Technical Appendix S1

Ichthys Gas Field Development Project: the benthic environment of the Ichthys Project—invertebrate fauna, habitats and impacts

INPEX Browse, Ltd.
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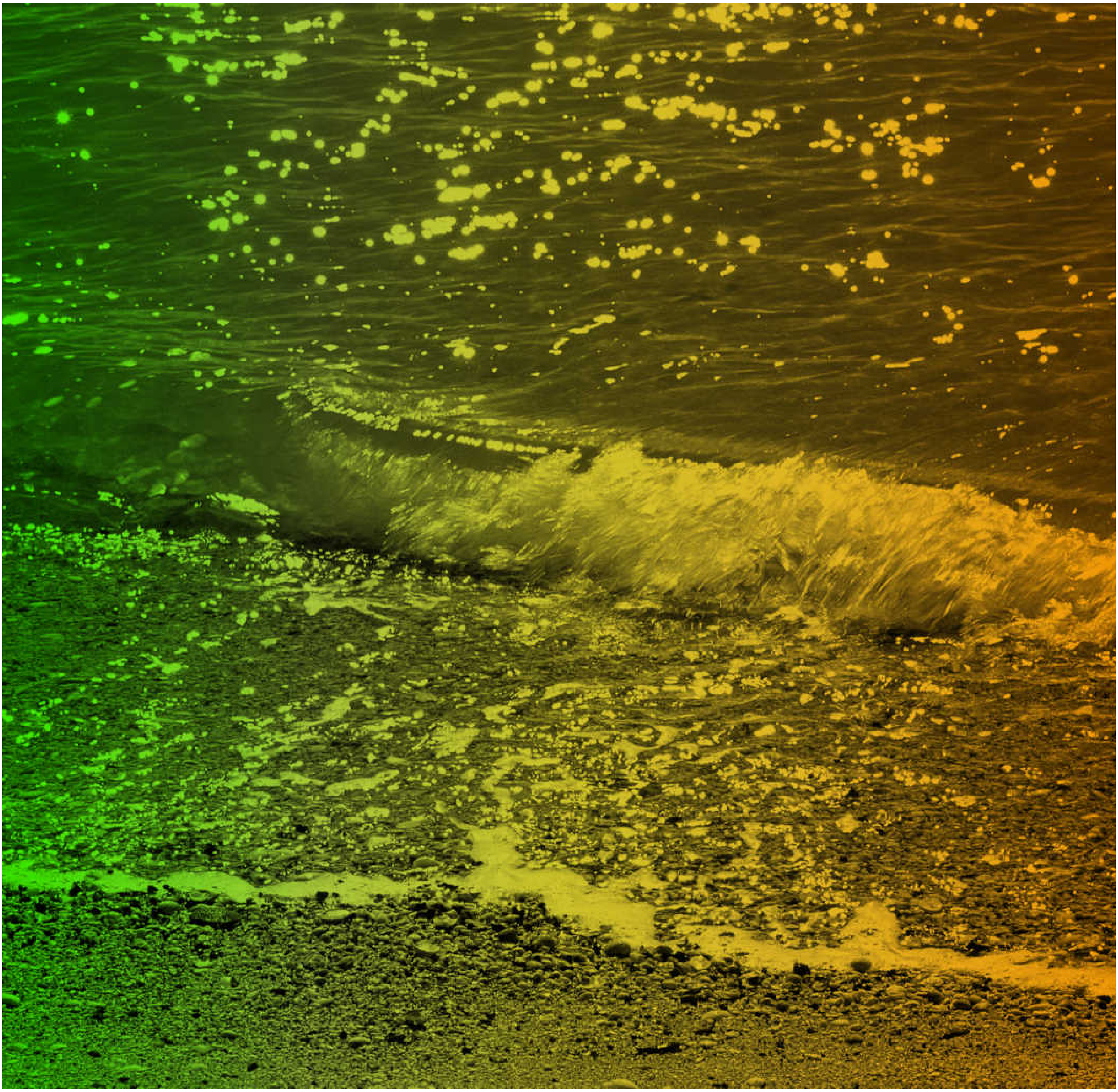

Ichthys Gas Field Development Project: the benthic environment of the Ichthys Project—invertebrate fauna, habitats and impacts

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1.0 Purpose

The purpose of this document is to support the preparation of a supplement to the Draft Environmental Impact Statement (EIS) for the Ichthys Gas Field Development Project. It addresses specific topics relating to the benthic ecosystem of Darwin Harbour and the adjacent offshore region. As a literature review the document collates, reviews and discusses information from research publications, technical reports and environmental impact assessments. The document focuses on:

- Soft substrate habitats and the invertebrate fauna that colonises them
- Filter feeder communities colonising hard substrates in Darwin Harbour and the Browse Basin.
- The potential impacts of dredging activities and associated disturbances on the benthic communities
- The resilience and recovery potential of benthic fauna in the context of the Ichthys project
- Maintenance of the trophic structure as a contributor to ecosystem resilience.

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2.0 Impact Assessment at Ecosystem Level

Environmental legislation and guidance emphasise that impacts from a proposed project ultimately need to be assessed with respect to the effects they have on the integrity and function of the ecosystem.

The term ecosystem describes a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. It is characterised by energy and matter flows between the different elements that compose it. In the context of conservation and environmental protection and management, ecosystem approaches are favoured because they emphasise 'interconnectedness' of physical, chemical and biological components thus providing both an integrative and holistic perspective that facilitates/aids impact assessment. The importance of environmental protection at the ecosystem level is postulated in the Convention of Biological Diversity that has been ratified by 192 countries elevating it to global political significance (United Nations Environment Programme 1992). Australia commits to an ecosystem approach stating in its Biodiversity Conservation Strategy: "An ecosystem approach to biodiversity conservation should be used to maximise conservation outcomes" (National Biodiversity Strategy Task Group 2009). Similarly environmental impact assessment policies and legislation at State level require consideration of the ecosystem. The Environmental Protection Authority (EPA) in Western Australia, for example, has used the ecosystem approach to develop its principles and risk-based environmental protection framework (Environmental Protection Authority (WA) 2004). Similarly, the Northern Territory environmental impact assessment process includes ecosystem considerations (NT Environment Protection Authority 2009). The Darwin Harbour Regional Management Strategic Framework for instance states that one of its goals is ensuring the function of its ecosystems is maintained (Darwin Harbour Advisory Committee 2009).

In order to comply with the EIA process it is important that impacts can be described and interpreted in the ecosystem context. This means that the major elements of the ecosystem and its functioning have to be understood in order to recognise what impacts an ecosystem can tolerate before major structural changes occur, and how reversible these changes are.

However, the ecosystem approach is a more conceptual, less practical approach. Very often ecosystem properties and boundaries are abstract and the complex details of ecosystem interactions are not well understood (Olenin and Ducrotoy 2006). To reduce complexity ecosystems can be broken down into smaller components. In the case of a marine ecosystem two interacting subsystems, benthic and pelagic, are commonly distinguished. The benthic ecosystem relates to the seafloor, its substrates and colonising biota (benthos). The pelagic realm (pelagial) describes the water column with its organisms. Benthos represents a large component of marine biodiversity and ecosystem productivity. It is the focus of this report.

Its major properties are:

- Structure
- Function
- Dynamics.

Biodiversity is an element of the benthic ecosystem. Its different components, such as habitats and species and their interactions with the environment define part of the structure, function and dynamics of the ecosystem.

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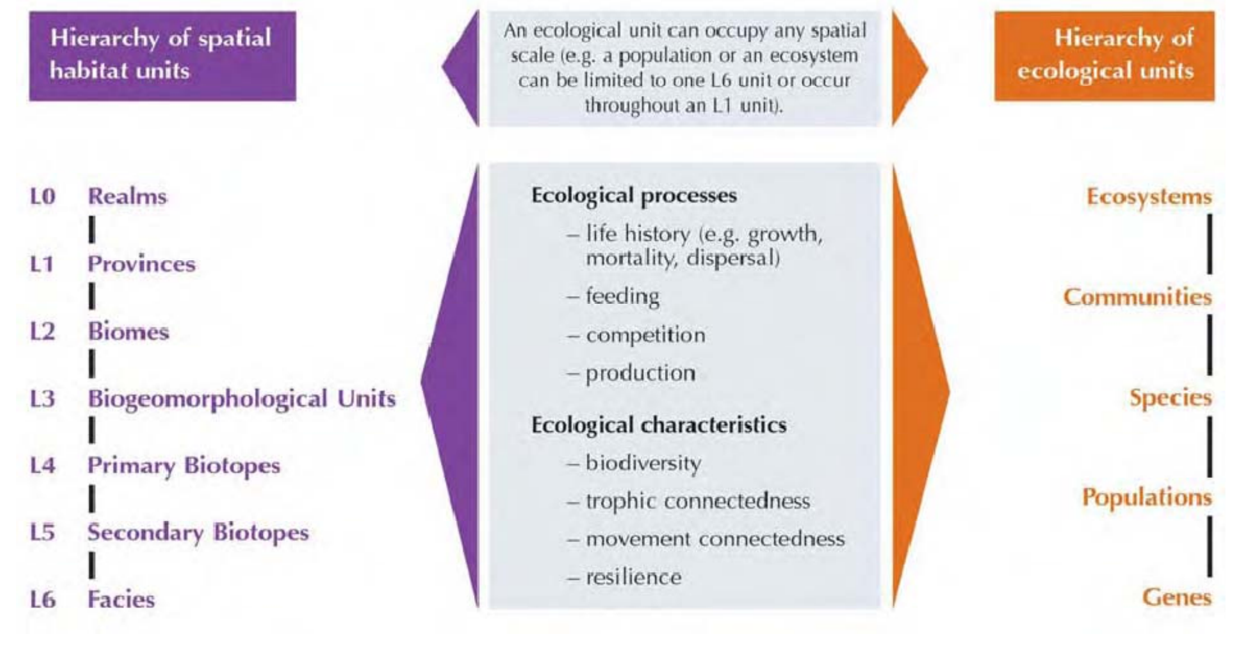
3.0 Fauna Diversity, Distribution, Composition and the Assessment of Impacts

Fauna diversity as part of marine biodiversity is an important characteristic of ecosystems. It can be described on many different levels and geographic scales. An overview of such ecological levels and spatial scales is shown in Figure 1. Which levels and scales are appropriate choices to describe and assess the environment depends on the context of the investigation and the questions to be addressed.



Proposed hierarchical structuring of marine biodiversity using either habitat (left tree) or ecological (right tree) descriptors. The habitat levels are spatially-based while the ecological levels may traverse a number of habitat levels – depending on the ecological question(s) under investigation (the linkages in the middle). For example, a fish species may rely primarily upon a small number of biotopes (Level 4/5) within which it feeds, but larvae of that species may disperse over a much wider area characterised by a biome (Level 2). The habitat classification used here (left tree) is designated as the CSIRO Habitat Classification Version 1.2.

Figure 1 Spatial scales and ecological levels of biodiversity reproduced from (Lyne et al. 2006)

The Ichthys Gas Field Development Project has a spatially defined footprint that includes an area of the Ichthys Field, a narrow pipeline corridor from the Ichthys Field to Darwin Harbour and an infrastructure and associated impact footprint in Darwin Harbour. This layout informs the choice of spatial units for ecological considerations. The questions to be addressed within this spatial context relate to the development activities and the disturbances they cause to the environment, in particular the level of impact the marine ecosystem will suffer. It is important to determine whether the anticipated disturbances are likely to damage the ecosystem irreversibly. To achieve this, an adequate level of ecological information has to form the basis of such an impact assessment.

The project extends over four different bioregions: Oceanic Shoals, North West Shelf, Bonaparte Gulf and Anson Beagle (INPEX Browse, Ltd. 2010). Using these ecological units, defined by biological and physical characteristics including the distribution of demersal fishes and benthic invertebrates, seafloor geomorphology and sediments as well as oceanographic data, structures the approach to understanding the ecosystem and its possible responses to impacts. Following this concept, a systematic approach of describing the ecological environment is presented in the Draft EIS (INPEX Browse, Ltd. 2010). The literature review undertaken here synthesises information from research studies and technical reports relating it to impact relevant spatial scales and ecological units. The type and detail of faunal and habitat information required to inform an impact assessment at ecosystem level is here discussed by first evaluating categories of biodiversity such as habitats, functional groups and taxonomic groups in light of their ability to reflect important characteristics and processes of the ecosystem. Subsequently the type and level of information for three focus areas is reviewed and assessed with respect to whether they can provide sufficient detail to support an impact assessment at ecosystem level:

- The benthic fauna of the Darwin Harbour Region, and the Browse Basin
- Soft substrate habitats
- Epifaunal filter feeder communities of hard substrates.

Descriptors of diversity that are commonly used are:

- Habitat Units
- Functional Groups
- Taxonomic Groups.

3.1 Habitat Units

Habitat diversity is often used as an indicator and surrogate for species diversity. Habitat types such as coral reef, intertidal mudflat or seagrass bed already define a level of complexity and associated diversity of life forms. In impact assessment it is a useful unit to consider because the size of habitats is of a relevant scale to many development activities and impacts are often habitat specific. In the ecosystem context habitat degradation, destruction, fragmentation and loss are important impact assessment considerations (Fraschetti et al. 2008).

3.2 Functional Groups

Functional groups also express diversity while describing a functional unit within the ecosystem. Functional groups can be defined by the structure they provide as habitat formers or habitat modifiers. Hard corals, for example, build biogenic structures that become habitats to other animals and plants. Examples of habitat modifiers are infaunal groups that change the structure of sediments by their bioturbation activity. Functional groups can also be defined on the basis of their feeding mode such as filter feeders or the trophic level they represent such as benthic primary producers. Other functional groups are defined by their sensitivity profile which makes them indicator species for anthropogenic impacts or natural environmental changes. Keystone species are species whose impact on the community or ecosystem is large or disproportionally large relative to their abundance.

3.3 Taxonomic Groups

The species is a basic taxon that represents an evolutionary unit in nature. This fact makes it a good descriptor of diversity. Each species has specific adaptations, sensitivities and tolerances defining an ecological niche. Species richness for a defined area is the most commonly used measure of diversity. Species are placed within a phylogenetic system that ideally reflects their evolutionary history and forms superior taxa such as genera, families, classes and phyla based on shared characteristics.

Depending on the objective of the study, species level identifications may not always be required (Wilson 1998). Some studies provide a taxonomic resolution to family level but (Wilson 1998) questions whether taxonomic levels such as family are useful units in this context. “Higher taxonomic levels are arbitrary groupings that are not intercomparable Taxa, such as families, have differing sizes and differing relative historical significance. Rapidly evolving families may have hundreds of recently evolved species, whereas other families may have only one or two species representing ancient taxa. Although modern taxonomists attempt to group species into monophyletic clades, most existing classifications contain many paraphyletic or, even worse, polyphyletic groups. Such groupings, many of which are poorly understood, substantially degrade any historical significance that might accrue to a truly monophyletic superspecific group. Even worse, different phyla of animals have different taxonomic traditions for creating higher taxa: for example, amphipod crustacean families are highly divided into narrowly defined groups while individual families of polychaete worms may include a broad diversity of forms. By grouping historically independent species into larger arbitrary groups, patterns owing to the distribution of these species may be masked or lost. A single species may have a particular suite of responses to unknown environmental features or other species, but arbitrary groups of species may exhibit many different, possibly conflicting reactions to each other and the environment” (Wilson 1998).

It is argued here that the taxonomic resolution required depends on the objective of the study. In the context of assessing the potential impacts of disturbances at ecosystem level, an analysis based on the diversity and distribution of habitats and functional groups is meaningful and provides insights into biodiversity, trophic structure, interconnectivity and resilience. The example that supports this view is a study investigating the fauna of mangrove habitats in Darwin Harbour (Metcalfe 2007). The author concludes that “Analyses based on functional groups such as feeding guilds, can further simplify ecological investigations, as they may reveal reactions of more general importance than the responses of populations of individual taxa (Bonsdorff and Pearson, 1999). The seminal work by Fauchald and Jumars (1979) and more recently by Pagliosa (2005) on polychaetes provided the foundation for valuable investigations on the faunal response - at the level of feeding guild - to environmental impacts.”

Species level information is required to assess levels of endemicity and to identify indicator and keystone species within an ecosystem. Based on the arguments provided by (Wilson 1998) it is, however, questionable whether information based on family level is superior to the insights that can be derived from habitats and functional groups.

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4.0 Benthic Focus Areas

Impact assessment relies on knowledge of the existing environment of the project area. For instance, in order to determine which habitats and biota are being affected by disturbances, their distribution and diversity has to be understood. Furthermore the types of impacts and their severity and consequence for the whole ecosystem can only be evaluated on the background of a comprehensive understanding of the ecological context. The present literature review aims to discuss and assess potential impacts from development activities on the benthos of the Ichthys Gas Field project development area. To achieve this an overview of the currently available project relevant information is provided in the following sections. To facilitate the processing and interpretation of information the topic has been divided into focus areas.

Two major benthic areas can be distinguished. These are namely the Port of Darwin with its adjacent nearshore shallow region and an offshore area that extends for several hundred kilometres from this nearshore area to the Ichthys Field (Figure 2). The majority of this benthic area consists of soft substrate and their associated fauna. Where hard substrates occur, these are often colonised by sessile filter feeders, in particular sponges and soft corals (Smit, et al. 2000). In turbid environments such a Darwin Harbour the photic zone has only a limited extent (10 metres), (Smit, et al. 2003). Reduced light penetration limits the distribution of marine plants and hard corals that compete for hard substrate habitat leaving the majority of hard substrates to be colonised by organisms that do not rely on photosynthesis.

Benthic focus areas have been selected for more detailed investigation on the basis of their exposure to potential impacts from development activities. The focus areas are:

- Benthic habitats and Invertebrate fauna of Darwin Harbour and shallow nearshore region
    - Infauna and epifauna of soft substrates
    - Filter feeding communities of hard substrates
- Invertebrate fauna of offshore region
    - Infauna and epifauna of soft substrates.

Before impacts on habitats and faunal communities can be discussed, it is necessary to clearly understand and define the classification system that underpins such assessments.

4.1 Benthic Classification System

Benthic habitats are useful categories because they allow studying biodiversity at a spatial scale that is relevant to project development areas and can be investigated with several different techniques. The recognition of benthic habitats and their diversity is underpinned by a hierarchical benthic classification system.

A review of classification systems from Australia and other countries (Ball et al. 2006, Fraschetti et al. 2008) reveals that most consist of several hierarchical levels ranging from more general categories at larger spatial scales to more detailed categories at smaller spatial scales. The most common criteria used to define and select categories are geomorphology, geology, bathymetry, ecology, mapping techniques and study objective. Many top level large scale categories such as continental shelf or abyssal plain are based on geomorphology while substratum type classes such as terrigenous sand or limestone reef refer to geological findings. Zonation type classifications, the most popular referring to the tidal zones, relate to bathymetry and the hydrological regime. Ecologically defined units include colonising biota in relation to their structure (e.g. seagrass beds), function (e.g. filter feeders) or abundances (e.g. *Acropora* dominated reef). The use of satellite image analysis, aerial photography and various acoustic systems for seafloor mapping has led to the selection of categories that these specific techniques recognise. Many studies have a focused approach resulting in a choice of categories that answer a particular question. For example, the category Benthic Primary Producer Habitat (BPPH) is used to respond to the high significance given to Benthic Primary Producers (BPPs) in some impact assessments.

Marine benthic assessments rely on classification systems to structure results and present them in a meaningful context. Such benthic assessments take place on a variety of spatial scales suitable for hierarchical approaches.

Although the existing classification systems have some major conceptual similarities, they vary widely in their application of categories and terminology making it difficult to compare findings and use results for the conservation and management of coastal and marine ecosystems beyond a regional scale. In Australia the development of an ecosystem based classification for marine and coastal environments (IMCRA Technical Group 1998) provides an overarching meso-scale classification system (Figure 2). Local classification systems have been developed in Victoria, Queensland, South Australia, Tasmania and Western Australia (Ball et al. 2006). The most relevant study of this type describes the benthic environment of the North West Shelf providing categories that can be applied to the project area (Lyne et al. 2006).

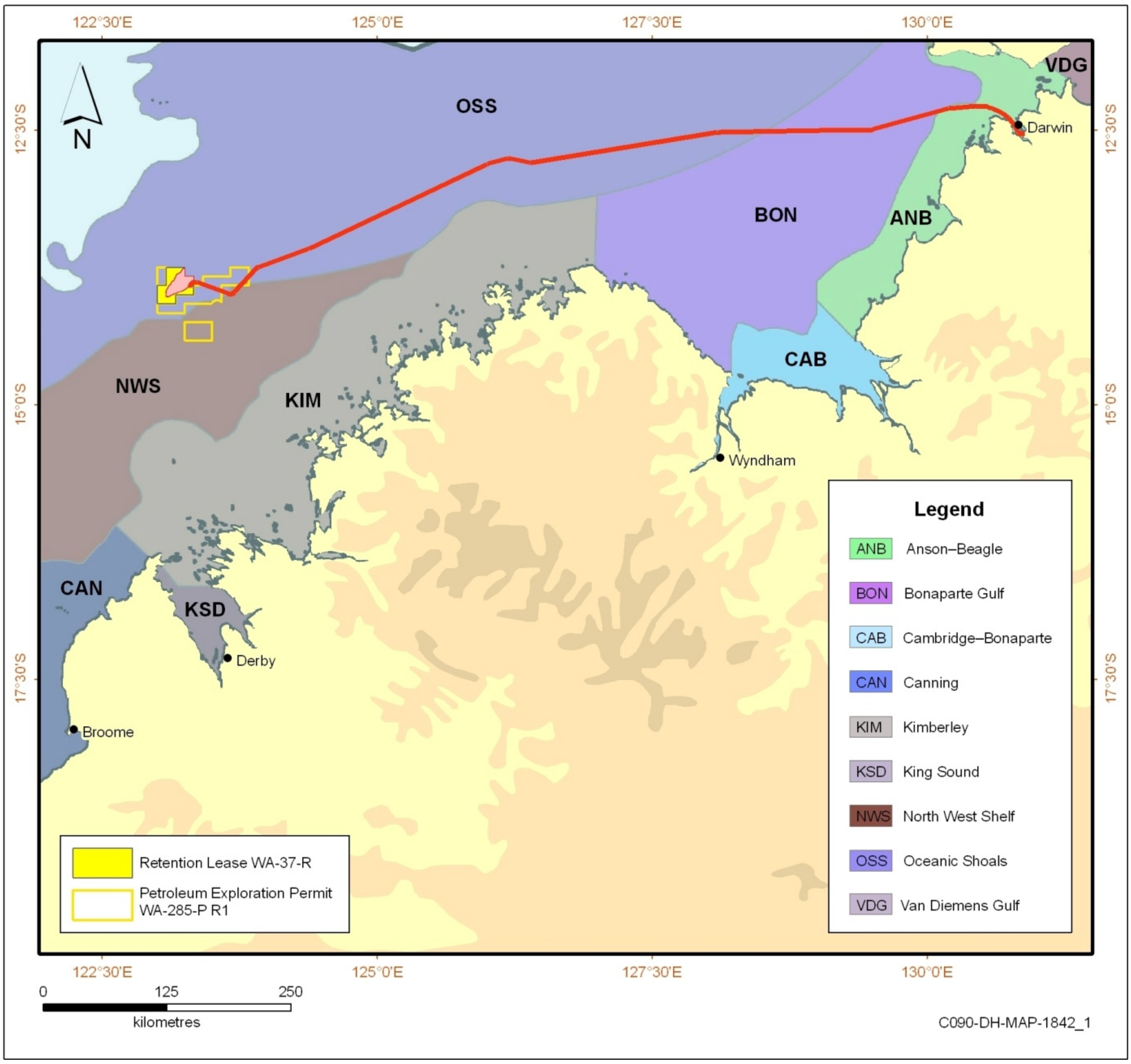


Figure 2 Meso-scale bioregions of north-west Australia within project development area, source (INPEX Browse, Ltd. 2010)

4.2 Benthic Habitats

Considerable development activity and associated disturbances will take place in Darwin Harbour. It is therefore important that the faunal diversity, communities and habitats in this area are understood in sufficient detail to inform impact assessment. For this purpose a benthic habitat map that predicts the distribution of habitats over the entire harbour area has been prepared by Geo Oceans (2011) and is presented in Figure 3. It describes the benthic harbour environment and documents the extent and locations of different habitats. The criteria used for the classification of benthic habitats is documented in a supplementary technical report (Geo Oceans 2011)

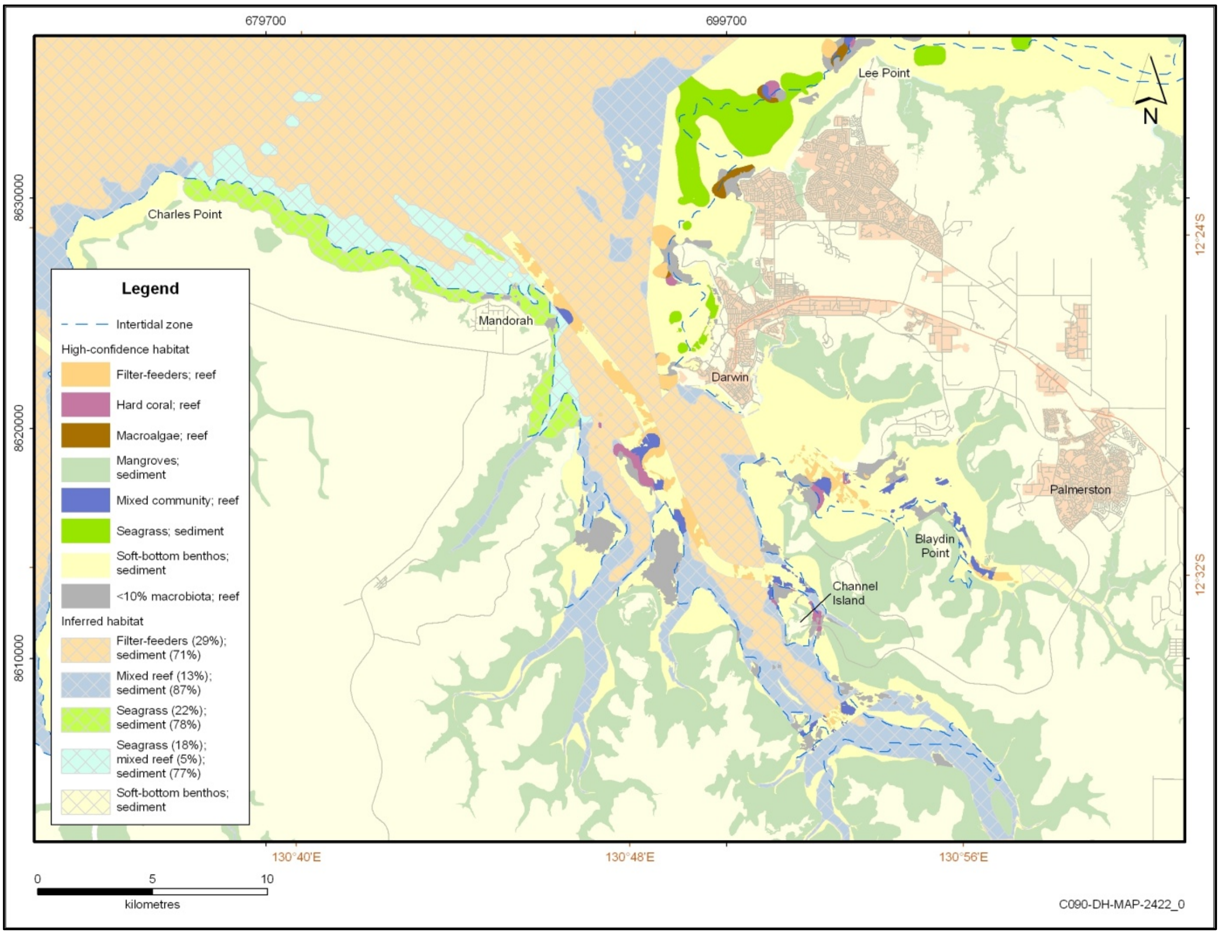


Figure 3 **Habitat map of Darwin Harbour Region (Source: Geo Oceans 2011)**

Currently, a unified habitat definition does not exist in the literature. This is due mainly to the co-existence of multiple classification systems and multiple understandings of the term habitat. Most classification systems, however, include an ecological unit of varying terminology (e.g. eco-units, primary/secondary biotopes, biological facies) that equates to what is generally understood as a local-level habitat (Ball et al*.* 2006).

Habitats can be investigated through the use of a number of mapping and sampling techniques. They have been recognised as basic classification units in defining conservation values, assessing human impacts on the environment and providing a measure for biodiversity. Yet, the diversity and distribution of habitats on a global scale is still not known in sufficient detail (Fraschetti et al*.* 2008). Efforts to fill this gap are limited by a lack of a non-ambiguous and shared habitat classification.

Reviews of the current status of habitat classifications have identified a total of 1121 marine habitat types in the European context alone (Fraschetti et al. 2008). The high number of habitats reflects the diversity of the marine environment but it is also partly due to ambiguous habitat classifications resulting in overlap and assessment at different spatial scales. The coexistence of multiple definitions of what denotes a habitat results in multiple habitat types describing similar environments. For example:

- A space which abiotic factors determine as suitable for colonisation by biota. (Semeniuk et al. 1982)
- A specific type of environment inhabited either permanently or temporarily by organisms (in Ball et al. 2006)
- Environment defined by specific abiotic and biotic factors, in which the species lives at any stage of its biological cycle (in Fraschetti et al. 2008)
- A focus on the dominant features determining structural complexity in the environment such as the presence of plants (e.g. seagrass beds), animals (e.g. oyster beds), or other geological features such as hard substrates and muds (in Fraschetti et al. 2008).

One of the main ambiguities in habitat definitions is the inconsistency in habitat defining criteria, particularly the in- or exclusion of biota.

Habitat definitions that are solely based on abiotic features have shown to be poor surrogates for biodiversity (Stevens 2003, Fraschetti et al. 2008). An analysis of effective habitat definitions supports using tidal level and primary substrate in geological terms as abiotic criteria in combination with biotic criteria. The latter should be based on biota that have structural properties, the so-called habitat formers or are functionally important groups such as bioconstructors, habitat modifiers and ecosystem engineers (Table 1). The ecological significance of a habitat is related to three main structural variables, namely heterogeneity, complexity and relative abundance. This is reflected more clearly through structural and functional properties of the defining biota than through their spatial dominance alone (Fraschetti et al. 2008).

Table 1 Selection of habitat defining criteria

Habitat Defining Criteria	Examples
Abiotic	
Tidal level	Intertidal, subtidal
Geology	Igneous rock, sandstone
Geomorphology	Limestone platform, granite boulder
Sediment	Sand, silt
Biotic	
Habitat formers	Macroalgae, seagrass, coral
Bioconstructors	Hard corals, Serpulid worms (forming worm rocks)
Habitat modifiers, ecosystem engineers	Worms (bioturbation), sea urchins (grazers)
Trophic level	Benthic Primary Producers, filterfeeders
Communities	Sponge/soft coral
Composite Habitats	
Tidal level & morhplogy	Intertidal flat
Tidal level & sediment & morphology	Intertidal mudflat
Geomorphology & geology	Rocky reef, limestone pavement
Biota & geomorphology	Macroalgal bank, coral slope

Another problem in marine benthic habitat definition is that the concept has been derived from the field of terrestrial ecology where vegetation-based habitats with clear boundaries dominate. In the marine environment sessile benthic organisms often function as habitat formers similarly to plants in the terrestrial environment (e.g. Pittman et al. 2004). Distributions of many marine organisms however, are governed by dispersal of planktonic larvae via ocean currents resulting in different distribution patterns than those found in the terrestrial environment. Patchiness at a range of scales is a common feature. Often discrete boundaries around those patches are not readily apparent, their fuzziness caused by a gradient of declining density. To account for these characteristics of the marine environment a new approach integrating general landscape ecology theory into benthic ecology produced the concept of benthoscapes that applies particularly well to soft sediment benthic landscapes (Zajac et al. 2003).

Despite the challenges and uncertainties in the classification and definition of benthic habitats, the marine environment of the Darwin Harbour and Nearshore Region as well as the vast offshore area can been described in many of the currently accepted categories illustrating the habitat defining criteria commonly used. The criteria used for the classification of benthic habitats and for the generation of Darwin Harbour habitat map are provided in Geo Oceans (2011).

4.3 Characteristics of Soft Substrate Habitats in Relation to Faunal Communities

Vast areas of the ocean floor consist of bare or sparsely covered soft substrates such as sand and mud. This is also the case for Darwin Harbour and the adjacent nearshore region and offshore areas. In fact, it is estimated that 80 per cent of the substrates of Darwin Harbour are soft substrates (Smit et al. 2003). Consequently the majority of disturbances and impacts associated with marine developments involving activities such as dredging, excavation, translocation and deposition of materials are affecting soft substrate habitats. It is therefore important to identify these habitats, understand the role they play within the ecosystem and to assess their sensitivity profiles in light of impact sustainability and the maintenance of ecosystem health and integrity.

Traditionally environmental investigations for impact assessment and scientific research in Australia have focussed attention on coral reef and vegetated habitats such as seagrass meadows because of their accepted environmental values reflected by their biodiversity enhancing properties, their sensitivity and global protection profiles and their support of economically important activities such as fisheries.

Unlike the more ‘charismatic’ habitats that are colonised by distinctive fauna such as hard corals, sponge and soft corals or mussel beds, soft substrate habitats often appear visually uniform, extensive and without clearly discernable borders. Colonising fauna of soft substrates is often microscopic in size and has a burrowing habit which does not aid easy recognition and distinction of soft substrate habitats based on their inhabiting fauna.

Yet, it would be wrong to assume homogeneity. Rather, such benthic landscapes (benthoscapes) are heterogeneous and complex environments with rich and fascinating patch structures that vary over a wide range of spatial scales (Zajac et al. 2003).

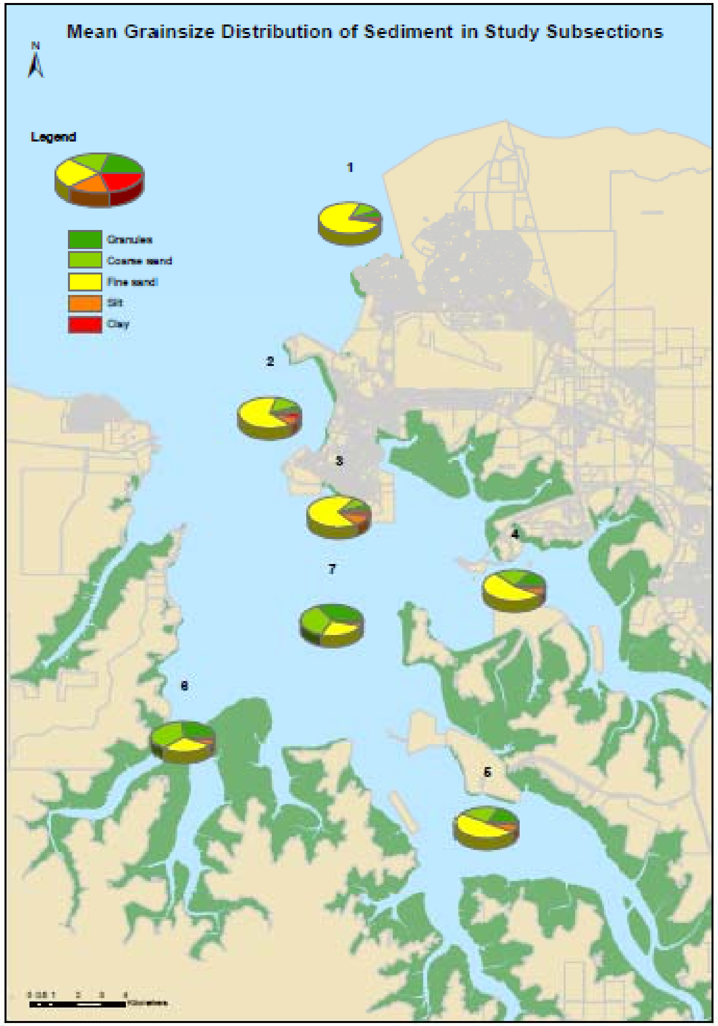
Functionally, “bare sedimentary habitats by their sheer scale and extent relative to other more spatially restricted habitats, are likely to play an important role in cross-habitat exchanges of material and energy, and must be considered as just-as-valuable links in the function of the ecological chain” (Barrio Frojan et al. 2009). Intertidal mudflats, for example, play an important role in regulating primary productivity by storing and recycling nutrients and therefore act as potential buffer against increased nutrient loads (Smith and Haese 2009). They also support demersal fish populations and waders.

To facilitate understanding and capture the specific nature of marine benthic environments dominated by soft substrates new concepts have emerged. These approaches view the seafloor as an underwater landscape with physical and biological characteristics that parallel terrestrial landscapes. Recent studies have investigated how such benthic landscapes termed ‘benthoscapes’ are structured examining specifically the relationship of benthic communities and their substrates (Zajac et al. 2003). An investigation of soft substrate habitat at Long Island Sound (Connecticut, USA) identified distinct benthoscape elements based on the interpretation of side-scan sonar mosaic images. Such elements, each producing a distinct side-scan mosaic signature, were categorised as sand/mud, mud/sand and mixed rubble, for example. The different benthoscape elements were also separable by their infaunal communities with each community showing a distinct species composition and abundance. The consideration of transition zones between identified benthoscape elements revealed variation in the faunal communities with a tendency to increased abundances in transition zones compared to main benthoscape elements (Zajac et al. 2003). This example illustrates the potential complexity of an underwater landscape dominated by soft substrate. The use of side-scan sonar technology to identify soft substrate habitats can be a successful approach particularly when large areas are being investigated. The technique relies on the reflection of sonar signals by the substrate. The way signals are returned depends on the properties of the substrate, its density, topography, thickness and several other factors. A combination of these factors contributes to the side-scan mosaic image. However, such factors can also be investigated separately and analysed with respect to how they may determine the type of inhabiting faunal community.

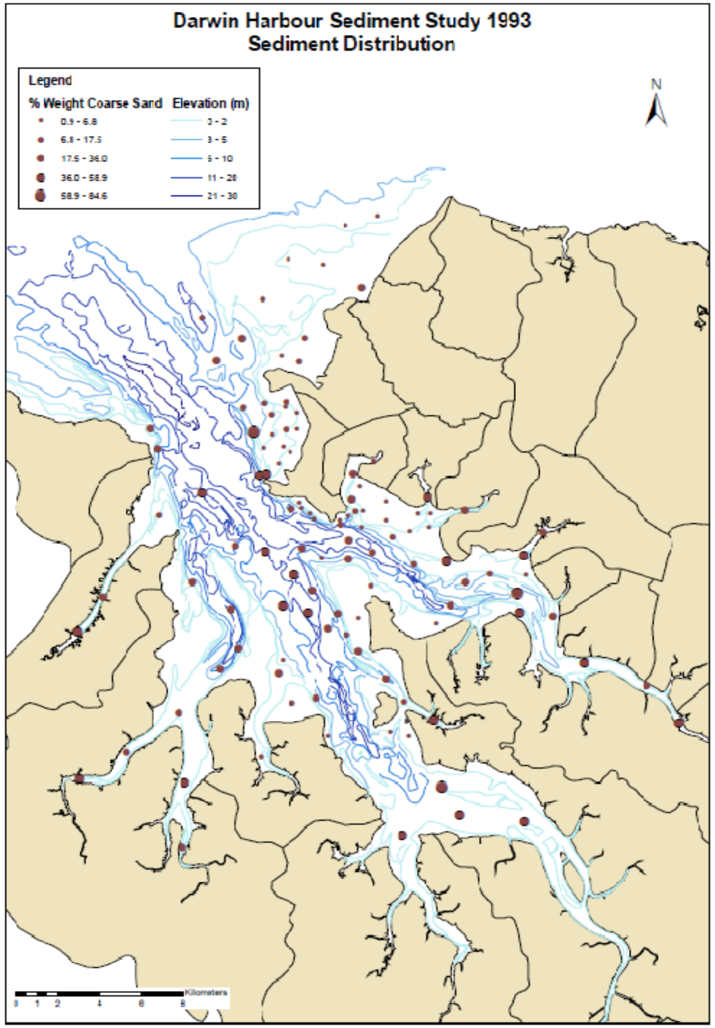
Several studies have investigated the relationship between abiotic factors and faunal communities of soft substrates. Independently of the locations of these studies, they demonstrate that faunal communities and their structures are correlated with a combination of abiotic factors and marine processes. The most commonly investigated include sediment properties such as sediment type classification, grain size and carbonate content, depth, exposure, bedform and sediment mobility.

Grain size of substrates has been identified as an important factor involved in the feeding mechanism of organisms particularly of deposit and suspension feeders. The size and morphological structure of the feeding apparatus determine an optimum grain size range for effective feeding. This is the case for fiddler crabs (Rosenberg 2002). Several species of fiddler crab occur associated with mangrove and mudflat habitat in Darwin Harbour and a relationship between species distribution and grain size of sediments has been documented (Metcalfe 2007). Results of sediment investigations including examples of grain size distributions for Darwin Harbour are shown in Figure 4. They illustrate the variability of sediment types and compositions that create a heterogeneous benthoscape within the harbour area. Distinct faunal communities of foraminiferans have been described from Darwin Harbour reflecting grain size and sediment type distributions (Michie 1987).

Investigations of the nearshore area, namely the Beagle Gulf, has also documented considerable heterogeneity in sediment type distribution and associated grain sizes (Figure 5) and was able to document an association of sediment type and faunal community. The detailed study concludes, however, that there was no single physical parameter that explained the classification for all faunal groups. For instance, the separation of some faunal groups was best explained by latitude and percent gravel content, and related factors (e.g. percent < 2 mm grain size fraction), whereas another faunal group was best explained by percentage mud content (Smit et al. 2000).

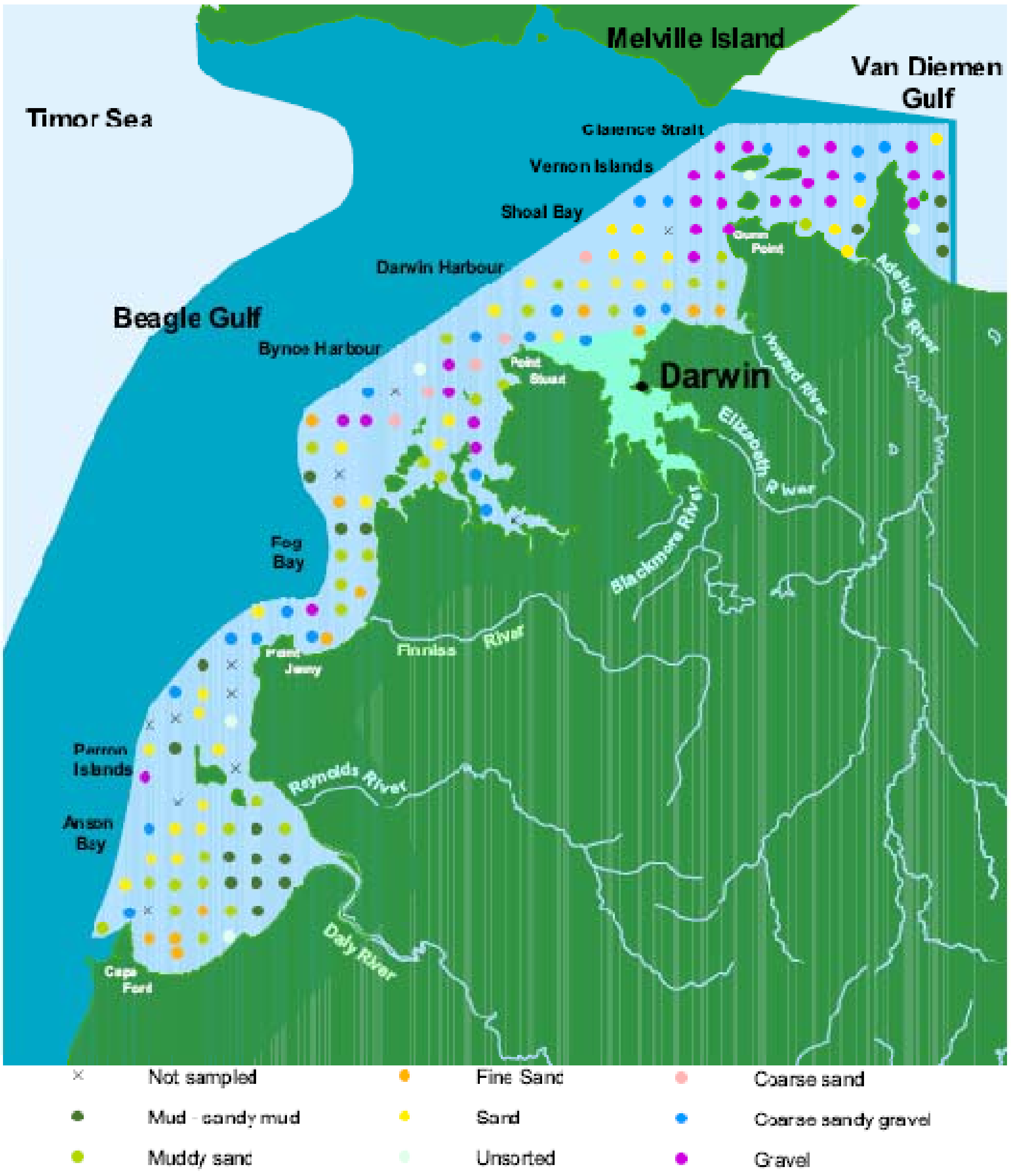


Mean grainsize distribution for sediment study areas



Coarse sand fraction distribution

Figure 4 Examples of sediment composition and distribution from Darwin Harbour (Fortune 2006)



Beagle Gulf Survey, benthic collection sites. depth range: 0 to 35 m.

Figure 5 Sediment distribution based on the classification of sediment grain size, after (Smit et al. 2000)

A study investigating macrofaunal distributions and abundances in the Gulf of Carpentaria (Post et al. 2006) indicates the importance of process-related variables, in particular seabed exposure and sediment mobility, in defining the distribution and diversity of benthic macrofauna. Grain size parameters and water depth were also important factors in delineating benthic communities on both a local and broader scale across the Gulf.

Similar conclusions can be extracted from international studies. Two studies have been selected to provide examples of this. The distribution of macrobenthic assemblages in the Bays of Veys (English Channel) was determined by sediment properties, especially the percentage of fine particles, and depth (Dauvina et al. 2004). Two distinct faunal communities were recognized by a study of benthic fauna from the shallow marine environment of the Seychelles Plateau (Mackie et al. 2005). Depth and sediment type were identified as the major determining factors.

In deeper water (>100 m depth) food availability becomes one of the major factors controlling benthic faunal communities. An investigation of infaunal macroinvertebrate assemblages in deep waters of the eastern Great Australian Bight set out to assess the utility of sediments as a predictor for biological communities and concluded that depth is the factor most strongly correlated with infaunal community structure. Species richness and diversity was high, where through upwelling or increased pelagic productions, food availability was increased (Currie et al. 2009).

Similar findings were reported from deep water benthos near Mauritius (Ingole et al. 1992). The study investigated the faunal composition and its distribution in relation to sediment characteristics, primary production and depth. Food availability was the major factor controlling distributional patterns. For fauna depending on bacteria and detritus primary production in the surface waters and the absolute amount of organic matter reaching the seafloor were important.

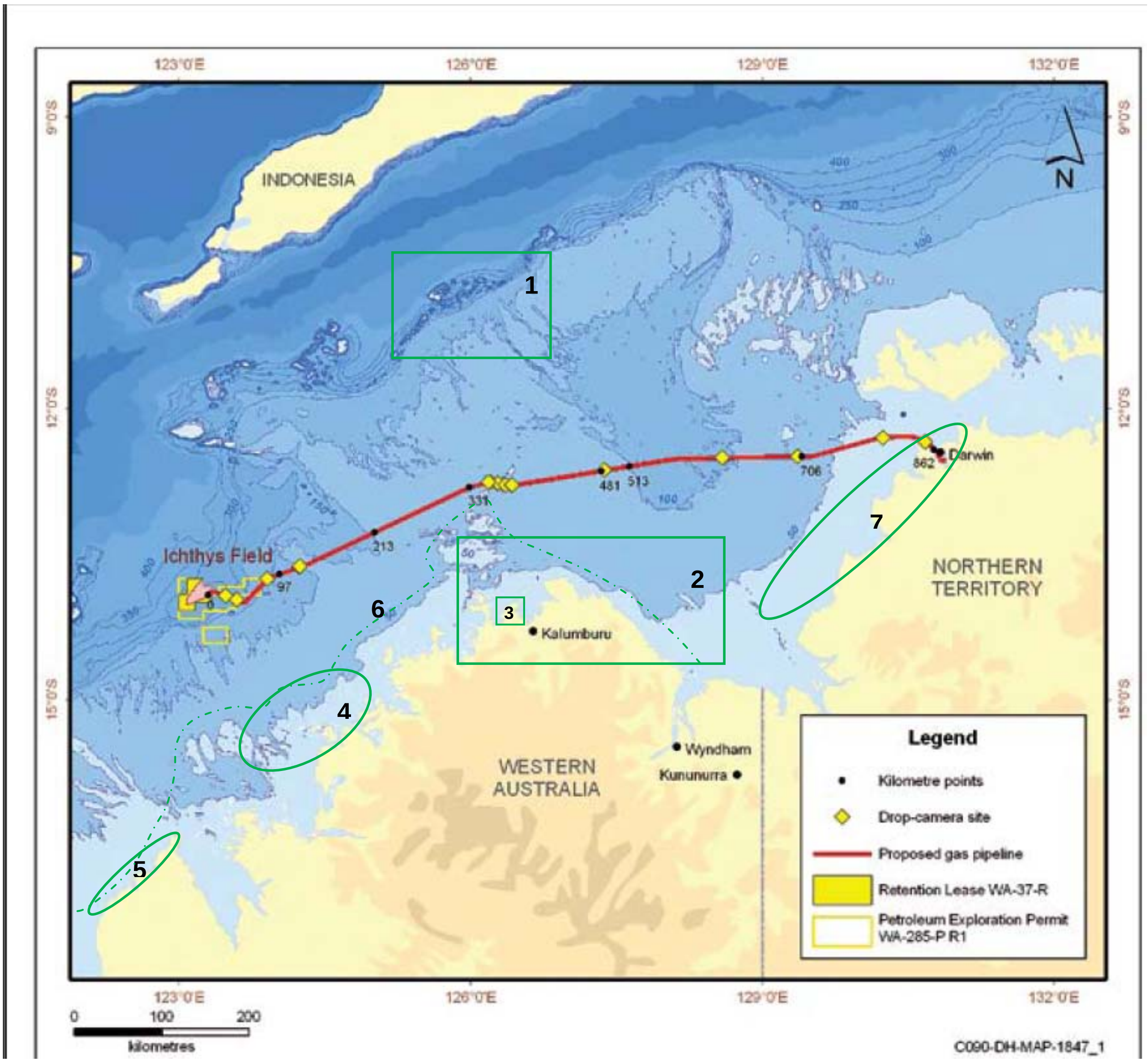
A review of ecological information on tropical soft bottom benthos compared soft bottom benthos from temperate regions concludes that the faunal diversity and densities are often lower than in temperate regions (Alongi 1989). The shallow coastal environments of the tropics are characterised by severe environmental stress. Intertidal regions are subjected to high temperatures making them inhospitable for many species. Seasonal monsoonal activities cause increased freshwater runoff, fluctuations in salinity and increased sediment loads. Faunal communities exposed to this type of regime experience seasonal mortality and associated changes in community structure (Alongi 1989). This is a scenario that resembles conditions of the Darwin Harbour Region. Species diversity under these circumstances is low with a dominance of opportunistic species. They consist of surface deposit- and suspension feeders which appears to be an adaptive strategy to respond quickly to erratic environmental changes.

The highest faunal densities occur in sheltered habitats while the lowest densities are found in exposed, coarse sandy beaches (Alongi 1989). Meiofaunal and macrofaunal communities appear to repopulate quickly following climatological disturbances (Alongi 1989). Tropical intertidal habitats differ greatly in macrofaunal community composition from temperate intertidal assemblages. Tropical intertidal sandflats and beaches are dominated by decapod crustaceans. While temperate mud and sand flats are dominated by bivalve molluscs, tropical mudflats have a high proportion of polychaetes and micro-crustaceans (Alongi 1989). Tropical crustaceans and bivalves are more motile and possess more rapid escape mechanisms than their temperate counterparts to avoid high temperatures, salinity and desiccation in the tropics (Ansell and Trevallion 1969, McLusky et al. 1975, Jones, (1979 in Alongi 1989).

The benthic fauna of tropical continental shelves is characterised by a faunal composition dominated by epibenthic organisms such as lancelets (*Branchiostoma*) and large foraminiferans. Infaunal communities consist mainly of small (< 5 mm) opportunists such as polychaete worms. Tropical continental shelves are generally shallow, driven by intermittent intrusions of upwelled nutrient rich water and by estuarine outwelling of detritus and input of reef detritus of generally higher nutritional quality. Nutrient influx in these offshore locations causes benthic communities to thrive (Alongi 1989).

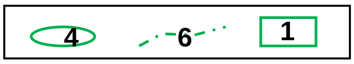
4.4 Benthic Fauna Studies

The vast extent of the project area with its pipeline footprint is shown in (Figure 2 and Figure 6). Faunal investigations have been conducted by INPEX Browse Ltd. in Darwin Harbour and along the pipeline footprint (Figure 6). Several other biological surveys have also documented invertebrate fauna in or near the development area. Figure 6 shows approximate areas of such additional studies.



Overview of infrastructure footprint with survey sites of epi-benthic communities along pipeline route (INPEX Browse, Ltd. 2010).

Approximate locations and areas of relevant benthic fauna surveys from literature (indicated with green outlines)



1 (Heyward et al. 1997); 2 (Walker et al. 1996); 3 (DEC, Marine Ecosystems Branch 2008); 4 (Wells et al.1995); 5 (Fry et al. 2008); 6 (Morgan et al. 1992); 7 (Smit et al. 2000)

Figure 6 **Location and extent of INPEX Gas Field Development Project**

4.4.1 Benthic Fauna of Darwin Harbour

Darwin Harbour is colonised by a diverse range of marine invertebrates, believed to be in excess of 3000 species (Russel and Hewitt 2000). Despite such diversity no species are known to be restricted to the harbour itself, although there are some species recorded from Darwin Harbour that are new to science and whose distribution is unknown (Metcalfe 2007). One of the major benthic invertebrate groups within Darwin Harbour include foraminiferans. Eighty-six species of foraminiferans are known to exist in Darwin Harbour. Three different foraminiferan assemblages could be identified according to the substrates they colonise, coralline substrates, tidal flats and reworked sediments in channels (Michie 1987). Sponges are commonly found on hard substrates in the area between a reef and subtidal mud flats with some species also colonising soft-bottom substrates. They provide habitat for many invertebrate and small fish species (Smit et al. 2003). Fifty-six species of sponge are known to occur in the harbour, though this probably represents only a fraction of those that actually occur. (Hooper 1988).

Darwin Harbour has a low diversity of soft corals and gorgonians, probably due to the high turbidity of the water. Marine worms comprising nematodes, polychaetes and sipunculids are found in the harbour with polychaete diversity estimated at 600 species (Hanley 1987). Crustaceans are estimated to include 1000 different species (Hanley 1987). Mollusc species are also numerous. A list compiled by Dr R Willan of the Museum and Art Gallery of the Northern Territory contained 924 species for the Darwin Harbour Region. Echinoderms include sea urchins, sea cucumbers, seastars, featherstars and brittlestars. Estimates by Hanley (1987) record the number of echinoderms in Darwin Harbour as 60.

A recent study on the mangroves of Darwin Harbour records a total number of 332 invertebrate species from mangrove habitats including adjacent intertidal mudflats (Metcalfe 2007). It also details temporal and spatial variability in species distributions and the influence of wet and dry season on species distributions. The Museum and Art Gallery of the Northern Territory holds the records of species collected from Darwin Harbour with associated locations and habitats.

Darwin Harbour is considered to be one of the best described regions for the Northern Territory waters in terms of species diversity (Smit et al. 2003).There is a substantial body of knowledge on the biological and physical condition of Darwin Harbour that ranges from ecosystem description (McKinnon et al. 2006) to detailed descriptions of habitats and their fauna (Metcalfe 2007, Michie 1987) to description and analysis of the hydrological environment (Williams et al. 2007).

In addition several surveys were conducted in the Harbour to specifically document the biological environment in areas of anticipated impact. The sites included areas of infrastructure footprint such as the planned offloading facility at Blaydin Point, East Arm Wharf and part of the pipeline route as well as hard substrate habitats with anticipated high biodiversity such as South Shell Island, Channel Island, Walker Shoal, Weed Reef, Plater Rock, the Bayu-Undan pipeline and several wrecks. Diver surveys from these sites produced video footage and habitat and biota descriptions. Detailed descriptions document coral coverage and dominant epifauna (INPEX Browse, Ltd. 2010 Appendix 8). Results categorise sites of high, moderate and low abundances.

Channel Island had the highest percentage cover (up to 100% in areas) and diversity (29 species) of hard corals of all sites. South Shell Island and the Weed Reef site had similar cover (15-20% and 15% respectively), and diversity (21 and 22 species respectively). Only moderate abundance of biota was found on the relatively sparse hard substrate present within the proposed disturbance areas, most notably the rubble covered pavement located to the north of Blaydin Point. Lowest abundances of biota were found on areas of soft substrate, particularly intertidal mudflats and subtidal sandbars. Examples are the area near Elizabeth Island and the subtidal sandbar north of Channel Island. The proposed pipeline route within the harbour was found to have a very low abundance of epibenthic biota. This contrasts with the nearby Bayu-Undan pipeline which had a dense covering of sessile epifauna.

Soft substrates were further investigated using infauna grab (n = 39) samples from locations in the zone of impact at Blaydin Point, at the proposed jetty location off the east side of Wickham Point and at the pipeline shore crossing. Results are documented in detail in (INPEX Browse, Ltd. 2010 Appendix 8).

The total number of individuals identified was 416 from 17 families. Crustaceans were the most abundant taxon with amphipods dominating this group (126 individuals, 30.3% of the total). Polychaetes were the second most abundant taxon (112 individuals, 26.9% of the total). The results of this study indicate that infaunal communities are dominated by either crustaceans or by polychaete worms (INPEX Browse, Ltd. 2010 Appendix 8).

4.4.2 Fauna of Sedimentary Habitats of Mangroves and Intertidal Flats

Intertidal flats and mangroves form special habitats at the interface of sea and land. They are locations where fine sediments settle and are characterised by a high content of organic materials. Influx of terrigenous sediments and break down of organic materials brings nutrient enrichment and high productivity. Mangrove habitat in Darwin Harbour is extensive, covering an area of 27,350 hectare (ha) between Charles Point and Gunn Point.

The most detailed study on the invertebrate fauna of sedimentary habitats was conducted by Metcalfe (2007) who investigated mangrove habitats including their muddy substrates and adjacent intertidal mudflats of Darwin Harbour. Her study documents a total of 290 invertebrate species exceeding the diversities recorded from mangrove habitats elsewhere in the Indo-Pacific region. In her study she analysed the major marine groups crustaceans, molluscs and worms. A general trend of increasing abundance and diversity was observed along a seaward gradient.

Crustaceans were the most dominant group followed by polychaetes and molluscs. Surface deposit feeders (10 species) and herbivores (8 species) were predominant among the worms of undisturbed mangroves, and filter feeders were the only guild not well represented (1 species). The abundance of sub-surface deposit feeders differed significantly between assemblages, presumably in response to seasonality and marked variations in soil moisture, texture and organic content with tidal elevation (Alongi and Sasekumar 1992 in Metcalfe 2007) and from wet to dry seasons. Overall, herbivores were the most numerous, with carnivores, sub-surface deposit feeders, surface deposit feeders and filter feeders in decreasing order of abundance. The observed partitioning within the feeding guilds appears to reflect the high primary productivity and sedimentary characteristics of mangrove habitats. For instance, nereidid worms—the most abundant polychaetes comprising 29% of all records in this study—were all herbivorous or surface deposit feeders. The diet of nereids is known to include fine plant detritus of mangrove leaf origin, algae and micro-crustaceans (Odum and Heald 1972 in Metcalfe 2007) and their diversity and abundance in the mangroves of Darwin Harbour is indicative of the characteristically high organic detrital content of these systems (Hsieh 1995 in Metcalfe 2007)). Further, such observations substantiate the importance of polychaetes as re-cyclers of mangrove litter and as pivotal links in trophic pathways (Kumar, 2003; Sarkar et al. 2005 in Metcalfe 2007). Known as first-order opportunistic species, these deposit feeders proliferate in highly reduced sediments and include widely distributed species such as *Capitella capitata* and *Scolelpis fuliginosa* (Grall and Glémarec 1997 in Metcalfe 2007)).

Yet despite the growing body of information linking changes in the trophic structure of communities to a range of environmental impacts, such functional group analyses have not been widely used in studies of the effects of disturbance on marine invertebrate communities (Bonsdorff and Pearson 1999, Pagliosa 2005 in Metcalfe 2007). Polychaete worms exhibit wide variation in their biology and are amongst the most diverse and abundant invertebrate groups in intertidal environments (Fauchald and Jumars 1979 in Metcalfe 2007). Because they are reliably present in intertidal areas and tend to respond quickly to environmental change (Faraco and Lana, 2003; Chollett and Bone 2007 in Metcalfe 2007), and differ widely in feeding ecology, habitat preferences, mobility, reproductive strategies and life span (Glasby et al. 2000 in Metcalfe 2007) they make ideal indicators of disturbance. Some groups of species will respond positively to disturbance, while other groups may disappear (Morissey et al. 1996 in Metcalfe 2007)). Furthermore, Grall and Glémarec (1997) (in Metcalfe 2007) note that that is due to their differing sensitivity to anthropogenic disturbance; the relative abundances of different groups may allow identification of different stress levels and stages of overload.

A detailed study, consisting of transect surveys, investigated potential impact zones at Blaydin Point and south of Wickham Point. A total of 1,231 specimens from 13 species were recorded. Infauna samples were collected from the same area recording 33 species with 17 of these polychaetes (INPEX Browse, Ltd. 2010).

Studies conducted in other areas can provide a regional context and comparison for the fauna described from the project area. A number of surveys have been conducted along the Kimberley coast to the west of the project development area.

The three marine biological surveys, Kimberley Island and Reef Expedition (Morgan et al. 1992), Southern Kimberley Cape Leveque to Montgomery Reef Expedition (Wells et al. 1995) and Survey of the Eastern Kimberley (Walker et al. 1996) (Figure 6), include in their investigations intertidal sedimentary habitats and mangroves. Depending on the sampling location, the environmental conditions of the sites are variable. Sites located in mangrove fringed estuaries and embayments are more closely comparable to Darwin Harbour than exposed sites that are subject to extensive scouring. The latter have been described as depauperate in faunal terms. The studies provide species lists for the major invertebrate taxa molluscs, crustaceans, polychaetes and echinoderms. Analysis of the presented diversity and its degree of similarity with records from Darwin Harbour generally supports the notion of biogeographic affinity of the regions and a low endemism potential. Only a study on intertidal crustaceans (Wells et al. 1995) indicates a level of endemicity with a proportion of the fauna not shared with records from the Northern Territory.

4.4.3 Fauna of Shallow Subtidal Sediments

The fauna of subtidal sediments can be divided into epifauna and infauna and further into mobile and sessile components. Compared to the colonisers of hard substrates, sessile epifauna only makes up a small proportion of soft substrate fauna. They usually require solid anchor points that the fine grained soft substrates do not offer. Some soft substrates consist of gravel or incorporate rocky components in which case they have the potential to support a greater proportion of sessile organisms. Some sessile species have adapted to live within soft substrates. Amongst them are notably some sponges (Ilan and Abelson 1995) soft corals such as sea whips and seapens. They generally occur in low densities in the harbour environment (INPEX Browse, Ltd. 2010 Appendix 8). Underwater video surveys have documented the seafloor characteristics and epifauna on the spoil ground (Tek Ventures Pty Ltd 2009) and along the pipeline route (INPEX Browse, Ltd. 2010 Appendix 4). Generally sponges, soft corals, bryozoans, crinoids and seapens are found in low densities and patchy distributions. A detailed description is provided in the Draft EIS (INPEX Browse, Ltd. 2010).

Soft sediments are the domain of infauna. Factors that determine the community composition and structure of infauna have been discussed in Section 4.4.1. The sediment structure expressed in particle size composition and the water depth are important determinants for infauna communities. This has been demonstrated by (Michie 1987) using Foraminifera communities. Michie (1987) could show that Darwin Harbour contains a number of different types of soft substrates and that there is a close correlation between the sediment composition and texture and the inhabiting fauna. An unstable, frequently reworked coarse sediment type is characteristic of the channel substrate and it is these characteristics that make it almost inhospitable to infauna. “The scour zone of the channels in the harbour is largely bare of fauna” (Hanley 1987). Consequently this habitat would be the least sensitive area for impacts.

When shallow areas outside the confines of the harbour are considered, the same relationship between sediment type and faunal community and depth exists. Several studies relevant for the project area document this (Long and Poiner 1994, Smit et al. 2000). In fact it was found that depth is one of the factors most strongly correlated with changes in infaunal communities (Long and Poiner 1994, Currie et al. 2009) making shallow communities distinct from deeper ones.

An overview of phyla colonising Darwin Harbour including its soft substrates is given in section 4.4.2.

The species lists compiled during the above studies (Long and Poiner 1994, Currie et al. 2009) show some overlap with species documented from the project area supporting the finding of a general biogeographical affinity with Indo-West Pacific fauna. The listed surveys document species from a variety of habitats including intertidal, mangrove and subtidal soft and hard substrate habitats.

The review of these surveys provides a regional context and comparison for findings from the project development area but it has to be noted that surveys vary in methodology and effort. The number of taxa collected in a survey is dependent on:

- The sampling effort in relationship with area covered in the survey
- How taxa are defined
- How the sample sites are arranged within the study area.

Beagle Gulf Survey:

A total of 8,109 animals representing 874 taxonomic units were collected from 159 sampling locations. The major taxonomic groups found are listed as crustaceans, molluscs and echinoderms making up 55.2% of the total species number. The survey showed considerable variability in abundances and species composition. Several distinct infauna communities were identified and associated with sediment types and locations. The Beagle Gulf Survey overlays with an area of the project development footprint, part of the pipeline route and the spoil deposition ground Figure 5 (Smit et al. 2000).

Surveys of the Kimberley

Video based investigations have also been carried out in the Canning bioregion (Figure 6) off the Kimberley coast by Fry et al. (2008). The study documents similar faunal groups and distributions.

An associated study collected epibenthic sled samples from the same areas in the Canning bioregion and provides species level identifications for a large proportion of the collected specimens (Irvine and Keesing 2009). The fauna collected in this study is likely to extend in its distribution into Northern Territory waters providing expanded regional context.

Four marine biological surveys (Figure 6) investigating habitats and biota of shallow marine environments, Kimberley Island and Reef Expedition (Morgan, et al. 1992), Southern Kimberley Cape Leveque to Montgomery Reef Expedition (Wells et al. 1995) and Survey of the Eastern Kimberley (Walker et al. 1996) and Survey of Benthic Habitats in the Anjo Peninsula Area (DEC, Marine Ecosystems Branch 2008) (Figure 6), include in their investigations soft substrate habitats.

The Anjo Peninsula survey classifies the dominant habitat type of sedimentary areas of Napier Broome Bay (>10 m) and off the west coast of Anjo Peninsular as bioturbated sediment with occasional sparse density filter feeding communities.

The other three surveys conducted between 1992 and 1996 provide detailed species lists and discuss the fauna in light of species diversity and biogeography. The documented fauna exhibits strong biogeographical affinity with the Indo-Wes Pacific region.

Areas in stressful and naturally disturbed environments (exposure to tidal scour, high turbidity) appear to be depauperate in terms of biodiversity (Walker et al. 1996). Subtidal soft bottom habitats were found to be low in biodiversity compared to reef habitats (Morgan et al. 1992, Wells et al. 1995). (Morgan, et al. 1992) also remarks that decapod crabs were uncommon in subtidal soft substrates.

Gulf of Carpentaria

Infauna grab samples were collected from the Gulf of Carpentaria at depths greater than 20 metres (m). Polychaetes numerically dominated the infauna (47 %) followed by crustaceans (32 %) and echinoderms (5 %). As functional groups scavengers (44 %) and deposit feeders (43%) numerically dominated throughout the gulf. Suspension feeding was less prevalent (13 %) and few herbivores were found (< 1 %). The 15 numerically dominant taxa were comprised mainly of opportunistic and second stage colonising taxa. Infaunal biomass was patchy and did not follow trends in abundance and species richness. Two thirds (438) of 684 taxa were represented by fewer than four individuals and 36 % were represented by one individual. More than two-thirds of taxa were represented by fewer than five individuals. It is difficult to imagine how individuals of the small (< 5 mm) species are able to locate mates successfully at such low densities. The animals were found in densities of 1-4 individuals per 30 m^2. The rare species were distributed throughout the gulf. A significant decrease of abundance with depth was recorded. The infaunal communities of the gulf appeared to be regulated by physical factors that correlate with sediment grain size and depth (Long and Poiner 1994)

Comparing results of different surveys that were conducted using different levels of effort and different methodologies with different objectives has to be approached with caution. The comparison of results from infauna surveys provides indicative information only.

The Beagle Gulf Benthic Survey (Smit et al. 2000) reported 874 taxa collected from grab samples. This represents the highest diversity compared with (Long and Poiner 1994) reporting 684 taxa from grab samples collected in the Gulf of Carpentaria and (Heyward et al. 1997) recording 209 taxa from grab samples at the Big Bank Shoals of the Timor Sea. The infauna survey near the Ichthys Gas Field and Echuca Shoals (RPS 2007) documents 117 nominal species from ten phyla and 94 nominal species from nine phyla for September 2005 and May 2007 respectively.

These findings indicate a greater infaunal diversity in shallow habitats compared to deeper one. However, additional basic scientific research may be required to confirm such a conclusion.

4.4.4 Evaluation of Available Information Nearshore Region

The information on faunal diversity in Darwin Harbour is considerable. Although there is no doubt that there are still many species yet to be discovered, a substantial group of invertebrate species has been documented. In addition, biogeographical affinities of the documented species have been described as representative of the Dampierian Province of the Indo-West Pacific (Hanley 1987). In fact, comparison of faunal data from Darwin Harbour with faunal lists from the Dampier Archipelago (Jones 2004) finds considerable species overlap. This together with the fact that many benthic species have dispersive planktonic larvae makes highly localised distributions or endemisms unlikely.

There is also an extensive knowledge of the types of habitats that species and different functional groups colonise. A habitat map prepared by INPEX Browse, Ltd. (Figure 3) shows habitat predictions for the entire Darwin Harbour. Combined with the knowledge of impact sites, this information allows predicting which habitats, faunal groups and spatial extent may be impacted by disturbances. This semi-quantitative assessment of disturbances and loss may also help establish whether the local reduction of a functional group or habitat type may be significant in the maintenance of trophic relationships and ecosystem connectivity.

The invertebrate fauna associated with Darwin Harbour soft substrates, in particular the muddy substrates of mangrove habitats and adjacent mudflats have been investigated in some detail (Metcalfe 2007). Distinct faunal communities have been recognised for some of the soft substrate habitat types. Of those the coarse channel substrates support the fewest species and abundances and are therefore rated as least sensitive habitats to disturbances.

For the wider nearshore region there is comprehensive information on infauna relevant to the project development area from the Beagle Gulf survey. A relationship between physical factors such as grain size of sediments and water depths has been clearly established in the literature (Michie 1987, Metcalfe 2007). Common observations of dominant taxa consisting of polychaetes and crustaceans and the descriptions of functional groups within these taxa support the findings of specific studies conducted at potential impacts sites (INPEX Browse, Ltd. 2010).

Based on the available information it is possible to identify habitat types that are repositories for high species diversity and whose reduction would affect species diversity more significantly than the loss of other types of habitats. It is known that high species diversity can occur in relatively small areas. This is exemplified by a count of 275 sponge species from approximately 1,600 km² at the Dampier Archipelago. Of the habitats considered in this report, habitats with high species diversity potential are mangrove habitats with their adjacent intertidal mudflats (Metcalfe 2007) and subtidal hard substrates that are colonised by epifaunal filter feeder communities (Smit et al. 2003).

Another consideration for assessment is whether there is a risk for local extinctions due to the impacts imposed on the benthic fauna. Local extinctions are likely to occur if, for example, all or a large proportion of a population has been lost. Apart from direct impacts that cause mortality of organisms, indirect impacts such as reduction and loss of habitat and food resources can contribute to local extinctions. Maintenance of interconnectivity with populations outside the impact area is important to ensure reproduction and re-colonisation. The fragmentation of habitats is often thought to be detrimental to ecological integrity (Fraschetti et al. 2008) but some habitats particularly in the marine benthic context are naturally patchy. There are few studies that investigate the effects of changes in patch configuration and size on benthic faunal communities other than hard corals (Roberts and Poore 2005). It is recognised as a biological phenomenon of the marine environment that some species occur in low numbers in a patchy distributional pattern (Magurran and Henderson 2003). This phenomenon has been described for sponge fauna from the Dampier Archipelago where a large proportion (61 %) of sponge species occur in low numbers at single or at few sampling locations (Fromont et al. 2006). What sustains and regulates such distributional patterns is not fully understood. It may be characteristic of the patchy resource distribution of tropical environments (Alongi 1989).

It becomes clear that the risk of local extinction can only be accurately assessed on the background of a more substantial ecological and biological knowledgebase than is currently available. It is also clear that taxonomic knowledge such as species level identifications do not necessarily improve impact assessment.

The present literature review shows that the information on the benthic fauna of Darwin Harbour is substantial and can inform impact assessment at the ecosystem level with respect to biodiversity, trophic structure and interconnectedness. It is available at a spatial scale of local habitats that allows impact specific delineations. Faunal information is recorded at various taxonomic resolutions with comprehensive species lists available for all major marine phyla. Data on functional groups is related to their habitats and thereby linked to a location and area within the harbour. It is, however, clear that continuing basic scientific research can provide still further insights into the understanding of the local ecosystem.

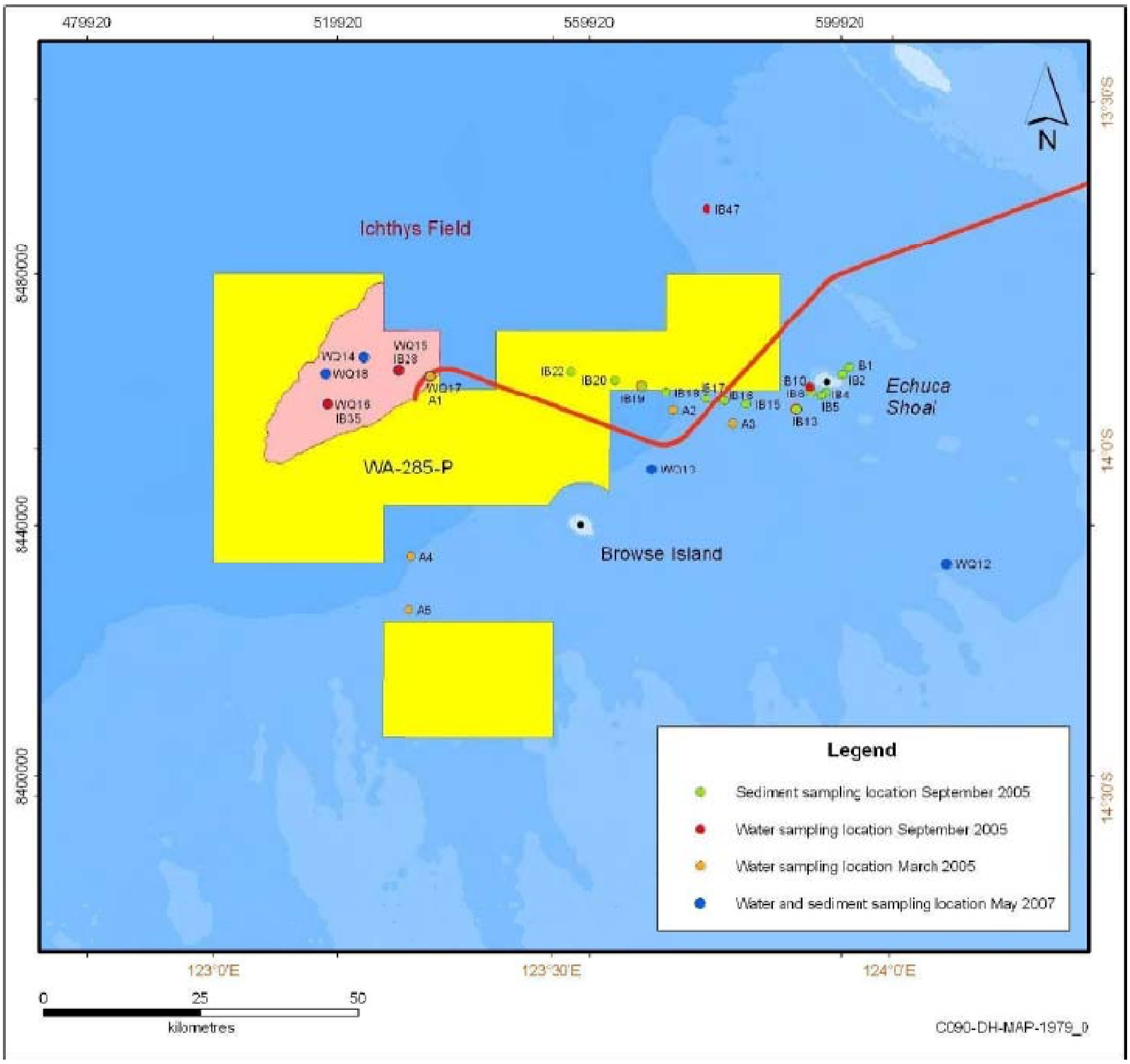
4.4.5 Fauna of Offshore Region (Browse Basin)

Only limited information is currently available from deeper offshore regions. The results of two studies with relevance to the project development area are summarised below.

Ichthys Field, Echuca Shoals and Pipeline Route Survey

Infauna grab samples were collected from the Ichthys Field the Echuca Shoals and from the pipeline route (Figure 7). The depth range of sampling sites ranged between 60 and 250 m. One hundred and eighty six individuals representing 117 nominal species from ten phyla were collected in September 2005 from 13 sites around the Echuca Shoal and Ichthys Field. In May 2007, 419 individuals from nine phyla and at least 94 nominal species were collected from eight offshore locations (RPS 2007). Polychaetes and crustaceans were the most species rich and numerically abundant taxa, contributing over 60 percent of the species and over 75 percent of all identified animals on each sampling occasion. A relationship between water depth and species richness and total number of individuals was apparent with both species richness and abundance decreasing with increasing water depth. Species richness and abundance was also influenced by oceanographic conditions, productivity rates, availability and range of food sources and habitats and sediment grain size composition (INPEX Browse, Ltd. 2010 Appendix 4).

In addition to infauna investigations, underwater video surveys have documented the seafloor characteristics and epifauna along the pipeline route and at the Ichthys Field. Locations of video transects are marked in Figure 6. Generally sponges, soft corals, bryozoans, crinoids and seapens are found in low densities and patchy distributions. A detailed description is provided in the Draft EIS (INPEX Browse, Ltd. 2010, Appendix 4).



Water quality, infauna and sediment sampling sites at the offshore development site

Figure 7 **Sampling locations near Ichthys Gas Field (Source: INPEX Browse, Ltd. 2010)**

Atlas of Big Bank Shoals

The Atlas of the Big Bank Shoals adds to the still largely incomplete picture of the Oceanic Shoals by documenting the benthic infauna at three sites on the Australian Continental Shelf of the Timor Sea, in water depths of greater than 50 metres. The survey area lies north of the pipeline route (Figure 6) in the bioregion Oceanic Shoals (Figure 2) and hence provides useful data. A number of sites on the Continental Shelf, adjacent to the Big Bank Shoals, were sampled to determine the infauna of the region.

Regional infauna: in all, 1,620 animals representing 209 taxa were sorted from the grab samples at the three sites. The two major taxa encountered were polychaetes and crustaceans which made up over 84 % of the total species found at each site. They were also the most abundant animals, accounting for more than 88 % of the total number of individuals found, with echinoderms, molluscs, nemerteans, sponges and fish making up the remainder.

In a comparison of the three sites it was found that the sites at Bayu-Undan were characterised by low species richness (number of species present per sample), and abundance (number of animals per sample). In broad terms the infauna collected from the three regions was very similar. For example, the number of species of polychaetes and crustaceans at each of the sites was much the same, although the abundance of the particular taxa varied notably. The overall percentage of polychaetes at Bayu-Undan is nearly double the values for Elang Field and Mallee East-1. The mean number of species and mean abundances at Bayu-Undan sites were less than half those at the Mallee East-1 site and the Elang Field site. This may have been attributable to sediment grain size, which is known to directly affect community composition of benthic systems (Heyward et al. 1997).

4.4.6 Evaluation of Information Offshore

Literature information from the offshore region, particularly of infaunal communities is limited. Comparing visual footage from different studies it appears that epifauna documented from the pipeline route is similar to other regions such as North West Shelf and Canning bioregion.

With increasing depth, factors that regulate and determine infauna community composition and structure change. Factors such as food availability and oxygen availability increase in importance. The dominant infaunal taxa comprise polychaetes and crustaceans. Surface deposit feeders are identified as the predominant functional group.

The current investigations indicate that the habitats and consequently their colonising fauna occurs over a wide benthic area. Based on these findings there is no reason to assume that the characteristic biota of these substrates would be threatened by the development activities. In relation to the availability of suitable habitat the offshore impact sites represent only very small proportions of the total available habitat.

4.5 Filter Feeding Communities

Filter feeders are defined as a group based on their mode of feeding. They are also often referred to as suspension feeders. Filter feeders use specialised feeding structures to capture food particles such as plankton from the water column. Representatives of filter feeders can be found in many marine taxa. They comprise sponges and soft corals, molluscs, such as mussels and other bivalves, crustaceans, marine worms and ascidians. Species in all of these groups occur in the project development area. Infaunal suspension feeders are present in soft substrates both in the intertidal and subtidal zone.

This report gives particular consideration to filter feeder communities that colonise hard substrates. Sponges and soft corals dominate this type of substrate. They are recognised as habitat formers because they provide a three dimensional structure that can have considerable complexity. It provides habitat to a variety of other invertebrate species and fish. By hosting a multitude of associated fauna (Duffy 1996, Tanaka and Aoki 1998, Thiel 2000) mixed sponge and soft coral communities have a biodiversity enhancing function. This type of ecological function is well recognised for coral reefs but not as well documented for filter feeder communities. As filter feeders they convert planktonic biomass into benthic biomass. There is no doubt that they perform multiple important functions within the ecosystem. Their functional significance together with their abundance make them important faunal elements of Darwin Harbour.

A habitat map prepared by Geo Oceans (Figure 3) for the Darwin Harbour region shows the extent and distribution of sponge/soft coral habitat. It is based on substantial survey work involving both remote video and diver surveys. The resulting habitat descriptions and all associated information is documented in a supplementary technical report (GeoOceans 2011).

The majority of filter feeder habitat is predicted to occur in small patches surrounded by soft substrate forming a fragmented, mosaic pattern related to substrate type distribution. Where reefs, rocky outcrops or shoals exist filter feeder communities can be more extensive and dense, particularly in deeper water. Such larger patches also attract fish and other predators.

The diversity of sponge species in Darwin Harbour has currently been listed as 56 species and the number of soft coral species is estimated as 20 to 25 (Smit et al. 2003). Fromont et al. (2006) review existing studies on sponges in tropical Australia and highlight high species diversity in these waters with over 600 species recorded.

To be able to assess impacts of specific disturbances on organisms some general knowledge on the biology of the organisms is required.

Sponges

Sponges are sedentary, filter-feeding organisms which most commonly live on the sea floor attached to rock, shell, coral, algae and other hard surfaces. They compose the phylum Porifera, and are relatively simple multicellular animals. Sponges have a variety of sexual and asexual reproductive modes, but are renowned for remarkable regenerative powers. The ability to regenerate is closely correlated with asexual reproduction. A bud or small fragment broken from the parent sponge can generate a new sponge. Some sponges produce special, asexual reproductive bodies called gemmules. Gemmules remain viable for extended periods of time. Some types are even resistant to freezing and desiccation. When suitable conditions are found a gemmule can grow to form a new sponge, genetically identical to the parent. Gemmules provide a means of dispersal and are a way of maintaining local distribution and abundance. They allow the genotype of an individual sponge to persist through extreme environmental conditions. The majority of sponges are hermaphroditic, and therefore capable of producing both sperm and eggs, though generally at different times. Mature sperm are shed into the water column, where they are carried into the water canals of neighbouring sponges and where they fertilise their eggs. Fertilised eggs are then either carried into the water column where they undergo further development in the sea or, as is the case with most sponges, they are brooded and develop within the body of the parent sponge. Embryonic development leads to free-swimming larvae, a stage that is important for species dispersion in sessile animals. After a brief free-swimming existence, the larvae settle to the bottom and develop into adult sponges.

Soft Corals

Soft corals are sessile filter feeding organisms. They belong to the phylum Cnidaria. They are commonly found in benthic habitats that are subject to persistent currents. Like sponges soft corals can reproduce asexually. This type of propagation is frequently the dominant reproductive mode. It serves to produce large populations from a single, founding colony and can result in localised, high density patches. Sexual reproduction follows the pattern characteristic of all anthozoans, with both internal and external larval development having been recorded. The fertilised eggs develop into planula larvae which settle and differentiate to produce polyps. They then multiply into colonies.

4.5.1 Evaluation of Information

The Draft EIS (INPEX Browse, Ltd. 2010) provides detailed information on filter feeder habitats at an appropriate spatial scale to capture predicted impacts from anticipated disturbances. The distribution and extent of habitats mapped is derived from interpretation of side-scan sonar and ground truthing using video footage at select locations.

The developed habitat map displays the broad patchy distribution of filter feeder communities throughout the harbour. A loss of large patches of hard substrates colonised by filter feeders can potentially reduce connectivity of populations if the location is in a strategic position for maintaining connectivity. Adaptive reproductive modes such as asexual reproduction, however, can facilitate rapid re-colonisation. To some extent the proposed infrastructure will provide additional hard substrates that are likely to be colonised by filter feeders and can in time compensate for losses.

The understanding of the role and function of filter feeder habitats in the ecosystem has also been documented. It is, however, acknowledged that more basic scientific research is needed to fully understand their significance in the ecosystem. In addition there is little information on how filter feeders respond to specific disturbances such as increased suspended sediments and sedimentation. A workshop on research priorities for improving the capacity to manage dredging impacts on tropical coral communities in Western Australia (The Centre for Marine Ecosystems Research Edith Cowan University 2009) has identified and prioritised filter feeders as an area that is poorly understood and has formulated the following priority topics for urgent investigation:

- Providing first-instance information on the response of filter feeders to environmental gradients
- Development of thresholds and indicators of filter-feeder response to dredging related pressures
- Conduct research to improve the understanding of the ecological significance of filter-feeding biota including:
    - Distribution and abundance in relation to habitat characteristics
    - Filtration capacity
    - Trophic significance.

5.0 Disturbances and Impacts on Infauna and Filter Feeding Communities

This section investigates how identified disturbances affect specific habitats and associated fauna. The processes and concepts explained are similar for the habitats and fauna in the harbour area and in the offshore section.

5.1 Removal of Organisms

In the footprint areas of dredging where substrates are removed it is expected that organisms colonising these substrates will also be removed. Defaunation by this cause is indiscriminate of whether the colonising benthos is residing inside substrate as infauna or colonising the surface as epifauna and whether the organisms are mobile or sessile. In this context mobile benthic fauna has to be considered too slow to escape and infaunal organisms only colonise the surface layers of sediments that are subject to removal. The dredging footprint is shown in Figure 8 for the marine infrastructure and approach channel near Blaydin Point and in Figure 9 for the pipeline section.

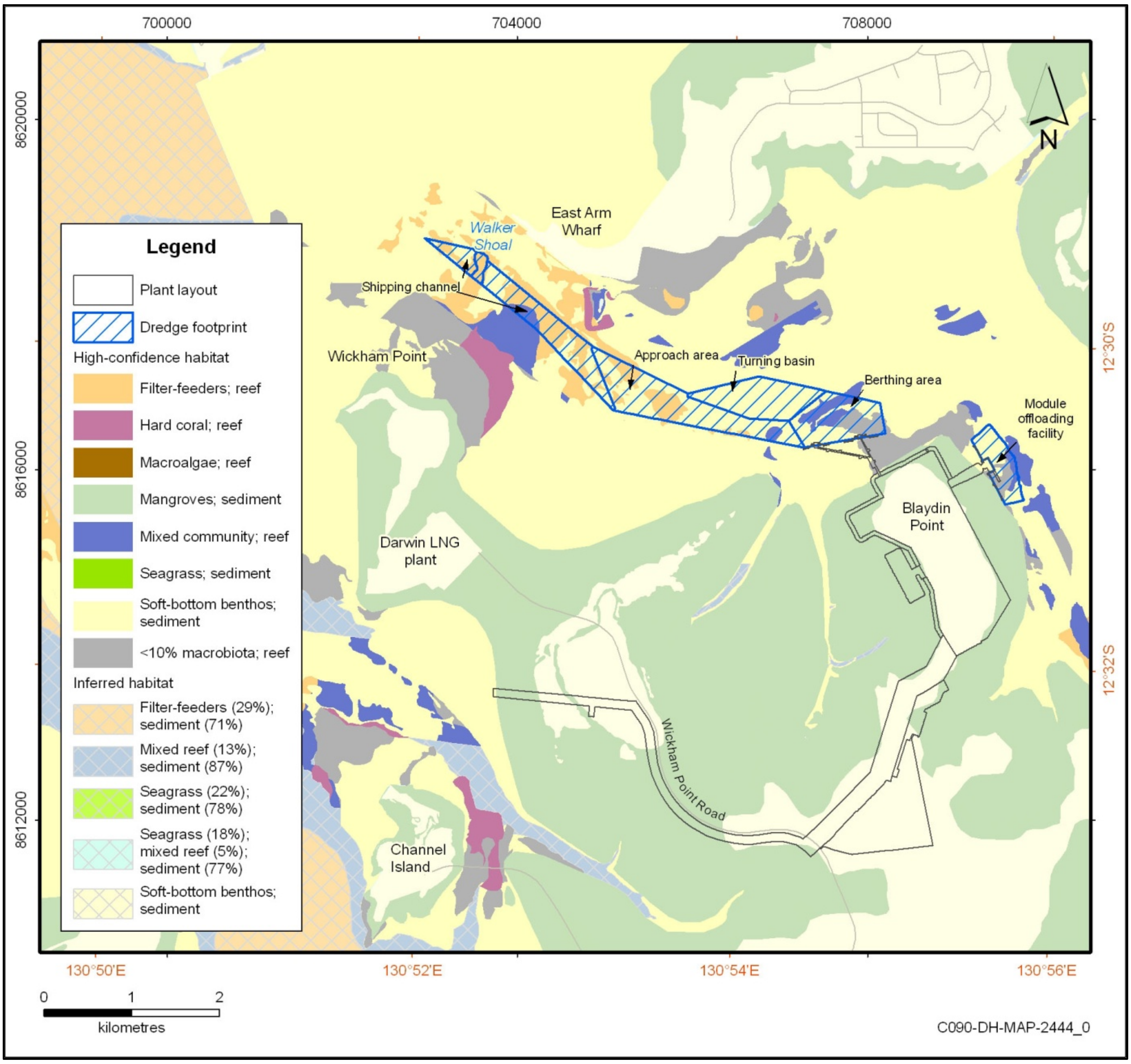


Figure 8 Dredge footprint over habitat map (Source: Geo Oceans 2011)

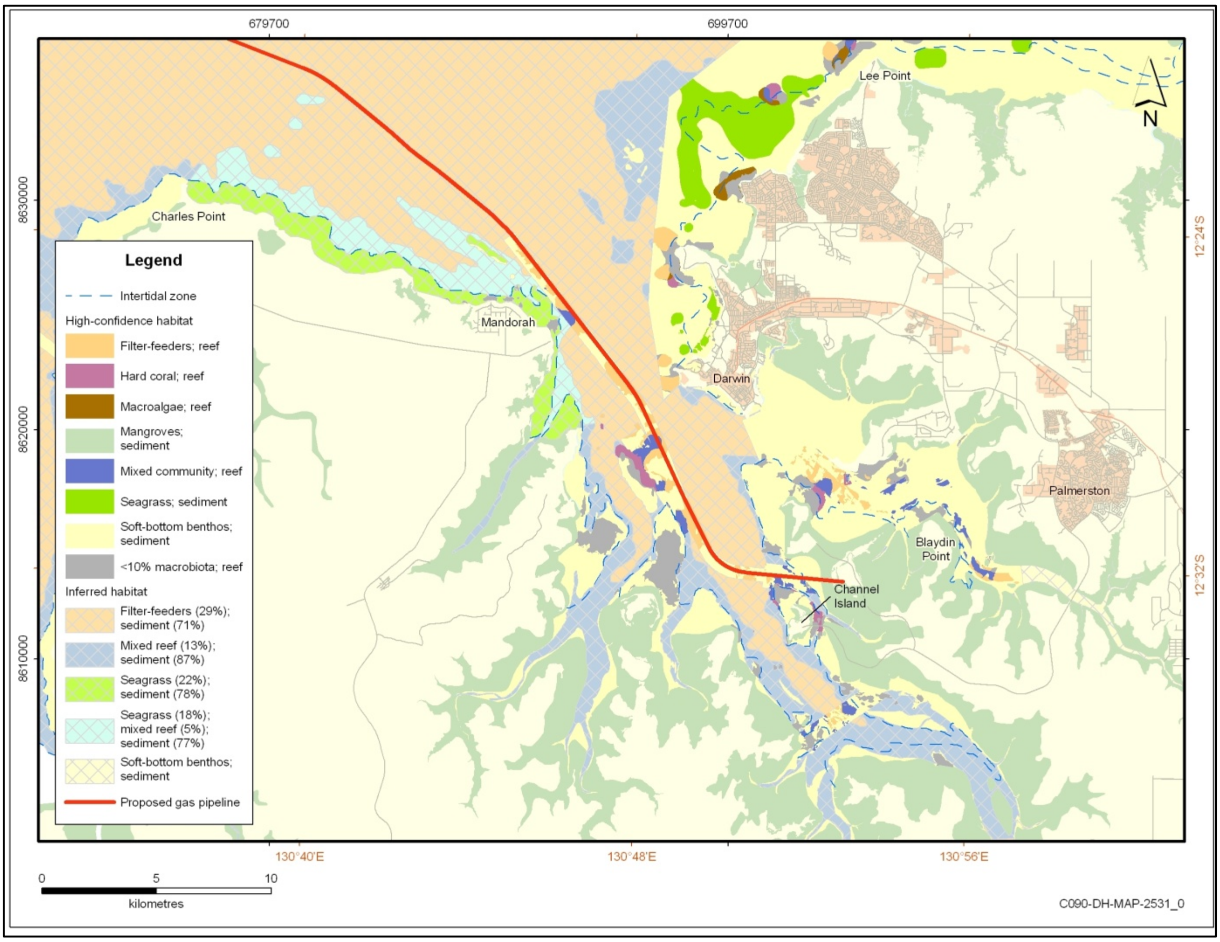


Figure 9 **Pipeline footprint over benthic habitat (Source: Geo Oceans 2011)**

5.2 Burial of Organisms

Burial and smothering of organisms occurs when sediment is deposited on top of the colonised substrate.

It is part of the dredging process that sediments become suspended in the water column and eventually, depending on their properties, settle again either near their origin or at a location to which they have been transported. For the project area, sediment dispersal and accretion has been modelled according to the specifications of dredging work planned and the prevailing hydrological conditions. The details of the derived predictions are comprehensively reported and discussed in (INPEX Browse, Ltd. 2010 Appendix 13). The outputs of such models can help to assess the impacts that accretion will have on the benthic fauna in the development area. Figure 10 shows the locations of accretions after phase 6 dredging. Phase 6 represents peak dredging activity and hence is a good choice to review maximum depositions.

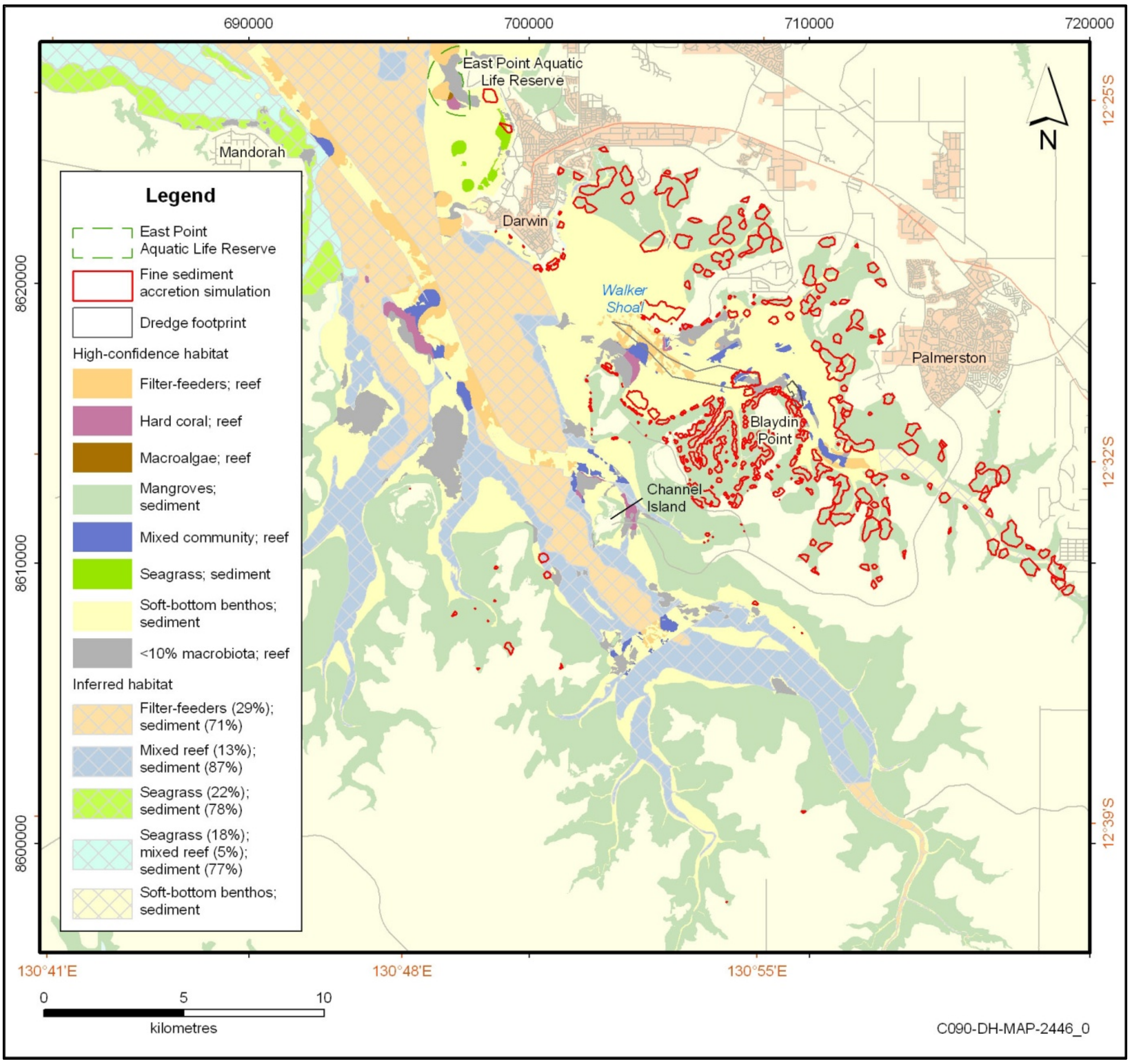


Figure 10 Accretion after dredging phase 6. (Source: Geo Oceans 2011)

It is easy to see that the majority of fine sediment accretion will occur in mangrove habitats followed by intertidal mudflats. It is predicted that 850 ha of mangrove habitat will receive up to 10 mm of accretion over four years while 2 ha will experience accretion up to 100 mm during this time (INPEX Browse, Ltd. 2010). The intertidal mudflats of specified locations are expected to receive less than 100 mm accretion at the end of the pipeline trench dredging. Peak accretion (50 mm) is expected at the end of phase 5 at the north side of the port and at the end of phase 6 (500 mm) at the berthing pocket. As the berthing pocket has been excavated causing defaunation, elevated accretion in this location does not worsen the impact. Apart from mangrove habitat and intertidal mudflats only very limited areas of other habitat types are affected (Figure 10). They are predicted to be mainly ‘soft bottom benthos’ types. The model output predicts accretion of fine substrate. Coarser sediment will settle close to the dredging location causing elevated sedimentation near the dredge footprint.

Dredged coarse and fine sediment will be disposed off at the offshore spoil ground where it is predicted that the deposition height will reach 1 m to 2 m. The disposal of sediment at the spoil ground will cause fine sediment plumes to form which will later settle in and near the Adelaide River, Shoal Bay and Lee Point. Accretion could reach a maximum of 50 mm at the mouth of the Adelaide River (INPEX Browse, Ltd. 2010).

It is important to note that when accretion or sediment deposition is recorded, the thickness of the deposited layer is not the same as depth of burial. The first indicates the thickness of the layer covering the sediment. The second indicates the thickness of the layer on top of the individual. When the individual is living on top of the sediment, it will take some additional layer thickness to bury this individual. In order to bury an adult suspension feeder like a mussel, as tested by Kranz (1974), the deposited layer must at least exceed the dimensions of the exposed shell in order to bury the shell. Using the depth of burial to represent the thickness of the deposited layer underestimates the amount of sediment required to bury the organism.

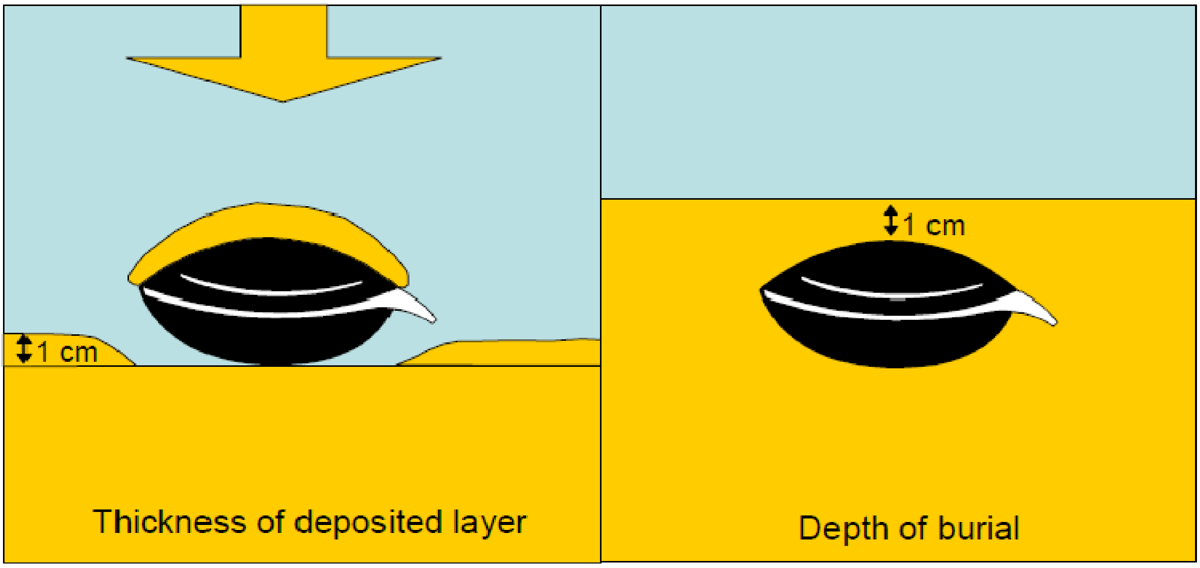


Illustration of difference of the expression of Predicted Environmental Concentration (PEC) (thickness of deposited layer) and the nature of the data used to derive the threshold value (depth of burial). Reproduced after (Smit et al. 2006)

Figure 11 **Burial of benthic organisms by sediment**

Whether organisms will be buried and ultimately suffer mortality by deposited sediments depends on the specific properties of the sedimentation event and the specific sensitivity profile of the receptor organisms. A general statement derived from in situ experiments of burial of marine invertebrates conducted by Nichols et al. (1978) reported in (Chou et al. 2004) declares that most species common in soft-bottom communities could avoid burial with 5 to 10 cm of sediment. This is supported by laboratory studies conducted on invertebrates from Delaware Bay (USA) (Miller et al. 2003). In this study most snails were able to re-emerge from a 10 cm thick sand layer but a species of reef building polychaete could only cope with a one cm thick layer while a 2 cm layer proved lethal.

Factors characterising the sedimentation event and determining the impact on benthic fauna are listed in Table 2. They describe the nature of the sediment by its grain size, texture and components as well as its interaction with the environment once deposited, such as movement along the seabed. The sedimentation rate and the layer thickness are measures of the severity of the impact. For instance, the ability of mobile invertebrates to escape the impact of being buried depends on the amount of sediment that is being deposited on top of them at any one time. If the sedimentation rate is low, only small amounts are deposited giving the animal time to escape before it becomes buried. Similarly, burrowing infauna organisms are able to adjust their position in the sediment while maintaining access to the surface if the sedimentation rate is low. This is independent of the thickness of the layer that eventually accumulates on top of the surface. A study investigating the impacts of sedimentation on soft bottom benthic communities in the Southern Islands of Singapore (Chou et al. 2004) found that a sedimentation rate in the order of 0.085 g cm^{-2} d^{-1} clearly had an adverse effect on fauna while a sedimentation rate of 0.02 g cm^{-2} d^{-1} did not result in observable biological effects. Results from similar investigations from a Norwegian Fjord by Olsgard and Hasle (1993) are cited in (Kjeilen-Eilertsen et al. 2004) reporting that a sedimentation rate of four to five cm per year resulted in changes in fauna composition, while at a rate of 1 mm per year no impact was observed. As illustrated by these examples measurement units for sedimentation rates are not consistent and make it difficult to compare data.

A relationship between infauna species and grain size of the sediment they colonise exists and is well documented (Kohn 2003, Long and Poiner 1994). Consequently a change in sediment composition will have species specific effects that result in changes in the faunal community. A literature review on the effects of sedimentation (Kjeilen-Eilertsen et al. 2004) refers to a study from Southern California by Maxon et al. (1997) that indicated sediment changes in faunal communities are mainly influenced by sediment composition. In this study grain size alone was the best predictor of amphipod mortality. The type of sediment deposited may also influence the animal's ability to burrow. Some grain sizes form more compact sediments that are hard to penetrate. The silt content of the sediment is an important parameter which may change the ability of the fauna to regain the upper sediment after burial. Silty sediments are more compact, and generally contain less oxygen than coarse sediments. Several studies have documented increased mortality rates in silty compared to sandy sediments (Glude 1954, Jackson and James 1979, Maurer et al. 1986, Chandrasekara and Frid 1998 in Kjeilen-Eilertsen et al. 2004). When considering the effect that deposited sediments have on the soft bottom fauna it is important to identify its similarity or dissimilarity to the native sediment.

Table 2 Factors characterising the sedimentation event and determining the impact on benthic fauna

Characteristics of Sedimentation Event	Category of Effect	Receptor
Grain size and texture	Physico-chemical: changes in sediment matrix, changes in oxygen availability	Specific infauna species - Effect on burrowing - Effect on access to surface - Effect on physiology: respiration, metabolism
Sedimentation rate	Physical: severity	Infauna and Epifauna - Structural damage to organisms on surface - Escape potential
Layer thickness	Physical: magnitude/severity	Infauna and Epifauna - Incomplete or complete burial - Effect on access to surface
Organic material/nutrients	Physico-chemical: changes in sediment matrix, changes in oxygen availability	Specific infauna species - Effects on food resources
Contamination/toxins	Chemical	Infauna and Epifauna - Toxicity - Effects on food resources
Duration(long term/short tem)	Temporal: magnitude/severity	Infauna and Epifauna
Sediment stability	Physical: deposited sediment shifting under prevailing conditions, causing surface/shear stress at interface	Infauna and Epifauna - Effects on infauna burrowing - Damage to epifauna attachment

5.3 Tolerance to Sediment Deposition

The tolerance of organisms to the effects of sediment deposition is greatly determined by the organisms' characteristics specifically their:

- Size
- Morphology
- Habitat preference: position on or in the substrate
- Mobility (escape potential)
- Physiology.

It is easy to determine that the most vulnerable species would be those that are sessile and have low escape potential. In fact functional classification of fauna in addition to size is a useful approach when establishing degrees of vulnerability. Generally small animals would be more vulnerable than larger ones particularly if they reside at the surface (Figure 11).

5.3.1 Sessile Epifauna

Small sessile epifauna are the most vulnerable category. Examples of animals of this category are mussels, barnacles, small sessile worms as well as small, solitary and colonial ascidians and encrusting sponges. These are representatives of the major marine phyla crustacea, molluscs, polychaetes, tunicates and sponges. Most of them are filter or suspension feeders.

Also vulnerable to the effects of sedimentation is larger sessile epifauna. Examples of these are large tube worms, ascidians, sponges, soft corals and seapens. Most sessile filter or suspension feeders attach themselves to hard substrates but some like seapens and some species of sponge find anchor points within soft substrates. Insightful observations on the response of sponges to increased sedimentation come from a study investigating the effects of natural sedimentation on tropical sponge assemblages from Mexico (Carballo 2006). This study showed that increased sediment deposition reduced sponge diversity and density. Morphological diversity also decreased when perturbation increased. The most abundant species before the high rate of sedimentation was registered were massive, massive-branching, cushion-shaped, or encrusting with vertical projections. Generally, the encrusting sponges were the most abundant all the time. Sponge assemblages in areas seasonally influenced by sedimentation stress may display a growth and retraction dynamic. The study also documented that although many species showed rapid decline in abundance, the recovery of some species was relatively fast. Thus the results suggest that sponge assemblages are more dynamic than previously thought.

Increased sedimentation rates can also disturb the settlement of larvae of sessile animals by creating an unstable thus unsuitable substrate. Settlement is reported to be particularly difficult on hard substrates that are covered by very thin layers of moving sediment. Under these circumstances sedimentation can impair recruitment, re-colonisation and recovery.

5.3.2 Mobile Epifauna

Due to their mobility this category of fauna has a higher escape potential. Larger animals would be less affected than smaller ones. Small animals such as small amphipods or small worms could be quickly impaired in their mobility by the deposition of sediment resulting in a low escape potential. Large animals such as large crabs and feather stars have the ability to move fast resulting in high escape potential. Some larger animals such as sea cucumbers, sea urchins and seastars may have a lower escape potential due to their slower movements. In general terms mobile macrofauna probably has the highest tolerance to sediment deposition.

A study comparing faunal assemblages in disturbed and undisturbed mangrove habitat of Darwin Harbour (Metcalfe 2007) found an increase in the diversity and abundance of surface deposit feeding worms that was possibly due to changed sediment properties, especially grain size and silt and clay content. The study reported that overall, invertebrate diversity and abundance did not decline in response to moderate levels of anthropogenic disturbance. This contradicts the general statements declaring that declines in species richness, diversity and abundance are characteristic of highly stressed marine benthic communities (Belan 2003 in Metcalfe 2007)

5.3.3 Infauna

The assessment of the response of infauna organisms to elevated sedimentation can be complex. This is illustrated by an analysis of the tolerance of selected bivalve functional groups (Table 3). The analysis demonstrates that functional groups may be useful in the prediction and assessment of impacts. It also shows that the sensitivities of infaunal organisms belonging to the same class, Bivalvia, can differ greatly.

Species that suffer most from burial with a sediment type different from the native one, are the infaunal non-siphonate suspension feeders, infaunal mucus tube feeders and labial palp deposit feeders. When buried with native sediment, the mucus tube feeders and labial palp deposit feeders seem to be the least affected groups. The group least affected by burial with exotic sediment are infaunal siphon feeding bivalves. This could be explained by the fact that the members of this group do not demonstrate any significant escape burrowing. The vertical migration by the buried infauna may be dependent on the depth and the duration of burial, structure and temperature of the sediment (Maurer et al. 1981, 1986 in Kjeilen-Eilertsen et al. 2004). Bivalve species with a low capability to move through the sediment may eventually suffer from low oxygen concentrations in the sediment (Essink 1999 in Kjeilen-Eilertsen et al. 2004). Most species present in muddy sediments or in high-energy, dynamic sediments are, however, well adapted to changes in their substrate. Especially species with burying behaviour, experience hardly any effect (Bijkerk 1988).

Table 3 Depth of burial for different bivalve functional groups, at which the escape potential is 10 % (EP10)*

Bivalve Group	Species from Darwin Harbour (belonging to the same functional group but have not undergone experimental testing)	EP10* exotic sediment (cm)	EP10* native sediment (cm)
Epifaunal Species		Source: (Kranz 1974 in (Kjeilen-Eilertsen et al. 2004)	
Suspension feeders (on hard substrate)	*Saccostrea dactylena* Iredale, 1939 *Musculus cumingianus* Reeve, 1857	0 to 4	
Infaunal Species			
Labial palp deposit feeders	*Nuculana corbuloides* (E.A. Smith, 1885) *Nuculana novaeguineensis* (E.A. Smith, 1885)	10	> 45 to >57
Mucus tube feeders	*Austriella corrugata* (Deshayes, 1843) *Anodontia philippiana* (Reeve, 1850)	2 to 12	41 to > 52
Non-siphonate suspension feeders	*Placuna placenta* Linnaeus, 1758 *Tawera laticostata* (Ohdner, 1917) *Barbatia amygdalumtostum* (Röding, 1798);	1 to >10	5 to > 15
Siphonate suspension feeders (deep burrowers)	*Lutraria australis* Reeve, 1854 *Divaricella irpex* (Smith, 1885)	>15	>11
Siphonate suspension feeders (shallow burrowers)	*Antigona chemnitzii* (Hanley, 1844)	> 6 to >40	10 to >45
Siphonate deposit feeders	*Tellina emarginata* (Sowerby, 1825)	>40	>36
*EP10 means that 10% of the individuals are able to escape the given (maximum) depth of burial and successfully re-establish themselves in normal feeding position at normal living depth			

Examples of reported tolerances for non-bivalve invertebrates are listed in Table 4. The selected examples (Table 3 and Table 4) document variability in tolerance levels that is closely related to the organism's life style and position in the sediment. An astonishing resilience to burial is evident in some invertebrate groups that can re-emerge from sediment depositions of up to half a metre.

Table 4 **Tolerance levels for sediment depositon for selected invertebrates**

Species	Functional Group	Tolerance level for Sediment Depositon	Author
Infaunal mudworm *Marenzellaria viridis*	Obligate deposit feeder, deep burrower	>5 cm	(Miller et al. 2003)
Epifaunal motile snail *Ilyanassa obsoleta*	Obligate omnivore	10-30 cm	(Miller et al. 2003)
Reef building polychaete *Sabellaria vulgaris*	Sessile suspension feeder	<2 cm	(Miller et al. 2003)
Infaunal tube building crustacean *Corophium volutator*	Deposit feeder	10 cm/month	(Birklund and Wijsman 2005)

In evaluating the tolerance level of organisms to sediment deposition some studies report on EP10, a value that denotes that 10% of organisms can escape this level of smothering. EP10 has been chosen based on the experience that survival of 10% of the population will allow recovery over time.

5.3.4 Darwin Harbour Context

Predictive modelling of accretion levels forecast 100 mm of sediment accretion over two ha of mangrove habitat over three years while 28 ha of mangrove habitat will receive 50 to 100 mm over three years. Generally sediment depositions of 17 to 35 mm thickness per year are expected in these areas (INPEX Browse, Ltd. 2010). Mangrove habitats are predicted to receive the majority of the sedimentation, which consists of fine silty material that can only settle out in protected calm areas.

Coarse sediment generated from dredging is predicted to deposit mainly over the dredge footprint (INPEX Browse, Ltd. 2010 Appendix 13) which after dredging will be devoid of fauna. Severe impacts from accretion of coarse materials are therefore not expected in Darwin Harbour. Burial by coarse sediments, however, is likely to occur at the spoil ground where large amounts of material will be released in a short period of time.

In light of these predictions for accretion levels and the assumption that the invertebrate fauna of local mangrove and mudflat habitats will respond in a similar way as documented for the same functional groups in the literature, it is not unreasonable to conclude that the impacts on the resident faunal communities may only be slight to moderate. Tolerance levels indicated in the literature by far exceed the accretion rate predicted. Although total accretion may amount to 100 mm thickness, the build up over three years will be slow allowing animals to escape or adapt. It is therefore unlikely that effects from sediment deposition will be lethal for most invertebrates in the accretion areas.

Additional influx of sediment may increase nutrient levels and also change particle size composition although mostly fine particles similar to those naturally occurring there are predicted to settle out. Expected effects would be temporary changes in faunal community structure similar to those described by (Metcalfe 2007) for disturbed mangrove habitats.

5.4 Tolerance to Suspended Sediments and Turbidity

One of the major impacts of elevated turbidity is caused by the associated reduction in light penetration. The majority of the fauna discussed in this report do not belong to the benthic primary producers and hence will not be affected by this factor. However, some species of sponge and soft coral also contain zooxanthellae. Part of their energy demand is met by the products of photosynthesis. The distribution of these species is restricted to the photic zone (≤10 m) (Smit 2003). Their sensitivities are similar to those of hard corals that are discussed and assessed in other documents. The present literature review undertaken here focuses on heterotrophic filter feeders only.

5.4.1 Effects of Suspended Sediments on Filter Feeders

Filter feeder organisms appear to be the most sensitive functional group in this context. This is because they capture their food directly from the water column which means that their delicate feeding apparatus comes into direct contact with the suspended sediment particles. The exact effect of this interaction depends on the morphology of the specific feeding apparatus and the type and amount of the sediment particles. It is, however, likely that sediment loads that differ significantly from those that naturally occur in the system will have a detrimental effects on filter feeders. Particles can clog or damage the filtration apparatus reducing the feeding efficiency of the organisms thus ultimately reducing growth rates and reproductive potential. Experimental studies on sponges have demonstrated a negative effect of sediment load on sponge pumping rate and feeding efficiency (Gerrodette and Flechsig 1979). Excessive sedimentation can even lead to a complete stop of filtration since a considerable amount of energy is necessary in order to clean the obstructed canals and orifices (Carballo 2006). However, sponges are able to adapt to a sedimentation regime by changing their morphology to prevent sediment settlement (Carballo 2006).

The tolerance levels for suspended sediment particles can vary significantly between different filter feeding taxa. This variation is illustrated in Table 5, which compares indicative tolerances from studies on various filter feeders. The comparison indicates that amongst the filter feeders, bivalves such as mussels are the most tolerant organisms while sponges belong to the more sensitive groups.

There are two commonly used analytical methods for the determination of sediment suspension, suspended sediment concentration (SSC) and total suspended solids (TSS). They are not identical but can in some instances produce similar results. In this report both SSC and TSS are referred to according to the reference from which the information is derived.

Table 5 Indicative tolerances of sessile filter feeders to suspended solids (Port of Melbourne Corporation 2007)

Common Name/Species	Total Suspended Solids (TSS) [mg/L]	Exposure Duration	Source
Green Lip Mussel *Perna viridis*	Up to 1000	Short periods	(Hawkins et al. 1999)*
Blue Mussels *Mytilus edulis*	200 120	Short periods <20 days	(Plummer and Jenkins 2003)*
Blue Mussel *Mytilus edulis*	560	21 days	Mackin 1961*
Juvenile Hard Clam *Mercenaria mercenaria*	25	21 days	(Briceij et al. 1984)*
Oyster *Crassostrea gigas*	<90	Short periods	(Banille et al. 1997)*
Sea Squirt *Halocynthis pyriformis*	0-46	21 days	(Armsworthy 2001)*
Sea Squirt *Pyura stolonifera*	135	Short periods	(Griffiths 1980)*
Sea Squirt *Pyura stolonifera*	159	Short periods	(Berry and Schleyer 1983)*
Sea Squirt *Ciona intestinales*	30	Short periods	(Birklund and Wijsman 2005)
Sea Squirt *Botryllys schlosseri*	25	7 days	(Birklund and Wijsman 2005)
Sponge *Verongia lacunosa*	10	4 days	(Gerrodette and Flechsig 1979)
Sponge *Cinachira apion*	49	10 days	Rice 1984
Sponge *Haliclona urceolus*	0-30	Short periods	(Birklund and Wijsman 2005)
Lace Coral (Bryozoa) *Electra crustulenta*	30	2 days	(Birklund and Wijsman 2005)
* Reference in (Port of Melbourne Corporation 2007)			

Suspended particles not only interfere with the feeding mechanism but also with the food itself. Fine sediment particles may induce flocculation trapping planktonic organisms as described by Williams et al. (2007). Apparently flocculation happens naturally in the river arms where they enter into Darwin Harbour. This phenomenon demonstrates the complex interaction of hydrological, sedimentological and biological processes within the Darwin Harbour ecosystem.

In the same way that suspended sediment particles interact with planktonic food sources of filter feeders, they also interact with gametes and larvae that become part of the plankton once released into the water column. Many benthic invertebrates rely on the dispersal of larvae for their reproductive success. However, those species may still differ significantly on how they are affected by this factor. For instance, the length of time larvae spent in the water column before they can settle varies widely from hours to days to weeks. Even within taxonomic groups such as sponges different reproductive strategies occur. Some sponges are broadcasters releasing their gametes into the water where fertilisation occurs which is followed by larval development and settlement. Other sponges are brooders where the eggs are fertilised within the sponge and already developed larvae emerge that can settle close to the parental sponge. Interference by sediment particles can affect the dispersal of larvae interrupting connections between populations and impairing recruitment. Depending on the extent of this impact it could have an effect on the integrity and functioning of the ecosystem.

5.4.2 Darwin Harbour Context

It is clear that elevated levels of suspended sediments cause stress to marine organisms by interfering with their feeding and reproduction. The severity of this impact and whether it causes mortality is, however, difficult to predict. Impacts on filter feeding communities can range from mortality to changes in the community structure.

Darwin Harbour is a naturally turbid environment. Suspended sediment concentrations (SSC) in the harbour have been reported to average 15 mg/L with a range of 1.5 to 83 mg/L (INPEX Browse, Ltd. 2010 Appendix 9). According to the values produced in Table 5 this high variability would mean that some organisms could already be stressed by the naturally occurring sediment loads. Alternatively, it could indicate that the resident fauna in Darwin Harbour is well adapted to high turbidity. Modelling of dredge related sediment suspension predicts increased SSC levels. After dredge phase six, the most intensive dredge phase in the program, backhoe dredging will elevate SSC levels to 5 to 20 mg/L above background while an intensive dredging period using the cutter suction method will produce an elevation of 200 mg/L. Depending on dredging phase and the respective locations of dredging, elevated SSC levels will persist in the harbour at varying levels for approximately four years. After completion of the dredging program SSC levels are expected to return to their natural level.

Experimental studies on selected filter feeding species only tested the effects of elevated TSS levels over relative short periods of time (maximum 21 days, Table 5). The documented tolerance levels for some sponge species (Table 5) indicate that if Darwin Harbour species would exhibit similar sensitivity levels, the dredging program could cause an impact to sponges. However, observations on sponge recovery to impacts from sediments from the Pilbara in Western Australia indicate a good recovery potential for this type of benthic community (DSD 2010).

6.0 Benthic Environmental Thresholds and Indicators

The integrity of marine ecosystems can only be maintained if the ecosystems are protected from degradation. The greatest threat to the maintenance of ecological integrity is habitat destruction.

Setting environmental thresholds and selecting biological receptors is a useful tool in protecting ecosystem integrity by aiming to preserve its functional and structural units. The concept of thresholds relies on defining an effective tolerance level for a stressor that, once exceeded, will cause an effect in the receptor that has been defined as unacceptable or alarming.

6.1 Defining Stressors, Receptors and Tolerance Levels

Stressors in the marine environment can be physical, chemical or biological in nature and have a natural or anthropogenic cause. Impact assessments concern themselves with impacts from human activities. In the current context of marine infrastructure development, dredging is one of the major project activities carried out over a four year time frame. It causes disturbance to the seafloor by removing and dispersing substrates. At least one distinct stressor can be identified. The term stressor already indicates that these factors are selected on the basis of the effect, namely stress, they have on potential receptors. The stressor selected here is suspended sediment.

The way stressors are defined and reported is already guided by the choice of receptor. For example, suspended sediment can be described in terms of sediment load in the water column measured in mass per volume. This can then be broken down further into the type of sediment and the particle composition. Sediment suspension can also be expressed in light attenuation. This is a particularly useful approach when photosynthetically active organisms are considered as receptors but less meaningful for heterotrophic filter feeders. The knowledge of particle sizes of suspended sediments on the other hand is evidentially useful for the assessment of impacts on filter feeders as there is a close relationship between particle size and the potential to clog the filtration apparatus and impair feeding.

The selection of receptors that reflect important components of the ecosystem is a meaningful choice when the objective is to maintain and protect ecosystem integrity. It is also important to select a component of the ecosystem that is well represented or dominant in the considered project area. Finally the selection of receptors should be supported by a well understood relationship between impact and response (Berryet al. 2003). Indicator organisms used in ecotoxicology are a good example of evaluating the impact of stressors. Such organisms have undergone extensive testing and experimentation to determine clear causal relationships between, for example, toxins and mortality. Even though indicator organisms for ecotoxicology are used under well defined controlled conditions that can often not be replicated with organisms in the field, it is desirable to have substantial knowledge of the interactions between stressor and receptor and of the prevailing environmental conditions and the cumulative effects of background levels and impact levels on the receptor.

The selection of a biological community as a receptor can provide an ecosystem relevant response to stressors. In an ecological context it makes sense to monitor a biological community such as filter feeders that have a structural and functional role and hence its response as a whole to disturbances is more relevant to ecosystem maintenance than the response of one species within it.

Furthermore effects have to be clearly observable and measurable. For instance physiological changes or changes in reproductive success and feeding efficiency and behaviour are often difficult to observe and quantify. Some effects only manifest themselves a long time after the impact occurred which makes it difficult to monitor cause and effect.

When thresholds or tolerance levels are chosen, they can have different functions. They can be set at a low level to serve as early warning indicators or at a level that is informed by the recovery potential of the receptor. A tolerance level of 50% mortality, for example, could have been defined based on the knowledge that the population has shown good recovery in previous experiments or applications after 50 % reduction, but poor recovery when mortality was elevated beyond that level.

In Western Australia impact assessments for key receptors such as BPPs are routinely required to predict different zones of impact according to severity. Following decreasing severity these are termed “Zone of permanent Impact or Loss”, “Zone of temporary Loss/Damage” and “Zone of Influence”. This type of prediction allows the development of a spatial context by using modelled pressure fields representing threshold levels.

6.2 Developing Thresholds for Filter Feeders

In the current project context filter feeder communities have been identified as both functionally and structurally important components of the benthic ecosystem. They are also well represented in Darwin Harbour. In anticipation of potential stress to these communities it is desirable to define a tolerance or trigger level for suspended sediment levels that predict and prevent serious impacts. In order to develop such a threshold some knowledge about the receptor and its interaction with the stressor is required.

Table 6 Current knowledge of filter feeder community response to SSC*

Receptor Sponge/ Soft Coral Community on Hard Substrates	Type of Response	Current Level of Knowledge
Sensitivity to specified SSC*	Variable and uncertain	Information from some single sponge species’
Efffect of exposure duration	Variable and uncertain	Information from some single sponge species’
Differential response to different levels of SSC	Variable and uncertain	Information from some single sponge species’
Observable response to elevated SSC	- Mortality - Partial mortality - Reduction in: growth rate, reproductive success, feeding efficiency, - Adaptation to stressor through modified morphology - No response	Information from sponges and to limited extent from soft corals (e.g. Carballo et al. 1996; Riegl 1995, Riegl and Bloomer, 1995; Gibbs and Hewitt 2004, Lohrer et al. 2003)
Recovery potential	Variable and uncertain	Few studies on sponge communities and Inferred from knowledge of reproductive modes and capacity to regenerate,
* Suspended Sediment Concentration		

Currently very little is known about the response of filter feeding communities to SSC levels or in a broader context to the impacts from dredging activities including increased sedimentation. Consequently advancement of knowledge in this area has been identified as a research priority (The Centre for Marine Ecosystems Research ECU 2009). It is also not surprising that no previous projects to date have directly focused on sponges or filter feeding communities and their response to increased SSC or sedimentation.

Filter feeding communities in Darwin Harbour are likely to be impacted by the planned dredging activities. However, based on the currently available knowledge only general assumptions about predicted impacts can be made. Filter feeder communities comprise a variety of different species and each community at each impact site may differ in its composition and density and hence in its response. But even if all species within these communities were known, this would still not allow for a more accurate prediction. Taxonomic knowledge does not inform on the sensitivity profile of the species. In addition the same sponge species, for example, can have different morphotypes and it could be shown that tolerance levels are related to morphotype (Maldonado et al. 2008). Experiments with sponges also demonstrated that tolerance levels can vary greatly between sponge species.

There is little information on how communities and species from high turbidity areas such as Darwin Harbour react to elevated SSC levels. It remains speculation whether communities from turbid background conditions are well adapted to such elevated levels or whether they exist at their physiological tolerance limit.

Exposure duration is another parameter that has not been researched to any great extent. Experimental studies on sponges have only monitored organisms for a few days to a maximum of two weeks (Table 5) which provides no suitable background for impact assessments of the dredging campaign currently proposed. A general understanding of the combined impacts of concentration and exposure duration has been derived from findings in hard corals and illustrated in Figure 12.

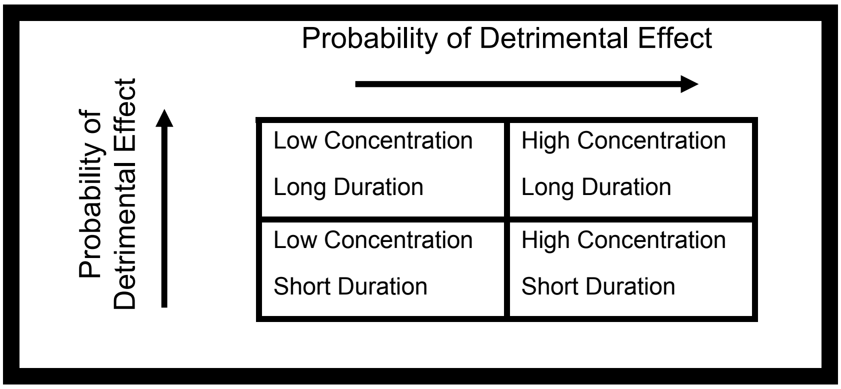


Figure 12 **Categories of potential exposure to suspended sediments in the vicinity of a dredging operation**

In most studies discussing the impacts of dredging on filter feeders, two aspects of sediment disturbance, suspended sediments and sedimentation, are considered. Sedimentation is judged to be the more severe impact on sponges (Ruetzler et al. 2007). One reason why a threshold for sedimentation is not suggested here, is that predictive modelling of accretion associated with the planned dredging in Darwin Harbour shows that the majority of sediment deposition will take place on intertidal flats and in mangrove habitats (Figure 10) away from the subtidal filter feeder communities. The other reason why a sedimentation threshold is not considered lies in the poor level of information available that could support such a threshold.

Studies documenting recovery of filter feeder communities after impact are also scarce. Information on selected sponge species indicates that they have a high capacity to adapt to changing and stressful conditions and recover quickly (Carballo 2006, Ruetzler et al. 2007). This high recovery capacity is partly due to their primitive level of organisation that gives them more plasticity and adaptation potential. In reviewing available information of impacts on sponges a survey conducted for the Pluto Project in Western Australia is summarised.

Sponge coverage was documented along transects using photography. Transects were recorded in 2006 before dredging commenced and after an intensive dredging campaign in 2008 and then in 2009. Declines in sponge cover were noted after the initial intense dredging phase but considerable recovery of sponge density was evident in the later surveys. Recovery was predominantly a result of sponges clearing sediment loads which had obscured them in the August 2008 survey with some re-growth or (at least spatial extension) of sponges to near their original size (DSD 2010)

Over 50 research articles and technical reports relating to the assessment of impacts on benthic invertebrates and the quantification of such impacts using or developing thresholds have been reviewed in the context of the literature study presented here. Only a fraction contained useful or applicable information on this topic.

Based on the currently available information that could support the development of thresholds or tolerance levels for the effects of SSC or sedimentation on the filter feeder communities of Darwin Harbour, it must be concluded that the development or application of such a threshold would not be scientifically sound. The review demonstrates that the current information has significant gaps that only extensive basic research and data collection can fill.

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7.0 Recovery Potential after Disturbance

Recovery describes a situation after disturbance when the original condition is restored. In the context of this review this means that full recovery is observed when the affected habitats and their colonising biota show no difference to the original pre-disturbance state. At an ecosystem level an accurate assessment of recovery can only be made through detailed pre- and post impact studies. Such studies can be used to inform and support assessments of recovery potential for comparable sites.

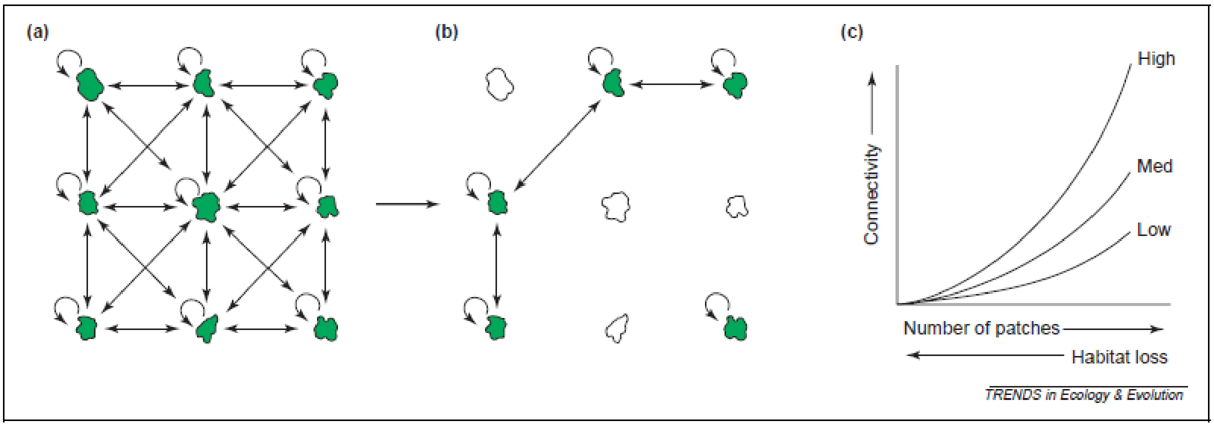
One of the important questions to be asked when impacts due to a development project are unavoidable is whether the system is able to cope with these and eventually recover from them. An ecosystem that is able to do that is considered resilient. Ecosystem resilience therefore refers to its capacity to adapt to changes and disturbances, yet retain its basic functions and structures. A resilient ecosystem can adapt to impacts, and rebuild itself when damaged.

This section examines whether the anticipated impacts on benthic fauna and their habitats are buffered within the resilience spectrum of the ecosystem thus not resulting in loss of any of its basic functions and structures. The basic elements of the ecosystem that need to be maintained are:

- Interconnectivity
- Biodiversity
- Trophic Structure.

7.1 Maintenance of Interconnectivity

The habitat map of the Darwin Region, Figure 3, shows distinct patches of hard and soft substrate habitats. Hard substrates in the deeper water are mainly colonised by filter feeder communities while soft substrates are the domain of small infauna and epifauna species. Although not represented as patches on the habitat map, soft substrate itself is not homogenous but exists as at least four distinct types according to sediment properties with associated distinguishable faunal communities (Michie 1987, Figure 4). This means that soft substrates and their habitats and fauna also exhibit patchiness and their interconnectivity is potentially subject to interruption by disturbances. A conceptual appreciation of patchy distributions and their interconnections is depicted in Figure 13. It illustrates very clearly how the loss of habitats or populations can affect the interconnectivity of the ecosystem and that the major factors determining the severity of the effect are the number of patches lost in relation to their total number and the distance between the remaining patches.



TRENDS in Ecology & Evolution

Larval dispersal among patches of habitat, a key process of maintaining marine populations and habitats. Arrows depict potential dispersal mechanisms among adjacent patches and self-seeding within patches.

a) An intact system with high connectivity
b) A damaged ecosystem showing reduced larval connectivity
c) The non-linear relationship between habitat loss and the strength of larval connections for species with high, medium and low dispersal abilities.

Species with limited dispersal are more vulnerable to recruitment failure.

Figure 13 Illustration of interconnectivity of patches (habitats, populations), reproduced after (Hughes et al. 2005)

Loss of interconnectivity also has implications for the recovery potential. Habitats that have suffered defaunation, for example, can be recolonised after disturbance and re-established in their function if vital recruitment sources exist nearby. It also becomes clear that the minimum distance between patches allowing maintaining connectivity is regulated by many factors such as the hydrological regime and the specific reproductive modes and dispersal abilities of each species represented in the faunal community. It not only requires a detailed knowledge of the species and their biology but may even require genetic studies at population level to identify source and sink populations. Rare species may have a scale of connectivity that extends far beyond the confines of the project development area and can only be revealed through large scale extensive studies. Such studies would be beyond the scope of current investigations.

The effect on biological receptors is always differentiated such that some species may maintain connectivity and others are disrupted. Similarly the process of restoring interconnectivity will occur in succession according to the biological profiles of species.

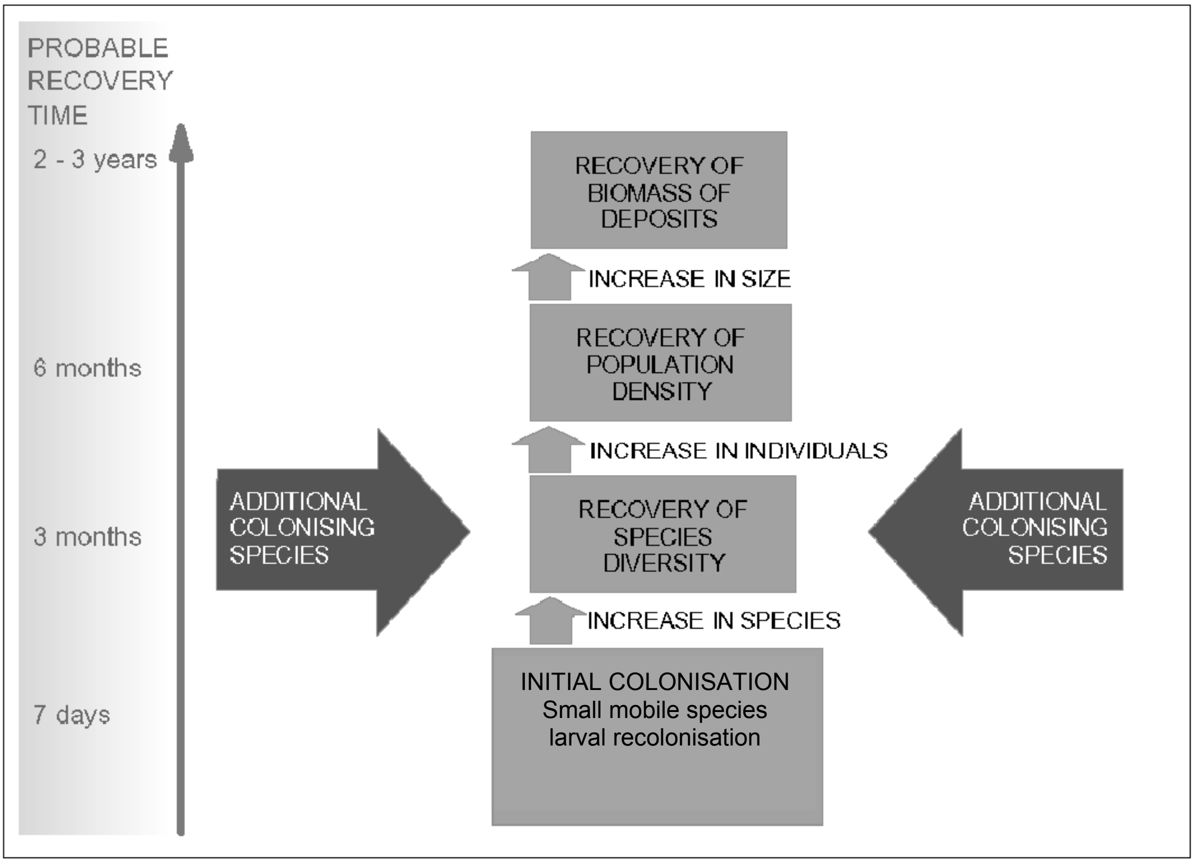
Due to the complexity of the ecosystem and the limited knowledge it would be difficult to describe fully the intricacy of all connective relationships. The best practical approach under these circumstances is to use available knowledge and to concentrate on major interactions that are more clearly understood.

7.1.1 Loss of Habitats and their Communities

The loss of habitat has been predicted for the project development area. The areas of permanent loss of hard substrate are shown in Figure 8 under the outline of the dredging footprint. They include Walker Shoal which is colonised by an established community of sponges and soft corals. The loss of hard substrates particularly those providing habitat for filter feeder communities must be considered as more severe than the loss of soft substrates because hard substrates are less widespread, have a more patchy distribution and their loss in most cases will be permanent as they cannot easily be replaced. This situation also highlights the vulnerability of hard substrate filter feeder communities and their associated fauna that depends on this type of habitat. It appears, however, that only a small percentage of all available hard substrate habitat in Darwin Harbour will be lost. It is therefore not likely that hard substrate habitats and their communities will be diminished to such an extent that their ecological function and the role they play for the ecosystem's integrity will be lost.

The most severe impact on soft substrate habitats may not be loss of habitat but the loss of its colonising fauna. Generally the severity of this impact must be judged in the context of the total available habitat colonised by such communities. An assessment of this situation based on superimposing impact footprints and pressure fields over a habitat map shows that there will be losses both in the Darwin Harbour and the offshore area. The extent of soft substrates throughout the harbour and the offshore area can be judged as substantially larger than affected areas thus providing a repository of organisms for re-colonisation. Such a repository helps maintain connectivity and facilitates recovery. It is therefore likely that the functions these communities fulfil are being preserved. A detailed post-impact monitoring study of benthic fauna in Botany Bay describes the re-colonisation and recovery of benthic soft substrate fauna (Wilson 1998). This study documents that although substrates that had been devoid of fauna due to dredging had been recolonised, the community structure and faunal composition had changed at many sites. Dredging had created different habitats resulting in changes in faunal composition. A post dredge monitoring study conducted near Fort Pierce Inlet, Florida also documents a change in infaunal community structure after dredging (Johnson and Nelson 1985). It is important to note that functional relationships within ecosystems can be preserved even if the species composition changes.

One of the impact areas of the project development area that is likely to suffer defaunation is the Dredge Material Deposition Ground (DMPG). It is a likely scenario that released material will accumulate in mounds where it reaches the bottom creating a hummock like topography. Benthic fauna smothered in that way is unlikely to survive. Studies investigating the recovery of DMPG fauna indicate that re-colonisation from adjacent areas begins soon after the impact occurs (Birklund and Wijsman 2005, Bolam and Rees 2003, Cruz-Motta and Collins 2004). An uneven distribution of dredge material appears to enhance this process by preserving unaffected patches within the DMPG from which recruits can be sourced. In addition a faunal community that is characterised by small opportunistic deposit feeders like those that are often dominant in infauna communities of tropical soft sediments (Alongi 1989) is pre-adapted to rapid re-colonisation. A study of the recovery of the faunal community at a DMPG in Cleveland Bay (North Queensland) documents initial reduction in abundance and diversity followed by an astonishingly rapid recovery within three months after the disturbance ceased (Cruz-Motta and Collins 2004). Generally recovery in disturbed, shallow environments is thought to be faster than in stable, deep environments (Kotta et al. 2009). This is mainly due to the pre-adaptation of the resident fauna to disturbances and its adaptive response (Bemvenuti et al. 2005). A schematic illustration of the recovery process is shown in Figure 14.



Generalised flow diagram showing the sequence of recovery of the macrofauna in coastal marine deposits in a high energy disturbed area (South coast of UK) following cessation of dredging. After (Newell et al. 2004)

Figure 14 Illustration of recovery process from a disturbed, temperate location

A three year study investigating the effects of dredge material deposition in the Pearl River Estuary, Hong Kong challenges the view that tropical and subtropical faunal communities recover more rapidly than temperate ones. In this study three sites of different disturbance levels were monitored with the result that recovery at these sites varied between one and four years. Recovery at the most stable, undisturbed site was slower than at the more disturbed locations. The authors conclude that it seems likely that the frequency of disturbance, instead of latitude is the major determinant for benthic recovery time. Moreover, the high concentration of suspended solids at the study site (100 mg/L at low tides), thought to have adverse effects on colonization could also have contributed to the slow recovery in the study area (Qia et al. 2003).

A comparison of recovery periods for DMPGs at different locations and under different conditions is presented in Table 7. The recovery time span varies between three months and over 2.5 years. The listed examples support the finding that shallow, disturbed sites recover faster than stable, deep sites.

Table 7 **Examples of recovery of faunal communities on spoil grounds**

Period and recovery	Habitat characteristics	Site	Reference*
3 months	Shallow (6 m), high-energy environment	Coffs Harbour, Solitary Islands, NSW, Australia	Smith and Rule (2001)
7 months	Wave-stressed coastal (9 m)	Monterey Bay, California, USA	
11 months, almost complete recovery	Shallow, exposed	Lewes, Delaware Bay, Delaware, USA	Leathem et al. (1973)
1 year	Shallow, unstable	Upper Chesapeake Bay, USA	
1 year, no recovery		Elliot Bay, Puget Sound, Washington, USA	
15 months	Fine sediments	Chesapeake Bay, USA	Harrison (1970 personal communication)
1 year, largely recovered	Shallow (approx. 5 m) sand	Torsminde, Norderney, Terschelling, De Haan, North Sea	Essink (1997)
1.5 years		Upper Chesapeake Bay, USA	Cronin et al. (1970)
1 year	Moderately wave-stressed coastal (18 m)	Monterey Bay, California, USA	Oliver et al. (1977)
1.5 years	20 m depth, strong tidal currents	Monterey Bay, California, USA	Oliver and Slattery (1976)
> 2 years	Fine sands, 55 m deep.	Anse a Beaufils, Baie des Chaleurs, Canada	Harvey et al. (1998)
1 year, almost recovered	60 m, semi-stable submarine ridge	Monterey Bay, California, USA	Oliver et al. (1977)
9 months, not recovered	Sandy, deep (64 m) stable site	Elliot Bay, Puget Sound, Washington, USA	Harman and Slywester (1974 personal communication)
1-4 years	Non-wave-stressed coastal (24 m)	Monterey Bay, California USA	Oliver et al. (1977)
10 months, far from recovered	Sheltered, 30 m deep, stable sediments	Columbia River, Oregon, USA	Richardson et al. (1977)
2.5 years, not recovered	Deep, fine sandy bay	Mirs Bay, Hong Kong	Anonymous (1996)
6 months, early stages of recovery	Deep, coastal	Atlantic coast of Boston, Massachusetts, USA	Lunz et al. (1997) personal communication
*References from (Bolam and Rees 2003)			

7.2 Maintenance of Biodiversity

Links between biodiversity and ecosystem function are difficult to demonstrate and quantify, yet the notion that higher levels of diversity safeguard the loss or damage of ecosystem functionality is well accepted (Barrio Frojan et al. 2009).

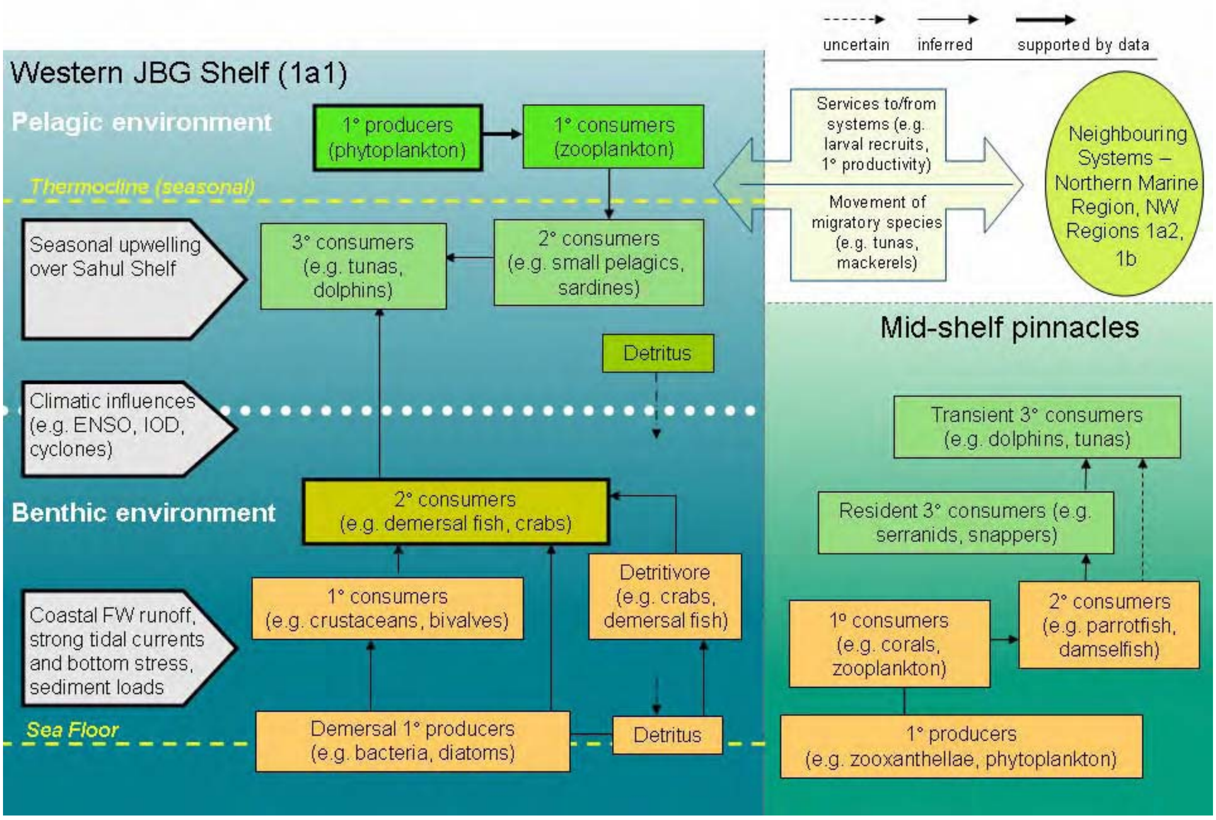
As discussed earlier the potential for endemic fauna is low reducing the potential for species extinction. In addition environmental stress is generally greater in the tropics. Factors such as massive riverine sedimentation, wet season activity causing exposure to low salinity and patchy food supply shape the faunal communities. To cope with such demanding conditions pioneering assemblages that are well adapted to respond quickly to changes and have the ability to re-colonise after disturbance have developed (Alongi 1989). The presence of these types of communities gives a level of resilience to the ecosystem. Assemblages made up of species that exhibit such resilience and are able to colonise changing and unstable habitats such as sediments that are frequently re-worked by currents are considered the least vulnerable in the ecosystem.

In terms of biodiversity enhancing functions, complex habitats such as those formed by filter feeder communities that provide a three dimensional structure and harbour many small cryptic invertebrates are of particular significance in maintaining biodiversity levels. Other species rich habitats are mangroves that sustain diverse groups of detritivores and their predators and intertidal flats that provide nutrient rich food resources. A reduction of these habitats may contribute disproportionally to the loss of biodiversity.

Although it is not likely that anticipated disturbances will cause local extinctions and the complete loss of certain habitat types in the development area because the assessment suggests that there is a sufficient remaining habitat area that will not be severely impacted, species that occur in low numbers in a rare patchy distribution pattern may be vulnerable and changes to abundances and faunal compositions may be observable at least in the intermediate time frame after impact. A post-dredge monitoring study at Botany Bay for example, reported that dredging had changed the benthic fauna composition in the order of 20% (Wilson 1998)

7.3 Maintenance of Trophic Structure

The trophic structure is one of the most important elements of the marine ecosystem because many of the known massive changes or phase shifts in ecosystems have been caused by changes in the trophic structure. Well known are those caused by overfishing where top predators are removed. The effect then cascades down the food chain and the outcome is not necessarily easy to predict because food webs can be quite complex and their interactions poorly understood. A schematic trophic model illustrates the potential complexity of such systems (Figure 15). It is interesting to note that when considering the benthic component of the ecosystem, the model identifies climatic influences, coastal freshwater runoff, strong tidal currents and bottom stress and sediment loads as drivers, the latter being directly related to the identified anthropogenic disturbances.



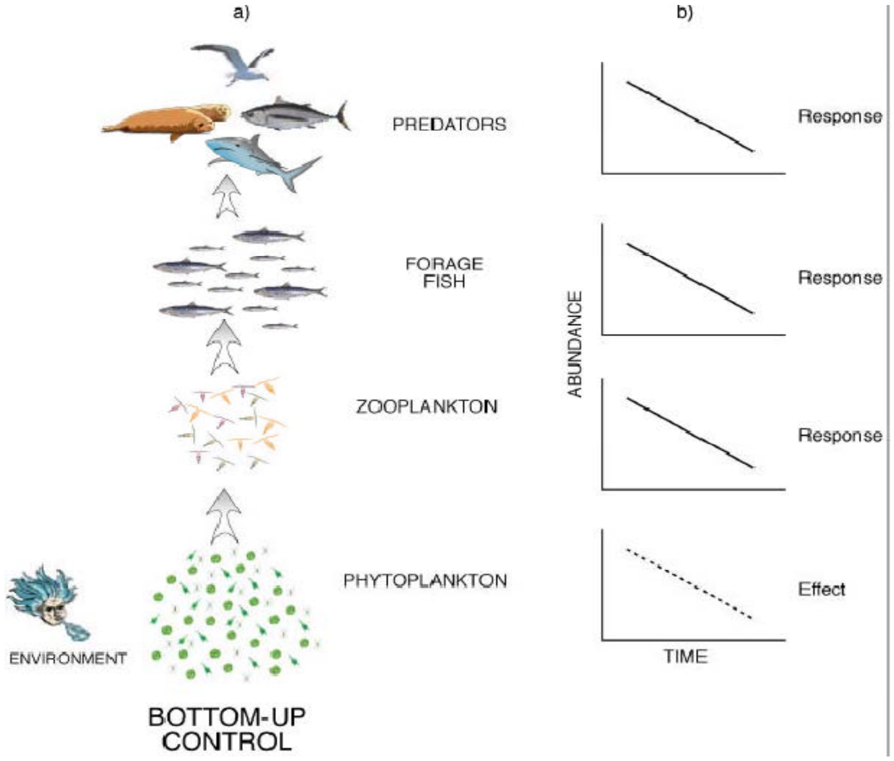
Schematic trophic model of the Western Joseph Bonaparte Gulf subregion showing information on the extensive habitat in the coastal and central shelf region (left) and a less extensive but important habitat (right).

Figure 15 Example of trophic model after (Brewer et al. 2007)

When discussing a benthic system it is appropriate to choose a bottom-up approach as is depicted in Figure 16. The illustrated example shows planktonic not benthic organisms but these can be replaced by benthic organisms such as detritivores, for example. Such a model allows imagining trophic pathways build on benthic organisms. A large body of correlative evidence indicates a positive relationship between infaunal biomass and total fish catch on subtropical and tropical shelves (Alongi 1989) supporting a bottom-up approach. An example of a trophic relationship from the Port of Darwin region is the trophic connection between dolphins as upper level predators and invertebrate fauna. Three species of dolphins, snubfin, Indo-Pacific humpback, and the Indo-Pacific bottlenose dolphin live in Darwin Harbour and forage there. An analysis of the diets of snubfin and Indo-Pacific humpback dolphins revealed that their diet consisted of four major taxonomic groups: fish, cephalopods, decapods and bivalves with snubfin dolphins including more benthic invertebrates in their diet than Indo-Pacific humpback dolphins (Parra and Jedensjö 2009). Consequently snubfin dolphins have a more direct dependence on benthic invertebrates but other species with a preference for pelagic species of fish and cephalopods also depend on the productivity that benthic invertebrates provide, albeit indirectly.

This trophic relationship also illustrates the role that biodiversity plays in the trophic structure. Snubfin dolphins had consumed a variety of 24 different fish taxa, in addition to several cephalopods and decapods that had not been identified. Sixteen different fish taxa and few unidentified cephalopods and bivalves were found in Indo-Pacific humpback dolphin stomachs (Parra and Jedensjö 2009). The diverse array of invertebrates that convert detritus into biomass clearly sustains a far reaching trophic relationship. Substantial changes on such invertebrate communities can therefore have an effect on upper trophic levels.

To create more complexity around this trophic connection another benthic functional group can be integrated into the food web. Filter feeder communities are habitat formers. The three dimensional structure of soft corals and sponges, for example, provide shelter and substrate for other invertebrates and fishes. Through their patchy distribution these communities concentrate fishes thus creating preferred feeding locations for upper level predators. A reduction in such trophic “hotspots” would then also affect the predators that they originally attracted.



(a) Bottom-up control within a simplified four-level food web in a marine ecosystem.

(b) The physical environment being less favourable controls the decrease in abundance of the phytoplankton, which in turn has a negative impact on the abundance of the zooplankton. The diminution of the zooplankton controls the decrease in abundance of the prey fish, which itself leads to a decrease in the abundance of the predators (the control factor is a solid line and the responses are dashed lines).

Figure 16 The functioning of marine ecosystems (Source: Cury et al. 2001)

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8.0 Environmental Impact Assessment and the Consideration of Infauna and Filter Feeding Communities

Environmental impact assessments require investigations of the marine environment that provide a solid knowledge base to realistically evaluate how disturbances associated with the project's development activities will affect the environment.

The amount and type of information that needs to be collected through surveys and original studies depends on several factors. The type of impacts that are anticipated and the existing knowledgebase for the specific environment are important considerations. The way environmental values are prioritised and expressed in guidelines and guidance statements varies depending on the State and Commonwealth environmental regulating authorities. In addition public expectations and political climate play a role.

A list of projects representing relevant marine development programs are presented in Table 8. Comparing different projects some general observations can be made. The number and detail of investigations required by environmental authorities increased in recent times reflecting a desire to acquire more substantial data sets upon which decisions are made. Marine biological investigations in Western Australia are prioritising the protection of marine benthic primary producers. The size of the project and its location influences the amount of investigative effort required as well as the close proximity to urban centres or particular environmental values that have public awareness (e.g. whale breeding grounds).

Table 8 Selection of marine development projects and type of investigations relating to infauna and filter feeder habitat

Project	Development	Investigatons
Ichtys Gas Field Development (INPEX Browse, Ltd. 2010)	**Offshore:** Ichthys Field, pipeline **Nearshore:** Port infrastructure, dredging, pipeline	**Subtidal Survey**: - Habitat description (gas field, pipeline route): - Infauna survey: (gas field) species level identification **Nearshore Subtidal Survey**: - Habitats, biota (incl. filter feeder), composition, video, mapping
Sunrise Gas Project (Woodside Ltd 2001)	Gas Field Development: Pipeline	**Subtidal Survey**: - Habitat description (gas field, pipeline route): - Infauna survey: (gas field) species level identification
Darwin LNG Plant, NT (URS Australia Pty Ltd 2002)	**Offshore:** Pipeline **Nearshore**: Port infrastructure, dredging	**Subtidal Survey**:, - Habitats, biota, video - Infauna (pipeline route), species level identification **Intertidal Survey**: - Habitats
Pluto LNG Development, WA (Woodside Ltd 2006)	**Offshore:** Pluto Field **Nearshore**: Pipeline routes and port facilities	**Offshore Survey**: - Habitats, biota (incl. filter feeder), video, ROV, - Infauna, grab samples, species level identifications - Epifauna (sled samples) **Nearshore Subtidal Survey**: - Habitats, biota (incl. filter feeder), composition, video, mapping **Intertidal Survey:** Habitats, biota, mapping

Project	Development	Investigatons
Devil Creek Development Project (Apache Energy Ltd 2008)	**Offshore:** Raindeer Field, pipeline **Nearshore:** Port infrastructure, dredging, pipeline	**Subtidal Survey**: - Habitats, biota (incl. filter feeder), composition, video, mapping **Intertidal Survey**: - Habitats, biota, species level identification
Gorgon Gas, WA (Chevron Australia Pty Ltd 2010)	**Barrow Island**: MOF, LNG jetty, feed pipeline, system and domgas pipeline	**Subtidal Survey** - Habitats, biota (incl. filter feeder), composition, video, diver, mapping - Sessile epifauna, dominant taxa, assemblages - Satellite imagery for habitat mapping **Intertidal Survey:** - Habitats, biota
Wheatstone Project, WA (Chevron Australia Pty Ltd 2010)	**Offshore**: Gas Field, pipeline **Nearshore**: Port infrastructure, dredging,	**Subtidal Survey**: - Habitats, biota (incl. filter feeder), composition, video, mapping **Intertidal Survey**: - Habitats, biota, species level identifications
Cape Lambert Port B, WA (Rio Tinto 2009)	**Port Development**: Channel dredging, spoil disposal	**Subtidal Survey**: - Habitats, biota (incl. filter feeder), composition, video, mapping - Pre- and post spoil disposal infauna survey **Intertidal Survey**: - Habitats, biota
Anketell Point Port Development (AECOM 2009)	**Offshore**: Spoil disposal **Nearshore**: Port infrastructure, dredging	**Subtidal Survey:** - Habitats, biota (incl. filter feeder), composition, video, mapping **Intertidal Survey**: - Habitats, biota
RGP6 Port Facilities (SKM 2009)	**Port Expansion**: Dredging for expansion of Nelson Point	**Subtidal Survey**: - Habitats, biota (incl. filter feeder), composition, video, mapping
New Parallel Runway Draft EIS/MDP, Qld. (Brisbane Airport Corporation Pty Ltd 2007)	**Dredging Project**: Sand extraction for runway	**Subtidal Survey**: - Infauna survey, species level identification - Epibenthic habitat and biota survey: mapping
Port of Melbourne Channel Deepening, VIC (Port of Melbourne Corporation 2007)	**Port Development**: Channel deepening, dredging	**Subtidal Survey**: - Habitat description, video, quadrat sampling, sponge assemblages - Infauna survey, species level identification

9.0 Conclusions

This literature review supports the conclusion that the tropical benthic ecosystem exhibits a greater resilience and recovery potential than comparable temperate ecosystems. The benthic fauna appears to be characterised by many forms that are adapted to stressful environments. Some groups such as sponges and soft corals, for example, have multiple reproductive modes that allow them to re-establish themselves and multiply quickly after disturbance. Soft substrates are colonised by opportunistic deposit feeders, the same functional group, that is characteristic for pioneering communities. This situation facilitates fast re-colonisation after disturbances. Sessile assemblages may also be naturally adapted to seasonal stress, such as the impact of wet season run-off and increased sediment suspension and deposition. Such communities often have a dynamic structure that can react to erratic stressful events with a 'growth and retract' response. The presence of species and communities with such resilience and recovery potential buffers the ecosystem against impacts and helps maintain a functional trophic structure.

Table 9 provides an overview of the key impacts and the associated risks to the benthic environment and summarises the findings derived from this literature review.

Table 9 Overview of key impacts on benthic ecosystem discussed in this report

Potential Impact	Risk	Evaluation	Rating
Reduction of hard substrate habitats	- Permanent loss of fauna, extinction - Disturbance of ecosystem interconnectivity - Disturbance of tropic relationships	- Low endemicity - Assessment of lost area in relation to retained area of similar habitat - Reduction of abundances	- Extinctions unlikely - Ecosystem interconnectivity likely to be maintained - Maintenance of trophic levels likely
Burial of mobile infauna and epifauna	- Changes in abundance and diversity - Disturbance of tropic relationships	- Low sedimentation rate, low impact - Good recovery potential - Impact only temporary	- Effect on ecosystem functions unlikely
Burial of sessile fauna on hard substrates	- Permanent loss of fauna, extinction - Disturbance of ecosystem interconnectivity - Disturbance of tropic relationships	- Most sedimentation occurs on soft substrates - Low impact on hard substrates - Some recovery potential	- Effect of ecosystem function unlikely
Exposure of filter feeders to elevated turbidity level over extended period	- Permanent loss of fauna, extinction - Disturbance of ecosystem interconnectivity - Disturbance of tropic relationships	- Low endemicity - Some recovery potential - Some adaptation potential - High resilience to impacts for specific taxa	- Temporary reduction in abundance - Temporary reduction in local diversity - Temporary changes in community structure - Ecosystem functions likely to be maintained by resilient and adaptive faunal elements

This literature review reveals some gaps in basic scientific knowledge. The ecology, function and sensitivities of filter feeder communities are not well understood. There is also a lack of information supporting the development of meaningful impact thresholds.

To assess the impacts of dredging on the marine environment, it is desirable to employ assessment indicators that can reflect the response of the biological environment. In this context coral and seagrass species often serve as indicator species. Their sensitivity profiles are such that they react adversely to reductions in light availability and to increased sedimentation. On the basis of these sensitivity profiles site specific threshold values have been developed for some projects that define levels of light availability and quantify sedimentation according to the indicator's response. This has led to the development and application of site specific threshold values for these parameters that are now used to determine acceptable levels of turbidity and sedimentation during dredging operations on various projects.

In Darwin Harbour much of the turbidity and sedimentation impact is received by organisms other than hard corals and seagrasses. For this reason it would be meaningful to apply thresholds derived from the response of indicator organisms that colonise these affected habitats. However, to qualify as indicator organism or community the relationship between the impact parameter and the organism's or community's response has to be clearly established and quantified. This is the scientifically accepted basis for the development of meaningful threshold values. However, this type of information is not available in the Darwin Harbour context.

Filter feeder communities are an important element in the local ecosystem and are present in impact areas but there is insufficient information to establish thresholds that apply to them. Sediment fate modelling predicts that much of the fine sediment accretion will take place in mangrove and intertidal mudflat habitats but not on filter feeder communities colonising hard substrates. A review of responses of functional groups to sedimentation indicates that the predicted levels of accretion will not have severe effects on the resident faunal communities and hence will not diminish ecosystem function.

Finally, a comparison of impact assessment documentations for projects relevant and comparable to the Ichthys Gas Field Development project show that investigative effort to collect information on benthic habitats and their fauna is very similar to that of other similar sized resource development projects in Australia and that the information is of a similar quality.

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