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3.2 Upper Intertidal Area North-west of Boodarie

3.2.1 Site B1

This site comprised a mixture of supra tidal flats, which by definition are considered to be terrestrial habitat, and intertidal flats. The supra tidal flats were typically a series of narrow peninsulas and small islands at an elevation of between 20 to 50 cm above the intertidal flats (**Plate 3-11a-b**), which themselves support scattered samphires (salt marsh BPPH) mostly of the species *Tecticornia halocnemoides* and *Muellerolimon salicorniaceum*. Cyanobacterial mats appeared to be present between the samphires on at least some of the intertidal flats. No mangroves occurred within this area as the shore height is too great to be wetted by most high tides. As a result, soil salinities are too high and soil moisture content too low to support mangroves (SKM 2007).

a. Intertidal flats in foreground and supratidal area in the background.	**b.** Intertidal flats in foreground, a supratidal peninsula or chenier in the middle distance. Mangroves lining a creek channel can be seen in the far distance.

- **Plate 3-11: Typical Habitat at Site B1**

3.3 Western Side of Existing Causeway across West Creek

The south bank of West Creek was surveyed on either side of the existing causeway (i.e. to the west and east) to Finucane Island. The existing causeway is of solid construction and has consequently altered the local hydrology by preventing tides flowing freely through the West Creek channel. Currently, the portion of the old channel adjacent to the causeway is a deposition site for fine mud and silt (**Plate 3-12a**), and over time this area may infill completely.

A review of aerial photographs indicates the mangrove habitat to the west of the causeway comprises closed canopy forest of *Avicennia marina* and *Rhizophora stylosa* (as either monospecific or mixed stands) close to the bank of West Creek and along banks of smaller channels that traverse the intertidal flat. With increasing distance from the creek and channels, the canopy becomes more open and tree height decreases. The dominant species in these areas is *Avicennia marina*, with a few scattered *Ceriops australis*. At increasing shore heights bare areas of tidal pan become apparent and there are also patches of salt marsh, dominated by the species *Tecticornia halocnemoides* (SKM 2007).

The field survey was undertaken in this area was to confirm the interpretation of the aerial photography and that vegetation associations and associated fauna were similar to those reported elsewhere (SKM 2007; Paling et al. 2003).

a. View looking southwest across West Creek, showing depositional area.

b. View looking northwest from causeway toward West Creek, over stand of *Avicennia marina*.

- **Plate 3-12: Southern Bank of West Creek**

3.3.1 Site SWCW1

Site SWCW1 lays immediately to the west of the causeway on the southern bank of West Creek (**Figure 2-1**). A stand of tall (4 to 6 m high), mature, closed canopy *Rhizophora stylosa* was recorded at this site on the landward side of a fringe of *Avicennia marina* that occupied the bank of West Creek. The *Rhizophora stylosa* trees recorded here were among the largest of this species observed during the field survey. Trees at the eastern end of this stand were closely packed and showed evidence of cyclone damage (**Plate 3-13a**).

The landward edge of the *Rhizophora stylosa* forest comprised a dense stand of much smaller trees with numerous prop and aerial roots. Behind this stand (to the landward side) was a mixed association of *Rhizophora stylosa* and *Avicennia marina*, which then graded into low, closed canopy, monospecific stand of *Avicennia marina*. The vegetation associations in this area, and their zonation in the intertidal, are typical of that observed elsewhere in the Port Hedland Harbour (SKM 2007).

The benthic fauna recorded at this site was more diverse than that seen at many other sites elsewhere in the harbour, and most closely resembled that found on Finucane Island in the area enclosed by the existing road and rail infrastructure (Site F10). These sites have similar characteristics: waterlogged substrate with black sulphurous mud, a large amount of decaying leaf litter, and numerous pneumatophores (**Plate 3-13b**). Drainage channels at site SWCW1 were typically shallow (less than 10 cm deep at low tide) and without well-defined banks, resulting in tidal sheet flow throughout this area (**Plate 3-13d**).

A shallow drainage channel running through closed canopy mangrove forest, parallel to the existing causeway, had abundant *Telescopium telescopium* and *Terebralia palustris.* Dense aggregations of these species were also seen at the seaward edge of the mangrove forest. These mud whelks ranged from relatively small juveniles through to large adults and were in an area of waterlogged substrate with black sulphurous mud, a large amount of decaying leaf litter, and numerous pneumatophores (**Plate 3-13c**). Other benthic fauna observed at this site were the mangrove arboreal snail, *Littoraria filosa*, fiddler crabs (*Uca flammula*), some sesarmids crabs (*Perisesarma* spp.) and the xanthid crab, *Epixanthus dentatus*.

a. *Rhizophora stylosa* showing evidence of cyclone damage.

b. Waterlogged, dark substrate with abundant leaf litter, pneumatophores and mud whelks.

c. Heavily bioturbated mud with numerous pneumatophores under *Avicennia marina.*

d. Tidal channel with banks of fine, deep mud and bed of coarse sand and gravel.

- **Plate 3-13: Typical Habitat at Site SWCW1**

3.3.2 Site SWCW2

Site SWCW2 was situated approximately 200 m to the north-west of the existing causeway (**Figure 2-1**). Between this site and the causeway, the seaward edge of mangrove forest was a tall (up to 7 m high) closed canopy of *Avicennia marina* backed by a tall stand of *Rhizophora stylosa* (up to 7 to 8 m high). Further landward, the *Rhizophora stylosa* trees rapidly diminished in height to form a dense, closed canopy thicket of varying width. This thicket gave way to a stand of low, closed canopy *Avicennia marina* (2 to 4 m high) and the interface between these two habitats was a mixed association of *Rhizophora stylosa* and *Avicennia marina*.

The substrate was heavily bioturbated and had numerous pneumatophores under the *Avicennia marina* in the areas close to the seaward edge. The dominant benthic organism was the fiddler crab *Uca flammula* and most of the bioturbation was due to the burrowing and feeding activities of this species. Very few mud whelks were present under the mangrove canopy except at the seaward margin and extending out onto the mudflat adjacent to West Creek (**Plate 3-14a**). On the edge of the mangroves, mud whelks were abundant and two species (*Telescopium telescopium* and *Terebralia palustris*) were recorded. The pulmonate mollusc *Onchidium damelli* was also common, both under and in front of the mangroves, and a few individuals of another species of *Onchidium* sp. were observed on the trunks of large *Avicennia marina* (**Plate 3-14b**). This species of arboreal grazer has been observed in mangrove areas further north such as Darwin and the Kimberley region (Hanley 1993).

At the western extent of this site some live specimens of the bivalve *Anadara granosa* were observed; the dead shells of this bivalve are the dominant component of the shells found in both middens and cheniers on the hinterland margins of many intertidal areas in the region. Between sites SWCW1 and SWCW2 the oyster *Saccostrea cucculata* and several barnacle species colonised hard surfaces (such as trunks, prop roots, pneumatophores and shells of large mud whelks) in dense clumps.

Common crabs were the mangrove crabs *Perisesarma* sp., *Parasesarma* sp. and *Metapograpsus frontalis*. Also, occasional individuals of the predatory crabs *Epixanthus dentatus* and *Scylla* sp. (**Plate 3-14c**) were observed. The small mudskipper *Periopthalmus* sp. was common while the large mudskipper *Boleopthalmus* sp. was abundant in the waterlogged mud at the extreme seaward edge of the mangroves (**Plate 3-14d**).

At the seaward edge between Sites SWCW1 and SWCW2, a number of mangrove-associated birds were observed in a feeding guild, formed when passerines of several species group together while foraging. The species recorded were the dusky flyeater (*Gerygone tenebrosa*), the mangrove fantail (*Rhipidura phasiana*), the mangrove (or yellow) white eye (*Zosterops lutea*) and the white-breasted whistler (*Pachycephala lanioides*). A number of pairs and individuals of the mangrove kingfisher (*Todiramphus chloris*) were also seen. None of these birds are listed as threatened under the Commonwealth EPBC Act (1999) or the Western Australian *Wildlife Conservation Act 1950* threatened fauna list.

a. Mud whelks were abundant at the seaward edge of the mangroves.

b. *Onchidium* sp. found on trunks of *Avicennia marina* near SWCW2*.*

c. Mud crabs (*Scylla* sp.) were common along the seaward edge of mangrove forest.

d. The large mudskipper *Boleopthalmus* sp. was very common on the deep fine muds at the seaward edge of mangrove forest.

e. Tidal channel lined with *Rhizophora stylosa*.

f. Under the closed canopy of the seaward fringe there was deep shade.

- **Plate 3-14: Typical Habitat and Species at Site SWCW2**

3.3.3 Site SWCW3

Site SWCW3 was located in the mid-upper intertidal, adjacent to the existing rail embankment (**Figure 2-1**) and to the rear of closed canopy mangrove forest. The area was a mosaic of open canopy, stunted *Avicennia marina* trees interspersed with samphires and areas of bare tidal flat (**Plate 3-15a-b**). The flora and associated fauna of this site was typical of that observed at similar shore heights elsewhere in Port Hedland Harbour. Refer to SKM (2007) for a comparison with these other sites.

a. View southwest from causeway toward scrubby mangrove habitat interspersed with large areas of bare tidal flat.

b. View west from causeway showing mangrove height decreasing further landward (left of photo).

- **Plate 3-15: Typical Habitat at Site SWCW3**

3.4 Eastern Side of Existing Causeway across West Creek

The area to the east of the existing causeway and associated infrastructure is not expected to be impacted by the proposed Outer Harbour Development. The field survey of this area was undertaken to provide potential reference sites of vegetation and associated fauna.

3.4.1 Site SWCE1

A coarse sand beach alongside the existing causeway at site SWCE1 sloped steeply down to a mixed association of *Avicennia marina* and *Rhizophora stylosa* mangroves of 2 to 5 m height, interspersed with some open patches of mudflat. On the landward edge there were a few *Ceriops australis* trees. The mangrove forest is more open and less dense than that on the western side of the causeway.

A broad, shallow channel (approximately 2 m wide) flows from the site toward the main creek, and becomes deeper closer to West Creek. The shallow reaches of the channel contained abundant *Telescopium telescopium* and *Terebralia palustris* mud whelks, with many juveniles present

SKM

(**Plate 3-16a**). Mud creepers (*Cerithidea* spp.) and the pulmonate gastropod, *Onchidium damelli*, were also observed but were less abundant. Drier areas of the substrate were dominated by the fiddler crab, *Uca flammula* (**Plate 3-16b**).

a. Juvenile *Telescopium telescopium* and *Terebralia palustris*.

b. Fiddler crabs, *Uca flammula*, were abundant on drier areas of the substrate..

c. Exposed mangrove root systems, caused by an erosion event.

d. Shallow channel running toward West Creek over a limestone base.

- **Plate 3-16: Typical Habitat and Species at Site SWCE1**

Closer to the seaward edge of mangroves was an area where an erosion event (possibly a cyclone) is the likely cause of removal of approximately 20 to 40 cm of the substrate, exposing much of the mangrove root system (**Plate 3-16c)**. Some trees in this area had developed new cable and prop root structures at heights reflecting the lower substrate level, while some younger trees were present where gaps in the canopy may have been caused by loss of mature trees.

A small, shallow channel (5 to 10 cm deep at low tide) crosses this area (**Plate 3-16d**) and flows over a base of hard limestone pavement. Turf algae and the macroalga *Padina* sp. covered the bed of this channel.

3.4.2 Site SWCE2

Along the seaward edge at SWCE2 the mangroves were typical for this intertidal height (**Plate 3-17a**) and comprised a tall closed canopy forest of multi-stemmed *Avicennia marina* (approximately 7 m high) (**Plate 3-17b**) backed by a zone of *Rhizophora stylosa* (**Plate 3-17c**). Behind this zone was a mixed stand of *Rhizophora stylosa* and *Avicennia marina*, backed by a zone of monospecific, closed canopy *Avicennia marina* scrub.

The fauna observed in the area between sites SWCE1 and SWCE2 is listed in **Table 3-5** and was of comparatively high diversity compared to other sites in the harbour (SKM 2007) where species such as larger mud whelks were absent. However, the majority of species were found at site SWCE1 close to the existing causeway where shallow streams flow alongside. The presence of the existing causeway could result in more surface water and lower salinities than would normally be expected at this shore height. If so, such altered hydrological conditions could be considered conducive to a greater diversity of benthic fauna inhabiting the area.

Another factor that may be affecting faunal diversity is the change to the sediments caused by the existing causeway. The depositional environment created by the closure of West Creek traps fine sediments and results in the retention of more organic material, both of which may support a higher diversity of fauna species than would normally be expected. Sediments of similar sized creeks in the harbour have a greater proportion of sand along the channel banks.

Table 3-5: Benthic Fauna Observed between Sites SWCE1 and SWCE2

Species	Abundance[1]
Terebralia semistriata (mud whelk)	common (in patches)
Terebralia palustris (mud whelk)	common (in patches)
Terebralia sulcata (mud whelk)	common (in patches)
Telescopium telescopium (mud whelk)	common (in patches)
Cerithidea largillierti (mud whelk)	common
Nerita balteata? (mollusc)	present
Littoraria articulata? (mollusc)	present
Onchidium damelli (mollusc)	common
Saccostrea cucculata (oyster)	present; common in patches near MSL
Neosarmatium meinerti (crab)	present
Parasesarma sp. (crab)	common
Perisesarma sp. (crab)	common
Metapograpsus frontalis (crab)	present
Uca flammula (crab)	common
Scylla sp. (crab)	present
Epixanthus dentatus (crab)	present
Thalassina anomala (mud lobster)	common
Periopthalmus sp. (mudskipper)	common

[1] Present = 1–5 individuals recorded; common = 5–20 individuals recorded; abundant = greater than 20 individuals recorded; MSL = mean sea level.

	
a. Seaward edge of mangroves with deep mud on tidal flat.	**b.** *Avicennia marina* comprised the seaward edge of mangroves.
	
c. Thicket of *Rhizophora stylosa* lying to landward side of the seaward fringe of *Avicennia marina*.	**d.** Species diversity of mud whelks was lower at site SWCE2 than at site SWCE1.

- **Plate 3-17: Typical Habitat and Species at Site SWCE2**

4 Distribution of BPP and BPPH in the Study Area

4.1 Mangroves

A map showing the distribution of the various mangrove associations that together comprise the mangrove BPPH is provided in **Figure 4-1**. The mangrove associations used in the classification are derived principally from the classification system devised by Semeniuk (2007), simplified to the following categories by reference to Paling et al. (2003), and the distribution of each vegetation association is based upon SKM (2009b) and the field survey reported here.

The mangrove associations used here are:

1. *Avicennia marina* (scattered) – comprising scattered individuals of the mangrove *Avicennia marina*, often with scattered samphires, but without high densities.

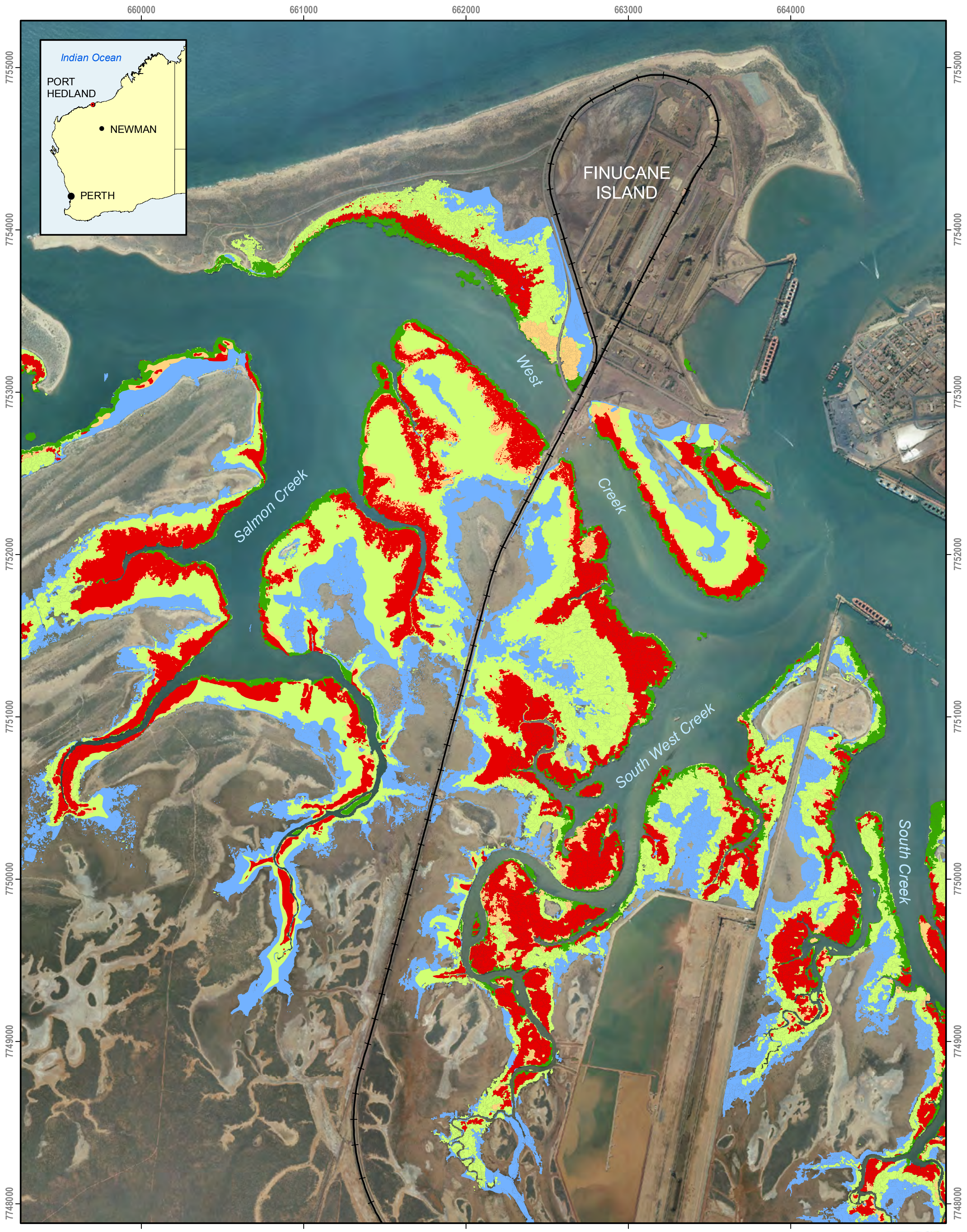
2. *Avicennia marina* (closed canopy, landward edge) – a forest/scrub comprising the typical zone of mangroves immediately behind the mixed association of *Avicennia marina* and *Rhizophora stylosa* and often up to 100 m in width or more and characterised by a decrease in vegetation height with increasing height on the shore.

3. *Avicennia marina/Rhizophora stylosa* (closed canopy) – a forest/scrub comprising a transitional zone between closed canopy forest close to the seaward edge of main channels and extending to landward along small channel banks.

4. *Rhizophora stylosa* (closed canopy) – a forest/scrub comprising a relatively thin zone often only a few trees wide behind the seaward *Avicennia marina* fringe and also lining steep banks on small channels.

5. *Avicennia marina* (closed canopy, seaward edge) – a forest comprising large, mature, multi stemmed *Avicennia marina* on the seaward edge of the main channels and also sheltered small bays.

Photographs depicting typical habitat in each of the above mangrove associations are shown in **Plate 4-1**. Other mangrove associations that were noted, such as the seaward fringe of *Aegiceras corniculatum*, the landward edge fringes of *Ceriops australis*, and the mixed associations of *Avicennia marina*, *Ceriops australis*, *Aegialitis annulata*, *Bruguiera exaristata* and *Osbornia octodonta*, could not be accurately delineated on a map due to their patchy distributions and the small areas of these associations, which are rarely more than a few metres in width.



Legend

Existing Rail

Mangrove Classification 2008

- *Avicennia marina*
- *Avicennia marina* (scattered)
- *Avicennia marina/Rhizophora stylosa*
- *Rhizophora stylosa* (closed canopy)
- *Avicennia marina* (closed canopy, landward edge)

0 250 500 750
metres

Scale = 1:30,000 at A4

Datum: GDA94
Projection: MGA94 Zone 50

bhpbilliton

Source:
Orthorectified Aerial Photograph: 06/2008 (BHPBIO)
Topography: Geoscience Australia, GEODATA Topo 250K V3
(Copyright Commonwealth of Australia, 2006)
Mangrove Classifications: Based on 2008 Aerial Photography Interpretations (SKM, 2009)

Figure 4.1 - Distribution of mangrove vegetation associations

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a. *Avicennia marina* (scattered).

b. *Avicennia marina* (closed canopy, landward edge).

c. *Avicennia marina* (closed canopy, landward edge) viewed from above.

d. *Avicennia marina*/*Rhizophora stylosa* (closed canopy).

e. *Rhizophora stylosa* (closed canopy).

f. *Avicennia marina* (closed canopy, seaward edge).

- **Plate 4-1: Mangrove Associations used for the Vegetation Classification**

4.2 Salt Marsh and Cyanobacterial Mats

The survey noted the presence of samphires (dominant species of the intertidal salt marshes) and also the presence of dormant fragments of cyanobacterial mats in some areas of the upper intertidal zone.

Assessment of the extent of cyanobacterial mats is challenging due to a lack of knowledge about the factors that control their distribution (SKM 2009a). What is known suggests substantial variability in the extent of mats on an interannual basis (SKM 2009a), driven primarily by rainfall, which makes mapping difficult and introduces doubt over long terms estimations of areal coverage.

An initial evaluation has been undertaken to describe the distribution of cyanobacterial mat communities in the (Port Hedland Industrial Area) Management Unit. Analysis of multispectral imagery indicated that 1,798 ha of mat may be present in the Management Unit, but this number represents the results of a first pass classification algorithm, with no ground truthing undertaken to confirm this distribution.

The salt marsh plant community is dominated by samphires, predominantly the by the species *Tecticornia halocnemoides*. Paling et al. (1993) estimated 758 ha of samphire existed in the Management Unit based on aerial imagery, but this was not ground truthed. In the current survey, qualitative observations of samphire distribution were recorded, but quantitative estimations of areal coverage were not made.

5 Discussion

In general, the intertidal BPPH and the BPP supported is typical of the greater area of the intertidal zone within the Management Unit (EPA 2001).

The exception is the small patch of mangroves at site F6 where a vegetation association includes the two locally rare species *Osbornia octodonta* and *Bruguiera exaristata*. Both these species are near the southern limit of their range in Western Australia and are more common further north (Duke 2006). Both species occupy a habitat (sandy substrate over limestone basement at landward edge) which is found at other sites in the harbour, but recent surveys have not noted these species elsewhere (SKM 2007).

The fauna observed during the survey are also typical of the fauna associated with mangroves throughout northern Australia, although the diversity and abundance of species was generally low compared to mangroves north and south of Port Hedland (see **Section 5.1.1**).

The field survey data and the vegetation map will be used to develop an impact assessment of the proposed Outer Harbour Development on mangroves and other intertidal BPP and therefore there is value in a discussion of what is known of the ecological functions and comparative values of the different intertidal BPP types located within the study area.

5.1 Ecological Functions of Different Intertidal BPP

The different mangrove vegetation associations and other intertidal BPP present in the Management Unit are expected to show functional differences across a range of ecological elements. Key ecological elements include faunal diversity and primary productivity. In this section, faunal associations are compared between mangrove vegetation types and discussion is also provided for samphires and cyanobacterial mats.

For the purpose of comparing ecological function, mangrove associations have been grouped into two generalised functional groups:

- closed canopy mangrove forest; and
- sparse *Avicennia marina* (with or without samphires).

With reference to the mangrove associations used in the vegetation classification (**Section 4** of this report), the four mangrove associations that have been grouped together as closed canopy mangrove forest are:

- *Avicennia marina* (closed canopy, landward edge);
- *Avicennia marina/Rhizophora stylosa* (closed canopy);

- *Rhizophora stylosa* (closed canopy); and
- *Avicennia marina* (closed canopy, seaward edge).

The description of closed canopy areas of mangroves provided by Semeniuk (2007) is of 'low forest to scrub' and the broad category as defined applies to a range of vegetation heights and physical appearance, reflecting variation in factors such as substrate type, frequency of inundation and soil salinity. The majority of closed canopy mangrove forest along the channels of the harbour is better described as 'low forest' rather than 'scrub', and the single-species stands of both *Avicennia marina* and *Rhizophora stylosa* along the larger channels usually contain some relatively large trees (in the Port Hedland context). The best examples of closed canopy mangrove forest reflect their proximity to mean sea level and frequent tidal inundation.

Compared to mangrove trees growing at higher levels on the shore in the Management Unit, such as sparse *Avicennia marina*, the trees of the closed canopy mangrove forest are generally better developed with larger trunks, greater canopy height and more continuous canopy cover.

In the Port Hedland Harbour region, the sparse *Avicennia marina* habitat occurs on areas of mid-intertidal mudflat, and is often a mixed association of shrub-like *Avicennia marina* trees and samphires, most commonly *Tecticornia halocnemoides* (SKM 2007). These areas represent a gradient between the 'true' mangrove forests at lower shore heights, and the upper intertidal areas that are typically occupied by only samphires and cyanobacterial mats.

The upper intertidal areas are typically a mosaic of bare mudflat interspersed with patches of samphires and patches of mangrove. Often the mangroves tend to be associated with very small channels draining the tidal flat and these channels are typically only a few centimetres deep, drying quickly once the tide begins to recede, but there are also areas where both mangroves and samphires are truly intermixed with each other.

Relative to the closed canopy mangrove forest these areas have a much lower above-ground biomass and the mangroves are often less than 1 m in height. Density of trees and of samphires can vary widely in this BPPH type, with mangrove in higher densities near shallow drainage channels and depressions where the frequency of tidal inundation is higher. Densities of trees are very low when measured per hectare as even along the drainage channels where trees are densely packed; the band of trees is rarely more than one or two trees wide.

5.1.1 Fauna Associated with Mangroves

The number of species present in mangroves typically ranges from 4 to 8 (**Section 3**), but at one site 20 species were recorded under closed canopy forest (site F9).

Although the list of species reported at F9 typical of what might be found in many mangrove stands on the north western coast, the high number of species and relative abundance at this site is thought to be a consequence of an altered pattern of drainage in an area of mangroves on Finucane Island after construction of a causeway.

Given the different mangrove associations present in the intertidal zone of the Port Hedland Harbour, it can be expected that the fauna will show differences in species distribution, diversity and abundance in response to the same environmental conditions that influence the distribution, diversity and abundance of flora, such that fauna will decrease in diversity and abundance moving away from the tidal channels in response to rising salinity and less frequent tidal inundation.

5.1.1.1 Fauna of Closed Canopy Mangrove Forest

Compared to other mangrove trees growing at higher levels on the shore in the Management Unit, such as sparse *Avicennia marina*, the trees of the closed canopy mangrove forest are generally better developed with larger trunks, greater canopy height and more continuous canopy cover. All of these features are important in providing suitable niches for fauna and Johnstone (1990) documented eight species of bird that are largely dependent on mangroves in the Pilbara region where the mangroves form the only closed canopy forest in the region. All species are able to utilise more than one type of mangrove and all eight species of birds typically forage widely in all mangrove vegetation types and some also use samphires and tidal flats.

For some bird species, the presence of closed canopy forest and particularly larger trees appears to be critically important and this is reflected in discrete distributions that match the distribution of closed canopy mangrove forests (Johnstone 1990). For example, the presence of large hollow trunks in the seaward *Avicennia marina* zone provides suitable nesting sites for the collared kingfisher, *Todiramphus chloris*, which is apparently absent from areas of the coast which lack large *Avicennia marina* (Johnstone 1990). Similarly, the bar-shouldered dove (*Geopelia humerilis*) is widely distributed in north and north-western Australia where it is commonly found associated with a range of vegetation assemblages, but in the Pilbara this species is largely restricted to closed canopy mangrove forest for suitable nesting and roosting sites (Johnstone 1990). Johnstone (1990) also notes that birds such as the mangrove robin (*Eopsaltria pulverulenta*) and mangrove golden whistler (*Pachycephala melanura*) are heavily dependent on the presence of closed canopy forest, with the mangrove robin particularly dependent on *Rhizophora stylosa*.

The diversity of invertebrates and other mangrove associated fauna is typically higher in closed canopy forests in the tropics (Robertson et al. 1992; Hanley 1993). The presence and degree of shading of the forest floor appears to affect the relative abundance of some crab species (Nobbs 2003) such as *Uca flammula*, which was abundant under all types of closed canopy mangrove forest surveyed (SKM 2007). A survey of fauna (SKM 2007) also noted that different species of fiddler crabs were associated with closed canopy mangrove forest in Port Hedland

Harbour and that these animals were generally more abundant in these areas when compared with the more open *Avicennia marina* scrub. However, it should be noted that fiddler crab distribution and abundance is likely to be the result of a combination of factors including the frequency of tidal inundation, vegetation present, substrate type and salinity, rather than the presence of closed canopy mangrove forest alone.

Survey of the closed canopy mangrove forests at Harriet Point in Port Hedland (SKM 2007) concluded these areas supported a comparatively low diversity of benthic invertebrates and epifauna, and that sites both north and south of Port Hedland were known to support higher diversity (J. Hanley pers comm. 2009). The almost total absence of typical large and conspicuous mangrove-associated molluscs such as *Telescopium telescopium*, *Terebralia* spp., neritids and littorinids was notable (SKM 2007). The comparatively low diversity may be related to the low levels of litter on the forest floor, as it appears a large proportion of nutrient capital may be stored in dead roots below the forest floor (Alongi et al. 2000, 2003) rather than on the surface where it might be more easily accessed by grazing and deposit feeding invertebrates.

5.1.1.2 Fauna of Sparse Avicennia marina (With or Without Samphires)

The fauna associated with areas of sparse *Avicennia marina* is low in both diversity and abundance compared with closed canopy mangrove forests. Many of the eight species of bird associated with mangroves do use these areas to forage for food (Johnstone 1990), but given the lower density of vegetation it is likely that a relatively small proportion of time is spent foraging in sparse *Avicennia marina* compared to within closed canopy mangrove forests. Other species of birds that are not restricted mostly or entirely to mangroves would use these areas to forage and include a variety of insectivores, waders and herons (Johnstone 1990).

Very few species of benthic invertebrate fauna have been observed in areas of sparse *Avicennia marina* (SKM 2007). The most common was the large sesarmid crab *Neosarmatium meinerti*, which usually digs its burrows under canopies of *Avicennia marina* trees (Dahdouh-Gebas et al. 1999). This habitat type is important as foraging habitat for fishes and crustaceans such as prawns and crabs that enter the area on suitable high tides. These areas are unlikely, however, to support the same abundance and diversity of fauna found in closed canopy mangrove forest as they are not inundated for as long or as often, and are further from channels (Thomas & Connolly 2001).

5.1.2 Fauna Associated with Salt Marsh

The salt marsh habitat is dominated by the samphire *Tecticornia halocnemoides* and (SKM 2007), reported very few benthic invertebrate species from these areas at Port Hedland. No molluscs or insects were recorded, and the only crustacean commonly encountered was the sesarmid crab *Neosarmatium meinerti*. Areas of bare mud support the fiddler crab, *Uca elegans*, and this species appears to favour open areas devoid of shade (Nobbs 2003). However, it is unclear whether the amount of shade is important to this species, possibly because shading may restrict the production of algae and/or cyanobacteria, or rather that lack of shade is correlated with a particular height on the shore (Jones 2004).

The lack of fauna on the substrate is most likely related to the harsh environmental conditions faced by marine invertebrates at this height on the shore. Tidal inundation is infrequent and for short durations and the pore water and soil salinities are high. Recent surveys of soil water salinity for the BHP Billiton Iron Ore's Rapid Growth Project 5 (RGP5) monitoring program (SKM 2009c) demonstrated that at the edge of tidal flats behind mangroves, soil salinity was in the range of 60 to 70‰ (parts per thousand) and at these levels most intertidal organisms are excluded. The exception appears to be species such as the crabs *N. meinerti* and *U. elegans*, both of which are capable of digging deep burrows to reach depths where soil moisture is higher, and salinities are closer to that of seawater.

5.1.3 Fauna Associated with Cyanobacterial Mats

The areas of cyanobacterial mats observed at Port Hedland have mostly been surveyed during dry season conditions (SKM 2007) and all portions of mats observed were dormant with no signs of any invertebrate associates.

However, during the recent setup of the RGP5 mangrove monitoring program (SKM 2009c), areas of live, actively photosynthesising mats were observed at a number of sites around the harbour, but no evidence was found in the field of organisms feeding on the mats. Samples of mat were collected from several sites and were examined under microscope for evidence of micro invertebrates, but none were observed. The apparent absence of a cohort of invertebrates that can feed on the mats is consistent with observations made elsewhere (Stahl 2000). Although tolerant to high salinities up to 300‰ (Sheppard et al. 1992) and temperatures, the species diversity in cyanobacterial mats is known to decrease as soil salinity increases. Whilst these conditions are considered sub-optimal for cyanobacteria, mats may occur because at high salinities there is an absence of grazing by metazoans (animals such as crabs and molluscs), whereas, in more benign conditions such as lower in the intertidal zone, the presence of significant grazing prevents accumulation of biomass and binding of sediment (Stahl 2000). It is also the case that cyanobacterial mats contain toxic compounds and that would further discourage grazing organisms.

5.2 Environmental Services provided by Different Intertidal BPP

The Organisation for Economic Co-operation and Development (OECD 2008) defines environmental services as:

- disposal services which reflect the functions of the natural environment as an absorptive sink for residuals;
- productive services which reflect the economic functions of providing natural resource inputs and space for production and consumption; and

- consumer or consumption services which provide for physiological as well as recreational and related needs of human beings.

The range of environmental services provided by different intertidal BPPHs at Port Hedland include, but are not limited to, primary productivity, biodiversity (both floral and faunal), nutrient trapping and maintenance of water quality, protection against storm surge and erosion, and the recreational amenity value associated with fishing.

5.2.1 Closed-Canopy Mangrove Forest

Stands of closed canopy mangrove forest are located between the seaward edge and the mid-tidal level of the shore and these stands are among the most productive in the harbour (Alongi et al. 2005). At a species level, *Rhizophora stylosa* is more productive than *Avicennia marina* although both species are at the upper end of the range of estimates of productivity (in terms of both leaf litter production and photosynthetic rates) for these species elsewhere. The estimates of productivity are surprising as there is no doubt these arid-zone trees are under considerable stress (Alongi et al. 2005) and it might have been expected that their productivity would be at the lower end of the scale, reflecting the combination of latitude, rainfall and vegetation height that has elsewhere been shown to be highly correlated with productivity (Saenger & Snedaker 1993) measured as litterfall.

The primary productivity of closed canopy mangrove forests in the Port Hedland Harbour is higher than the other types of mangrove associations present (Alongi et al. 2005) and so, given that primary productivity is an important source of organic carbon in food chains both within the mangrove and externally (tidal creeks, coastal waters), then the ecological value per unit area of closed canopy mangrove forest would be high relative to other types of mangroves. While the relationship between nearshore fisheries and mangrove systems is often stated to be important (reviewed by Robertson et al. 1992 and Saenger 2002) there is however a large range of local variation dependent on a variety of local factors, such as the density and abundance of species form lower trophic levels (Manson et al. 2005; Hanley 2007).

Another environmental service provided by the closed canopy mangrove forests is the provision of habitat for fishes and other organisms (prawns, crabs) that swim up onto the flooded areas during high tides seeking shelter and food. The value of this service is variable, dependent on a number of factors, such as pneumatophore density, which provides habitat complexity (Bloomfield & Gillanders 2004; Thomas & Connolly 2001; Lewis & Gilmore 2007) but it is likely that areas of closed canopy mangrove forest are more important than other areas because they:

- lie close to the channels which provide a refuge at low tide;
- are structurally complex;
- are flooded on all high tides; and

- are flooded for longer periods compared to areas higher in the intertidal zone.

The provision of suitable areas of habitat for roosting, nesting and foraging by avifauna has been discussed in the earlier section on fauna associated with closed canopy mangrove forests (**Section 5.1.1.1**). The structural complexity provided by closed canopy mangrove forest provides other benefits including windbreak, storm protection and some degree of shoreline protection (Saenger 2002), and maintenance of tidal channel depths and contours (Wolanski 2006).

5.2.2 Sparse Avicennia marina (With or Without Samphires)

Sparse *Avicennia marina* habitat is likely to provide many of the environmental services provided by closed canopy mangrove forests, although the relative degree of contribution is likely to be lower.

Although no productivity data exist for sparse *Avicennia marina* habitat, it can be reasonably assumed that productivity would be lower than closed canopy mangrove forest due to lower above-ground biomass of plants. Sparse *Avicennia marina* areas would contribute to the food chain through production of organic carbon in the same way as closed canopy mangrove forest, however the rate of contribution is likely to be considerably lower. Since little or no accumulation of leaf litter has been observed in areas of sparse *Avicennia marina* (SKM 2007), it is assumed that leaf litter production would be very low compared to closed canopy mangrove forests and is unlikely to be exported to adjacent habitats in any appreciable amounts.

Birds and crabs forage for food within areas of sparse *Avicennia marina*, although many species spend a greater proportion of time foraging in closed canopy mangrove forests where prey species are generally more abundant. Foraging by fish and aquatic invertebrates is restricted to suitable high tides that allow such species to enter higher intertidal areas.

5.2.3 Salt Marsh

The estimation of potential primary productivity from salt marsh requires recognition of an important difference between Australian and overseas marshes. Salt marshes around much of the Australian coast occupy the upper intertidal and are typically dominated by samphires, and even at their lowest limit on the shore are not subject to daily flooding by tides (Adam 1995). In physiological terms, the habitat of tropical Australian marshes is more stressful than that of temperate salt marsh plants such as *Spartina alterniflora*, with greater fluctuation in salinity and higher maximum salinities. This greater stress is likely to lower the maximum potential productivity (Adam 1995). The lack of bioaccumulation of organic material in typical upper intertidal salt marshes indicates that much of the primary production will be utilised in detrital pathways, either in the salt marshes or adjacent waters (Adam 1995).

5.2.4 Cyanobacterial Mats

Cyanobacterial mats are rich in organic matter, nitrogen and phosphorus, and reduce erosion by binding and stabilising the substrate (Paling 1986). They play an important role in the nitrogen cycle through atmospheric nitrogen fixation, which later becomes available in the food web through grazing and/or decomposition as organic nitrogen. Subsequently, they have the potential to act as a biofertiliser for mangroves, which may aid in their sustainability and persistence.

5.3 Assignment of Relative Value to Intertidal BPP

5.3.1 Mangroves

The preceding overview of the two general functional groups of mangroves demonstrates that the range and scale of environmental services provided by each appears to be negatively correlated with height in the intertidal zone. There is a general trend of increasing stress in the intertidal zone moving from Mean Sea Level (MSL) to the uppermost limit of the tide at Highest Astronomical Tide (HAT) as soil moisture content falls and soil salinity rises. This impacts on the vegetation and is reflected in the distribution, diversity, size, density, and productivity of the floristic components. Similar trends are observed among the fauna found in the intertidal zone, particularly those species that appear to be wholly or partially dependent on the presence of benthic primary producers.

Differences in the ecological function and provision of environmental services are expected when comparing different mangrove types. As an example, differences in biodiversity would be expected although there may be instances where some level of overlap exists, particularly in areas where two different mangrove associations are adjacent to each other, or where the density and structure of the vegetation is similar between habitats.

Differences in the ecological function and provision of environmental services are also expected when comparing different stands of the one type of mangrove association, as it cannot be assumed that all areas would be equivalent on an areal basis. For example, different stands of closed canopy *Avicennia marina* would be expected to have different contributions on a per unit area basis, reflecting local-scale variation in the environmental and physiological conditions within stands.

The most useful summary of the relative value of specific stands of mangroves in the Port Hedland harbour may be provided by the adoption of a convenient metric such as Above Ground Biomass (AGB). The data compiled by Alongi et al (2005) and Clough et al (1997) have shown considerable variation in estimates of AGB at Port Hedland with a marked decline in AGB moving from the edge of tidal channels to landward.

The available data on the abundance and diversity of benthic invertebrates associated with mangrove vegetation in Port Hedland suggests a strong correlation with AGB despite generally low numbers of organisms.

Using the metric of AGB per unit of area, the relative value of the mangrove vegetation associations (from highest to lowest) at Port Hedland would be:

1. *Rhizophora stylosa* (closed canopy);
2. *Avicennia marina* (closed canopy, seaward edge);
3. *Avicennia marina*/*Rhizophora stylosa* (closed canopy);
4. *Avicennia marina* (closed canopy, landward edge); then
5. *Avicennia marina* (scattered) with or without samphires.

The relative value of stands of the first three types of mangrove vegetation is likely to be almost equivalent. The fourth category, *A. marina* landward does represent a significantly lower value category based on AGB, and the last category *A. marina* (scattered) typically has 10 to 20% of the AGB of the closed canopy categories (Alongi et al 2005).

5.3.2 Salt Marsh

The use of the AGB metric as a measure of the relative value of salt marsh area which are dominated by samphires can provide a comparison of these BPPH with nearby mangrove vegetation. It is however extremely difficult to find estimates in the literature of the AGB of tropical salt marsh, such as that found at Port Hedland.

Alongi (2009) reports that mangrove AGB is typically greater than that of salt marsh, but also cautions that AGB is not always a good measure of underlying primary productivity. The highest levels of AGB recorded for salt marsh plants are around 2000 g DW m^{-2} (grams dry weight per square metre), which is some 20 t DW ha^{-1} but these values are for salt marshes which are not dominated by samphires. At Port Hedland it is likely that typical AGB of the samphires per unit of area is less than this, given that coverage is not continuous over the substrate in most places and that the samphire-dominated salt marsh is typically found higher in the intertidal zone (Adam 1995). The likely level of AGB is expected to be similar to that estimated for the scattered *A.marina* vegetation type at Port Hedland and is therefore lower (typically by 10 to 20%) than that of the closed canopy forest areas.

5.3.3 Cyanobacterial Mats

In terms of a relative contribution to local ecological functions and environmental services, the application of the AGB metric as used for mangroves and salt marsh may not be justified if it can be shown that primary productivity from mats is high relative to production from equivalent areas of mangrove. This however is considered to be unlikely given that active primary production is restricted to those relatively short periods when a combination of tidal inundation and rainfall are present. In some years the lack of rainfall at Port Hedland may mean there are large areas of tidal flat otherwise suitable for mats which have no active mat formation at all.

For these reasons, cyanobacterial mats are considered here to be the least important of the intertidal BPPH in terms of inputs to ecosystem level function in the Management Unit.

SKM

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Appendix A List of Flora and Fauna Species

The following is a list of the flora and fauna species recorded during the field survey conducted at thirteen sites from 12–14 December 2007. No species are listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) or the *Wildlife Conservation Act WA 1950*.

Flora	**Fauna**
Aegialitis annulata	*Anadara granosa*
Aegiceras corniculatum	*Boleopthalmus* sp.
Avicennia marina	*Cerithidea largillierti*
Ceriops australis	*Clibanarius longitarsus*
Muellerolimon salicorniaceum	*Epixanthus dentatus*
Osbornia octodonta	*Gerygone tenebrosa*
Padina sp.	*Littoraria articulata?*
Rhizophora stylosa	*Littoraria filosa*
Sporobolus virginicus	*Metapograpsus frontalis*
Tecticornia halocnemoides	*Neosarmatium meinerti*
	Nerita balteata?
	Nerita oualensis?
	Onchidium damelli
	Pachycephala lanioides
	Parasesarma sp.
	Periopthalmus sp.
	Perisesarma sp.
	Rhipidura phasiana
	Saccostrea cucculata
	Scylla sp.
	Telescopium telescopium
	Terebralia palustris
	Terebralia semistriata
	Terebralia sulcata
	Thalassina anomala
	Todiramphus chloris
	Uca elegans
	Uca flammula
	Uca mjobergii
	Zosterops lutea