HABITATS AND INVERTEBRATE ASSEMBLAGES OF BOUGUER PASSAGE AND THEIR REGIONAL SIGNIFICANCE

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Chicoreous cornucervi

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1. INTRODUCTION

API Management Pty Ltd (API) proposes to develop the West Pilbara Iron Ore Project (WPIOP), an iron ore mining operation located on the western fringe of the Hamersley Ranges, south of Pannawonica, in the Pilbara region of Western Australia. The project involves development of a series of open cut mines, a railway and establishment of port facilities, including a loading wharf, berth pockets, a turning basin and shipping channel, off Anketell Point.

Anketell Point is situated on the mainland at the eastern end of Nickol Bay, immediately adjacent to the eastern end of Dixon Island in the Shire of Roebourne and approximately 10 km south-west of the existing Cape Lambert port facility (Figure 1).

Part of the Proposal involves the establishment of a causeway crossing Bouguer Passage thereby linking Anketell Point with Dixon Island. The final causeway design will include a 100 m long pile bridge, of which the central 75 m span will provide for tidal flow.

In the course of the environmental impact assessment process, public submissions have been received that suggest the marine habitats and biota of the Passage are unusually diverse and rich in species.

This report presents the results of a brief inspection of the area in vicinity of the proposed causeway (Figure 2) and a re-assessment of the intertidal and shallow subtidal habitats and invertebrate species present. The observations made allow a provisional assessment of the regional significance of the area's habitats and invertebrate fauna in terms of relative species diversity and abundance.

2. METHODS

The writer accompanied Spencer Shute (API) on an inspection of the sites during late afternoon low tides on the 21st and 22nd of March, 2011[1]. The party accessed the study area by charter vessel (Miss Rani) from John's Creek. Landings were made on the north-eastern shore of Dixon Island during the ebbing tides. The three major intertidal habitat types present in this area are mangal, mud/sand flat and rocky shore. Each of these was inspected, on foot as the tide fell, from the supra-littoral fringe to the lower-littoral zone of the intertidal flats (tracks made during each site inspection are shown in Figure 2).

[1] Other people who joined the author and Spencer for a single visit were Nicole Stein (API), Glenn Shiell (Oceanica), Wayne Young and Claire Moulin (DPA), Marissa Speirs and Fiona Esszig (DEC).

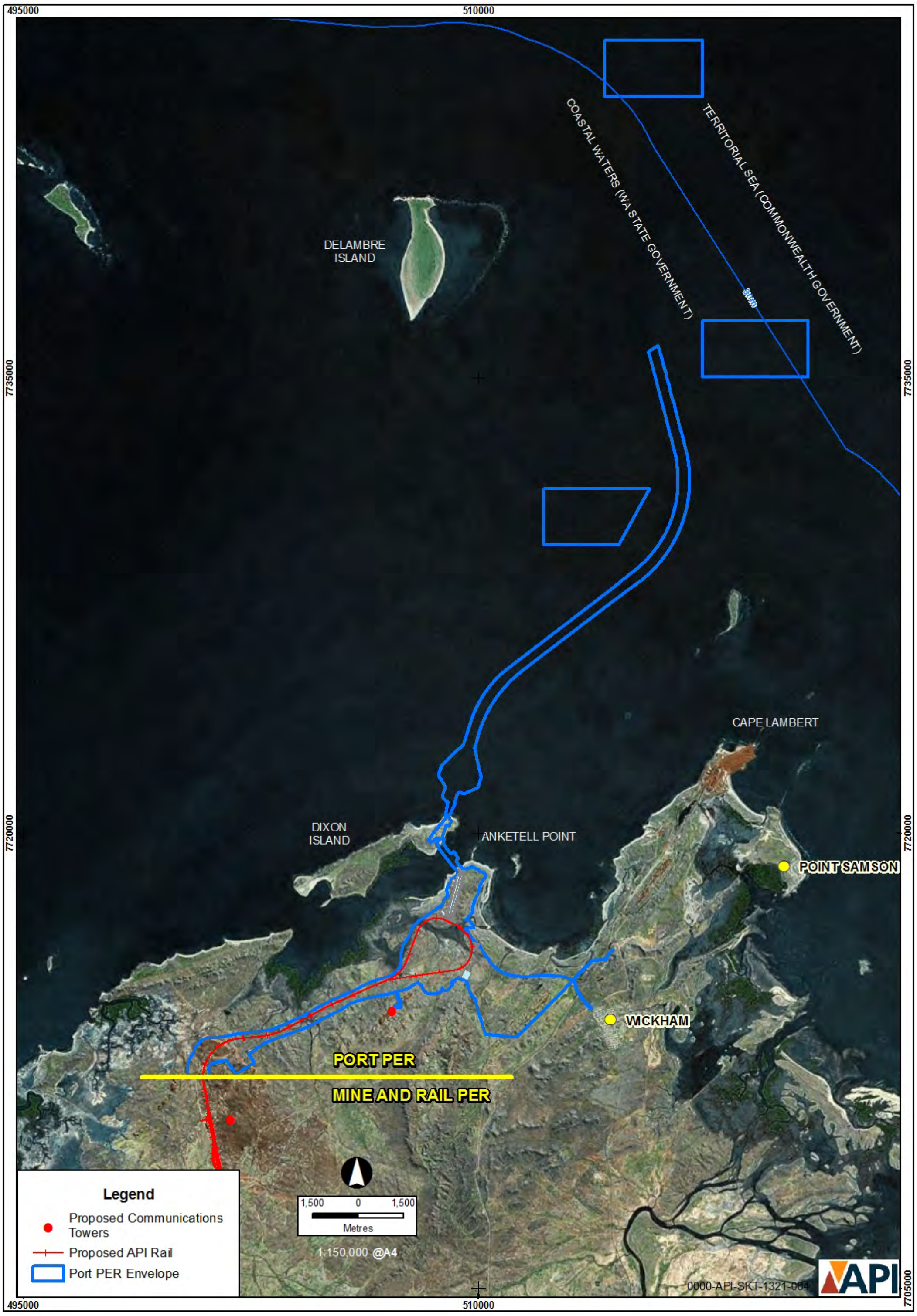


Figure 1 – Anketell Point Port PER Envelope

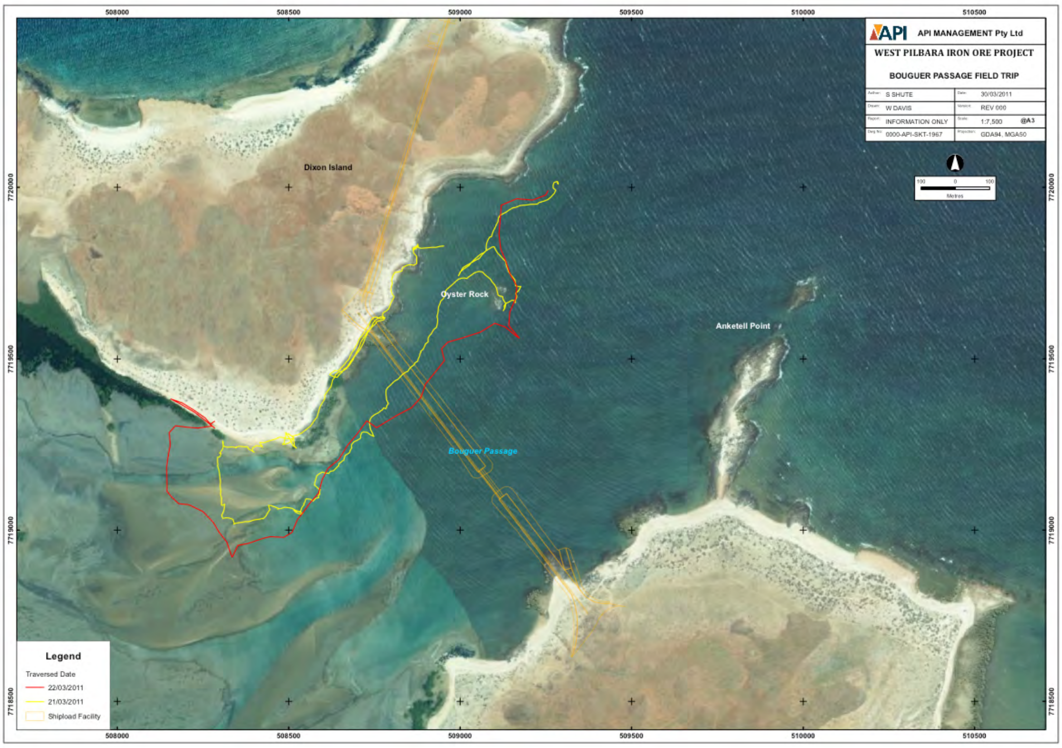


Figure 2 - Traverses made during site inspections of intertidal fringing mangal, sand flat and rock flat habitats at low tide on the afternoons of the 21st and 22nd March, 2011. At their western ends the traverses were over mud and sand flats while the north-eastern sections lay along rocky flats.

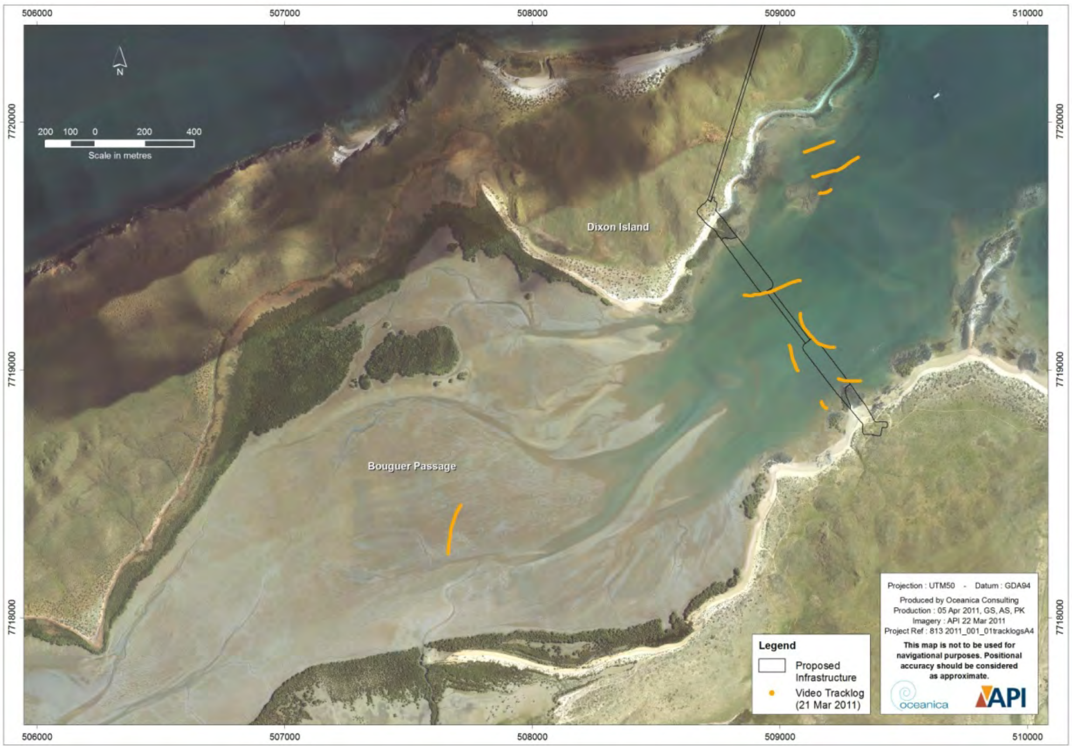


Figure 3 - Location of towed video transects within Bouguer Passage - 21 March, 2011.

Within the limits of the writer's expertise (mainly molluscs, echinoderms and corals) key invertebrates were identified on the spot to species or generic level. Sample specimens or photographs were taken of key species when their identities were unknown or uncertain. Those specimens are to be lodged in the collections of the Western Australian Museum for future reference. Samples of macro-algae were taken and referred to other specialists for identification. Lists of the molluscs and echinoderms identified during the inspection are presented in Appendices 1 and 2. A small sample of common intertidal macro-algae was also collected and their identifications are presented in Appendix 3. While these lists are by no means comprehensive, they are indicative of the faunistic character of the area's invertebrate fauna and macro-algal flora.

A provisional habitat classification has been prepared with rough indications of the trophic structure of invertebrate communities in each habitat unit. No attempt was made to obtain quantitative data as this was beyond the capacity of the team given the limited time and the size of the area inspected.

In addition to the above, shallow subtidal benthic habitats in the north-eastern parts of the Passage were inspected by means of a towed video system. This was done on the 21st during the mid-day high tide period. Short transects were made across the seabed in areas considered to be of particular interest (see Figure 3). The quality of the images obtained was generally good and the footage may be interrogated properly at a later date. Provisional notes are recorded here in the interim.

3. INTERTIDAL HABITAT CLASSIFICATION

It is important that standardised nomenclature be adopted for habitat surveys, using mappable units. In accordance with common practise, a three-level habitat classification hierarchy is applied to intertidal habitats:
i) tide level
ii) biogeomorphic descriptors
iii) biotic descriptors.

Each of these may be then subdivided and described in biogeomorphic terms.

The tidal categories are:
- supra-littoral fringe - above Spring High Tide level [SHTL]
- upper-littoral – between Neap High [NHTL] and SHTL
- lower littoral – between Neap Low [NLTL] and Spring Low [SLTL] tide levels
- sub-littoral (= subtidal) - below SLTL.

In the present circumstance, the principal biogeomorphic categories are:
- supra-littoral fringe
- beach slope
- rocky shore
- mangal
- mud flat
- sand flat

• subtidal benthic – hard substrate (rocky, rock pavement), soft substrate (sediment).

Biotic descriptors are usually based on conspicuous or ecologically important organisms that may be cited either:

- in general terms (e.g. mangal, seagrass, leafy macro-algae, coral, sponge)
- by species (e.g. barnacle zone, tube worm zone)

Intertidal habitats may then be cited by a combination of each of these three categories (e.gs. lower-littoral basalt rocky shore with corals and sponges dominant; or mid-littoral sand flat within faunal bivalves and epifaunal gastropod (nassarid and naticid) predators).

4. PRINCIPAL HABITATS OF THE STUDY AREA

Dixon Island is a Proterozoic basalt ridge and the shores comprise either basalt boulders or steep sandy beaches. There is no Pleistocene limestone but Holocene beach rock is present on many beach slopes and there is a Holocene limestone crust on some rocky shores (Figure 4).

Inspection of aerial photographs reveal beaches and narrow intertidal rock platforms on the seaward (western) shores. The eastern shores of the island (within Bouguer Passage) are subject to little regular wave action and they are characterised by very wide intertidal flats that are rock platforms, sand flats or mud flats, or a combination of these. Rock platforms or rocky sand flats occur near the north-eastern entrance of the Passage. Mud and sand flats are exposed at low tide for most of the length of the Passage and it is possible at Spring Low Tide to walk from the mainland to the island.

The following notes relate to subtidal and intertidal habitats along the north-eastern shore and the adjacent sub-littoral sea bed, in the vicinity of a prominent structure in the passage known as Oyster Rock (see Figure 2).

Figure 4 - Shore with a Holocene crust over basalt – upper-littoral zone.

4.1 Supra-littoral fringe

Terrestrial habitats above SHTL generally comprise low, vegetated fore-dunes. In the study area there are some Holocene storm surge ridges of boulders but berms (flat areas above the beach slope) are lacking or narrow.

Supra-littoral biota

No turtle tracks were observed. No ghost crabs (Ocypode spp.) or their burrows were observed. Hills kangaroo (Euro) tracks and fox tracks were commonplace.

Habitat unit

Supra-littoral fore-dunes without marine macro-fauna

4.2 Beach slope

Beach slopes occupy the upper-littoral zone, their upper limit being the SHT mark and the lower limit usually marked by a distinct change of slope where the beach meets the mid-littoral intertidal flat. The beach slopes of the study area are steep (c. 5-10°) and comprise coarse shelly and stony sand. They would be categorised as "tide-dominated" by coastal geomorphologists (Short 2006, 2007).

Beach slope biota

In the study area, there is very little macro-fauna on the beach slopes (although meio-fauna may be abundant) except for a metre or so above the break of slope at the base of the beach where the sand remains wet through most of the low tide cycle. In that zone the mesodesmatid bivalve Paphies (Actodea) striata is abundant, buried in the sand. It may be found by digging shallow trenches along the shore. The donacid bivalve Donax faba could be expected in this habitat also but was not seen during this brief survey. These bivalves are suspensory feeders and rely on particulate matter delivered to them by wave action. (They are easily accessible for much of the daily tidal cycle even during neap tides and, where populations of them are present, they may lend themselves to pollution monitoring programs.) The mid-littoral predatory gastropod Polinices conicus occasionally extends its range up into this zone.

Habitat units

Upper-littoral beach slope:
1. upper slope without macro-fauna
2. lowest level with infaunal bivalve (Paphies striata) zone.

4.3 Mangal

Mangal or mangrove habitat is extensively developed along both sides of Bouguer Passage, especially on the mainland side. Although the mangroves have been surveyed by consultants to API, the associated mangal fauna of Bouguer Passage remains undocumented. The mangals of the passage are certain to support assemblages of mangal invertebrates that are representative of Pilbara mangal ecosystems.

These animals are secondary producers that are generally present in vast numbers and are largely responsible for the breakdown of the products of the mangrove and micro-flora primary production and conversion of them into organic particles that are consumable by other organisms. The well-being of these assemblages is crucial to the "ecological integrity" of coastal ecosystems of the region. They are vulnerable to pollution and especially to changes in water circulation and sedimentary processes. For this reason the following notes are provided as an introduction to this complex and vitally important part of the mangal ecosystem.

4.3.1 Mangal invertebrates in the Pilbara

Within the Pilbara region, a distinctive mangal obligate invertebrate fauna is moderately well developed. Most of the key species are detrital feeders that consume organic material derived from the mangal macro and micro-flora and play key secondary production roles. Gastropod molluscs, brachyuran crabs, barnacles and polychaete worms are the most diverse and abundant invertebrates involved. Of these, the all-important polychaetes of Pilbara mangals are yet to be studied and documented. The typical suite of the other groups include the following, all or any of which might occur within the Bouguer Passage mangals.

Gastropod molluscs

Four families of gastropods contain species that are mangal obligates. These are all either detrital feeders or micro-phagous grazers. The common Pilbara species are:

- Neritidae (micro-phagous grazers) - Nerita balteata.
- Littorinidae (micro-phagous grazers) - Littoraria (Littorinopsis) scabra, L. (L.) pallescens, L. (L.) filosa, L. (L.) cingulata, L. (Palustorina) sulculosa, L. (P.) articulata, L. (P.) undulata.
- Potamididae (mud creepers; detrital feeders) - Terebralia palustris, T. semistriata, Telescopium telescopium, Cerithidea largillierti, Cerithideopsilla cingulata; tree creepers (micro-phagous grazers) - Cerithidea reedi.
- Ellobiidae (detrital feeders - Cassidula angulifera, Melampus spp.).

Barnacles

Barnacles are suspensory feeders. There are at least three species of mangal obligate barnacles in Pilbara mangals:

- Fistubalanus sp. (undescribed) lives attached to mangrove branches, trunks and pneumatophores.
- Hexaminius popeiana lives on mangrove trunks and branches.
- Hexaminius foliorum lives on mangrove leaves.

There are also several species that live on mangroves but are found also on wooden structures in the intertidal zone outside mangroves. These include Chthamalus malayensis and Microeuraphia withersi.

Brachyuran crabs
Two families of burrowing crabs, Sesarmidae and Ocypodidiae, are adapted for life in the intertidal zone and contain mangal obligate genera and species. The families Portunidae and Grapsidae both have species that inhabit mangroves although most of them are not mangal obligates.

Family Ocypodidiae
This family contains four genera, Ocypode (Ghost crabs), Scopimera (Bubble crabs) Mictyris (Soldier crabs) and Uca (Fiddler crabs) that live in mangroves or on associated tidal mud and sand flats. Ocypodes burrow on upper beach slopes and forage widely for dead vegetation and animal remains. The other genera live in dense colonies, feeding on the micro-organisms growing on the mud or mud surface.

- Ocypode – there are three species of ghost crab in the Pilbara of which O. fabricii commonly lives on beaches within or associated with mangal ecosystems.
- Uca - seven species of Uca are known from Pilbara mangals, any or all of which might be expected to occur in Bouguer Passage: Uca elegans, U. flammula, U. polita, U. mojbergi, U. dampieri, U. capricornis U. hirsutimanus.
- Scopimera – species of this genus are present on muddy sand flats associated with mangals in the Pilbara but the species remain unstudied.
- Mictyris - species of this genus are present on muddy sand flats associated with mangals in the Pilbara but the species remain unstudied.

Family Sesarmidae (Marsh crabs)
The taxonomy of Western Australian sesarmids is presently being studied. These crabs burrow in mud within mangrove forests and on associated mud flats. They feed on organic material gathered from the mud surface. Species of three genera known to be present in Pilbara mangroves are:

- Neosarmartium meinteri
- Perisesarma semperi, Perisesarma sp. (undescribed)
- Parasesarma hartogi.

Family Portunidae (Swimming crabs)
These large crabs are predators and scavengers.

- Scylla serrata (the mangrove mud crab)
- Thalomita (spp.)

Family Grapsidae

- Metopograpsus frontalis - a small, predatory crab that is generally abundant in Pilbara mangals.

Mud Lobsters and Ghost Shrimps
Mud Lobsters (family Thalassinidae) are another group of burrowing, detrital-feeding crustaceans thought to play important secondary production roles in mangal ecosystems. These animals are deep burrowers that build conspicuous conical turrets, usually among the mangrove trees. Three species Thalassina squamifera, T. emerii and T. anomala are reported from Pilbara mangals. There are two families of Ghost Shrimps, the Callianassidae and Upogebiidae. They are small and inconspicuous crustaceans that are rarely seen because of their deep and inconspicuous burrows. Species of this group are known to be in Pilbara mangals but they remain unstudied.

4.3.2 Mangal invertebrates of Bouguer Passage
Only the small mangals on the north-eastern shore of Dixon Island were inspected by this survey team (Figures 3 and 5). Three species of mangrove were present, Avicennia marina, Rhizophora stylosa and Ceriops australis, the latter relatively uncommon. They occurred as a narrow mangal fringe at the base of the beach slope, growing on muddy sand or basalt cobbles. In such a situation the full assemblage of mangal obligate gastropods, barnacles and crabs should not be expected.

Gastropod molluscs
Of the expected potamidid gastropods, the two species of Terebralia were present though not common. Neither Telescopium telescopium nor Cerithideopsilla cingulata was seen. No live specimens of the tree creeper Cerithidea reedi were observed on the mangrove trees although old shells were seen on the mud and in beach drift nearby.

Nerita balteata was very common on mangrove trunks throughout the mangals examined.

Of the seven mangrove littorinids that might be expected to occur, three species were observed: Littoraria filosa (one adult), L. pallescens (many juveniles) and L. sulcosa (one juvenile). Clusters of juvenile L. pallescens were observed in the leaves of Avicennia some shells less than 1 mm long, indicating recent and on going settlement.

Brachyuran crabs
No sesarmid crabs, or their burrows, were observed. The grapsid Metopograpsus frontalis and the portunids Scylla serrata and Thalomita (spp.) were common.

Mud lobsters
Burrows, possibly of one of the Mud Lobster species (Thalassina sp.) were common among the mangroves. This record will need to be confirmed.

Barnacles
Two species of barnacles were common adhering to trunks and branches of the mangrove trees (Figure 6) - the mangal obligate Fistubalanus sp. (undescribed) and the non-obligate species Microeuraphia withersi.

4.3.3 Conclusions

The invertebrate fauna of the fringing mangals examined on the north-eastern shore of Dixon Island is a restricted assemblage, deficient in both species diversity and biomass. Of particular note was the absence of sesarmid crabs. The more extensive mangals that occur further south on the eastern shores of Dixon Island and on the adjacent mainland may be expected to have more extensive development of the mangal invertebrate assemblages that occur in the Pilbara region (Figure 3).

Habitat unit

Upper-littoral, fringing mangal with Avicennia and Rhyzophora:

1. over basalt cobbles
2. over mud

Figure 5 - Fringing mangal (Avicenia marina) on basalt boulder shore. NE of Dixon Island, just south of the proposed causeway location. This small mangal is habitat of a restricted assemblage of mangal invertebrates.

Figure 6 - Two species of barnacle on a branch of Avicennia - Fistubalanus sp. (the largest specimens) and Microeuraphia withersi.

4.4. Sand and mud flats

The survey examined intertidal sand and mud flats occupying the mid-littoral and lower-littoral zones along the north-eastern shore of Dixon Island west of the proposed causeway (Figure 2). In this area, the tidal sediment flats extend across the whole passage, except for drainage channels. There is no simple zonation pattern across the flats relating to tidal level. Rather, there is a complex mosaic of low areas of finer sand and higher banks and ridges of coarse sand and shelly gravel. The patterns are created by complex tidal flows and may be constantly re-arranged through the neap and spring tidal cycles. Sediment grain size is the dominant factor governing the composition and distribution of soft substrate benthic communities and mapping biotic assemblages in such changeable circumstances is not easy to do. In this preliminary survey it was possible only to distinguish between the mid-littoral near shore mud and muddy sand flats and the complex of mid-littoral and lower-littoral sand flats further offshore. Nevertheless, in spite of changeability of the substrate, the sand flat habitats of Bouguer Passage are species-rich and, at least in patches, support a high infaunal biomass.

The inner mid-littoral mud and muddy sand flats near shore also graded seaward into medium-grained and coarse-grained sand flats within the passage.

4.4.1 Nearshore mid-littoral mud and muddy sand flats

Mid-littoral flats fronting the patches of mangal were of mud while flats at the base of beach slopes comprised muddy sand but the two graded into each other laterally. Mud flats had a smooth surface but with some drainage gutters and shallow depressions made by rays, fiddle sharks and mud crabs. The sediment was grey, ranging from soft clay to sandy mud, and graded seaward into sand flats at lower levels of the mid-littoral zone. Muddy sand flats fronting beach slopes were generally finely rippled but they often had a smooth surface (Figure 7).

Muddy sand flat biota

This habitat is normally characterised by high organic content in the sediment and significant micro-organism biomass and primary production on the sediment surface.

Typically, mid-littoral muddy flats support diverse assemblages of detrital-feeding and carnivorous polychaete worms with high biomass. No attempt was made to examine this element of the infauna. (Apart from the sampling difficulty, polychaetes have not been studied in the region and there is a severe taxonomic impediment.) One very common errant polychaete, active on the wet surface at low tide, is a bright green carnivorous phyllodocid, one of many of its class that remain to be identified.

Infaunal bivalves are also typically diverse and abundant in this habitat and a non-quantitative assessment of species composition may be achieved by examination of freshly dead shells scattered on the sediment surface. Epifaunal gastropod, echinoderm and crustacean assemblages are also easily assessed.

Detrital and suspensory feeding bivalves were common in the surveyed nearshore muddy sand flats including species of the families Cardiidae (Cardium unedo, Fulvia aperta, Acrosterigma dupuchense), Tellinidae (Tellina piratica, T. staurella, T. virgata) and Veneridae (Anomalocardia squamosa, Gafrarium tumidum, Pitar citrinus, Placamen berryi, Tapes variegatus) and Laternulidae (Laternula cf. anatina). Also common were species of the family Lucinidae (Anodontia sp., Ctena bella, Divaricella ornata). Lucinids are relatively tolerant to anaerobic conditions and high sulphide levels and they sustain symbiotic sulphur-oxidising bacteria in their gills. Fresh shells of the arc Anadara granosa were very common and although no living specimens were seen, it was evident that there is a significant living population of this bivalve in the vicinity. (A. granosa is a prominent component of kitchen middens in the region.) Several predatory gastropods were common. The naticids Polinices cf. conicus and Natica gualtieriana were active, buried in the sand and leaving long erratic trails as they moved about in search of their prey. Two buccinids, Cominella acutinodosa and Nassarius dorsatus were active crawling on the surface. In shallow pools the large detrital-feeding ceriths Pseudovertagus aluco were conspicuous. Also present were the small columbellid Mitrella essingtonensis, the tiny trochid gastropod Isanda coronata, and an unidentified shelled opisthobranch. These small molluscs are detrital-feeders and, with high biomass, are likely prey of wader birds.

Echinoderms were not prevalent on the inner muddy sand flats except for a species of the asteroid Astropecten granulatus (that preys on small bivalves). Tests of a small biscuit urchin, Peronella tuberculata were present but no live specimens were observed.

The brachyuran crabs Scylla serrata and Thalamita sp. were common. On slightly elevated muddy sand ridges adjacent to a beach slope there were colonies of a fiddler crab, Uca polita, that were very active at their burrow entrances soon after exposure by the ebbing tide.

Habitat unit
Upper mid-littoral mud to muddy sand flat with infaunal bivalves (Anomalocardia, Anodontia, Laternula), predatory gastropods (Nassarius, Polinices, Natica, Cominella), detrital-feeding gastropods (Dentimitrella, Isanda) and colonies of a fiddler crab (Uca polita).

Figure 7 - Slightly muddy sand flat nearshore, south of the proposed causeway location, NE Dixon Island. Infaunal detrital and suspensory feeding polychaetes and bivalves dominate this habitat and support a diverse assemblage of predatory invertebrates as well as migratory wader birds.

Figure 8 - Highly mobile sand waves at the edge of a drainage channel, south of the proposed causeway location, NE Dixon Island. This not an easy habitat and the invertebrates there are necessarily rapid diggers.

4.4.2 Outer mid-littoral and lower-littoral sand flats

The sand flats across the centre of the passage have varied profiles and various degrees of rippling. Large, relatively flat areas judged to be within the mid-littoral zone, were finely rippled and probably moderately stable. There were also many higher banks and ridges of coarser, yellow sand that seem to be changeable in their position. They have either smooth surfaces or strongly rippled surfaces. In the many deep drainage channels within the passage there were large, asymmetrical sand waves, spaced up to 3 m apart and up to 50 cm high, indicating strong tidal flows (Figure 8). In these situations the sand was white, coarse and shelly.

Sand flat biota

The intertidal sand flat biota of Bouguer Passage is very diverse although, as is usually the case with this habitat, biomass is probably relatively low (except perhaps for infaunal polychaetes). A collection of mollusc shells (Appendix 1) illustrates the richness of the bivalve fauna of the Bouguer Passage sand flats.

Bivalves of intertidal sand flat assemblages are predominantly suspensory feeders. The families Cardiidae, Mactridae, Tellinidae, Psammobiidae and Veneridae are especially species-rich. Most of the species are infaunal burrowers and are not seen alive unless they are searched for but their shells are abundant on the sand flats. Exceptions are two species of razor clam (Pinnidae), Pinna bicolor and Atrina vexillum, that bury vertically in the sand with the posterior ends of their shells emergent at the surface.

Gastropods of sand flat assemblages are predominantly either detrital-feeders, scavengers or predators. Gastropod predators eat a broad variety of prey including polychaetes, bivalves and other gastropods. Ranellids eat ascidians and cassids eat echinoderms.

Several of the gastropods found on the Bouguer Passage sand flats are of particular note, being regional endemics with restricted geographic distributions. Examples are the muricids Murex acanthostephes, M. macgillivrayi, Haustellum multiplicatus, Pterynotus acanthopterus and Pterynotus akation, and the volutids Amoria damoni, A. dampieria, A. ellioti, A. grayi, A. jamrachi, A. praetexta and Cymbiola oblita. All of these species have direct development, that is, the larvae hatch directly from the egg capsules laid on the sea floor as miniature snails and there is no pelagic larval stage. Because of this, in addition to restricted ranges on the North West Shelf, these species are prone to local genetic variability and are vulnerable to local extinction.

Another species of the asteroid genus Astropecten, A vappa, was common on these sand flats. The large species Protoreaster nodulosa was also present here, as well as on sandy patches of the nearby rocky flats. During this survey a specimen of the rare multispined sea star Anseropoda rosacea was found on the lower-littoral sand flat (Figure 9c,d). Tests of three species of heart urchin were found: Breynia desorii, Echinolampus ovata and Schizaster compactus (Figure 9a). These animals are detrital-feeders.

Habitat unit

Mid-littoral and lower-littoral sand flats of varied profile and sediment grade, with a highly diverse invertebrate infauna. [Data not sufficient to specify any dominant species at this time.]

Figure 9 a. Schizaster compactus.

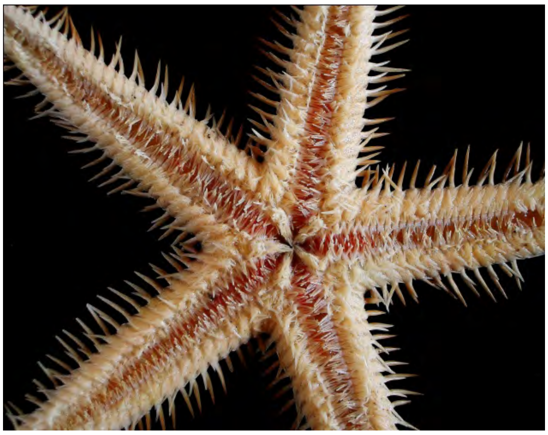


Figure 9 b. Astropecten vappa, a common predator on sand flat molluscs.

Figure 9 c. The rare sea star Anseropoda rosacea (ventral view)

Figure 9 d. The rare sea star Anseropoda rosacea alive on the muddy sand flat.

Figure 9 e. The sea star Protoreaster nodulosus.

Figure 9 f. The sea star Culcita schmideliana.

Figure 9 - Some echinoderms of the intertidal flats of Bouguer Passage.

Figure 10a. Amoria preatexta **10b. Cymbiola oblita** **10c. Ficus eospila**

Figure 10 - Three species of the predatory gastropods that are common on sand flats of Bouguer Passage. All are direct developing species endemic to the North West Shelf.

Figure 11 - A female volutid gastropod Cymbiola oblita attending to her egg mass. From each capsule a single larvae will hatch after several weeks, emerging as a crawling miniature snail like its parents. There is no pelagic larval stage and this species has restricted geographic range and local genetic forms as a consequence of limited connectivity.

4.5. Rocky shore

Within the study area, rocky shores comprise medium-sized basalt boulders and cobbles. The profile of the upper-littoral zone is irregular and steep, grading into a mid to lower-littoral rock flat with a thin sand veneer over the rock pavement and fields of small to medium-sized basalt boulders. There are no steps in the profile of the rock flat and no reef crest. Rather, the rock flat simply slopes gradually into the sub-littoral zone. However, there are several offshore rocky outcrops in the passage that become exposed at low tide.

Holocene limestone beach rock deposits are present on most beach slopes and these may also be regarded as a form of rocky shore.

4.5.1 Rocky shore biota

Upper-littoral

The red alga Bostrychia tenella is present on rocks up to the supra-littoral fringe splash zone, forming a red-orange band at that level. Rocky shore invertebrate assemblages characteristic of the Pilbara are poorly developed at this locality, perhaps as a result of low wave action within the sheltered passage. For example, within the region up to five species of the gastropod family Littorinidae may be present in the upper-littoral of rocky shores but at this locality only the ubiquitous Echinolittorina trochoides was seen. In the Pilbara, this tiny snail is the highest marine mollusc on the shore and is almost always present in vast numbers. At this locality the species was abundant on both basalt rocks and the Holocene beachrock.

There were two species of Neritidae, Nerita undata and N. squamulata. Another small gastropod, Planaxis sulcatus clusters in large colonies in depressions that retain water at low tide. Only two species of limpet, Patella flexuosa and Patelloida sp. were observed, neither common, and there was only one species of siphonarian limpet Siphonaria. The spiny black chiton Acanthopleura spinosa, normally conspicuous on rocks in the lower part of the upper-littoral was not present, but its congener, A. gemmata, was moderately common. All these animals are grazers on surface film and interstital micro-flora.

Colonies of a rock oyster, Saccostrea sp., normally form a distinct oyster zone at the bottom of the upper-littoral but at this locality this biotic zone was poorly developed with the oysters generally small and scattered on rocks. (The rock oyster in sheltered conditions such as these is usually S. echinata but the species present was not identified.) Upper-littoral rocky shore barnacles and other crustaceans were not observed. Two muricid gastropods, Thais aculeata and Morula granulata, typical residents of the oyster zone, prey on the barnacles, mussels and oysters.

Habitat units

Upper-littoral rocky shore (a) basalt rocks (b) Holocene limestone crust

1. upper littorinid zone
2. middle rock-oyster zone
3. lower neritid zone

Mid-littoral
The mid-littoral zone of the study area was not adequately examined but many of the key invertebrate species that characterise it were observed and biotic zonation patterns were typical of Pilbara mid-littoral rocky shores in sheltered, low wave action conditions. In the upper part of the mid-littoral zone, immediately below the oyster zone, the rocks and rock pavement bore a low, sand-matted algal turf, giving way further out on the rocky flat to leafy macro-algae. A collection of the most conspicuous algae was made, taken from the flats in the vicinity of Oyster Rock (Appendix 3).

Key herbivorous gastropods that mark the top of the mid-littoral zone, Turbo cinereus, Monodonta labio and Trochus lineatus, were all present. At least one species of the slug genus Onchidium was also common. Throughout the Pilbara, the mytilid bivalve Brachidontes ustulatus forms sand-embedded mats on the rock pavement and clusters under stones in this zone. These animals are the prey of several species of muricid gastropods, especially Cronia crassulnata and Cronia margariticola. The mussel and its two major gastropod predators were all present in the area. Further details of the upper mid-littoral in the study area were not investigated but the impression was gained that the suite of invertebrates that characterise this upper part of mid-littoral rocky shores in the Pilbara was poorly developed.

Mid-littoral rock flat habitat in the Pilbara is generally exceedingly rich in invertebrate species, characterised by surface-dwelling herbivorous grazers and detritus-gatherers and a large number of cryptic species that live under stones and in rock crevices. Families of cryptic gastropods such as the Cypraeidae (cowries) Conidae (cones) and Trochidae are species-rich in this habitat. Species-diversity is even greater in mixed habitat where there are sand surfaces among the rocks. Judging from the diversity of dead molluscan shells observed, this is certainly the case in the study area. (A fair representation of the mid-littoral rocky shore molluscan fauna of the region is included in the provisional list of species given in Appendix 1).

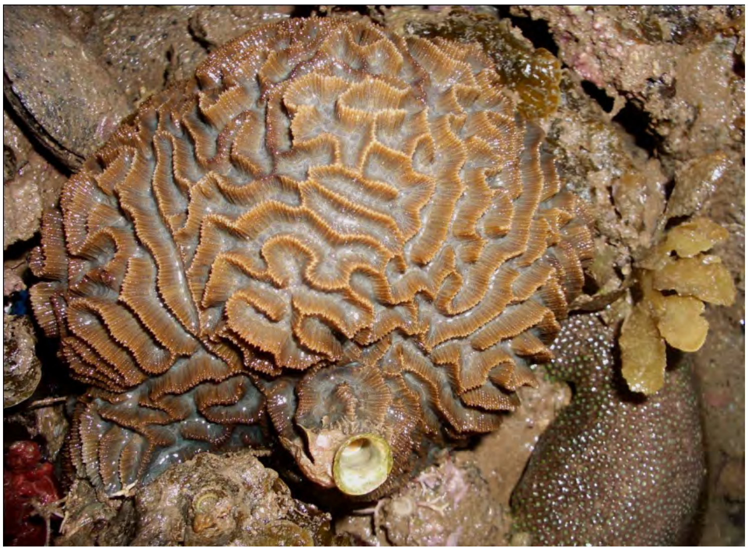
Habitat units
Mid-littoral basalt rocky flat with:
1. upper trochid/turbinid zone (Monodonta labio; Turbo cinereus)
2. middle macro-algal zone

Lower-littoral
This zone of intertidal flats is exposed only briefly during periods of Spring Low Tide. On mainland rocky shores of the North West Shelf, and around nearshore islands, biotic assemblages of the lower-littoral are dominated by filter-feeding organisms of two main invertebrate groups, sponges and corals (scleractinians and alcyonarians). Both of these groups contribute significantly to the structural complexity of lower-littoral habitats. The species composition of none of these assemblages has been studied and this part of the coastal fauna, which is sometimes extremely colourful and species-rich, remains an enigma, in terms of both its taxonomy and ecological functions.

Corals

The scleractinian coral assemblages of this zone comprise species that are known from the sub-littoral zone and from coral reefs in the region. However, the writer's personal observations, at mainland localities from Onslow to the Dampier Peninsula, suggest that the assemblages of coral species in these generally rather muddy, rocky shore, lower-littoral habitats are of distinctive species composition. The coral fauna may comprise up to fifty species or more, but these are not coral reefs in the sense of coral assemblages that are reef-building, that is, constructing biogenic carbonate structures. Rather, they are coral communities comprising scattered colonies growing on abiotic rock substrata. While these corals are certainly significant contributors to carbonate sediment production in the ecosystem they are not functioning, in this situation, as reef-builders. Furthermore, while most of the coral species present are zoothanthellate (hermatypic), the relative importance of nutrition by means of suspensory feeding and symbiont photosynthetic activity is unknown. The importance of these coral communities as "benthic primary producers" is conjectural.

Like most other mainland localities, the intertidal coral assemblages within Bouguer Passage are dominated by massive faviids, such as species of Goniastrea, Favia, Favites, Platygyra and Montastrea. Mussids are also well represented. Robust species of Acropora sometimes occur as isolated colonies. At least one species each of the genera Fungia and Herpolitha occur. Several species of the genus Turbinaria are conspicuous in the Bouguer Passage intertidal coral communities, as they are at other mainland localities. The lack of any documented account of the species composition of the intertidal coral communities of the Pilbara coast is a significant impediment to environmental impact studies in the region.



a) Goniastrea sp.

b) Acropora sp.

c) Turbinaria spp. and Favia sp.

Figure 12 - Four kinds of coral from the rocky lower-littoral flat north of the proposed causeway location, NE Dixon Island. These are scattered coral colonies on a sandy rockflat. They are not reef-building and are best referred to as coral communities not as coral reefs.

Sponges

During this survey, highly diverse, lower littoral sponge communities of the north-eastern Dixon Island shore were examined and photographs were taken but specimens were not collected. At this locality, sponges are more conspicuous than corals in the lower littoral zone of rocky shores. These intertidal sponge assemblages are colourful and spectacular and local people refer to them (as elsewhere in the Pilbara) as “sponge gardens” (Figure 13). However, they remain unstudied and no information can be provided at this time on the extent of this element in the fauna or its ecological importance. Nor is it possible to make comparisons of the Bouguer Passage sponge assemblages with those of other localities within the region.

There is a large diversity of benthic sponges in the Pilbara. In a pioneering study, Fromont (2004) listed 275 species of sponge from the Dampier Archipelago, indicating a species-rich element in the regional fauna. She found that benthic sponge communities in the region were very patchy and that the highest intertidal diversity of sponges occur on the sides of channels where there was strong tidal water movement. This is clearly the situation on the north-eastern shores of Dixon Island that border the strongly tidal Bouguer Passage.

Sponges, like corals, are principally suspensory-feeders and play significant secondary production roles in coastal ecosystems. However, also like corals, some species habour cyanobacterial symbionts and supplement their nutrition by means of photosynthetic activity. While the study by Fromont (2004) provides a taxonomic foundation, ecological research on Pilbara intertidal sponge assemblages is needed.

a)

b)

Figure 13 - Macro-sponge species on the lower-littoral sandy rock flat north of the proposed causeway location, NE Dixon Island. Note also the Holothuria atra that are common in this habitat, and a variety of other filter-feeding invertebrates.

Figure 14 - Sponge garden on the lower-littoral flat, near Oyster Rock, north of the proposed causeway, north-eastern shore of Dixon Island. Sponges dominate this habitat but scleractinian corals, soft corals and leafy macro-algae are also present, growing on a sandy rock flat.

Other invertebrates

The rocks, corals, sponges and sand patches of lower-littoral rocky flats along the north-eastern shore of Dixon Island provide a complex habitat of irregular relief. In addition, the strong current flows of the passage ensure an abundant supply of planktonic food for suspensory-feeders. Accordingly, there is a high diversity of invertebrates at this locality. The ecosystem is based principally on suspensory-feeding but on that basis there are trophic pathways that include micro-phagous detrital-feeders, herbivorous grazers and a wide range of scavengers and predators. This observation is based on assessments of the molluscan and echinoderm assemblages. No collections were made (except in a few instances where voucher specimens were retained for identification purposes) but photographs and field observations allow the following notes to be made.

Bivalve and gastropod molluscs are a conspicuous feature of rocky lower-littoral flats. The bivalves are suspensory-feeders and mainly byssate species such as arcids (Arca ventricosa, Barbatia amygdalumtostum) mytilids (Modiolus sp., Septifer bilocularis, Brachidontes sp.) isognomonids (Isognomon isognomon, I. legumen) pectinids (Chlamys, Complicachlamys wardiana, Decatopecten radula) spondylids (Spondylus sp.) and oysters (Dendostrea folium). In sand patches among the rocks live two pinnids (Pinna deltodes and P. bicolour). The tubular bivalve known as the watering pot shell (Brechites australis) also lives in this habitat.

Gastropods are even more diverse. Suspensory-feeding vermitids (Serpulorbis sp. and Petaloconchus sp.) live cemented to rocks. Common herbivorous grazers include trochids (Angaria delphinus, Tectus pyramis) and turbinids (Turbo petholatus, T. haynesi, T. squamosus, Astralium stellare, A. pileolum, A. rotularia). Detrital-feeding species include ceriths (Cerithium novaehollandiae, Rhinoclavis brettinghami) and a stromb (Strombus urceus).

Common predatory gastropods inhabiting rocky lower-littoral flats include three cones (Conus novahollandiae, C. victoriae, C. monachus) several muricids (Thais echinata, Cronia avellana, Morula margariticola, M. spinosa, Chicoreus cornucervi, Hexaplex stainforthi) and a buccinid (Cantharus erythrostomus). Two muricids, Pterynotus acanthopterus and P. akation, also live in sandy patches associated with these rocky flats. The large gastropod predators Syrinx aruanus and Melo amphora are present in this zone.

Echinoderms are also a conspicuous element in rocky lower-littoral flat habitats of this area. Five species of holothurian were observed (identified by Glenn Shield). Of these H. atra and H. edulis were both common lying among the stones, corals and sponges; H. impatiens and Stichopus horrens were common under stones. A fifth species, tentatively identified as H. leucospilota (closely resembling H. atra) was also observed. There were three large asteroids living in the open among rocks and corals - Culcita schimideliana, Protoreaster nodulosus and Pseudoreaster obtusangulus. Two species of echinoid were observed - Diadema setosum sheltering under ledges in deep pools and Temnopleuris alexandri among tufts of macro-algae. There were many kinds of ophiuroid and several species of crinoid living under stones.

Crustaceans, especially grapsid crabs, were also conspicuous in this habitat but their identification would have required making a large reference collection and was beyond the scope of the survey.

Habitat unit
Lower littoral basalt rocky flat with sandy patches; corals and sponges dominant

4.6 Subtidal benthic habitats

Nine short drift video tows were made in Bouguer Passage late on the morning of the 21st March, at around the period of high tide. One tow was located in the centre of the passage approx. 800 m southwest of the proposed causeway site, five were around the vicinity of the proposed causeway and three were near Oyster Rock (Figure 2). The following provisional notes were made.

Central passage site
This tow was made over sand flats that would be later exposed at low tide. At the time of this tow the depth was around 3m. The substrate was level sand with shell fragments. The only epifauna visible were abundant polychaete tubes. These animals were not seen on the flats closer to shore when the survey team walked over them later in the day at dead low tide.

Causeway sites

These tows were at depths between 4 m and 5 m, indicating that the sites were over subtidal benthic habitats. The substrate was variable, even within tows, including areas of smooth shelly sand, strongly rippled sand and stony ground with sand, sponges, corals, alcyonarians and numerous holothurians. The scleractinian corals were predominantly small faviid and Turbinaria colonies. The scattered benthos on the stony ground probably comprises variations of the invertebrate assemblages seen later at low tide on the rocky lower-littoral flats (see above).

Oyster Rock sites

The depth at these there sites was around 5 m, indicating that they were shallow subtidal habitats. The seabed was variable but mostly stony with scattered corals and sponges. Again the corals were predominantly faviids and Turbinaria (at least three species of the latter). The density of corals was quite varied – in places they could be regarded as the dominant benthic assemblage but they were not reef-building. Patches of Acropora were encountered, with several species of that genus including small plate colonies and areas of moderately robust branching species. These appeared to be mainly associated with a subtidal tongue of rocks extending northwards from Oyster Rock. The spatial extent of these Acropora patches was not determined but it is unlikely that they were much more than 10 m2 in area and probably would not warrant designation as patch reefs.

5.1 Biogeographic affinities of the intertidal fauna

From the observations made during this brief survey, the intertidal habitats and invertebrate assemblages of Bouguer Passage are judged to be typical of the Pilbara (Nearshore) Bioregion (IMCRA). The majority of the species present are widespread in the Indo-West Pacific Realm and across Northern Australia.

5.2 Endemism

Wilson and Allen (1987) estimated that the level of endemism in the fish and invertebrate faunas of the North West Shelf varies from around 10% to 15%, depending on the taxon. Endemism is greatest in coastal and benthic shelf assemblages of the Pilbara, Eighty Mile Beach, Canning and Kimberley Bioregions and very low in the offshore and shelf-edge coral reef ecosystems of the Oceanic Shoals Bioregion. Within the coastal bioregions, endemism is especially high in taxa that lack pelagic larvae, thereby having restricted dispersal capacity. For example, in the gastropod family Volutidae all the species have direct development and lack pelagic larvae. Regional endemism in this group is 100% and the species typically have restricted geographic ranges and they are especially vulnerable to local extinction.

In Australian and international conservation programs, regionally endemic species are generally afforded special protection measures. In this regard, the presence within Bouguer Passage of breeding populations of all the volutid species endemic to the Pilbara and adjacent Bioregions is of particular significance. Similar circumstances are likely to apply in certain other taxa.

In the table of molluscs recorded from Bouguer Passage (Appendix 1) endemic species are indicated. Three categories of endemism are considered, in the following order of priority: a) the North West Shelf, b) the Pilbara and West Coast and c) northern Australia generally. Environmental impact assessment and future management decisions will need to take these species into account.

5.3 Species diversity

A comprehensive inventory of intertidal and shallow subtidal fishes and invertebrates of the greater Dampier Archipelago was published by the W.A. Museum (edited by Jones, 2004). It was compiled over several years based on samples from a wide range of habitats. This publication revealed very high species diversity in all groups and led to the conclusion that the Dampier Archipelago is a "hot spot" of marine species diversity.

Molluscs

The Museum report recorded 695 species of intertidal and shallow subtidal mollusc (Slack-Smith and Bryce 2004). This is a very high figure for a regional molluscan fauna. Appendix 1 of this report lists 198 bivalve and shelled gastropod molluscs recorded within Bouguer Passage. For comparison, the table also includes records of 204 species of mollusc previously recorded by the writer at Gnoorea Point, Regnard Bay in the eastern part of the Dampier Archipelago (Figure 15). Intertidal and shallow subtidal habitats at that locality are directly comparable to those of Bouguer Passage, except for the absence of significant mangals. Collecting effort (in terms of person-power and duration of the survey) was greater at Gnoorea Point. These two surveys were much less intense, sampled a lesser range of habitats and covered a lesser range of molluscan taxa than the Museum survey. Nevertheless, taking account of the restricted variety of habitats sampled, the results of both surveys indicate species-rich molluscan faunas consistent with the high biodiversity that characterises the region.

Neither the Bouguer Passage nor the Gnoorea Point survey sampled the respective molluscan faunas comprehensively. They were both somewhat cursory and the majority of the species recorded were those that are common in the respective habitats. Further intensive collection, targeting specialised habitats, would certainly reveal many more “rare” species at both localities. Also, the range of habitats within Bouguer Passage that were sampled was limited and wider coverage of the area would identify a larger fauna. It follows that further collecting would significantly increase the species numbers and reduce the apparent differences evident in the present lists. However, based on the present data, it is reasonable to conclude that these two mainland localities support very similar, species-rich molluscan assemblages.

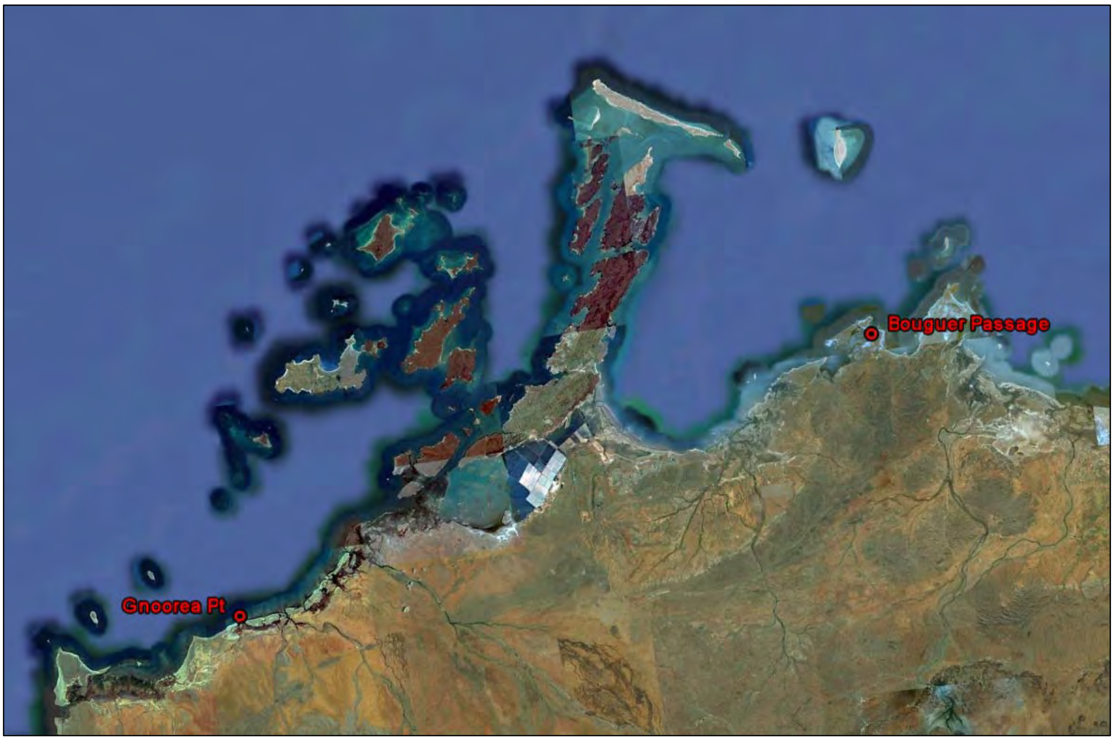


Figure 15 - - Map of the Dampier and Nickol Bay region indicating the locations of Bouguer Passage and Gnoorea Point, the two mainland shores where representative mollusc collections were made.

Comments were made in submissions claiming that the Bouguer Passage intertidal fauna was unusually species-rich in molluscs. The data presented here supports that claim insofar as available information indicates a richly diverse fauna like that of areas with comparable diverse habitats elsewhere in the region. However, considerably more collecting effort and more sophisticated sampling techniques would be needed to provide a measure of the levels of similarity or difference between the Bouguer Passage molluscan fauna and those of other localities.

It has also been said that Bouguer Passage is particularly important as habitat of certain gastropods that are of special interest to amateur and commercial collectors, notably species of the families Volutidae and Muricidae. The species in question were almost all recorded by this survey from this locality. They are all widely distributed within the Pilbara (Nearshore) Bioregion but they have specialised habitat requirements and their distribution is patchy. They are generally regarded as "rare".

It may well be true that these species are more numerous in Bouguer Passage than elsewhere but it is not possible to objectively demonstrate that this is or is not the case. Anecdotal information has been offered that, at certain times of the year, some of these species aggregate for breeding in their respective habitats within the passage which would make assessing relative abundance problematical. However, as they are all regional endemic species (see Appendix 1) some with local short-range endemic forms, they thereby warrant specific consideration in management programs whether or not they are more common in Bouguer Passage than elsewhere.

Echinoderms

In the brief surveys reported here, species of asteroid, echinoid and holothurians were collected and identified. Ophiuroids and crinoids were not identified or collected and these animals are not included in the list. Nevertheless, it was observed that a variety of species of these two classes was also present. The information from the survey is not sufficient to draw conclusions about the species richness of echinoderms in the area. However, with two exceptions (the asteroid Anseropoda rosacea and Schizaster compactus) all of the identified species are commonly found in comparable intertidal habitats in the Dampier Archipelago and indications are that the echinoderm fauna of Bouguer Passage is representative of the Pilbara (Nearshore) Bioregion which is an acknowledged "hotspot" of echinoderm diversity (Marsh and Morrison 2004).

5.4 Ecosystems

Within the study area (Figure 2) four basic intertidal ecosystem types were inspected: beach slope, mangal, sand/mud flats and rocky shores.

Beach slope

The steep beach slopes of the study area lack the ocypode crabs normally found in this habitat but this may be a seasonal factor. The abundant Paphies striata population at the base of the beach is a typical feature in the Dampier region. Beach slope habitats are particularly vulnerable to pollution. (Paphies striata may be an ideal species for monitoring pollution as it is an abundant filter-feeder and is easily collected during most states of the tidal cycle.)

Mangal

The fringing mangal habitats inspected were all small with restricted floral structure and invertebrate assemblages. They are not representative of the mangals of Bouguer Passage which include some extensive, structurally complex mangrove forests. Further study is needed to determine the range of mangal invertebrate assemblages in the area and their importance as contributors to secondary production that supports local coastal marine ecosystems.

Sand and mud flats

The sand flat and mud flat habitats within Bouguer Passage are complex, varied in structure and apparently changeable through the tidal cycles. Their invertebrate infaunal and epifaunal assemblages are species-rich and abundant and assessed as being typical of sand and mud flat habitats in the Pilbara (Nearshore) Bioregion.

The dominant factor in shaping and maintaining these habitats, and their invertebrate assemblages, is the strong tidal flow in the passage. Tidal currents play two fundamental roles in sustaining these soft substrate ecosystems. They control the geomorphic patterns of sediment distribution and character, which in turn determines the distribution, character and function of the infaunal and epifaunal species assemblages. They also maintain high flows of nutrients and suspended food resources into and out of the passage. The majority of the infaunal and epifaunal species are suspensory or detrital feeders (plus the predators and scavengers of trophic levels above them). High current flow is a major factor in supporting high species-richness and high biomass in communities of this kind.

Rocky flats

Rocky intertidal flats and rock outcrops along the north-eastern shores of Dixon Island are also species-rich in invertebrates, assessed as typical of rocky shore assemblages in the Pilbara (Nearshore) Bioregion in their species composition. However, in this case, lower-littoral assemblages of corals and sponges appear to be exceptional in their diversity and abundance. This is a subjective judgement as there are no quantified data for this locality or elsewhere within the region.

The taxonomy of corals of the Bioregion is now moderately well known (Griffith 2004) but there is no information on the composition of coral assemblages on rocky intertidal shores. Observations made north of the proposed causeway during this brief inspection indicated that up to 50 species of scleractinian corals occupy this habitat, suggesting either that coral diversity there may be unusually high or that high level of coral diversity in this habitat may have been unrecognised previously within the Pilbara Bioregion.

The same observations may be made of the lower-littoral, rocky flat sponge assemblages on the shores of Dixon Island north of the proposed causeway. The variety and abundance of sponges there is very impressive. However, the taxonomy and assemblages of intertidal sponges in the region remain inadequately studied. Fromont (2004) published an account of sponges of the Dampier Archipelago which is a major contribution but much remains to be done before the regional significance of the intertidal sponge fauna of Bouguer Passage can be assessed.

As is the case with sand and mud flat communities, lower-littoral rocky flat corals and sponges are essentially secondary producers, reliant on input of nutrients and suspended food resources from the tidal flats in the passage and from the open sea. The intertidal corals and their assemblages are best referred to as coral communities and not as coral reefs. The importance of these common but scattered colonies over the rocky flat as primary producers needs to be documented.

6. SUMMARY

Endemism
Regional endemism, at several levels of geographical range, is significant within the Pilbara (Nearshore) Bioregion and the available provisional data (Appendix 1) confirm that many of the endemic species are represented by breeding populations in Bouguer Passage intertidal habitats. These species have high conservation value and future management of the area will need to give consideration to protection of their habitats.

Diversity
The diversity of intertidal invertebrates of Bouguer Passage is high, consistent with the recognised status of the Pilbara (Nearshore) Bioregion as a "hotspot"" of marine invertebrate biodiversity. Although there are no statistical data, anecdotal evidence and observations made during this brief survey, suggest that the passage habitats may support diverse invertebrate communities at the upper end of the diversity range within the region. Strong tidal flows through the passage and diversity of intertidal habitats, including extensive benthic primary production habitat (mangal), support diverse and abundant secondary producer (filter-feeding) invertebrate communities.

Importance of current flow
Strong tidal flows through Bouguer Passage may be critical to the diverse mangrove and invertebrate communities and the ecological services they provide to coastal ecosystems within the region. Maintenance of tidal currents within the passage is important to both Benthic Primary Production (mangal habitat) and the "ecological integrity" of the coastal zone within the region.

Cessation or substantive change of tidal flows would be likely to have seriously impact on the biodiversity and both primary productivity and secondary productivity of the passage. Design of the proposed causeway should seek to avoid or minimize any change in tidal flows.

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APPENDIX 1

INTERTIDAL BIVALVE AND SHELLED GASTROPOD MOLLUSCS FROM BOUGUER PASSAGE AND GNOOREA POINT, DAMPIER ARCHIPELAGO.

The following table lists bivalve and shelled gastropods observed and recorded from Bouguer Passage and, for comparison, Gnoorea Point in Regnard Bay on the eastern side of the Dampier Peninsula. These two mainland locations have similar intertidal marine habitats comprising rocky shores and sand flats and areas where these two habitats are mixed. Both study areas also have minor mangal habitats fringing the shore.

The Bouguer Passage data were obtained from walk surveys on two successive days of low spring tide (21-22 March, 2011 – see Figure 2) supplemented by some records provided by Anna Vitenbergs of Point Samson. The Gnoorea Point data were obtained during low tide surveys by a joint Murex Consultants and the Santa Barbara Natural History Museum in 1992, supplemented by work done at that locality in association with RPS Australia in 2006. The Bouguer Passage data are split into separate columns for rocky shore, sand/mud flat and mangal habitats. The Gnoorea Point data have been extracted from another document and species habitats are not differentiated.

In terms of person-hours spent, survey effort at Gnoorea Point was more intensive than that at Bouguer Passage but the two data sets are more-or-less comparable. Neither data set can be regarded as comprehensive, that is, as representing the full intertidal faunas of the respective localities. However, they indicate a high degree of similarity and, if lumped together, would represent the majority of common bivalve and shelled gastropods living in intertidal sandy and rocky habitats of the mainland shores of the Pilbara (Nearshore) Bioregion.

Table 1 - APPENDIX 1 MOLLUSC LIST

Species	Bouguer Passage (2011)					Regions			
	rocky shore	sand/mud flat	mangal	all	**Gnoorea Pt (2006)**	NWS	NWS/West C.	N. Aust	Indo-West Pacific
POLYPLACOPHORA									
CHITONIDAE									
Acanthopleura gemmata (Blainville, 1825)	1			1	1				*
Acanthopleura spinosa (Bruguiere, 1792)					1				*
BIVALVIA									
ARCIDAE									
Anadara granosa (Linnaeus, 1758)		1		1					*
Anadara crebricostata		1		1	1				*
Arca avellana Lamarck, 1819	1			1	1				*
Arca navicularis Bruguiere, 1789	1			1	1				*
Barbatia amygdalumtostum (Röding, 1798)	1			1	1				*
*Barbatia coma (*Reeve, 1844)					1			*	
Barbatia sp.	1			1	1				*
Trisidos semitorta (Lamarck, 1819)		1		1	1				
GLYCYMERIDAE									
Glycymeris dampierensis Matsukuma, 1984		1		1	1	*			
Glycymeris persimilis (Iredale, 1939)					1	*			
Tucetona odhneri Iredale, 1939					1				
MYTILIDAE									
Botula fusca (Gmelin, 1791)					1				*
Brachidontes ustulatus (Lamarck, 1819)	1			1	1		*		
Gregariella sp.					1				
Lithophaga malacana (Reeve, 1858)					1				*
Lithophaga teres (Philippi, 1846)					1				*
Arenifodiens vagina (Linnaues 1758)		1		1					*
Lioberus sp.		1		1			*		
Modiolus philippinarum (Hanle,y 1843)		1		1					*
Modiolus sp.	1			1	1	*			
Septifer bilocularis (Linnaeus, 1758)	1			1	1				*
Stavelia horridus Dunker, 1856	1			1					*
PINNIDAE									
Atrina vexillum (Born, 1778)		1		1					*
Pinna bicolor Gmelin, 1791	1			1	1		*		
Pinna muricata Linnaeus, 1758					1				*
PTERIIDAE									
Pinctada albina (Lamarck, 1819)	1			1	1				*
Pinctada margaritifera (Linnaeus, 1758)					1				*
*Pinctada maxima (*Jameson, 1901)	1			1					*

PECTINIDAE									
Complicachlamys wardiana Iredale, 1939					1			*	
Mimachlamys lentiginosa (Reeve, 1853)	1			1	1				*
SPONDYLIDAE									
Spondylus eastae Lamprell, 1992	1			1	1	*			
LIMIDAE									
Lima vulgaris (Link, 1807)					1				*
Limatula cf. *japonica* (Adams, 1863)					1				*
OSTREIDAE									
Dendrostrea folium (Linnaeus, 1758)			1	1					*
Saccostrea cucullata (Born, 1778)	1			1	1				*
Saccostrea echinata (Quoy & GGaimard, 1832)	1			1					*
MALLEIDAE									
Malleus albus Lamarck, 1819	1			1	1				*
Malvufundus regula (Forskal, 1775)	1			1	1				*
Vulsella vulsella (Linnaeus, 1758)	1			1					*
UNGULINIDAE									
Felaniella sp.		1		1	1				
CARDITIDAE									
Cardita marmorea Reeve, 1843		1		1	1				*
Cardita variegata Bruguière, 1792	1			1	1				*
CRASSATELIDAE									
Eucrassatella decipiens (Reeve, 1842)					1	*			
CARDIIDAE									
Acrosterigma angulata (Lamarck, 1819)		1		1					*
Acrosterigma dupuchense (Reeve, 1845)		1		1	1	*			
Acrosterigma fultoni (Sowerby, 1916)		1		1	1	*			
Acrosterigma reeveanum (Dunker, 1852)		1		1	1		*		
Acrosterigma wilsoni (Voskuil & Onverwagt, 1991)		1		1	1	*			
Fragum erugatum (Tate 1889)		1		1			*		
Fragum unedo (Linnaeus, 1758)		1		1	1				*
Fulvia aperta (Bruguiere 1789)		1		1					*
*Lunlicardia retusum (*Linnaeus, 1767)		1		1	1				*
Plagiocardium setosum (Redfield, 1848)		1		1				*	
TRIDACNIDAE									
Tridacna maxima (Röding, 1798)					1				
MACTRIDAE									
Lutraria australis Reeve, 1854					1		*		
Mactra cumingii Reeve, 1854		1		1			*		
Mactra explanata Reeve, 1854		1		1	1	*			
Mactra olorina Philippi, 1846		1		1	1			*	
Mactra sericea Reeve, 1854					1			*	
Meropesta nicobarica (Gmelin, 1791)		1		1	1			*	
DONACIDAE									
Donax cuneatus Linnaeus, 1758					1			*	
TELLINIDAE									
Leporimetis spectabilis (Hanley, 1844)		1		1				*	

Tellina perna Spengler, 1798		1		1					*
Tellina (Merisca) piratica Hedley, 1918		1		1	1				*
Tellina rostrata Linnaeus, 1758					1				*
Tellina staurella Lamarck, 1818		1		1	1				*
Tellina virgata Linnaeus, 1758		1		1	1				*
PSAMMOBIIDAE									
Asaphis violascens (Forsskal, 1775)		1		1					*
Gari maculosa Lamarck, 1818)		1		1					*
Gari occidens (Gmelin, 1791)		1		1					*
Gari weinkauffi (Crosse, 1864)		1		1	1				*
SEMELIDAE									
Semele jukesii (Reeve, 1853)		1		1	1			*	
SOLENIDAE									
Ensiculus cultellus (Linnaeus, 1758)		1		1					*
Solen aureomaculatus Habe, 1964		1		1	1				*
VENERIDAE									
Anomalocardia squamosa (Linnaeus, 1758)		1		1					*
Antigona chemnitzii (Hanley, 1844)		1		1	1			*	
Antigona lamellaris Shumacher, 1817		1		1	1	*			
Antigona resticulata (Sowerby, 1853)					1				*
Callista impar (lamarck, 1818)		1		1	1		*		
Callista planatella (Lamarck, 1818)		1		1			*		
Circe nana Melvill, 1898		1		1					*
Clementia papyracea (Gray, 1825)		1		1					*
Dosinia contusa (Reeve, 1850)		1		1				*	
Dosinia deshayesii Adams, 1855					1	*			
Dosinia juvenilis (Gmelin, 1791)		1		1				*	
Dosinia scalaris (Menke, 1843)					1			*	
Dosinia sp.		1		1					
Gafraium tumidum Roding, 1798		1		1	1				*
Gomphina cf. unulosa (Lamarck, 1819)					1			*	
Globivenus embrithes (Melvill & Standen, 1899)					1				*
Lioconcha fastigiata (Sowerby, 1851)					1				*
Paphia semirugata (Philippi, 1847)		1		1		*			
Placamen gravescens (Menke, 1843)		1		1	1	*			
Sunetta contempta Smith, 1891					1				
Sunetta perexcavata Fulton, 1915					1	*			
Tapes dorsatus (Lamarck, 1818)		1		1				*	
Tapes literatus (Linnaeus, 1758)		1		1					*
Tapes platyptycha PIlsbry, 1901		1		1		*			
Tapes variegatus Sowerby 1852		1		1					*
Tapes sericeus Matsukuma, 1986					1			*	
CHAMIDAE									
Chama limbula Lamarck, 1819					1				*
Chama sp.	1			1	1				
CORBULIDAE									
Corbula macgillivrayi Smith, 1885					1			*	

Corbula tunicata Hinds, 1843					1				*
CLAVAGELLIDAE									
Brechites australis (Chenu, 1843)		1		1	1	*			
GASTROCHAENIDAE					1				
Gastrochaena sp.					1				
PHOLADIDAE									
? *Pholadidea* sp.					1				
GASTROPODA - EOGASTROPODA									
ACMAEIDAE									
Patelloida saccharina (Linnaeus, 1758)					1				*
PATELLIDAE									
Cellana radiata (Born, 1776)					1				*
Patella flexuosa Quoy & Gaimard, 1834									
GASTROPODA - ORTHOGASTROPODA									
NERITIDAE									
Nerita balteata Reeve, 1855			1	1					*
Nerita squamulata Le Guillou, 1841	1			1		*			
Nerita undata Linnaeus, 1758	1			1	1				*
FISSURELLIDAE									
*Diodora jukesii (*Reeve, 1850)	1			1	1	*			
HALIOTIDAE									
Haliotis squamata Reeve, 1846	1			1	1	*			
TROCHIDAE									
Astele sp.					1				
Eurytrochus macculochi (Hedley, 1907)					1	*			
Calthalotia mundula (Adams & Angas, 1864)	1			1	1		*		
Calthalotia strigata (Adams, 1853)	1			1	1				*
Clanculus atropurpureus (Gould, 1849)	1			1	1				*
Chrysostoma sp.					1				*
Herpetopoma atrata (Gmelin, 1791)	1			1	1				*
*Jujubinus polychromus (*Adams, 1853)					1				*
Monodonta labio (Linnaeus, 1758)	1			1	1				*
Pseudostomatella papyracea (Gmelin, 1791)					1				*
Trochus hanleyanus Reeve, 1842	1			1	1				*
Tectus fenestratus (Gmelin, 1791)	1			1	1				*
Tectus pyramis (Born, 1778)	1			1	1				*
TURBINIDAE									
Angaria delphinus (Linnaeus, 1758)	1			1	1				*
Astralium pileolum (Reeve, 1842)	1			1	1			*	
Astralium rotularia (Lamarck, 1822)	1			1				*	
Astralium stellare ((Gmelin, 1791)	1			1	1				*
Liotina cf. *peronii* (Kiner, 1839)	1			1	1				*
Phasianella solida (Born, 1778)					1				*
Turbo cinerea Born, 1778	1			1	1				*
Turbo haynesi Preston, 1914	1			1	1				*
Turbo petholatus Linnaeus, 1758					1				*

Turbo squamosus Gray, 1847	1			1	1			*	
MODULIDAE	1			1					
Modulus tectus (Gmelin, 1791)	1			1	1				*
CERITHIIDAE									
Cerithium novaehollandiae Adams in Sowerby, 1855	1			1	1			*	
Cerithium zonatum (Wood, 1828)					1				*
Clypeomorus batillariaeformis Habe & Kosuge, 1966)	1			1	1				*
Clypeomorus bifasciata (Sowerby, 1855)	1			1	1				*
Pseudovertagus aluco Linaeus, 1758)		1		1	1				*
Rhinoclavis articulata (Adams and Reeve, 1850)	1			1	1				
Rhinoclavis bituberculata (Sowerby, 1865)					1			*	
Rhinoclavis brettinghami Cernohorsky, 1974	1			1	1			*	
Rhinoclavis kochi (Philippi, 1848)	1			1	1				*
Rhinoclavis vertagus (Linnaeus, 1758)					1				
PLANAXIDAE									
Planaxis sulcatus (Born, 1780)	1			1	1				*
POTAMIDIDIAE									
Cerithidea reidi Houbrick 1986			1	1		*			
Cerithideopsis cingulata (Gmelin, 1791)			1	1	1				*
Terebralia palustris (Linnaues 1758)			1	1					*
Terebralia semistriata (Morch, 1778)			1	1	1		*		
LITTORINIDAE									
Littoraria filosa (Sowerb,y 1832)			1	1					*
Littoraria pallescens (Philippi, 1846)			1	1	1				*
Littoraria sulcosa (Philippi, 1846)			1	1		*			
Echinolittorina vidua (Gould, 1859)					1				*
Echinolittorina trochoides (Gray, 1839)	1			1	1				*
SILIQUARIIDAE									
Siliquaria ponderosa (Morch, 1860)	1			1	1				*
Siliquaria sp.		1		1	1				
STROMBIDAE									
Strombus campbelli Griffith & Pidgeon, 1834		1		1	1			*	
Strombus urceus orrae Abbott, 1960	1			1	1	*			
Strombus vomer iredalei Abbott, 1960		1		1	1	*			
CALYPTRAEIDAE									
Cheilea equestris (Linnaeus, 1758)					1				*
Crepidula aculeata (Gmelin, 1791)					1				*
PHENACOLEPADIDAE									
Phenacolepas crenulata (Broderip, 1834)					1				*
VERMITIDAE									
Dendropoma sp.	1			1	1				
Petaloconchus sp.	1			1					
Serpulorbis sp.	1			1	1				
TRIVIIDAE									
Trivia oryza (Lamarck, 1810)		1		1	1				*
CYPRAEIDAE									

Cypraea assellus Linnaeus, 1758	1			1					*
Cypraea brevidentata Sowerby, 1870					1			*	
Cypraea caurica Linnaeus, 1758	1			1	1				*
Cypraea clandestina Linnaeus, 1758	1			1	1				*
Cypraea cribraria Linnaeus, 1758	1			1					*
Cypraea cylindrica Born, 1778	1			1	1				*
Cypraea eglantina Duclos, 1833	1			1	1				*
Cypraea errones Linnaeus, 1758	1			1	1				*
Cypraea flaveola Linnaeus, 1758	1			1					*
Cypraea gracilis Gaskoin, 1849					1				*
Cypraea hirundo Linnaeus, 1758	1			1	1				*
Cypraea kieneri Hidalgo 1906	1			1					*
Cypraea limacina Lamarck, 1810	1			1					*
Cypraea lutea Gmelin, 1791	1			1					*
Cypraea lynx Linnaeus, 1758	1			1					*
Cypraea miliaris Gmelin, 1791	1			1					*
Cypraea moneta Linnaeus, 1758					1				*
Cypraea pallidula Gaskoin, 1849	1			1					*
Cypraea pyriformis Gray, 1824	1			1					*
Cypraea quadrimaculata Gray, 1824	1			1					*
Cypraea staphylea Linnaeus, 1758	1			1					*
Cypraea stolida Linnaeus, 1758	1			1					*
Cypraea subviridus dorsalis Schilder & Schilder, 1938	1			1		*			
Cypraea ursellus Gmelin, 1791	1			1					*
Cypraea vitellus Linnaeus, 1758					1				*
NATICIDAE									
Natica euzona Récluz, 1844					1				*
Natica fasciata (Roding, 1798)		1		1	1				*
Natica gualteriana Récluz, 1844		1		1	1				*
Natica pseustes Watson, 1881					1				*
Natica sp.					1				
Polinices cf. *conicus* (Lamarck, 1822)		1		1	1	*			
Polinices melastomus (Swainson, 1822)					1				*
Polinices powisiana (Récluz, 1844)					1				*
RANELLIDAE									
Cymatium exaratum (Reeve, 1844)	1			1	1				*
Cymatiu pileare (Linnaeus, 1758)	1			1					*
Cymatium labiosum (Wood, 1828)					1				*
TONNIDAE									
Tonna chinensis (Dillwyn, 1817)					1				*
CASSIDAE									
Phalium bandatum (Perry, 1811)					1				*
FICIDAE									
Ficus eospila (Peron, 1807)		1		1	1	*			
MURICIDAE									
Chicoreus cervicornis (Lamarck, 1822)	1			1		*			

Chicoreus cornucervi (Roding, 1798)	1			1		*			
Cronia avellana (Reeve, 1846)	1			1	1		*		
Cronia crassulnata (Hedley, 1914)	1			1	1	*			
Cronia margariticola (Broderip, 1833)	1			1	1				*
Favartia salmonea (Melvill & Standen, 1899)					1			*	
Haustellum multiplicatus (Sowebry, 1895)		1		1		*			
*Hexaplex stainforthi (*Reeve, 1843)	1			1	1	*			
Homalocantha secunda (Lamarck, 1822)	1			1		*			
Morula granulata (Duclos, 1832)					1				*
Morula spinosa (H. & A. Adams, 1853)					1				*
Murex acanthostephes Watson, 1883		1		1	1	*			
Murex macgillivrayi Dorn, 1862		1		1				*	
Pterynotus acanthopterus (Lamarck, 1816)		1		1		*			
Pterynotus akation Vokes, 1993		1		1		*			
Thais aculeata Deshayes & Milne Edwards, 1844)	1			1	1				*
Thais echinata (Blainville, 1832)	1			1	1				*
TURBINELLIDAE									
Syrinx aruanus (Linnaeus, 1758)							*		
BUCCINIDAE									
Cantharus fumosus (Dillwyn, 1817)					1				*
Cantharus erythrostomus (Reeve, 1846)	1			1	1				*
Cominella acutinodosa (Reeve, 1846)		1		1	1	*			
Engina concinna (Reeve, 1846)					1				*
Latirus paetelianus (Kobelt, 1876)					1	*			
Latirus walkeri Melvill, 1895	1			1	1	*			
Peristernia incarnata auct. [non Kiener, 1830]					1				*
Phos senticosus (Linnaeus, 1758)		1		1	1				*
NASSARIIDAE									
Cyllene sulcata Sowerby, 1859					1				*
Nassarius clarus (Marrat, 1877)		1		1	1				*
Nassarius dorsatus (Roding, 1798)		1		1	1			*	
Nassarius fraudator Cernohorsky, 1980					1	*			
Nassarius cf. *particeps* Hedley, 1915		1		1	1			*	
Nassarius pauperus (Gould, 1850)		1		1	1				*
COLUMBELLIDAE									
Mitrella essingtonensis (Reeve, 1859)		1		1	1	*			
Pyrene flava (Bruguiere, 1789)	1			1	1				*
Pyrene varians (Sowerby, 1832)					1			*	
OLIVIDAE									
Ancillista cingulata (Sowerby, 1830)		1		1	1			*	
Ancillista muscae (Pilsbry, 1926)		1		1	1			*	
Oliva cf. *australis* Duclos, 1835					1		*		
Oliva caldania Duclos, 1835		1		1	1			*	
MITRIDAE									
Scabricola barrywilsoni (Cate, 1968)	1			1		*			
COSTELLARIIDAE									
Vexillum vulpeculum (Linnaeus, 1758)		1		1	1				*

VOLUTIDAE									
Amoria damonii damonii Gray, 1864		1		1	1	*			
Amoria dampieria Weaver, 1960		1		1		*			
Amoria grayi Ludbrook, 1953		1		1	1		*		
Amoria jamrachi Gray, 1864		1		1		*			
Amoria praetexta (Reeve, 1849)		1		1	1	*			
Cymbiola oblita (Smith, 1909)		1		1	1	*			
Melo amphora (Lightfoot, 1786)		1		1	1			*	
CONIDAE									
Conus dorreensis Peron, 1807					1		*		
Conus monachus Linnaeus, 1758	1			1	1				*
Conus novaehollandiae Adams, 1853	1			1	1	*			
Conus reductaspiralis Walls, 1979		1		1	1	*			
Conus spectrum Linnaeus, 1758		1		1	1				*
Conus trigonus Reve, 1848		1		1	1	*			
Conus victoriae Reeve, 1843	1			1	1	*			
TEREBRIDAE									
Duplicaria crakei Burch, 1865					1	*			
Duplicaria duplicata (Linnaeus, 1758)		1		1		*			
Hastula rufopunctata (Smith, 1977)					1				*
GASTROPODA - HETEROBRANCHIA									
PYRAMIDELLIDAE									
Pyramidella sp.					1				
GASTROPODA - OPISTHOBRANCHIA									
BULLIDAE									
Bulla ampulla Linaeus, 1758		1		1	1				
GASTROPODA - PULMONATA									
SIPHONARIIDAE									
Siphonaria zelandica Quoy & Gaimard, 1833	1			1	1				
ELLOBIIDAE									
Marinula sp.	1			1					
Ophiocardelus sp.	1			1					
Species count	**98**	**94**	**8**	**198**	**204**				

APPENDIX 2

Intertidal echinoderm species collected at Bouguer Passage 21-22 March, 2011-04-06 (not including Crinoidea or Ophiuroidea)

Class Asteroidea
- Family Astropectinidae
  - Astropecten vappa sand flats
  - Astropecten sp. muddy sand flats
- Family Oreasteridae
  - Culcita schmideliana rocky flat, among rocks and algae
  - Protoreaster nodulosus rocky sand flats
  - Pseudoreaster obtusangulus rocky flat, among rocks and algae
- Family …
  - Anseropoda roseacea muddy sand flat

Class Echinoidea
- Family Diadematidae
  - Diadema setosum rocky flat, tide pools under ledges
- Family Temnopleuridae
  - Temnopleuris alexandri rocky flat, among algae on rocks
- Family Laganidae
  - Peronella orbicularis muddy sand flat
- Family Schizasteridae
  - Schizaster sp. muddy sand flat among rock
- Family Loveniidae
  - Breynia desorii sand flat
  - Lovenia elongata sand flat

Class Holothuroidea
- Family Holothuriidae
  - Holothuria atra rocky sand flats
  - Holothuria edulis rocky sand flats
  - Holothuria impatiens rocky sand flats
  - Holothuria cf. leucospilota rocky flats, under stones
- Family Stichopodidae
  - Stichopus horrens rocky flats, under stones

APPENDIX 3

Prominent intertidal macroalgae from Bouguer Passage

A sample of the prominent mid/lower-littoral macro-algae was collected by Spencer Shute (22 March, 2011) from the rocks of the sandy rock flat on the north-eastern shore of Dixon Island, in the vicinity of Oyster Rock just north (seaward) of the proposed causeway location. Identifications are as follows:

Dictyota ciliolata
Dictyota sp.
Halimeda cylindracea
Halimeda discoidea
Laurencia sp.
Acanthophora spicifera
Jania adhaerens
Sargassum sp.1
Sargassum sp.2