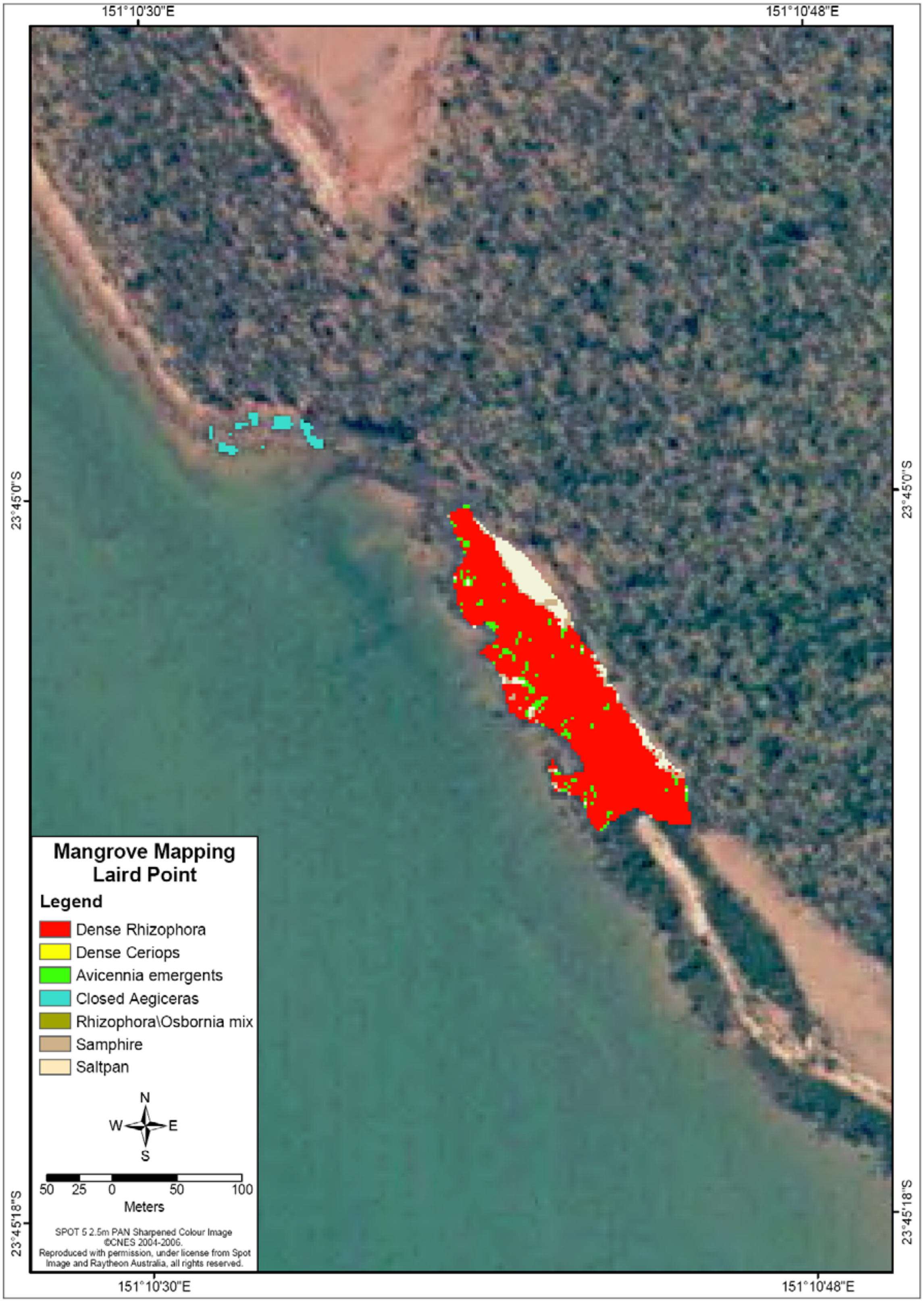


Figure 17. Dominant mangrove communities at Laird Point (Phase I).

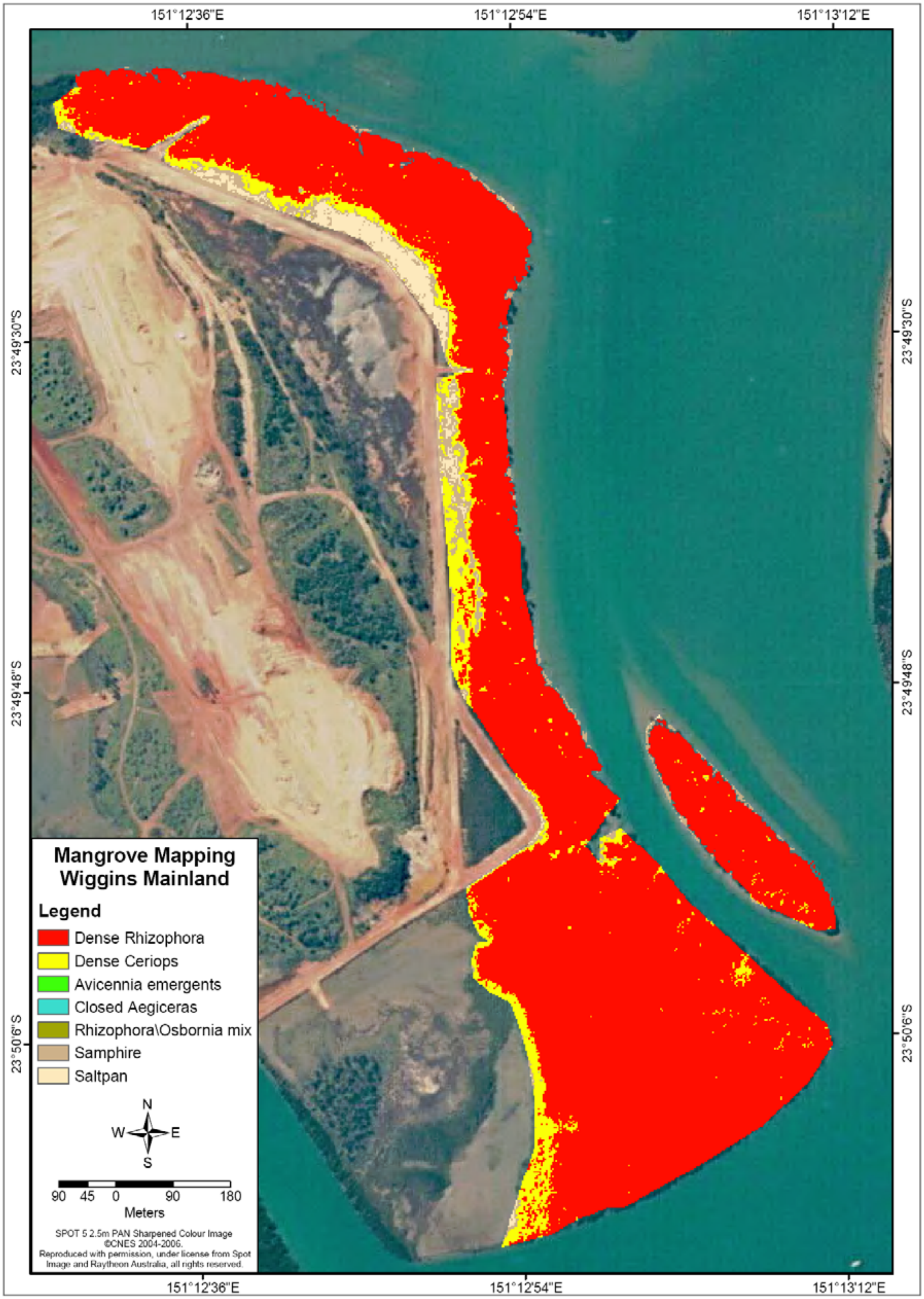


Figure 18. Dominant mangrove communities at the Wiggins Mainland site (Phase II).

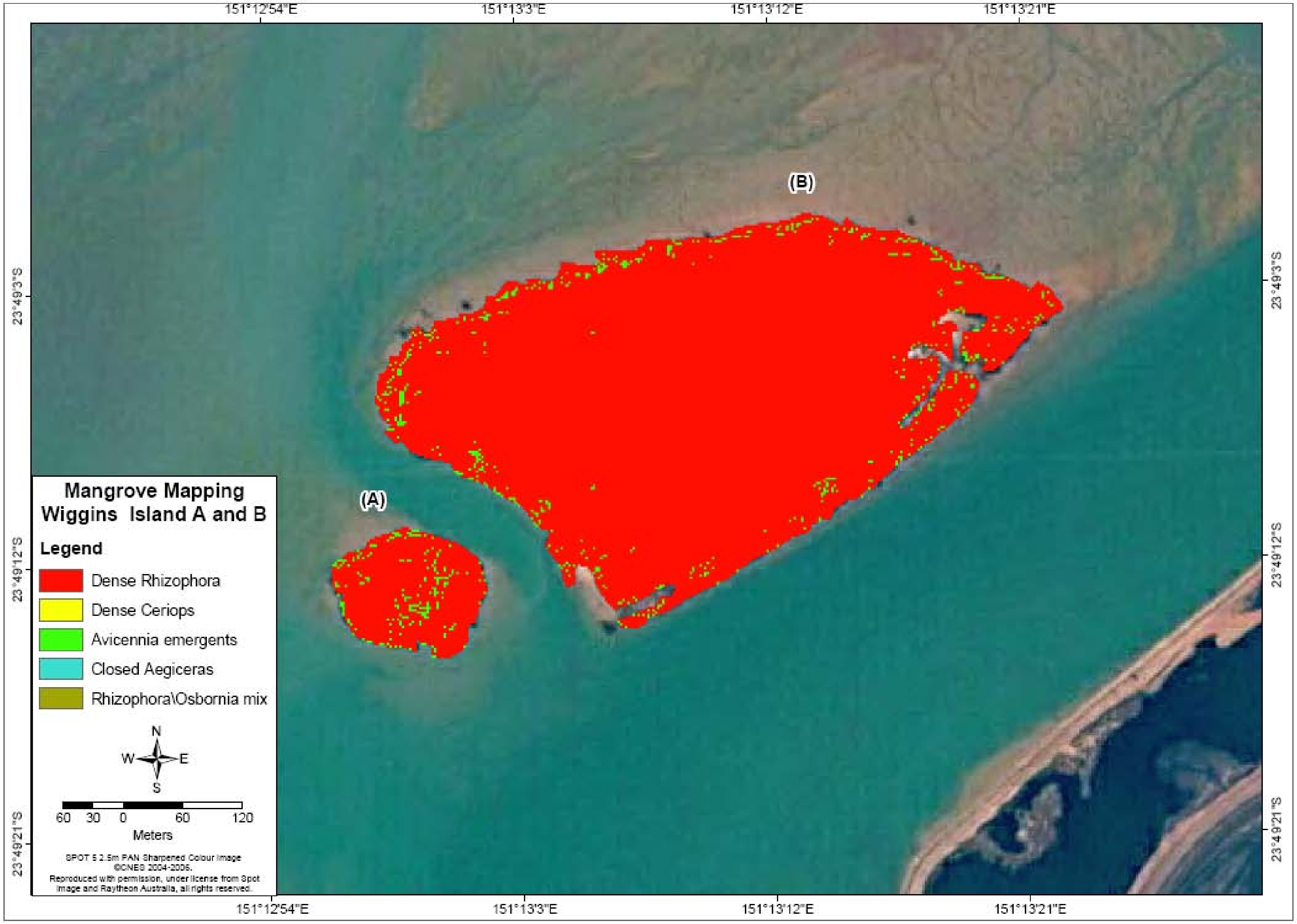


Figure 19. Dominant mangrove communities at Wiggins Island A and B (Phase II).

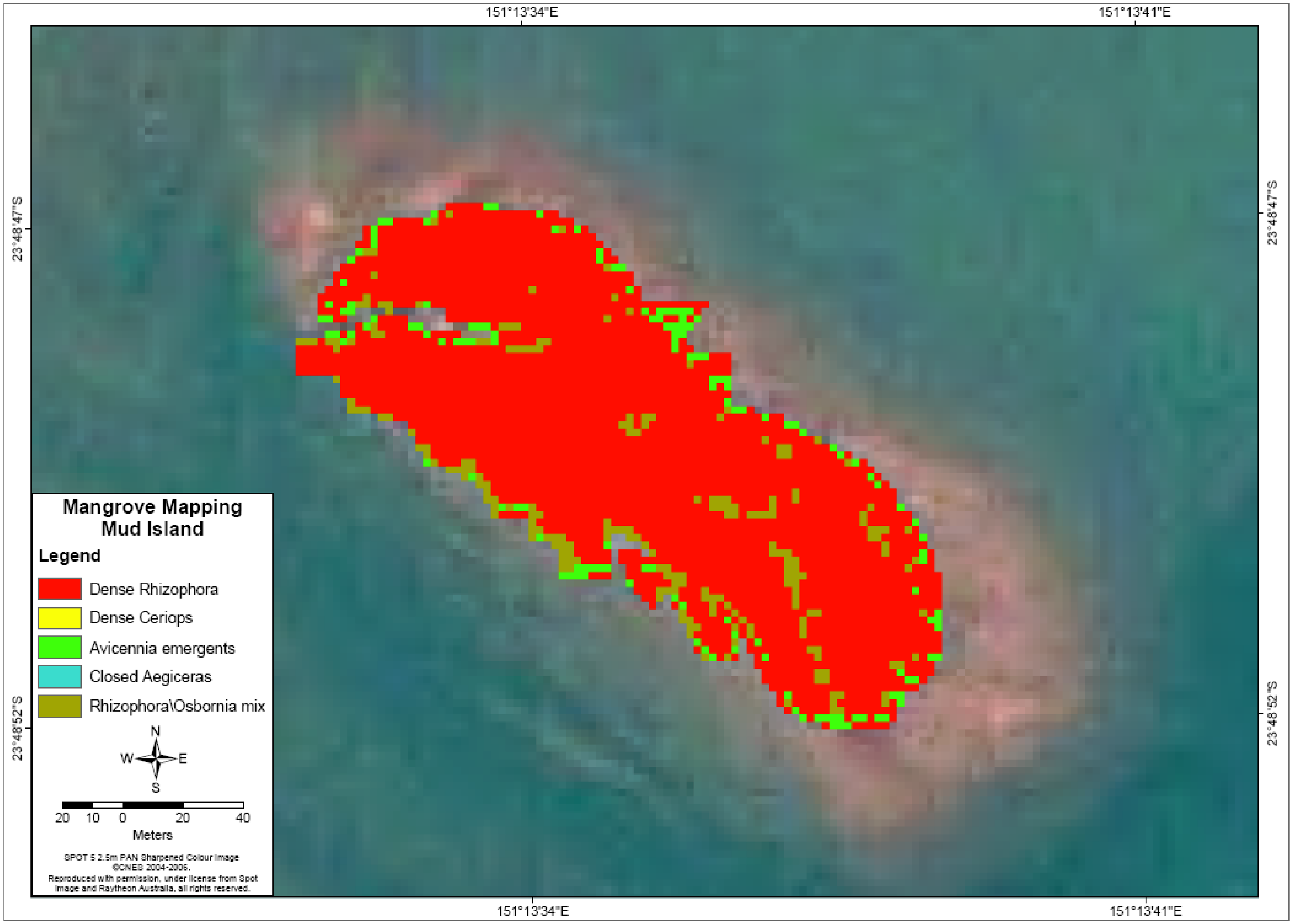


Figure 20. Dominant mangrove communities at Mud Island (Phase II).

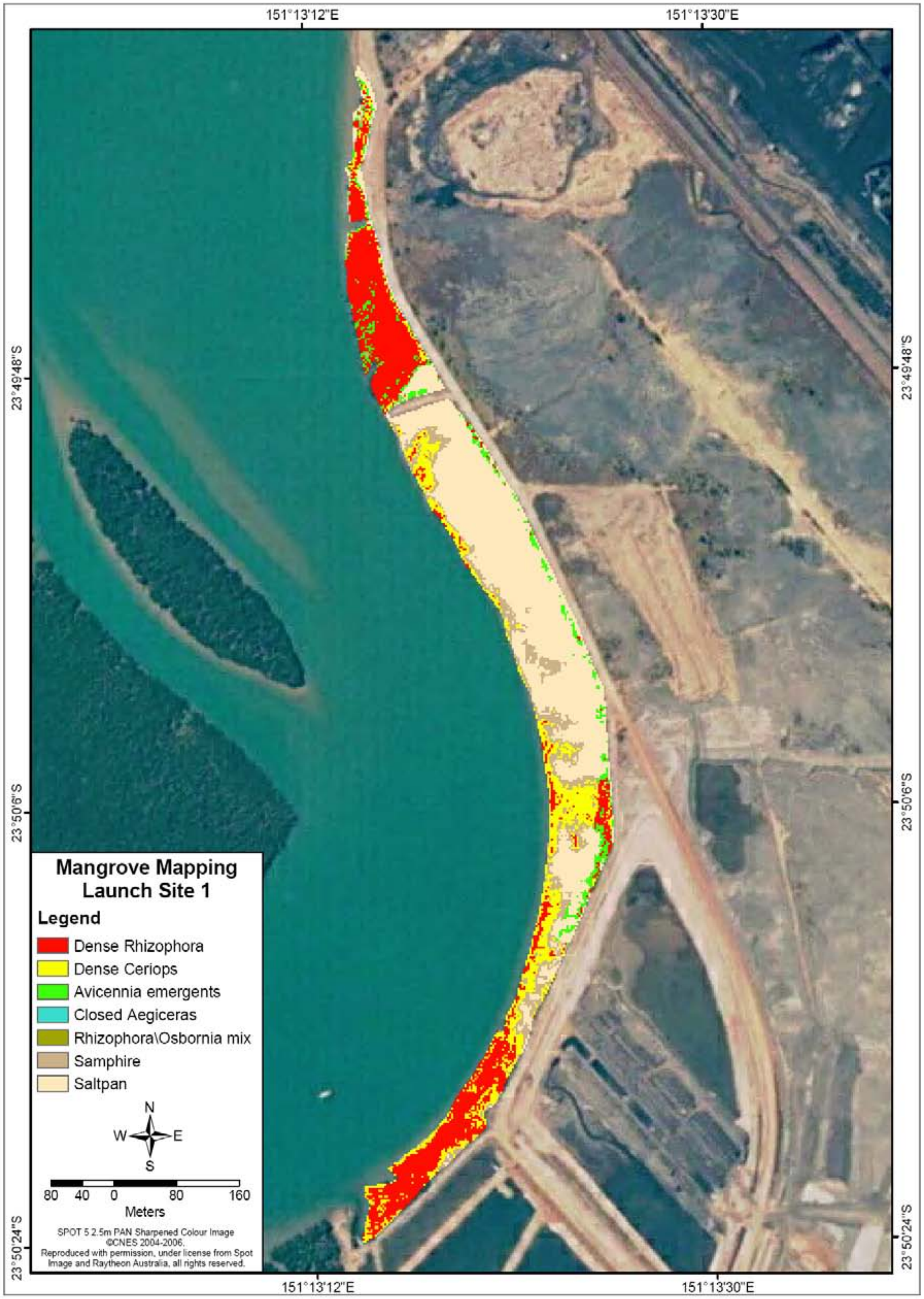


Figure 21. Dominant mangrove communities at Launch Site 1 (Phase II).

3.5 Nekton Assemblages

In Port Curtis, a total of 1,262 fish and macroinvertebrates (nekton) from 29 species were collected from all sites, using a cast net; these species being representative of soft sediment shallow habitats, mangroves and other vegetation lined banks. The most common species recorded were the banana prawn, *Fenneropenaeus merguiensis,* (41%); the spotty-face anchovy, *Stolephorus waitei*, (17%); the greenback mullet, *Liza subviridis*, (16%); the southern herring, *Herklotsichthys castelnaui, (*10%); and the common ponyfish, *Leiognathus equulus*, (7%). See Table 12 for a list of species recorded at all sites for both monitoring programs and Appendix IV for photographic plates.

A further 36 fish and macroinvertebrates from 11 species were collected using a gill net during both sampling events, to sample the species representive of the large sized nekton assemblages in deeper water channels. diamondscale mullet, *Liza vaigiensis*, made up the highest numbers of nekton sampled using a gill net during Phase I of the monitoring program, whereas the giant queenfish, *Scomberoides commersonnianus*, and blue catfish, *Ariopsis graeffei*, made up the highest numbers during the Phase II monitoring program. Other species collected using gill nets included green turtles, *Chelonia mydas*; beach salmon, *Leptobrama muelleri*; blue threadfin, *Eleutheronema tetradactylum*; and the mud crab, *Scylla serrata*. Frequent checking of nets ensured that organisms could be released without harm.

Overall, there were no significant differences ($P > 0.05$) in nekton total abundance, diversity or species evenness among the mangrove lined, shallow water estuarine sites within Port Curtis and the Calliope River for both sampling events. However, there were significantly higher ($P = 0.01$, $F = 3.23$; df 11; Figure 22) densities at Targinie Creek and Calliope River compared to the other sites (up to two fold higher). Moreover, there were slight assemblage differences (ANOSIM Global R-statistic 0.161; $P < 0.05$) in nekton composition among sites (Figure 23) during Phase I of the study, with the Calliope River and The Narrows showing the biggest difference in community composition (R-statistic

0.343; *P* = 0.032), as well as Friend Point and Laird Point (R-statistic 0.289; *P* = 0.017). The species that contributed to highest dissimilarity among sites (SIMPER) included the greenback mullet, southern herring, spotty-face anchovy, and the banana prawn.

Wiggins Island B and the Launch Site 1 were the most dissimilar sites in nekton assemblages for Phase II of the study, with Mud Island and the Wiggins Mainland sites showing highest similarities (Figure 24). In terms of both sampling trips, Friend Point was the most dissimilar site compared to all other sites (30%) similarity, with Mud Island, Wiggins Mainland and Targinie Creek showing highest similarities. See Figure 25 for a representation of grouped similarities among sites for both sampling trips.

Table 12. List of nekton assemblages collected from cast net and gill net surveys at all sites within Port Curtis during Phase I and II.

Family Name	***Species name***	**Common Name**
Sparidae	Acanthopagrus australis	Yellowfin Bream
Sparidae	Acanthopagrus berda	Pikey Bream
Myliobatidae	*Aetobatus narinari*	Spotted Eagle Ray
Ambassidae	Ambassis marianus	Estuary Glassfish
Terapontidae	Amniataba percoides	Barred Grunter
Ariidae	*Ariopsis graeffei*	Blue Catfish
Tetraodontidae	Arothron manilensis	Narrow-lined Pufferfish
Carangidae	Carangoides humerosus	Epaulette Trevaly
Carcharhinidae	*Carcharhinus leucas*	Bull Shark
Cheloniidae	*Chelonia mydas*	Green Turtle
Tetraodontidae	Chelonodon patoca	Milk-spotted Pufferfish
Polynemidae	Eleutheronema tetradactylum	Blue Threadfin
Serranidae	Epinephelus coioides	Goldspot rockcod
Penaeidae	Fenneropenaeus merguiensis	Banana Prawn
Clupeidae	Herklotsichthys castelnaui	Southern Herring
Gerreidae	Gerres subfasciatus	Common Silverbiddy
Gobiidae	Glossogobius biocellatus	Estuary Goby
Hemiramphidae	Hyporhamphus dussumieri	Slender Garfish
Leiognathidae	Leiognathus equulus	Common Ponyfish
Leptobramidae	*Leptobrama muelleri*	Beach Salmon
Mugilidae	Liza subviridis	Greenback Mullet
Lutjanidae	Lutjanus russelli	Moses Perch
Mugilidae	Mugil cephalus	Sea Mullet
Clupeidae	Nematolosa erebi	Bony Bream
Platycephalidae	Platycephalus indicus	Bar-tail Flathead
Sciaenidae	*Protonibea diacanthus*	Black Jewfish
Scatophagidae	Scatophagus argus	Spotted Scat
Carangidae	Scomberoides commersonnianus	Giant Queenfish
Portunidae	Scylla serrata	Mud Crab
Sillaginidae	Sillago ciliata	Sand Whiting
Scatophagidae	Selenotoca multifasciata	Striped Scat
Siganidae	Siganus lineatus	Goldlined Rabbit Fish
Sphyraenidae	Sphyraena jello	Pickhandle Barracuda
Engraulidae	Stolephorus waitei	Spottyface Anchovy
Tetraodontidae	Tetractenos hamiltoni	Common Toadfish

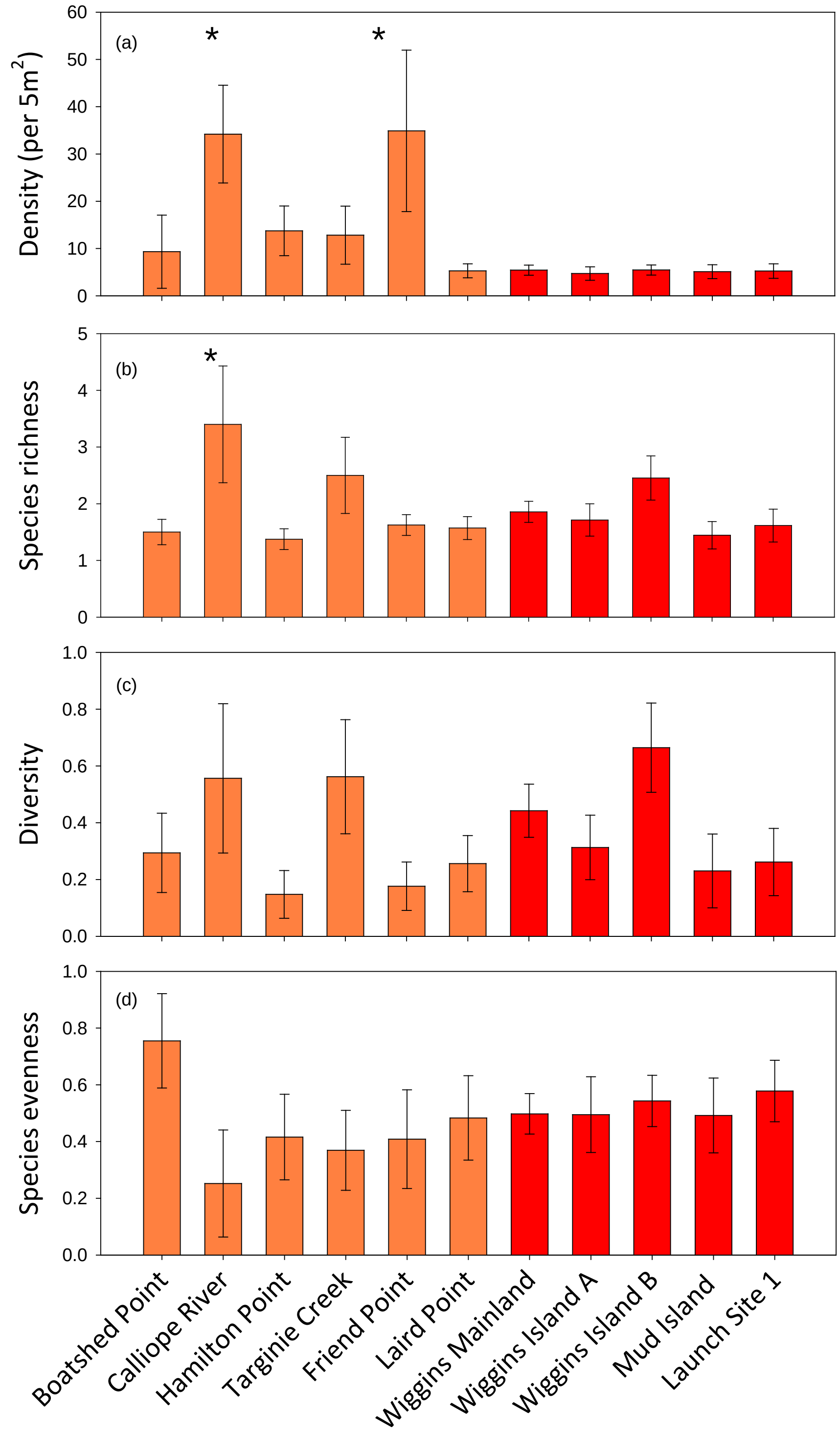


Figure 22. Mean (±se) nekton (a) density, (b) species richness, (c) diversity and (d) species evenness (per 5 m^2) within Port Curtis and Calliope River using a cast net (Ø3 m). * Denote significant ($P < 0.05$) differences among sites. Orange bars denote Phase I sites (May 2010) and red bars denote Phase II sites (Feb 2011).

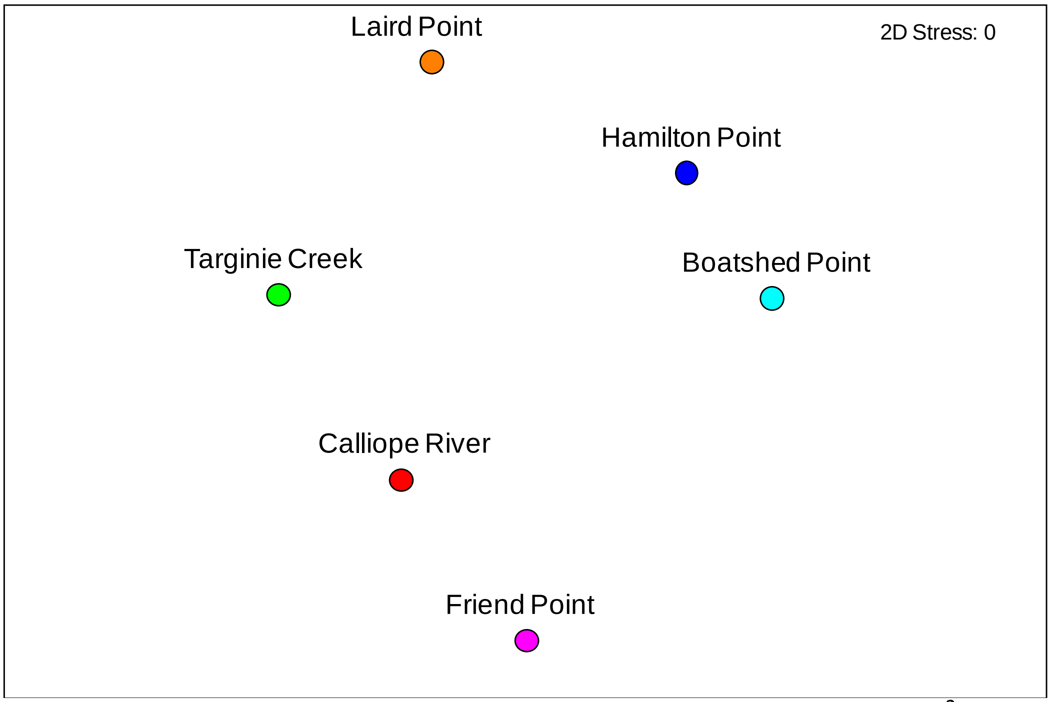


Figure 23. 2D Ordination plots (*n*-MDS) of nekton assemblages (per 5 m^2) surveyed during the Phase I monitoring program using a cast net (Ø3 m). Matrix calculated using Bray-Curtis similarity at sites within Port Curtis. Data were standardised and weight dispersion corrected.

Figure 24. 2D Ordination plots (*n*-MDS) of nekton assemblages (per 5 m^2) surveyed during the Phase II monitoring program using a cast net (Ø3 m). Matrix calculated using Bray-Curtis similarity at sites within Port Curtis. Data were standardised and weight dispersion corrected.

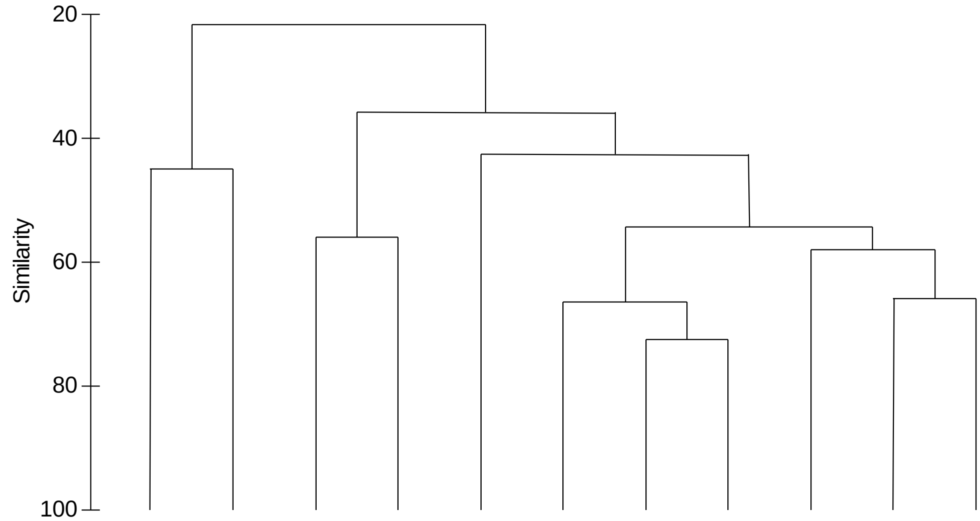


Figure 25. Cluster analysis of grouped site averages for Phase I and II fish assemblage data. Data were standardised and analysed using Bray-Curtis similarly indices.

Three baitfish species that were common among most sites during the Phase I sampling event were the greenback mullet, the southern herring, and the spotty-face anchovy (Figure 26). The smallest greenback mullet size classes recorded within all sites was in Targinie Creek, with an average size range of 30 mm to 120 mm total length (TL). Boatshed Point, Calliope River and Hamilton Point had moderate sized mullet, ranging from 120 mm to 150 mm in total length, and The Narrows had the largest mullet, ranging between 150 mm to greater than 180 mm. Southern herring were similar in size classes (TL: 60 mm to 90 mm) throughout all sites except for The Narrows, where they were absent. The Narrows had the smallest size class of spotty-face anchovy (TL: 30 mm to 50 mm), with Calliope River, Hamilton Point and Targinie Creek hosting the largest sizes (TL: 70 - > 130 mm; Figure 26). The greenback mullet was the only baitfish to be encountered at all sites during the Phase II sampling trip, with highest frequencies of smaller fish encountered in the Wiggins Mainland and Launch Site 1 sites (Figure 27). Sizes ranged from 90-170 mm (Figure 27).

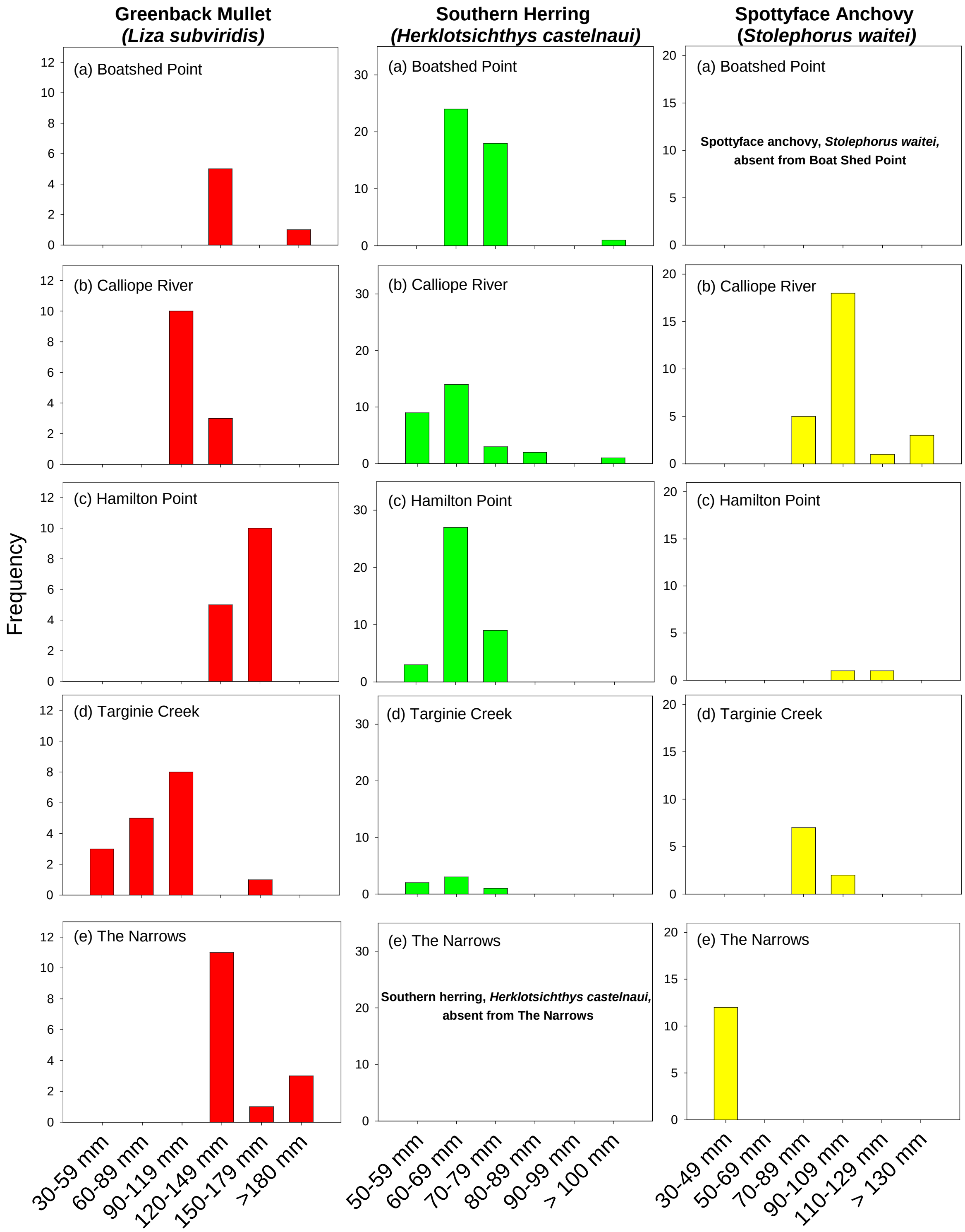


Figure 26. Size frequency histograms of the three most common baitfish collected during Phase I by cast net at all sites, including greenback mullet (red bars), southern herring (green bars) and spottyface anchovy (yellow bars).

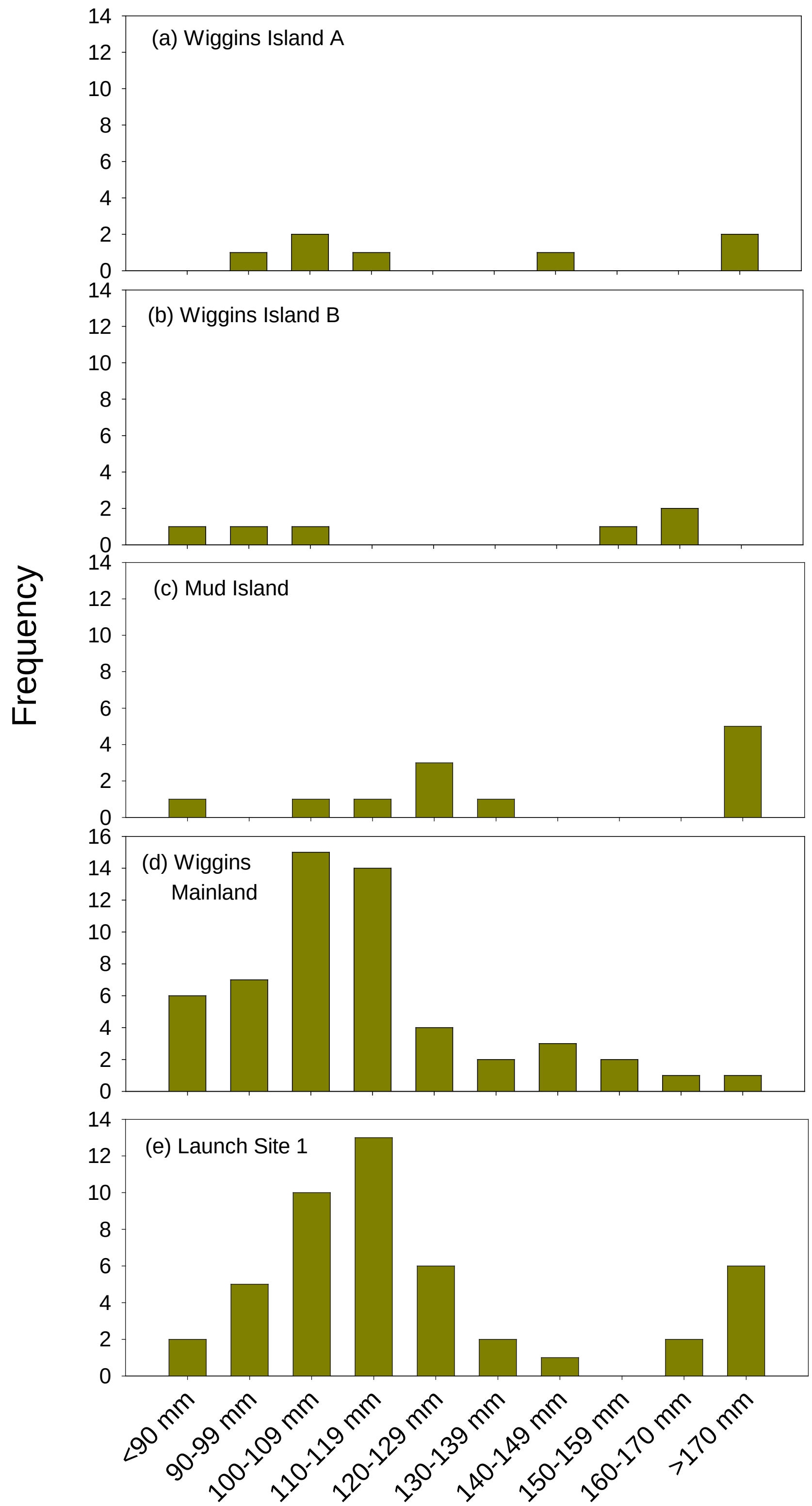


Figure 27. Size frequency histograms of the greenback mullet collected during Phase II by cast net at all sites.

For larger nekton, representative of deeper channels, Boatshed Point had the highest relative abundance and species richness compared to all other sites during Phase I monitoring, followed by Hamilton Point and The Narrows (Table 13). Targinie Creek had the least amount of biodiversity representing larger nekton size classes. During Phase II monitoring, Wiggins Island had the highest relative abundance and species richness, followed by Wiggins Mainland and Mud Island, with Launch Site 1 reporting the lowest numbers (Table 14).

Table 13. Relative abundance and species richness of larger nekton in Port Curtis during Phase I using a 60 m panel net (2', 3' & 4') soaked for 2 hours at each site.

	Relative abundance	Species richness
Boatshed Point	11	5
Calliope River	2	2
Hamilton Point	6	5
Targinie Creek	1	1
The Narrows	3	3

Table 14. Relative abundance and species richness of larger nekton in the Calliope River during Phase II using a 60 m panel net (2', 3' & 4') soaked for 2 hours at each site.

	Relative abundance	Species richness
Wiggins Mainland	2	2
Wiggins Is A	4	3
Wiggins Is B	4	4
Mud Island	2	2
Launch Site 1	1	1

4.0 DISCUSSION

4.1 Water Quality

Changes to marine and estuarine water quality can be attributed to seasonal and/or natural processes such as wind, waves, currents and rainfall. However, water quality can also be affected by land-based pressures such as industrial and urban development, potentially affecting fragile habitats and coastal zones.

Although there were no significant differences in water quality parameters among sites within each monitoring program, there were some differences between Phase I and Phase II, with slightly elevated temperatures observed during the February 2011 Phase II monitoring program when compared to the May 2010 Phase I program, mainly due to higher air temperatures at the time of year. Conductivity was also lower during Phase II of the monitoring program compared to Phase I, most probably attributed to increased freshwater runoff during the wetter season. Moreover, the wet season of 2010-2011 was one of the wettest ever recorded (Bureau of Meteorology). This also explains the elevated turbidity in the water during Phase II, associated with resuspended particles in the water column from freshwater discharge in neighbouring creeks and rivers.

4.2 Sediments

Hydrodynamic forces such as wave action, tides, currents and rainfall can have an effect on deposition and resuspension of sediment carbon content as well as organic inputs such as mangroves (Meksumpun *et al*., 2005; Sakamaki and Nishimura, 2007). Changes in these hydrodynamic forces can ultimately lead to changes in carbon content inputs within sediments. During the Phase II sampling (wet season February 2011), a significant amount of carbon content (was reported at most sites, particularly the subtidal sites, compared to the Phase I sampling (dry season May 2010). The most likely source was runoff from large rainfall events during the wet season.

Small changes in sediment size classes can be attributed to many factors, including wave action, currents and discharge from local point sources (Wright and Mason, 1999; McAnally and Mehta, 2002; Sakamaki and Nishimura, 2007). Changes to local hydrology can affect sediment deposition and resuspension rates, ultimately affecting macroinvertebrate assemblages (Valente *et al*., 1999; Koel and Stevenson, 2002; Kaller and Hartman, 2004; Peeters *et al*., 2004). Higher mud/silt sediment fractions were recorded during the Phase I monitoring program in both intertidal and subtidal sites. Given that the Phase I monitoring program was conducted during the dry season, with low rainfall and runoff from neighbouring creeks and rivers, low energy sediment deposition may have accounted for the higher mud/silt fractions, particularly in the more open bays. However, larger particle sizes were evident at Targinie Creek and The Narrows, which have smaller areas with larger volumes of water, and hence, higher currents. This was also the case at all sites within the Calliope River during the Phase II monitoring program, with larger sediment fractions observed, particularly in the main channel (subtidal), with intertidal areas acting as potential depositional zones.

4.3 Macroinvertebrates (Seagrass)

Dominant seagrass beds have been recorded within Port Curtis in the past, particularly in areas around Fishermans Landing, Grahams Creek, Quoin Island and Wiggins Island (Connolly et al., 2006; Thomas et al., 2010). The seagrass communities within these areas included isolated or aggregated patches of light *Zostera capricorni* and *Halophila ovalis* with lower cover of other mixed species (Thomas et al., 2010). In the current study, there was no evidence of seagrass at any of the study sites for both monitoring phases.

There are many factors that can affect macroinvertebrate richness and biodiversity, such as increased urban and industrial development, as well as changes in sediment chemistry and physical properties. Increased development could result in changes to hydrology, currents and water quality of local streams, creeks and rivers, indirectly affecting freshwater, estuarine and marine macroinvertebrate assemblages by potentially reducing the quality of food and shelter, increasing turbidity and changing sediment particle structure (Cosser, 1988; Koel and Stevenson, 2002; Parr and Mason, 2003; Peeters *et al*., 2004; Angonesi *et al*., 2006; Bishop *et al*., 2006; De Sousa *et al*., 2008). Rainfall, on the other hand, can significantly scour creek channels and alter sediment particle sizes, potentially affecting macroinvertebrate communities (Voelz *et al*., 2000; Carvalho *et al*., 2005; Lucero R *et al*., 2006; Spruzen *et al*., 2008). Minimal disruption to local hydrology, waves and currents, can reduce the rate of change to macroinvertebrate assemblages. Significant differences in macroinvertebrate community composition, abundance, species richness and diversity was observed among sites and over the two monitoring events (Phase I & II). Differences may be attributed to both temporal and spatial variation, given that each site was independent of each other, with no two sites analysed during both sampling events. There were no seagrass beds present in any of the study areas.

4.4 Mangrove Communities

Mangroves are communities of halophytic trees that exist in intertidal zones, often fringing estuarine creeks and river banks (Blasco *et al.*, 1998). Mangrove forests are highly productive and play an important role in nutrient cycling. Mangroves act as nursery areas for a large array of organisms. They provide food for a number of juvenile fish and crustaceans (Manson *et al.*, 2005). In addition, they provide shelter from physical disturbances and protection from predators. Some organisms require specific types of mangroves, ultimately affecting biodiversity. For example, studies have shown that different crab species forage on specific mangrove species, while other predatory crabs and crustaceans indirectly rely on prey that are associated with specific mangrove species (Lee, 1998).

There is a southerly gradient decrease of mangrove species from 36 mangrove species found in Cape York Peninsular, to 20 species in the central Queensland region, including Port Curtis (Table 15), and only nine species found in the Moreton Bay region (Danaher, 1995; Bruinsma *et al.*, 1999).

Mangrove biodiversity can be influenced by tidal exposure and inundation. For example, some species of mangroves that live on the upper reaches of creeks and rivers prefer different water quality attributes such as pH, dissolved oxygen, salinity, sedimentation, wave exposure and organic content to those mangroves that inhabit the lower reaches

(Ridd *et al.*, 1990; Lovelock, 1993). Mangrove biodiversity is also influenced by geographical location, with highest biodiversity found in the warmer parts of the world and lowest biodiversity towards the cooler parts, in this case, a southerly gradient (Duke *et al.*, 1998). In the current study, the main species that contributed to mangrove habitat included the red mangrove, *Rhizophora stylosa,* the yellow mangrove, *Ceriops tagal,* and the grey mangrove, *Avicennia marina,* with significant densities (10-50 trees and 1-2 species per 25 m^2) and canopy cover (50-90%) throughout all sites. A total of 814 ha of mangrove and saltpan habitats were mapped during the two monitoring programs, with *Rhizophora* forests being the dominant species throughout all sites. Differences in mangrove community assemblages may be susceptible to changes in hydrology and land use, affecting rates of sedimentation, organic and nutrient input or inundation rates. Changing rates of sedimentation, organic loads, freshwater input and/or nutrient and contaminant loads due to increased urban and industrial pressures can have an effect on mangrove forest integrity, thus, ultimately changing community structure over time (Primavera, 2000; Islam and Wahab, 2005; Thu and Populus, 2007). Given that mangroves play an important host to a number of species, a change in mangrove communities can ultimately affect the trophic dynamics of overlaying mangrove and soft sediment food webs.

Table 15. Common mangrove species found in the central Queensland bioregion.

Species name	Common name
Acanthus ilicifolius	Holly mangrove
Acrostichum speciosum	Mangrove fern
Aegialitis annulata	Club mangrove
Aegiceras corniculatum	River mangrove
Avicennia marina	Grey mangrove
Bruguiera gymnorrhiza	Large-leafed orange mangrove
Bruguiera parviflora	Small-leafed orange mangrove
Ceriops tagal	Yellow mangrove
Crinum pedunculatum	Mangrove lily
Cynometra iripa	Wrinkle pod mangrove
Excoecaria agallocha	Milky mangrove
Heritiera littoralis	Looking-glass mangrove
Hibiscus tiliaceus	Native hibiscus
Lumnitzera racemosa	Black mangrove
Osbornia octodonta	Myrtle mangrove
Sonneratia alba	Mangrove apple
Rhizophora apiculata	Tall-stilted mangrove
Rhizophora stylosa	Red mangrove
Xylocarpus granatum	Cannonball mangrove
Xylocarpus mekongensis	Cedar mangrove

4.5 Nekton Assemblages

Many fish and larger macroinvertebrate species (nekton) occur in different marine, coastal, estuarine and freshwater habitats during their ontogenetic development. Fish assemblages can vary depending on the number of available aquatic habitats with a mixture of obligate freshwater species, which exist in the upper reaches of catchments trapped by weirs and/or dams, and diadromous fishes that live in both estuarine and freshwater environments of varying salinities throughout their life history (Moore, 1982; Leis, 2002; Hagan and Able, 2003; Manson *et al*., 2005). Fish passageways are important in maintaining connectivity between freshwater, estuarine and marine habitats, particularly for the diadromous fish species that require both environments during their development.

It is widely accepted that mangroves play an important role in the life history of many commercially and recreationally important fisheries (Laegdsgaard and Johnson, 2001; Ikejima *et al*., 2003; Manson *et al*., 2005; Alfaro *et al*., 2006). Some fish species depend on mangroves exclusively while others use the mangroves during a particular time in their life cycle, however, there are many fish species that use mangroves as transient locations to obtain immediate food and/or shelter (Laegdsgaard and Johnson, 2001; Manson *et al*., 2005). A study by Manson *et al.* (2005) demonstrated that many juvenile fish species used mangroves as nursery habitats. The results from the study showed that an increased mangrove habitat density was positively related to an increased numbers of juvenile fish assemblages.

In the current study, 53% of nekton sampled by cast net were categorised as offshore spawners that used estuaries as nursery grounds during their juvenile stages, 31% of nekton were offshore spawners that were usually found in estuaries throughout all life-history stages, 13% were visitors that appeared in estuaries for brief irregular visits and 3% were estuarine and freshwater spawners. The banana prawn and common ponyfish were the most common organisms that used estuaries as nursery grounds during their juvenile stages. The southern herring was the most common visitor that appeared in estuaries for brief irregular visits, and the estuarine glassfish made up the highest number of estuarine and freshwater spawners.

Differences in fish size classes among sites may be attributed to a number of factors including habitat type, connectivity, food resources and predation (Johnston and Sheaves, 2007; Johnston *et al*., 2007; Abrantes and Sheaves, 2009; Baker and Sheaves, 2009a, b; Sheaves, 2009). Although the southern herring and the spotty-face anchovy were common at all sites during the first monitoring trip (Phase I), there were very few numbers of these species in only some sites during the second sampling trip (Phase II). However, the greenback mullet was very common at all sites for both sampling trips, suggesting possible local migration during different times of the year or increased predation.

Other habitats adjacent to mangrove forests include mud flats, rocky reefs and seagrass beds (Hindell, 2006). Although seagrass beds are extensively used by juvenile fishes, studies have shown that large predatory fish inhabit seagrass beds at night. Seagrass beds supply ample habitat structure for refuge as well as provide food to many commercially and recreationally important fisheries (Hindell, 2006). Seagrass beds host a number of invertebrate communities as well, which provide staple food sources for many recreationally and commercially important fisheries (Coles et al., 1987; Coles et al., 1993). Although no seagrass beds were found in any of the sites within the study areas, it is well known that seagrasses and other habitat linkages provide crucial trophic links between macroinvertebrates and higher order fish assemblages (Coles et al., 1993; Manson et al., 2005).

The introduction of man-made weirs, dredging, port infrastructure and increased shipping can potentially affect habitat structure and crucial passageways, reducing the overall fish biodiversity to particular areas of Port Curtis. Furthermore, industrial infrastructure can have potential effects to estuarine hydrodynamics, affecting water quality and ultimately, nursery habitats and overlaying estuarine food webs (Primavera, 2000; Stephens and Farris, 2004; Camargo and Alonso, 2006).

5.0 CONCLUSIONS

In the current study, there were differences in particle size distribution and carbon content among sites, potentially due to differences in catchments areas or river discharge volumes. Sediment contaminant levels, including metals, OP/OC pesticides and PAH's, were within background concentrations within the Calliope River, with slightly higher concentrations observed at Launch Site 4N. Although seagrass has been recorded within Port Curtis in the past, particularly in areas around Fishermans Landing, Grahams Creek, Quoin Island and Wiggins Island, there was no evidence of seagrass at any of the study sites for both monitoring programs.

Overall, there were very few differences in macroinvertebrate and fish biodiversity within all sites during the two monitoring programs. Although there were few observed species of conservation value, such as the green turtle, the bull shark, and spotted eagle ray, biodiversity was representatively similar throughout sites within Port Curtis. Some sites were higher in densities and species richness, however, these differences were most probably attributed to natural seasonal migrations, given that biodiversity is variable in space and time. Changes to existing hydrology, disturbance and/or removal of sensitive habitat, as well as a decline in water quality (point source and diffusive pollution), can potentially alter species assemblages.

The development of LNG industry port infrastructure such as material offloading facilities, jetties and marine terminal facilities can have a number of interrelated effects on marine and estuarine habitats if not managed sustainably. For example, subtle changes in hydrology due to port infrastructure development can affect sediment deposition and resuspension rates, affecting particle size distribution and carbon content to localized habitats. Changes to sediment composition can then affect macroinvertebrate community assemblages and ultimately overlaying food webs, such as larger macroinvertebrate and fish (nekton) communities.

Mangrove communities supply significant habitat structure and refuge as well as provide food to numerous commercially and recreationally important macroinvertebrate and fish communities. Further, mangroves provide sediment stability and reduce erosion. Currently, there are significant mangrove forests within the study area. It is important that removal of mangroves is reduced to a minimum to avoid impacts from altered sediment transport and deposition in adjacent waterways.

6.0 REFERENCES

Able, K.W., 2005. A re-examination of fish estuarine dependence: Evidence for connectivity between estuarine and ocean habitats. Estuarine, Coastal and Shelf Science 64, 5-17.

Abrantes, K., Sheaves, M., 2009. Sources of nutrition supporting juvenile penaeid prawns in an Australian dry tropics estuary. Marine and Freshwater Research 60, 949-959.

Alfaro, A.C., Thomas, F., Sergent, L., Duxbury, M., 2006. Identification of trophic interactions within an estuarine food web (northern New Zealand) using fatty acid biomarkers and stable isotopes. Estuarine, Coastal and Shelf Science 70, 271-286.

Angonesi, L.G., Bemvenuti, C.E., Gandra, M.S., 2006. Effects of dredged sediment disposal on the coastal marine macrobenthic assemblage in southern Brazil. Brazilian Journal of Biology 66, 413-420.

ANZECC/ARMCANZ, 2000a. National Sediment Quality Guidelines. Australia and New Zealand Environment and Conservation Council & Agriculture and Resource Management

ANZECC/ARMCANZ, 2000b. National Water Quality Guidelines. Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Baker, R., Sheaves, M., 2009a. Overlooked small and juvenile piscivores dominate shallow-water estuarine "refuges" in tropical Australia. Estuarine, Coastal and Shelf Science 85, 618-626.

Baker, R., Sheaves, M., 2009b. Refugees or ravenous predators: Detecting predation on new recruits to tropical estuarine nurseries. Wetlands Ecology and Management 17, 317-330.

Bishop, M.J., Peterson, C.H., Summerson, H.C., Lenihan, H.S., Grabowski, J.H., 2006. Deposition and long-shore transport of dredge spoils to nourish beaches: Impacts on benthic infauna of an ebb-tidal delta. Journal of Coastal Research 22, 530-546.

Blasco, F., Gauquelin, T., Rasolofoharinoro, M., Denis, J., Aizpuru, M., Caldairou, V., 1998. Recent advances in mangrove studies using remote sensing data. Marine and Freshwater Research 49, 287-296.

Bruinsma, C., Danaher, K., Treloar, P., Sheppard, R., 1999. Queensland and coastal wetlands resource investigation of the Bowen region: Cape Upstart to Gloucester Island. Queensland Department of Primary Industries Fisheries, Brisbane.

Cai, L., Ji, K.F., Hyde, K.D., 2006. Variation between freshwater and terrestrial fungal communities on decaying bamboo culms. Antonie van Leeuwenhoek 89, 293-301.

Camargo, J.A., Alonso, Á., 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International 32, 831-849.

Carvalho, S., Moura, A., Gaspar, M.B., Pereira, P., Cancela da Fonseca, L., Falc, Drago, T., Leit, Regala, J., 2005. Spatial and inter-annual variability of the macrobenthic communities within a coastal lagoon (bidos lagoon) and its relationship with environmental parameters. Acta Oecologica 27, 143-159.

Clarke, K.E., 1993. Non-parametric multivariate analyses of change in community structure. Australian Journal of Ecology 18, 117-143.

Coles, R.G., Lee Long, W.J., Squire, B.A., Squire, L.C., Bibby, J.M., 1987. Distribution of seagrasses and associated juvenile commercial penaeid prawns in north-eastern Queensland waters. Marine and Freshwater Research 38, 103-119.

Coles, R.G., Lee Long, W.J., Watson, R.A., Derbyshire, K.J., 1993. Distribution of seagrasses, and their fish and penaeid prawn communities, in Cairns harbour, a tropical estuary, Northern Queensland, Australia. Marine and Freshwater Research 44, 193-210.

Connolly, R.M., Currie, D.R., Danaher, K.F., Dunning, M., Melzer, A., Platten, J.R., Shearer, D., Stratford, P.J., Teasdale, P.R., M., V., 2006. Intertidal wetlands of Port Curtis: Ecological patterns and processes, and their implications. Technical Report No. 43. CRC for Coastal Zone, Estuary and Waterway Management, Brisbane.

Cosser, P.R., 1988. Macroinvertebrate community structure and chemistry of an organically polluted creek in south-east Queensland. Marine and Freshwater Research 39, 671-683.

Danaher, K., 1995. Coastal wetlands resources investigation of the Burdekin Delta for declaration as fisheries reserve: Report to the Ocean rescue 2000. Queensland Department of Primary Industries.

Danaher, K., Rasheed, M., Thomas, R., 2005. The intertidal wetlands of Port Curtis. Information series QIO5031. Department of Primary Industries and Fisheries, Queensland.

De Sousa, S., Pinel-Alloul, B., Cattaneo, A., 2008. Response of littoral macroinvertebrate communities on rocks and sediments to lake residential development. Canadian Journal of Fisheries and Aquatic Sciences 65, 1206-1216.

Duke, N.C., Ball, M.C., J.C., E., 1998. Factors influencing biodiversity and distributional gradients in mangroves. Global Ecology and Biogeography Letters 7, 27-47.

ERDAS, 2009. ERDAS Field Guide™. ERDAS, Inc.

GBRMPA, 1998. Great Barrier Reef Marine Park - Mackay Capricorn Section zoning information. Great Barrier Reef Marine Park Authority, Townsville, Australia.

Hagan, S.M., Able, K.W., 2003. Seasonal changes of the pelagic fish assemblage in a temperate estuary. Estuarine, Coastal and Shelf Science 56, 15-29.

Hill, M.O., 1973. Diversity and Evenness: A Unifying Notation and Its Consequences. Ecology 54, 427-432.

Hindell, J.S., 2006. Assessing the trophic link between seagrass habitats and piscivorous fishes. Marine and Freshwater Research 57, 121-131.

Ikejima, K., Tongnunui, P., Medej, T., Taniuchi, T., 2003. Juvenile and small fishes in a mangrove estuary in Trang province, Thailand: seasonal and habitat differences. Estuarine, Coastal and Shelf Science 56, 447-457.

Islam, M.S., Wahab, M.A., 2005. A review on the present status and management of mangrove wetland habitat resources in Bangladesh with emphasis on mangrove fisheries and aquaculture. Hydrobiologia 542, 165-190.

Johnston, R., Sheaves, M., 2007. Small fish and crustaceans demonstrate a preference for particular small-scale habitats when mangrove forests are not accessible. Journal of Experimental Marine Biology and Ecology 353, 164-179.

Johnston, R., Sheaves, M., Molony, B., 2007. Are distributions of fishes in tropical estuaries influenced by turbidity over small spatial scales? Journal of Fish Biology 71, 657-671.

Kaller, M.D., Hartman, K.J., 2004. Evidence of a threshold level of fine sediment accumulation for altering benthic macroinvertebrate communities. Hydrobiologia 518, 95-104.

Koel, T.M., Stevenson, K.E., 2002. Effects of dredge material placement on benthic macroinvertebrates of the Illinois River. Hydrobiologia 474, 229-238.

Krishnamurty, K.V., Spirt, E., Reddy, M.M., 1976. Trace metal extraction of soils and sediments by nitric acid-hydrogen peroxide. Atomic Absorption Newsletter 15, 68-70.

Krogh, M., Scanes, P., 1996. Organochlorine Compound and Trace Metal Contaminants in Fish near Sydney's Ocean Outfalls. Marine Pollution Bulletin 33, 213-225.

Laegdsgaard, P., Johnson, C., 2001. Why do juvenile fish utilise mangrove habitats? Journal of Experimental Marine Biology and Ecology 257, 229-253.

Lee, S.Y., 1998. Ecological role of grapsid crabs in mangrove ecosystems: a review. Marine and Freshwater Research 49, 335-343.

Leis, J.M., 2002. Pacific Coral-reef Fishes: The Implications of Behaviour and Ecology of Larvae for Biodiversity and Conservation, and a Reassessment of the Open Population Paradigm. Environmental Biology of Fishes 65, 199-208.

Lovelock, C., 1993. Field Guide to the Mangroves of Queensland. Australian Institute of Marine Science, Townsville.

Lucero R, C.H., Cantera K, J.R., Romero, I.C., 2006. Variability of macrobenthic assemblages under abnormal climatic conditions in a small scale tropical estuary. Estuarine, Coastal and Shelf Science 68, 17-26.

Manson, F.J., Loneragan, N.R., Harch, B.D., Skilleter, G.A., Williams, L., 2005. A broad-scale analysis of links between coastal fisheries production and mangrove extent: A case-study for northeastern Australia. Fisheries Research 74, 69-85.

McAnally, W.H., Mehta, A.J., 2002. Significance of Aggregation of Fine Sediment Particles in Their Deposition. Estuarine, Coastal and Shelf Science 54, 643-653.

McClatchie, S., Millar, R.B., Webster, F., Lester, P.J., Hurst, R., Bagley, N., 1997. Demersal fish community diversity off New Zealand: Is it related to depth, latitude and regional surface phytoplankton? Deep Sea Research Part I: Oceanographic Research Papers 44, 647-667.

Meksumpun, S., Meksumpun, C., Hoshika, A., Mishima, Y., Tanimoto, T., 2005. Stable carbon and nitrogen isotope ratios of sediment in the gulf of Thailand: Evidence for understanding of marine environment. Continental Shelf Research 25, 1905-1915.

Moore, R., 1982. Spawning and early life history of burramundi, <I>Lates calcarifer</I> (Bloch), in Papua New Guinea. Marine and Freshwater Research 33, 647-661.

Nero, V.L., Sealey, K.S., 2005. Characterization of tropical near-shore fish communities by coastal habitat status on spatially complex island systems. Environmental Biology of Fishes 73, 437-444.

O'Neill, M.E., 2000. Theory & Methods A Weighted Least Squares Approach to Levene's Test of Homogeneity of Variance. Australian & New Zealand Journal of Statistics 42, 81-100.

Parr, L.B., Mason, C.F., 2003. Long-term trends in water quality and their impact on macroinvertebrate assemblages in eutrophic lowland rivers. Water Research 37, 2969-2979.

Peeters, E., Gylstra, R., Vos, J.H., 2004. Benthic macroinvertebrate community structure in relation to food and environmental variables. Hydrobiologia 519, 103-115.

Primavera, J.H., 2000. Development and conservation of Philippine mangroves: institutional issues. Ecological Economics 35, 91-106.

Ray, G.C., 2005. Connectivities of estuarine fishes to the coastal realm. Estuarine, Coastal and Shelf Science 64, 18-32.

Ridd, P.V., Wolanski, E., Mazda, Y., 1990. Longitudinal diffusion in mangrove-fringed tidal creeks. Estuarine, Coastal and Shelf Science 31, 541-554.

Roberts, D., 1996a. Patterns in subtidal marine assemblages associated with a deep-water sewage outfall. Marine and Freshwater Research 47, 1-9.

Roberts, D.E., 1996b. Effects of the North Head Deep-water Sewage Outfall on Nearshore Coastal Reef Macrobenthic Assemblages. Marine Pollution Bulletin 33, 303-308.

Sakamaki, T., Nishimura, O., 2007. Physical control of sediment carbon content in an estuarine tidal flat system (Nanakita River, Japan): A mechanistic case study. Estuarine, Coastal and Shelf Science 73, 781-791.

Secor, H., Rooker, J.R., 2005. Connectivity in the life histories of fishes that use estuaries. Estuarine, Coastal and Shelf Science 64, 1-3.

Sheaves, M., 2009. Consequences of ecological connectivity: The coastal ecosystem mosaic. Marine Ecology Progress Series 391, 107-115.

Smith, A.K., Ajani, P.A., Roberts, D.E., 1999. Spatial and temporal variation in fish assemblages exposed to sewage and implications for management. Marine Environmental Research 47, 241-260.

Smith, A.K., Suthers, I.M., 1999. Effects of sewage effluent discharge on the abundance, condition and mortality of hulafish, Trachinops taeniatus (Plesiopidae). Environmental Pollution 106, 97-106.

Spruzen, F.L., Richardson, A.M.M., Woehler, E.J., 2008. Spatial variation of intertidal macroinvertebrates and environmental variables in Robbins Passage wetlands, NW Tasmania. Hydrobiologia 598, 325-342.

Stephens, W.W., Farris, J.L., 2004. Instream community assessment of aquaculture effluents. Aquaculture 231, 149-162.

Terlizzi, A., Fraschetti, S., Guidetti, P., Boero, F., 2002. The effects of sewage discharge on shallow hard substrate sessile assemblages. Marine Pollution Bulletin 44, 544-550.

Thomas, R., Unsworth, R.K.F., Rasheed, M., 2010. Seagrasses of Port Curtis and Rodds Bay and long term seagrass monitoring. (DEEDI, Cairns).

Thu, P.M., Populus, J., 2007. Status and changes of mangrove forest in Mekong Delta: Case study in Tra Vinh, Vietnam. Estuarine, Coastal and Shelf Science 71, 98-109.

Underwood, A.J., 1997. Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge University Press, Cambridge, U.K.

Valente, R.M., McChesney, S.M., Hodgson, G., 1999. Benthic recolonization following cessation of dredged material disposal in Mirs Bay, Hong Kong. Journal of Marine Environmental Engineering 5, 257-288.

Voelz, N.J., Shieh, S.H., Ward, J.V., 2000. Long-term monitoring of benthic macroinvertebrate community structure: a perspective from a Colorado river*. Aquatic Ecology 34, 261-278.

Warwick, R.M., 1993. Environmental impact studies on marine communities: Pragmatical considerations. Austral Ecology 18, 63-80.

Wright, P., Mason, C.F., 1999. Spatial and seasonal variation in heavy metals in the sediments and biota of two adjacent estuaries, the Orwell and the Stour, in eastern England. The Science of the Total Environment 226, 139-156.

Zar, 1996. Biostatistical analysis. Prentice-Hall, New Jersey.

7.0 GLOSSARY

Diadromous fishes:

Diadromous fishes are fishes that require both freshwater and marine habitats to complete their life cycle. Examples of diadromous fish include eels and barramundi.

Halophytic:

Halophytic plants are plants that have adapted to grow, or can tolerate saline environments. Environments can include marine intertidal areas and semi-saline deserts.

Nekton assemblages

Nekton refers to active swimming aquatic or marine organisms in a body of water that are able to move independent of water currents. Organisms can include vertebrate species such as fishes and invertebrate species such as crabs and prawns. The alternative to nekton is plankton, which are organisms that passively float or drift in a body of water.

Ontogenetic development:

Ontogenetic development is the life history or process of development of an organism from conception, through birth and growth to adulthood. It encompasses all aspects of development.

Obligate species:

An obligate species is a species that is bound by a very specific environment. For example, an obligate parasite cannot live independent of its host.

Rhizomes:

Rhizomes are underground horizontal stems of plants that often send shoots and roots from its nodes.

Appendix I

Mean (±se) sediment metal concentrations among sites during the Phase II monitoring program. < Values denotes below instrument detection limits. Units are in µg/g dry sediment weight.

Sites	C1	C2	C3	C4	C5	4N	Guidelines
Aluminium							
Intertidal	17449 ± 527	11099 ± 2536	10727 ± 1455	8652 ± 373	9216 ± 750	13037 ± 618	-
Subtidal	3230 ± 360	2860 ± 150	9860 ± 2387	2692 ± 157	3823 ± 468	14009 ± 419	
Arsenic							
Intertidal	9.4 ± 0.8	8.8 ± 0.3	8.5 ± 0.6	6.9 ± 0.8	7.8 ± 0.6	14.3 ± 0.8	20
Subtidal	3.4 ± 0.1	3.5 ± 0.1	5.1 ± 0.6	2.2 ± 0.1	3.3 ± 0.3	11.0 ± 0.7	
Cadmium							
Intertidal	0.05 ± 0.01	0.03 ± 0.001	0.03 ± 0.002	0.02 ± 0.001	0.02 ± 0.001	0.02 ± 0.001	1.5
Subtidal	0	0	0.01 ± 0.003	0	0.01 ± 0.0038	0.03 ± 0.001	
Chromium							
Intertidal	19.7 ± 0.4	18.2 ± 0.9	17.2 ± 1.2	14.7 ± 0.8	14.1 ± 1.3	21.9 ± 1.0	80
Subtidal	6. ± 0.4	6.4 ± 0.4	12.9 ± 2.1	5.6 ± 0.3	8.5 ± 0.7	22.4 ± 0.4	
Copper							
Intertidal	29.4 ± 0.9	17.5 ± 0.8	16.9 ± 1.7	12.4 ± 0.8	11.7 ± 1.1	13.1 ± 0.7	65
Subtidal	4.7 ± 0.6	4.0 ± 0.1	11.0 ± 2.6	3.1 ± 0.1	6.3 ± 0.7	17.4 ± 0.5	
Cobalt							
Intertidal	14.7 ± 0.9	9.6 ± 0.4	9.8 ± 0.6	8.4 ± 0.3	8.3 ± 0.7	32.3 ± 2.7	-
Subtidal	5.1 ± 0.2	5.0 ± 0.1	7.5 ± 1.0	4.0 ± 0.1	5.4 ± 0.3	18.1 ± 1.2	
Nickel							
Intertidal	14.0 ± 0.3	11.3 ± 0.6	10.9 ± 1.0	8.8 ± 0.5	8.8 ± 0.8	15.2 ± 0.9	21
Subtidal	4.1 ± 0.3	4.0 ± 0.1	7.7 ± 1.3	3.2 ± 0.1	4.9 ± 0.43	14.3 ± 0.3	
Lead							
Intertidal	7.1 ± 0.1	6.1 ± 0.3	6.2 ± 0.5	5.2 ± 0.4	4.6 ± 0.4	6.6 ± 0.3	50
Subtidal	1.9 ± 0.1	1.6 ± 0.1	3.8 ± 0.6	1.2 ± 0.1	2.8 ± 0.3	7.5 ± 0.1	
Zinc							
Intertidal	50.8 ± 1.1	41.3 ± 1.8	37.4 ± 2.6	34.3 ± 1.8	28.5 ± 2.6	69.0 ± 3.6	200
Subtidal	14.2 ± 1.0	13.2 ± 0.3	28.2 ± 4.9	9.1 ± 0.4	18.7 ± 1.6	51.9 ± 1.5	
Manganese							
Intertidal	517 ± 11	227 ± 20	158 ± 15	239 ± 36	189 ± 34	380 ± 24	-
Subtidal	247 ± 14	262 ± 8	282 ± 84	192 ± 11	138 ± 6	287 ± 5	
Iron							
Intertidal	30858 ± 499	22219 ±900	20841 ± 2001	17128 ± 952	16522 ± 1902	39558 ± 1768	-
Subtidal	9016 ± 475	8600 ± 308	17014 ± 2962	6517 ± 119	9657 ± 694	30549 ± 906	

Appendix II

Mean (±se) sediment Polynuclear Aromatic Hydrocarbon (PAH) concentrations among sites during the Phase II monitoring program. < Values denotes below instrument detection limits. Units are in µg/g dry sediment weight. Inter denotes intertidal sites and sub denotes subtidal sites. Numbers in (brackets) denote low interim sediment quality guidelines.

	C1		C2		C3		C4		C5		4N	
Analytes	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**
Naphthalene (160)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Acenaphthylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Acenaphthene (44)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluorene (19)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Phenanthrene (240)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Anthracene (85)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluoranthene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Pyrene (665)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benz(a)anthracene (261)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chrysene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(b)fluoranthene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(k)fluoranthene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(a)pyrene (430)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Indeno(1.2.3.cd)pyrene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dibenz(a.h)anthracene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Benzo(g.h.i)perylene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sum of PAHs	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Appendix III

Mean (±se) sediment organochloride (OC) pesticide concentrations among sites during the Phase II monitoring program. < Values denotes below instrument detection limits. Units are in µg/g dry sediment weight. Inter denotes intertidal sites and sub denotes subtidal sites.

	C1		C2		C3		C4		C5		4N	
Analytes	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**
alpha-BHC	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Hexachlorobenzene (HCB)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
beta-BHC	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
gamma-BHC	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
delta-BHC	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Heptachlor	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Aldrin	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Heptachlor epoxide	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
trans-Chlordane	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
alpha-Endosulfan	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
cis-Chlordane	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dieldrin	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4.4`-DDE	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Endrin	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
beta-Endosulfan	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Endrin aldehyde	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Endosulfan sulfate	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4.4`-DDT	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Endrin ketone	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Methoxychlor	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Appendix IV

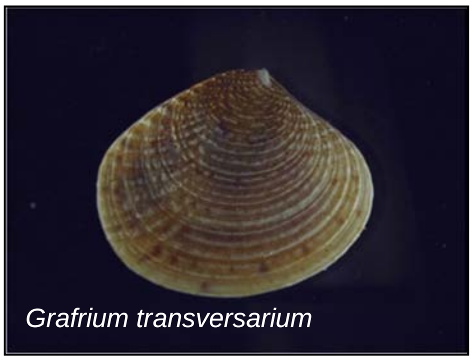
Mean (±se) sediment organophosphate (OP) pesticide concentrations among sites during the Phase II monitoring program. < Values denotes below instrument detection limits. Units are in µg/g dry sediment weight. Inter denotes intertidal sites and sub denotes subtidal sites.

	C1		C2		C3		C4		C5		4N	
Analytes	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**	**Inter**	**Sub**
Dichlorvos	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Demeton-S-methyl	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Monocrotophos	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Dimethoate	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Diazinon	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chlorpyrifos-methyl	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Parathion-methyl	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Malathion	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Fenthion	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chlorpyrifos	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Parathion	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Pirimphos-ethyl	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chlorfenvinphos	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Bromophos-ethyl	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Fenamiphos	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Prothiofos	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ethion	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Carbophenothion	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Azinphos Methyl	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

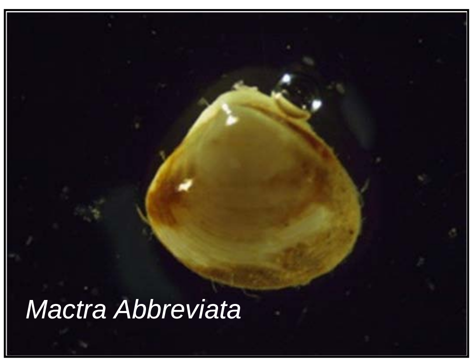
Appendix V


Arcidae sp. 2


Azorinus sp. 2


Grafrium transversarium


Nuclana Scaedleda crassa


Mactra Abbreviata

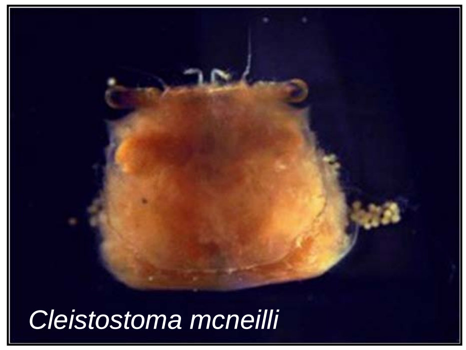

Tellina sp. 15

Appendix VI

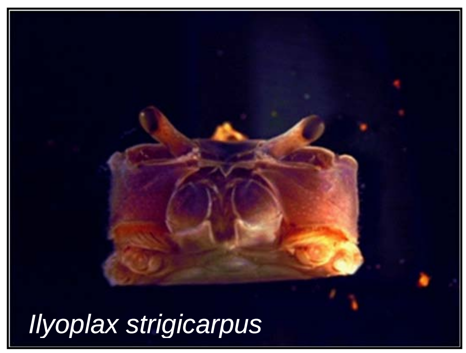

Grandidierella sp. 1


Alpheus pacifica


Ogyrides delli


Cleistostoma mcneilli


Corophium acutum


Ilyoplax strigicarpus

Appendix VII

Isolda pulchella

Amphinomida sp. 4

Notomastus sp. 2

Eunice vittata

Glycera sp. 1

Nephtys sp. 1

Nereis sp. 1

Sternapis scutata

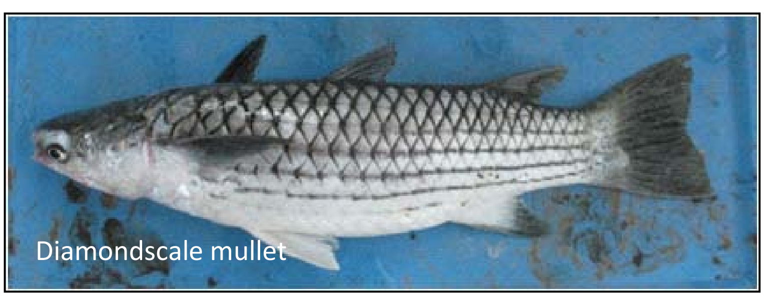
Appendix VIII

Spottyface anchovy

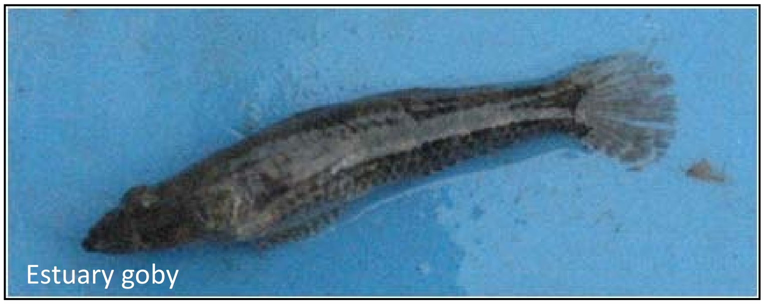
Pick-handle barracuda

Bar-tail flathead

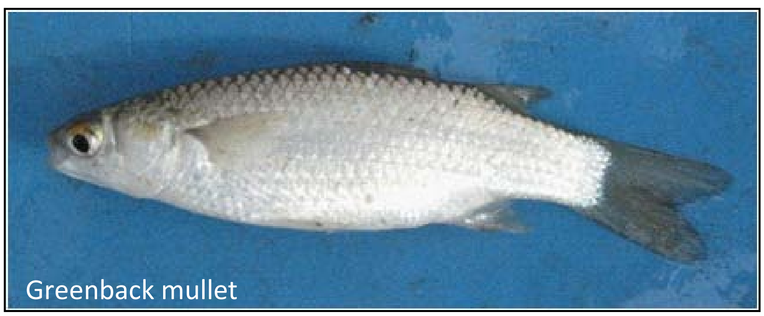
Blue threadfin



Diamondscale mullet


Estuary goby


Estuary glassfish

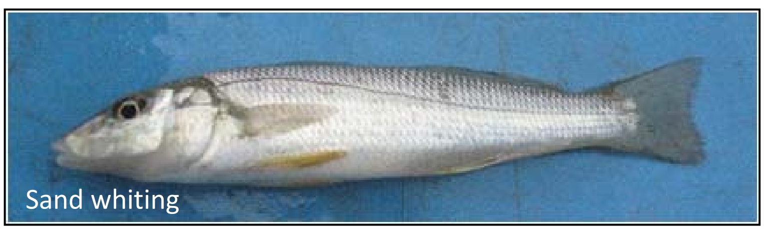

Greenback mullet

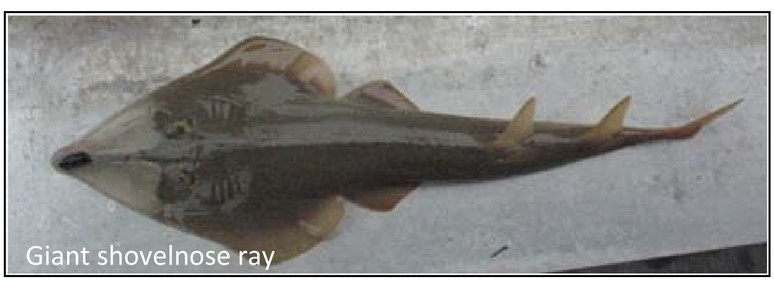

Barred grunter


Slender garfish


Grey mackerel


Milk-spotted pufferfish


Sand whiting

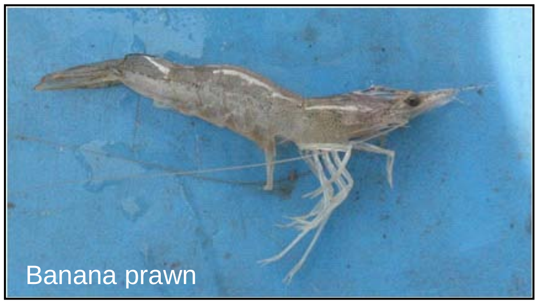

Giant shovelnose ray


Common silver biddy


Southern herring

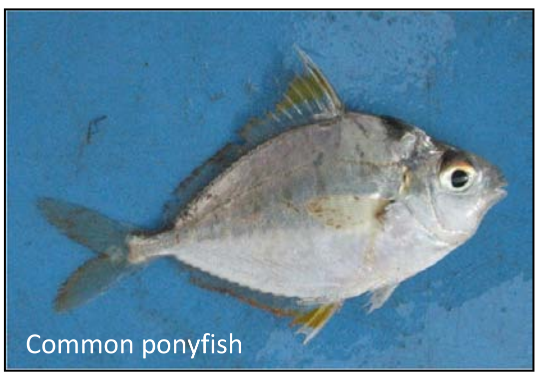

Beach salmon


Narrow-lined pufferfish



Banana prawn

Mud crab



Common ponyfish

Spotted scat


Black jewfish


Blue catfish


Bull shark


Moses Perch


Epaulette trevaly


Rabbit fish