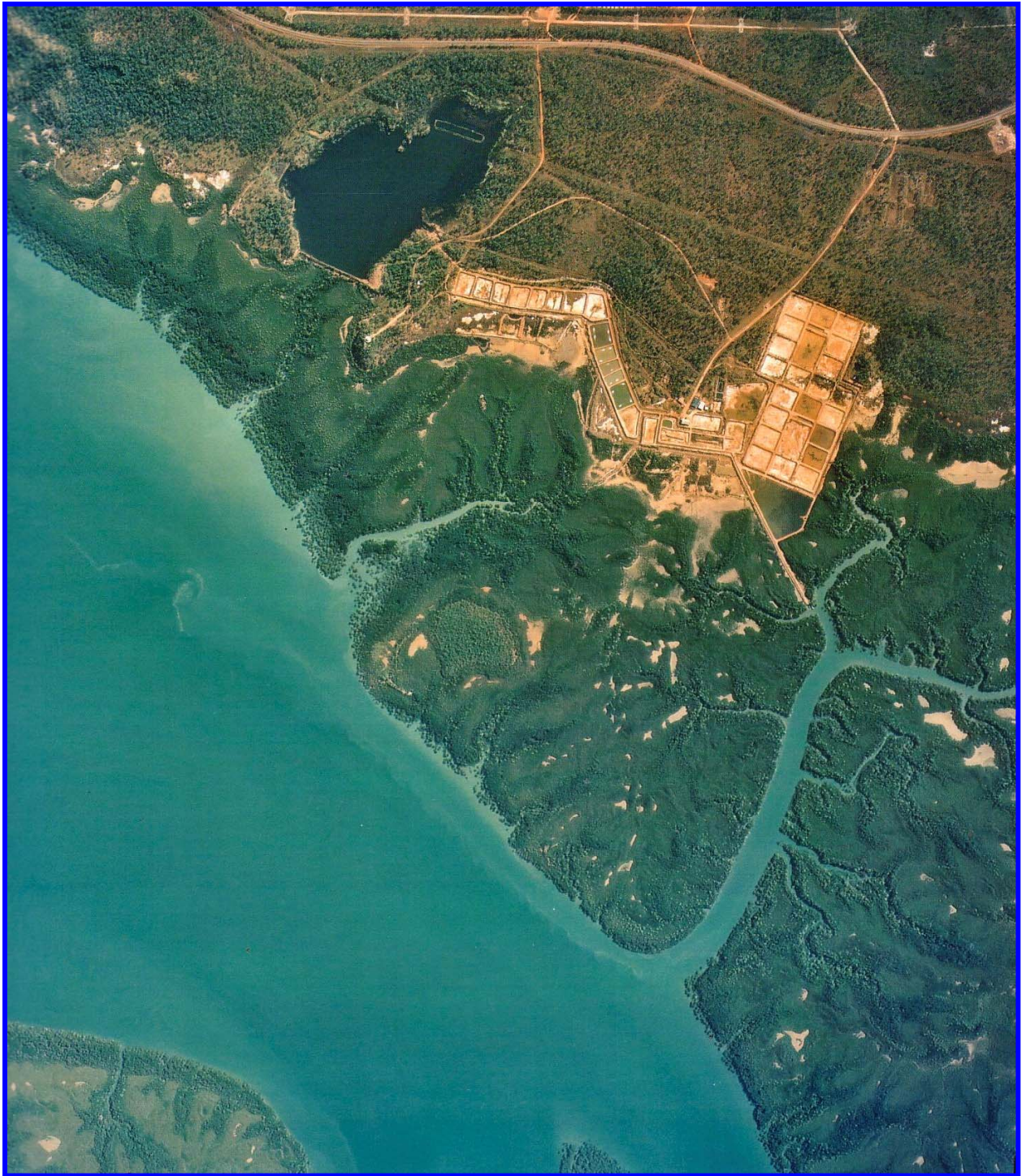


Appendix C

MANGROVE MONITORING REPORT

AUSSIE PRAWNS PTY LTD

**APPL DARWIN HARBOUR AQUACULTURE PROJECT
ENVIRONMENTAL IMPACT ASSESSMENT
&
MANGROVE MONITORING REPORT No. 1**



**PRE-CONSTRUCTION
APRIL 2005**



REPORT

APPL DARWIN HARBOUR AQUACULTURE PROJECT



Environmental Impact Assessment – Intertidal Flora & Fauna Pre-construction Mangrove Monitoring– Report No. 1

Prepared for

KBR

by

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**ENVIRONMENTAL IMPACT ASSESSMENT &
MANGROVE MONITORING REPORT****PRE-CONSTRUCTION - APRIL 2005****EXECUTIVE SUMMARY**

This report has three main objectives:

1. To describe the existing intertidal environment surrounding the APPL site
2. To compile an environmental assessment of the potential impacts of the proposed APPL prawn farm development on the intertidal flora and invertebrate fauna
3. To commence a long-term mangrove monitoring program, providing detailed pre-construction baseline data on mangrove flora and fauna

The Existing Environment

- The development site has a total lease area of 288 ha and is located on the landward edge of mangroves in Haycock Reach on the Blackmore River. The site includes sections of three relatively small catchments draining into the Middle Arm of Darwin Harbour - the upper catchment of one creek has been dammed to form a 33.1 ha freshwater reservoir
- The site is located on a relatively narrow terrestrial peninsula (traversed by the Channel Island Road), fringed to the north and south by extensive mangroves of Darwin Harbour - which cover an area exceeding 20,000 ha
- Aquaculture is rapidly developing within the Harbour and the APPL project represents the 4th prawn farm to be developed on the Blackmore River, Middle Arm
- With the recent increase in both industrial development and the number of aquaculture proposals for Darwin Harbour, it is becoming increasingly important to consider the cumulative impacts of aquaculture on the surrounding natural environment and the overall sustainability of aquaculture projects
- The previous EIS prepared for this project by Kinhill Engineers in 1992 provided floristic information on the 175ha of terrestrial vegetation and mapped the 113 ha of intertidal vegetation occurring within the project lease area

Environmental Assessment

- It is proposed that the APPL project will commence in 2005 with the redevelopment of the existing 14ha site to a completely upgraded 55ha development, to be constructed progressively over a number of years
- The prawn farm will have a total pond area of 42ha, approximately 25% of this area comprises a series of sedimentation and bio-filtration ponds. After passing through the bio-remediation ponds effluent will be released from two main discharge outlets (wide spillway structures) into lined channels designed to reduce the velocity of flow before disbursement into regularly flushed tidal channels
- Discharge points will be stabilised to prevent erosion
- On site, there is already a large amount of existing infrastructure in place including an established saltwater supply channel and a 3.2ha saltwater storage dam
- Given the current high levels of site development and disturbance and the very small area of construction proposed within the intertidal zone (a total of 15.9ha including 4.1 ha of saltflat and 8.9 ha of low mangrove, mainly comprising regrowth), habitat loss is not expected to be a key concern for environmental assessment
- Therefore, it is anticipated that the discharge of pond effluent will be the main environmental issue in terms of potential impacts on the surrounding environment

- A comprehensive bio-remediation system will be actively maintained in which mullet, crustaceans and molluscs (attached to bio-blocks, mesh and plastic structures) filter the pond water, reducing nutrient levels and suspended sediments before it is discharged
- The tidal creeks downstream of the two discharge outlets will receive approximately 35-45 ML per day of discharge water, with an upper limit of 63 ML per day.
- When possible, discharges will be released during high tides to assist dispersal
- Two main mangrove habitats, the *tidal flat* (adjacent to the farm) and *tidal creek* (downstream of discharge points) have been selected for long term monitoring studies
- At this stage it is not known whether there will be any detectable effects on downstream mangrove flora and invertebrate fauna and if so, whether it will be positive or negative. General consensus suggests that mangroves thrive around outlet points for prawn farms. However, the author is not aware of any long-term Australian studies to substantiate these commonly held beliefs
- Regular water quality monitoring (to be undertaken by others) at the discharge outlet and in the tidal creek system that eventually receives pond effluent, will provide baseline data on downstream water column characteristics. Water quality control sites will be located in an adjacent creek and in the Blackmore River channel

Monitoring of Mangrove Ecosystems

- To meet Northern Territory Government environmental requirements and to address issues listed in the Guidelines for Preparation of Public Environmental Report (PER), monitoring of forest characteristics and the health of mangrove habitats surrounding the APPL Aquaculture development was commenced in late October 2004.
- A long-term scientific monitoring program was designed and established in accordance with the *Environmental Code of Practice for Australian Prawn Farmers* (1999) to provide biological data that will enable the detection of impacts from prawn farming over and above natural variation and environmental change
- Once approval for the development is received, an updated Environmental Management Plan (EMP) will be prepared and the current mangrove monitoring program will be central to ongoing project environmental management
- The monitoring program follows a standard scientific approach to monitoring impacts referred to as a "BACI" design which incorporates measurements Before (B) and After (A) the development and involves comparisons between Control (C) and Impact (I) sites
- Consequently it is highly advantageous to obtain as much detailed pre-construction ('Before') information on which to more accurately base 'After' construction comparisons. Two pre-construction fauna and soils surveys will be conducted.
- By following previously trialed research and monitoring methodology the project can also benefit from the growing body of background baseline data from elsewhere in Darwin Harbour
- Field work was conducted between 18th October and 19th November 2004 during which time nine permanent 20m × 20m quadrats were established at key locations in the intertidal zone surrounding the development
- This program monitors *both* mangrove flora and invertebrate fauna and to date, represents the most comprehensive monitoring for any aquaculture development in Darwin Harbour
- Sites were carefully selected to monitor the effects of three main potential impacts anticipated at several key locations:
 - Altered nutrient, physico-chemical and drainage characteristics of mangroves immediately adjacent to the farm and potentially receiving diluted pond effluent at high tide (the *tidal flat* zone)
 - Changes in nutrient and physico-chemical status of mangroves located downstream of discharge outlets (the *tidal creek* zone)
 - Increased sedimentation, changes in drainage and the potential for acid sulphate leachate from pond construction (all impact sites)

- Matched control sites were selected close to the development, but within a different creek catchment, to facilitate the accurate detection of impacts (as distinct from widespread environmental change) if they should occur
- During the construction phase, interim monitoring will be undertaken every 6 months— involving photo-monitoring, seedling regeneration and measurement of sediment gauges. Invertebrate fauna will also be measured twice yearly during the construction phase.
- The full environmental monitoring program (flora, fauna, soils and sedimentation) will be repeated annually.
- Annual monitoring of mangrove sediments for salinity, pH, conductivity and moisture content in each of the 9 study quadrats is also being conducted.

Mangrove sediments

- Field measurement of soil salinity and pH was considered important baseline information given that construction will abut mangrove habitats and pond discharge may impinge on saltflat and mangrove areas
- Measures of soil conductivity and salinity were expected to be at peak levels during the field survey period (late dry) due to seasonal aridity and extremely high dry season evaporation rates
- Pre-construction levels of conductivity /salinity and pH indicated very high soil salinity in saltflat areas with similar high levels in adjacent *tidal flat* mangroves. The lowest salinity levels were recorded in regularly flushed *tidal creek* habitats.

Flora

- To monitor short-term changes in forest health and growth, canopy cover, seedling & sapling density, tree height and tree diameter were measured.
- Forestry measurements of stem density, basal area, species composition and condition were taken for long-term monitoring purposes.
- Algal cover (both benthic and epiphytic) and height to sediment levels were also recorded
- Four photographs were taken within each plot at fixed photo-monitoring points.
- Plant species diversity is typically low with 5 mangrove species recorded within *tidal creek* quadrats and 4 species in *tidal flat* plots
- The structure and species composition of the APPL *tidal flat* sites parallels that described for Zone 5 in Darwin Harbour mangrove mapping – a low community in which *Avicennia marina* tends to be dominant and often overtops *Ceriops*. The predominance of *Avicennia* reflects the high soil salinities at this tidal elevation
- *Tidal creek* mangroves were taller (average height 9.8m) and canopy cover was more dense (77%) than tidal flat habitats with an average height of 1.7 m and canopy cover of 38%.
- Overall, monitoring plots were floristically similar to other mangroves at similar tidal elevations elsewhere in Darwin Harbour.

Fauna

- Recent research and monitoring in Darwin Harbour has confirmed that invertebrates are sensitive indicators of disturbance and rapid biodiversity assessment techniques have been developed by the consultant to facilitate environmental monitoring in mangrove habitats
- Fauna data included the diversity and abundance of invertebrate species from benthic (ground-dwelling) and epi-faunal (on trees and roots) microhabitats. Sampling included everything visible to the naked eye (excluding insects) and mainly comprised molluscs, crustaceans, worms and mudskippers
- All specimens sampled were identified to species level where possible (a large proportion of the fauna still remains undescribed at species level).

- A total of 252 invertebrate fauna records were listed during initial monitoring with a total of 43 species recorded
- In line with other mangrove surveys in Darwin Harbour, the crustaceans (crabs, amphipods and isopods) are the dominant group. Crustaceans were the most diverse and abundant taxonomic group with 22 species recorded in this survey
- Molluscs were the next most diverse taxa with 17 species (comprising 14 gastropods and 3 bivalves).
- One *tidal flat* site (Site PC2) which is surrounded by salt flats and has been disturbed during previous pond construction activities had a distinctly different invertebrate fauna community from the other 3 sites. Sediments at PC2 are coarser and contain red terrestrial silt and these findings appear to indicate the sensitivity of invertebrate monitoring techniques
- With the exception of Site PC2, multivariate analyses of invertebrate community data indicate that control and impact sites are well matched and no clear pre-construction differences occur between the sites selected.
- To address the problem of habitat difference at PC2, a new quadrat was established to replace this site (PC3). The fauna, soils and vegetation of this new site is more typical of natural *tidal flat* habitats in the local area.
- Multivariate analyses of invertebrate diversity and abundance data indicated high similarity of all *tidal creek* sites - which in turn had a distinctly different fauna to *tidal flat* habitats.
- Overall, a total of 27 invertebrate species were recorded in *tidal creek* habitats and 29 species during sampling in the *tidal flat* habitat.



Small epiphytic mussels (*Brachydontes maritimus*) inside mangrove log



Mudskippers (*Periophthalmus* spp.) were included in surveys of mangrove fauna

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APPL AQUACULTURE PROJECT**ENVIRONMENTAL ASSESSMENT & MANGROVE MONITORING REPORT
PRE-CONSTRUCTION - NOVEMBER 2004****1. INTRODUCTION**

Mangroves on Australia's northern shoreline support valuable ecosystems that provide shelter, food and habitat to a vast array of ecologically and commercially important biota (Hutchings and Saenger, 1987). Increasing recognition of the ecological value of intertidal habitats has led to improved conservation and management of coastal developments that impinge on mangrove areas (Comley, 2002; URS (Australia) Pty Ltd, 2004). Aquaculture has had devastating effects on the mangroves of South-East Asia with wide-scale destruction for prawn farming (Dierberg and Hiattisimkul, 1996; Flaherty and Karnjanakesorn, 1995; Primavera, 1993) and we are in the privileged position to have the knowledge and resources to avoid a similar result occurring in Northern Australia. Thus to meet Northern Territory Government environmental requirements and to address specific issues listed in the Guidelines for Preparation of the Public Environmental Report (PER), environmental assessment and monitoring of the extensive mangrove ecosystems surrounding the APPL Aquaculture development was commenced in late October 2004.

This report aims to combine the information requirements for environmental impact assessment relevant to this project and for informed management of the intertidal area, while also gathering and presenting detailed quantitative information suitable for the initial round of mangrove monitoring. This information builds on that contained in the previous EIS for the project area – including baseline information on terrestrial and intertidal flora and fauna communities (Kinchill, 1992).

It is proposed that construction of the Aussie Prawns Pty Ltd (APPL) project, located on a 288ha lease at 1880 Channel Island Road, will commence in 2005 with the redevelopment of the existing 14ha pond area to a completely upgraded 44ha development. The project is to be developed progressively, with all three phases completed over several years. Environmental assessment for this development differs from many other projects of this nature, as the majority of development will not be within undisturbed natural habitats. With the exception of 39.6ha of terrestrial woodland and 15.9ha of mangroves, the 42pond development will largely overlie the existing disused ponds. The project area is already highly disturbed and a large freshwater dam (33.1ha) has been constructed in the upper catchment of the western-most creek. This dam supplies the freshwater for the project and a 3.2ha saltwater supply dam is located at the landward end of the inlet jetty (Figure 1).

The proposed prawn farm will have a total pond area of 42 ha with two main discharge outlets where pond effluent, that has passed through a series of sediment ponds, will be released as sheet flow into adjacent mangroves (Figure 1). Therefore, given the current levels of disturbance; the existing infrastructure (including an established saltwater supply jetty) and the minor area of construction proposed within the intertidal zone, it is anticipated that the discharge of pond effluent will be the major potential impact from this development on the surrounding environment. As with any developments involving intertidal sediments, the potential for acid sulphate soil generation is an important issue and all earthworks will require careful management of mangrove muds. These and other potential environmental impacts have been addressed in Section 5 of this report.

Once the project is approved, a revised Environmental Management Plan (EMP) will be prepared for the construction and operational phases of the development. The mangrove monitoring program that has been established (described in Section 6 this report) will comprise an important component of ongoing environmental management. The overall aim of monitoring the health and

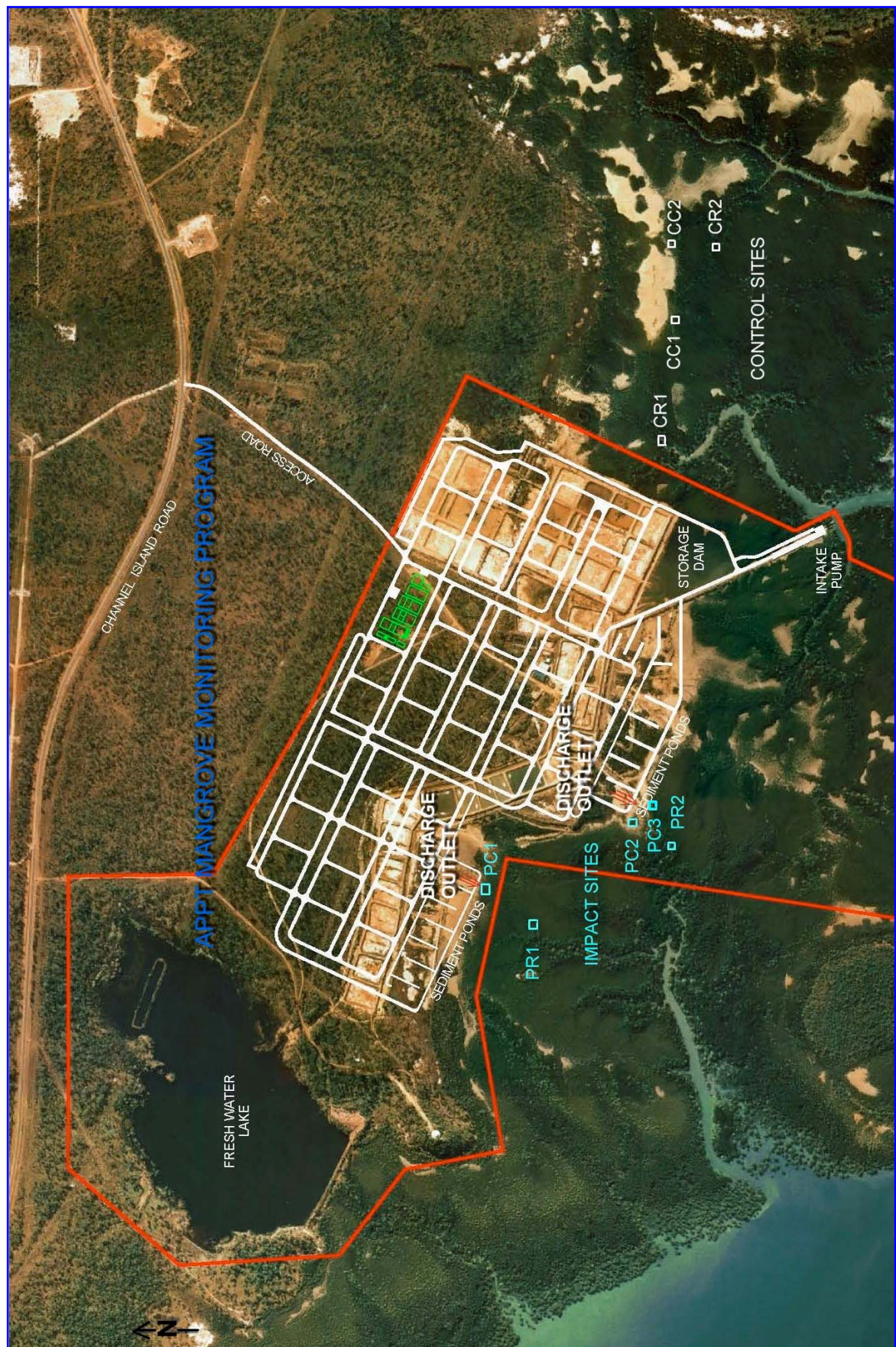


Figure 1: Proposed APPL development showing locations of discharge outlets and monitoring sites

forest characteristics of mangrove habitats is to quantify the extent and nature of any environmental changes attributable to the prawn farming operation. The environmental monitoring program aims to differentiate such environmental changes from naturally occurring environmental fluctuations. In this way monitoring can help to protect the mangroves from any significant adverse impacts that may arise from the proposed aquaculture project.

The monitoring program follows a standard scientific approach to monitoring impacts referred to as a “BACI” design which incorporates measurements Before (B) and After (A) the development and involves comparisons between Control (C) and Impact (I) sites. With BACI designs, it is thus highly advantageous to obtain as much detailed *pre-construction* (‘Before’) information on which to more accurately base ‘After’ construction comparisons.

Specific tasks of the mangrove monitoring program included documenting forest characteristics, soil chemistry, invertebrate fauna communities and the condition of the existing mangroves at key locations surrounding the project area. Permanent study sites have been established that will be monitored during the construction and operational phases of the project. Significant changes in forest structure or condition may thus be detected through comparisons of pre- and post-construction data, and any unusual changes can be verified by comparison of control and impact sites. Monitoring can thus provide an early warning system that can trigger an appropriate remedial response to a significant negative impact.

This report provides an outline of the objectives; describes the existing environment; provides details of the monitoring methodology implemented; and summarises the results of environmental assessment and initial monitoring. It is hoped that the ecological information will provide sufficient detail for informed environmental impact assessment and the baseline data gained will expand our knowledge of the response of mangrove ecosystems to environmental changes associated with aquaculture developments.

2. OBJECTIVES

The major aim of the study is to provide qualitative and quantitative baseline information on intertidal habitats surrounding the APPL aquaculture project both for environmental impact assessment and long-term monitoring purposes.

Surveys were designed to provide data and information that will facilitate scientific impact assessment during the construction and operational phases of the project. In the longer term, the pre-construction monitoring data will assist in the detection of change in mangrove fauna and vegetation.

Specific objectives were to undertake mangrove monitoring at key locations that will assist in the detection of changes relating to the main potential impact — the ecological effects of pond effluent on mangrove communities.

3. METHODOLOGY

3.1. BACKGROUND

The current aquaculture project is similar to other research and monitoring studies on the impacts of aquaculture (McKinnon et al., 2002; Trott and Alongi, 1998; Trott and Alongi, 2000) as the pond effluent will be discharged into regularly flushed tidal channels. Pond water pass over broad spillways and into lined channels leading to regularly flushed areas at around 2.5m AHD. Monitoring of the fate and ecological impacts of discharge has typically been undertaken by water quality measurements from within the water column of receiving tidal creeks. In this instance, suspended sediment levels, chlorophyll a and dissolved oxygen would be key parameters for monitoring studies. Studies of mangroves on the banks of tidal creeks downstream of discharge outlets have also been undertaken, but less often (Trott and Alongi, 1998).

The *tidal flat* zone is the most extensive mangrove zone in Darwin Harbour, occupying almost 50% of the total mangrove area (Brocklehurst and Edmeades, 1995). This assemblage is dominated by *Ceriops australis* which typically grows in dense, almost monospecific stands to only 2 or 3 m high. Where this zone abuts salt flats, which are a characteristic feature of the harbour at around an elevation of 2.5 m AHD, *Avicennia marina* is locally abundant to co-dominant with *Ceriops*. It is this vegetation community, mapped as Zone 5 (high tidal flat – *Ceriops australis*/*Avicennia marina* low closed forest, by Brocklehurst et al. (1995) that occurs immediately downstream of both discharge outlets and in which the key monitoring sites have been placed.

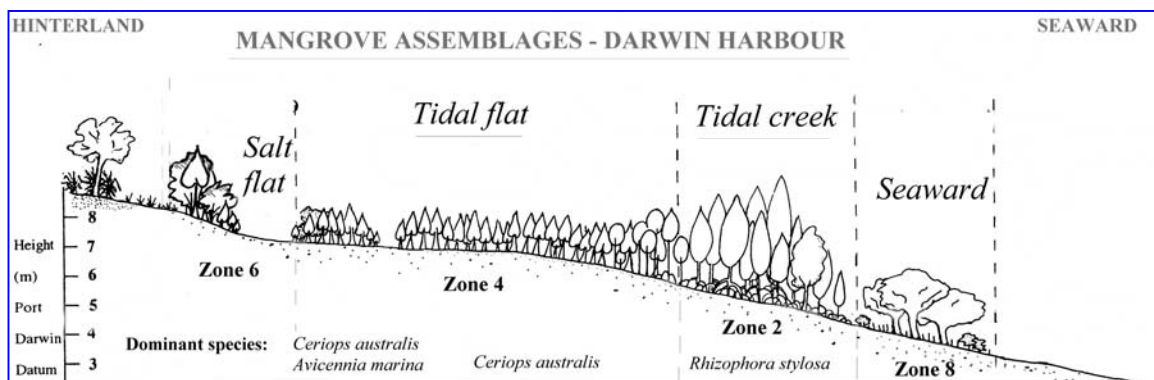


Figure 2: Schematic diagram of mangrove zonation in Darwin Harbour indicating topographic elevation of tidal creek and tidal flat zones

Despite daily discharge events into the *tidal flat* zone being timed to coincide with high tides (in order to obtain the best possible dilution of effluent), the rapid dispersal of effluent will not always be facilitated by tidal action. High spring tides will only reach the spillways (approx. elevation of 6.5 m Darwin Chart Datum or 2.5 m AHD) for one week in every fortnight. It is anticipated that during neap tides, little or no tidal dilution will be possible. Indeed, only 38% of annual tides reach a tidal elevation of 2.5 m AHD in Darwin Harbour (Metcalf 1999, p 66). Consequently the focus of environmental monitoring for this project is not in the creek system but within the *tidal flat* zone of the mangroves. The potential for downstream impacts on the taller, more productive *tidal creek* zone is also being studied and monitoring sites have been established on creek lines immediately downstream of both spillways.

As far as practicable, the standard methodology for monitoring of mangroves in Darwin Harbour was followed. The Conoco Phillips DLNG Mangrove Monitoring Program, the Phelps Panizza Blackmore River (East) Aquaculture Project and the DIPE Mangrove Monitoring Program all derive data on mangrove flora in the same manner (see Moritz-Zimmerman et al., 2002). There are clear advantages in applying matched monitoring methodologies. Data is directly comparable with other mangrove monitoring programs, and interchangeable - the sharing of control data from multiple sites is extremely valuable indeed.

Collectively these monitoring programs provide an expanding baseline from Darwin Harbour mangroves which also represents important background data for all future monitoring. Most important, well-designed monitoring programs produce statistically sound data and provide meaningful results capable of reliably detecting environmental change- including changes attributable to prawn farming. With the rapid development of the harbour, this kind of information is crucial for the long-term conservation of these important habitats.

3.2. EXPERIMENTAL DESIGN

Monitoring was based on a BACI (Before-After, Control-Impact) experimental design, considered to be the most rigorous and balanced approach for environmental assessment projects – typically providing both a solid basis for testing hypotheses and data suitable for statistical analysis. More accurately, the strategy is known as an MBACI design because it includes multiple (M) control

sites. Where it is appropriate to implement them, such MBACI designs are generally accepted as the best possible design strategy for biological monitoring projects (Underwood, 1991).

The specific objective of the program was to provide baseline data on the flora and invertebrate fauna of mangrove communities to serve as both an indicator of ecosystem health and as a benchmark against which the impacts of the project may be assessed over an extended period. Consequently the primary hypotheses to be tested are:

H₀: There is no significant change in the diversity and abundance of invertebrates in mangrove communities surrounding the Aussie Prawns aquaculture project, Darwin Harbour as a consequence of the construction (and operation) of the farm.

H₀: There is no significant change in the density, canopy cover, growth and regeneration of trees in mangrove communities surrounding the Aussie Prawns aquaculture project, Darwin Harbour as a consequence of the construction (and operation) of the farm.

The methodology followed involved the placement of permanent 20m x 20m quadrats within recognised mangrove communities or zones as mapped by Brocklehurst and Edmeades (1995) and in accordance with recommended mangrove monitoring practices detailed in English et al. (1994). The methodology used broadly follows the Transect-Line-Plot method (English et al., 1994) where quadrats are placed along an imaginary line from the landward to the seaward mangrove margin. However, this program does not include quadrats in each of the 4 major zones occurring along most transects, but does focus on the 2 main habitats – *tidal creek* and *tidal flat*. In this instance, 2 control transects (actually located just outside the lease area) were established at a nearby control location for comparison with 2 matched impact transects within the project area (Figure 1).

3.3. SITE SELECTION

Fieldwork was completed between 18th October and 20th November 2004, during which time nine 20m x 20m quadrats were established at the 4 locations selected (Figure 1 – Mangrove Monitoring Plan). Table 1 lists the GPS locations of control and impact sites for the study. The program was specifically designed to best monitor the potential impacts of sheet flow discharged directly into mangroves from two broad spillways. Thus Sites PC1, PC2 and PC3 were located directly downslope of these structures and PR1 and PR2 were located further downstream (Figure 1). However, since that time environmental concerns have prompted a change in the design of outlet points and effluent will be taken through lined channels and discharged into regularly flushed tidal channels. *Rhizophora stylosa* forests (which are inundated twice daily and receive 93% of annual tides) occur between 0.9 and 2.0m AHD within Darwin Harbour, with an upper limit of approximately 2.5m AHD (Metcalf, 1999). The revised design will discharge into tidal channels within *Rhizophora* forests to ensure regular flushing and rapid residence times. The location of sites PC1, PC2 and PC3 may have to be reviewed once the final design is established.

A total of 8 permanent 20m x 20m quadrats were initially established around the aquaculture development as part of long-term monitoring, representing 4 impact and 4 control sites within the two main zones (*tidal creek* and *tidal flat*). However, initial analyses of the invertebrate fauna and soils data indicated that site PC2 was substantially different from other *tidal flat* plots, apparently due to previous disturbance. Numerous channels have been constructed through the intertidal zone close to PC2 and it is thought that terrestrial fill has been used in this area to stabilise the banks of nearby bund walls (Chris Lim, pers comm.). Indeed, soils within the quadrat contained a high proportion of coarse, red (terrestrial) sediment, sand and gravel and the atypical invertebrate fauna community was probably a direct reflection the substrate conditions. Further, this particular site was almost completely encircled by saltflat habitats that support a different faunal community to mangroves. These observations were not ideal for a pre-impact baseline data set, particularly for an 'impact' site.

Consequently, the habitat differences and prior disturbance to site PC2 combined with doubts about the direction that effluent from the new spillway will actually flow (in accordance with the

previous design, now revised) prompted the establishment of a ninth quadrat, Site PC3 in less disturbed habitat (Figure 1).

It is anticipated that if there are any impacts arising from the development, they may be relatively localised in extent. Consequently monitoring sites have been placed in relatively close proximity (where possible within 50 m) of spillway or construction areas in the *tidal flat* and less than 250m downstream of the pond water discharge outlet in the *tidal creek* zone (Figure 1).

Table 1 - Summary table of APPL mangrove monitoring sites

MANGROVE ZONE	CONTROL SITES (WGS 84)		IMPACT SITES (WGS 84)		
	Site CC1	Site CC2	Site PC1	Site PC2	Site PC3
TIDAL FLAT	0712586 E 8607184 N	0712785 E 8607178 N	0711080 E 8607672 N	0711262 E 8607274 N	0711332 E 8607222 N
	Site CR1	Site CR2	Site PR1	Site PR2	
TIDAL CREEK	0712264 E 8607208 N	0712758 E 8607090 N	0710957 E 8607546 N	0711203 E 8607204 N	-

Care was taken to select suitably matched monitoring sites (ie. having similar vegetation structure and species composition, landscape position, etc) both within zones and between control sites and impact sites. For monitoring purposes it is desirable that control and impact sites have similar overall character with comparable fauna and floristic composition to reduce environmental background ‘noise’ in the data.

3.4. FLORA - METHODOLOGY

The main variables used to monitor forest health include tree canopy cover, regeneration (seedling and seedling density), species composition, tree growth and survival. Changes in sedimentation and soil characteristics (salinity/conductivity, moisture content and pH) were also measured. Overall, data was obtained by measurement and assessment of selected forest and environmental characteristics to detect both short and long-term floristic change, supplemented by standard photo-monitoring techniques. Figure 3 summarises the attributes measured for flora monitoring purposes:

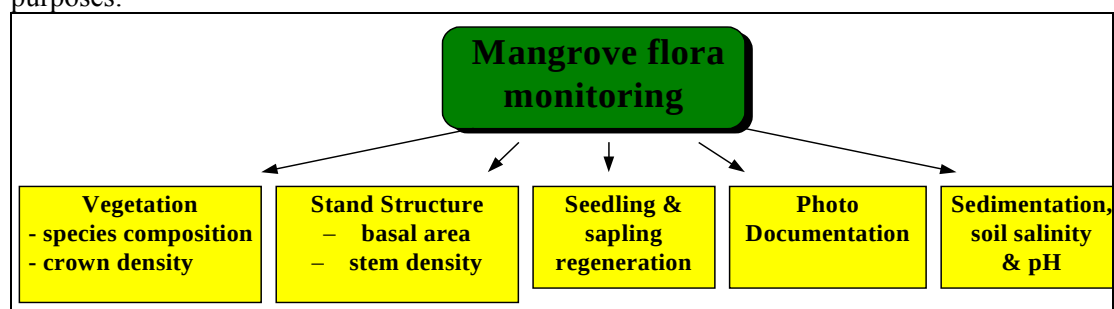


Figure 3 : Overview of mangrove monitoring methodology

Within each quadrat, the following vegetation characteristics were recorded, measured or estimated:

- Species composition
- Tree (stem) density
- Tree status (alive/dead)
- Average height of tree species
- Diameter at breast height
- Canopy cover
- Seedling and sapling density

Key environmental characteristics - including soil conductivity (salinity), pH and sediment levels – all of specific importance to mangrove plant species – were also recorded in each quadrat. The basic methodology selected for flora monitoring has been previously trialed (see Moritz-Zimmermann 2002; Metcalfe 2002; URS 2004) and was chosen so that results would be directly comparable with flora data from other projects in Darwin Harbour. Further refinement of the methodology has improved efficiency by dropping inappropriate measures and deleting any duplication from the monitoring program.

Monitoring of mangrove habitats was particularly thorough as it included surveys of the diversity and abundance of invertebrate fauna (Section 3.5). An ecological approach to monitoring was followed that combined surveys of flora, fauna and sediment characteristics at each site.

§3.4.1. SITE DATA

At each of the nine study sites environmental information on the site including tidal zone, species composition, tree height and condition was recorded. This information broadly characterises the site and the condition of the vegetation prior to assessment, information which, combined with detailed quantitative data, may be used in future analysis.

§3.4.2. CANOPY DENSITY

Canopy density was recorded as part of the stand structure inventory for each monitoring site, providing a pre-impact baseline. Canopy density indicates the percentage of the site occupied by the vertical projection of mid and upper vegetation strata. English *et al.*, (1994) recommend canopy density as a useful indicator for environmental stress, since leaf shedding and leaf growth are sensitive to a wide range of environmental factors. Changes in canopy density, together with other stand structure data, may provide indications of variations in mangrove health. Also, correlations with leaf litter productivity have been demonstrated elsewhere using a similar vegetation attribute, leaf area index (English *et al.*, 1994). Thus canopy density data may also function as a rough indicator of productivity.

Canopy density (McDonald *et al.*, 1990) was determined with a spherical forestry densiometer, consisting of a concave mirror with 24 x 6.5mm squares engraved in the surface. At four randomly selected sites within each monitoring site, four readings were taken, facing N, E, S and W for total (leaf and branch) cover. Thus a total of 16 readings were recorded and averaged and expressed as percentage foliage cover (FC) per plot. To obtain a percentage FC or FPC the counts for each randomly selected site were multiplied by 1.04. The overall canopy density of the site was calculated as the mean of all readings.

§3.4.3. SEEDLING/SAPLING DENSITY

Seedling and sapling density was measured to characterise natural recruitment and forest regeneration - another relevant measure of forest health and environmental change. Direct counts of seedling and sapling abundance were made within 1m x 1m quadrats. Five replicate samples were placed at randomly selected sites within each quadrat. Random locations were derived from pairs of numbers or coordinates (between 0 and 20) obtained from random number tables. The following definitions were applied to density and abundance assessments:

- Trees: DBH > 2cm/girth > 6.3cm; height > 1m
- Shrubs/saplings: DBH < 2cm/girth < 6.3cm; height > 1m
- Seedlings: DBH < 2cm/girth < 6.3cm; height < 1m

§3.4.4. STAND STRUCTURE

Stem density and basal area

Stand structure incorporates a number of vegetation attributes including stem density and basal area. Measurement of the number of stems per unit area (stem density) and their diameter at breast height (DBH) ie. at a height of 1.3m, allow the determination of forestry parameters including standing biomass and basal area for each site.

Stem density was measured from 4 replicates or random subplots (5m x 5m in extent). Within each subplot the species of tree, its living or dead status, number of stems and dbh was recorded. After dbh measurements were taken each stem was marked with a dot of spray paint to avoid duplicate measures. Many *Avicennia* trees were multi-trunked and occasionally over 90 trees were recorded per 5m x 5m plot in *Ceriops*, so stem density data is most time-consuming to gather. Where trees were multi-trunked, a single diameter measure was taken just below the division. However, *Avicennia* trees were often damaged and/or hollow and branching of the tree often occurred below ground level. In this instance, diameter measures were taken directly above the trunk division, the location of measurement marked with spray paint for random measures and with a zip-tie for permanent tagged trees (Figure 4).



Figure 4 : Multi-stemmed habit, stunting and hollow trunks of *Avicennia marina* trees posed difficulty in the measurement of tree diameter (for monitoring growth)

These initial measurements of forest density will enable characterisation of the stem density, basal area and species composition of the existing community and will allow the site to be placed within the context of the harbour as a whole. This parameter will not need to be remeasured again in the short term.

Stand basal area is a very useful parameter for quantifying a forest stand. It may be seen as a summary of the number and size of trees in a stand. In Australian forests stand basal area of fully stocked stands frequently lies in the range 20-50 m² ha⁻¹. Basal area (G) is the sum of the basal area of all (living) trees in a stand, expressed in m² ha⁻¹ calculated from measurements of the diameter (*dbh* in cm) of all trees in a known area (*a* in ha):

$$G = \pi / 40,000 * \sum dbh^2 / a$$

In the longer term, basal area data obtained over several years will allow the calculation of standing biomass, a component of primary productivity. This data will assist in determining whether the operation of the prawn farm has led to an increase or decrease in mangrove forest productivity.

Growth

To obtain a direct measure of short-term or annual tree growth (a parameter anticipated to be positively affected by pond discharge), 30 randomly selected trees per quadrat were tagged with plastic cable ties and permanent aluminium tags (labelled 1 to 30). Information on species, condition and DBH was obtained from these 30 marked trees and will be compared with future annual measurements.

§3.4.5. PHOTO-MONITORING

The centre of each 20m x 20m quadrat functions as the photo-point and 4 photographs (landscape format) were taken - while standing at the centre post and looking toward the 4 corners of each plot. Four (permanent) aluminium stakes were placed approximately 3m from the centre post to assist in accurate relocation of photo-monitoring points. The site marker board is placed on these aluminium stakes for photographic monitoring indicating the site ID, date and corner number of each quadrant.

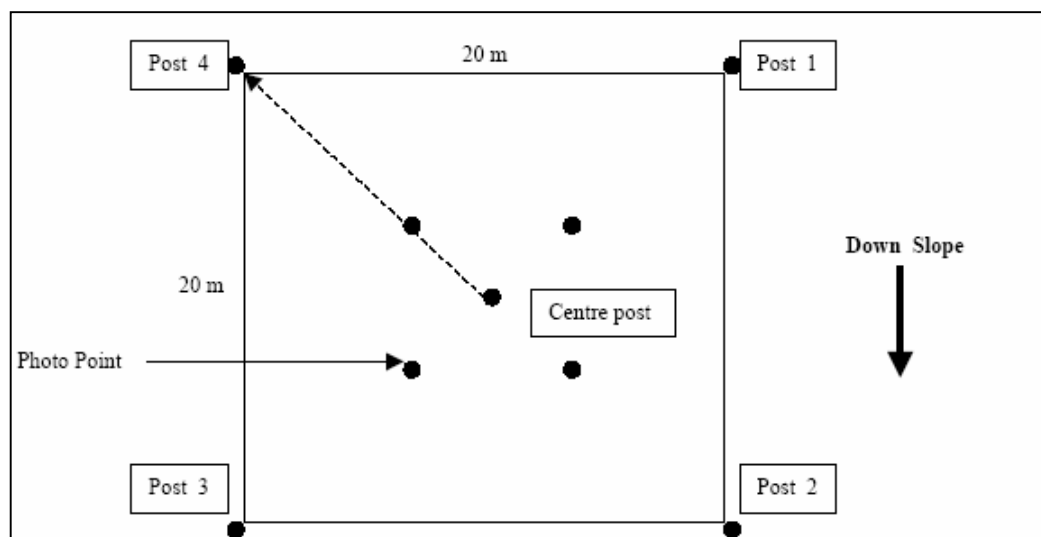


Figure 5: Design of monitoring plots with location of photo-monitoring points

§3.4.6. SEDIMENT GAUGES

The four corners and the centre of each quadrat were marked by PVC posts which also function as sediment gauges. 1.5m lengths of PVC were hammered into the mud until exactly 1,000 mm of PVC remained above the surface. Subsequent 6 monthly measurements of exposed PVC (5 gauges per plot) will indicate whether sediment accretion or erosion is occurring within the plots.

§3.4.7. SOIL CHARACTERISTICS

The pH and conductivity of mangrove soils within the 9 monitoring quadrats was measured from five randomly selected locations. A soil corer was used to extract a shallow soil core and a standard quantity of mud (approx. 20 g wet weight) from a depth of 15cm. Soil samples were taken at this depth as it was considered the most relevant to the roots of the surrounding mangrove trees. Sediment samples were immediately placed in a 1: 5 standard soil to water dilution with 120 ml distilled water and after shaking briefly, a *TPS Aqua-CP* meter was used to obtain field measures of soil conductivity, temperature, salinity and pH. Measurement of soil pH and soil moisture were also obtained directly from each core using a soil pH meter, for later correlation with pH obtained from dilutions measured with a water quality meter.

The laboratory measurement of salinity is typically calculated from a 1:5 dilution of oven or air-dried soil, after shaking for one hour. The method employed here is a rapid, field measure that will allow cross-comparison between sites and represents an efficient, cost-effective field technique for detecting changes in mangrove soil salinity. In previous mangrove research projects (Metcalf, 1999; Perrett, 1994), conductivity has been measured as an index of soil salinity and values expressed in mS cm^{-1} . The conversion of conductivity to salinity is a difficult one and often conductivity is considered an adequate indicator of soil salinity (Greenberg et al., 1992). In this instance the *Aqua-CP* meter provided both measures.

3.5. INVERTEBRATE FAUNA - METHODOLOGY

Invertebrates are sensitive indicators of environmental health in many marine and intertidal habitats (McGuinness, 1990; Underwood, 1994) and recent research in Darwin Harbour has shown that disturbance to mangroves is reflected by shifts in the diversity and abundance of invertebrate species (Metcalfé, in prep). Recent research and monitoring studies that include the two methods outlined below have recorded 317 species of invertebrates from mangroves of Darwin Harbour. The APPL monitoring program is comprehensive in its approach to aquaculture monitoring as it combines a rapid assessment of invertebrate fauna (Section 3.5.1 below) with flora monitoring to provide a more complete picture of the mangrove ecosystems under study.

§3.5.1. BENTHIC FAUNA

Benthic fauna, or the invertebrates living in, and on, the mud surface were sampled from within 1m x 1m quadrats (Figure 6). Each quadrat was randomly placed (using co-ordinates from random number tables) but always placed against the tree nearest to the co-ordinates. All organisms within the quadrat were either recorded directly onto data sheets or sampled for later identification. Specimens were preserved in 70% ethanol. Three replicate 1m x 1m quadrats were randomly placed within each 20m x 20m monitoring plot. This technique for sampling benthic fauna has been successfully applied to mangrove research and monitoring programs in recent years (Metcalfé, in prep; URS (Australia) Pty Ltd, 2004).

Surveys were timed to coincide with the spring tides associated with the full moon, when high tides inundate the mangroves to a minimum height of 6.8 m Darwin Chart Datum, twice daily. Timing invertebrate sampling according to tidal cycles is important, as mid- to upper *tidal flat* invertebrates will retreat deep into burrows and crevices during dry season neap tides to avoid desiccation.



Figure 6 : Quadrats were used to sample benthic (mud-dwelling) invertebrate fauna

Benthic fauna typically comprises molluscs, crabs, small fish including mudskippers and worms. Quadrats were sampled by passive observation over 2 minutes followed by active searching of the quadrat including the sediment to a depth of approximately 5cm for 15 to 20 minutes. A burrow count for each 1m x 1m quadrat provides a further indication of invertebrate activity.

§3.5.2. EPI-FAUNA

Epifauna or the invertebrate fauna occurring on the roots, trunks and leaves of mangrove trees was sampled to a height of 2m from trees within 1m x 1m quadrats. The species of tree and tree height was also recorded for each plot. Epifauna characteristically comprises molluscs, small crustaceans and occasionally worms. Samples were preserved in 70% ethanol (in separate jars to benthic fauna) for later identification.

Within both 1m² invertebrate quadrats and the area searched for epifauna (to a height of 2m) the cover of epiphytic algae was also noted. Although algae typically comprises simple plants (not invertebrate animals) this measure was recorded whilst sampling fauna quadrats and estimates of algal cover expressed as a percentage of the total area.

3.6. DATA ANALYSIS

Raw data from field proformas was input directly into *Excel* spreadsheets (flora and sediment data) or *Access* database format (invertebrate fauna). The flora data was summarised in graphs and tables (Section 6.1) but no comparative analyses (ANOVAs) were relevant to the T1 (pre-construction) baseline data. However, some general comparisons of the APPL monitoring sites with the wider mangrove communities of Darwin Harbour were possible for data on mangrove vegetation structure and composition (eg. stand density and basal area).

Multivariate analyses of community data on invertebrate fauna were run using *Primer v5* (Primer-E Ltd). Non-metric multi dimensional scaling (MDS) based on a Bray-Curtis samples by species similarity matrix was applied to T1 data and each analysis was run from 50 random restarts and the results presented as dendrograms and ordination plots. Points that are close together on MDS graphs represent sites that are very similar in invertebrate species composition, and points that are far apart correspond to very different invertebrate communities.

The stress value that appears on MDS graphs indicates how faithfully the high-dimensional relationships among the samples are represented by the 2-d ordination plot. Stress <0.05 gives an excellent representation with no prospect of misinterpretation. Stress <0.1 corresponds to a good ordination with no real prospect of a misleading interpretation. Stress >0.3 indicates that the points are close to being arbitrarily placed in the 2-dimensional ordination space and should be treated with a great deal of scepticism or discarded (Clarke and Warwick, 1994). (NB. All MDS ordinations for the APPL data had stress values between 0.03 and 0.19). The invertebrate fauna results are presented in Section 6.2

4. THE EXISTING ENVIRONMENT

Six main vegetation communities, including 2 upland communities and 4 intertidal habitats, were distinguished within and adjacent to the 288 ha APPL lease boundary. Figure 5 is a map of the distribution of terrestrial and intertidal vegetation communities within the project lease boundary and the surrounding area, compiled by a combination of previous vegetation mapping (Kinhill, 1992) and ground-truthing of recent aerial photography. The characteristics of the main vegetation types are summarised in Table 2 and described in Section 4.2. Extensive mangroves occur just south of the lease area with minor areas of savanna woodland between the farm and the Channel Island road. A large man-made freshwater lake also occurs within the lease area with minor sedgeland/ grassland on the fringes and scattered patches of *Melaleuca* spp. (Paperbark).

Discussion of the conservation significance of mangrove habitats and the cumulative impacts of aquaculture developments in Darwin Harbour is contained in sections 4.3 and 4.4 respectively.

4.1. PREVIOUS VEGETATION SURVEYS

The vegetation of the area has been mapped at a scale of 1:500,000 and described on a gross level by (Christian and Stewart, 1953). The region surrounding the study area (including the Darwin, Elizabeth and Blackmore Rivers) has also been mapped as part of Land Resource surveys (Fogarty et al., 1984) which describe and classify the landscape in terms of recurring patterns of landform, soils and vegetation. Thus the Land Units of the proposed development area, mapped at 1: 100,000 scale, provided a useful baseline for this study. Fogarty *et al* (1984) noted that much of the survey area is gently undulating to undulating and the terrain is frequently gravelly with shallow earth soils. Intertidal areas characteristically support dense mangroves on unconsolidated marine muds and clays. Overall, the vegetation in the region forms recurring spatial patterns that closely reflect the interplay of topography and soils and the influence of seasonal and temporal fluctuations of salt and fresh water supply



Figure 7 : Vegetation map of the 288ha lease area and surrounding environment indicating location of the proposed 44ha pond area development

Leach and Dunlop (1992) prepared a vegetation map and descriptions of terrestrial and estuarine vegetation within the current project area on the basis of airphoto interpretation and fieldwork for the Haycock Reach Aquaculture Development PER (1992). The previous PER distinguished five main plant communities present on the site (below approximately 5m AHD), prior to development.

More recently, mapping of the study area at 1:25,000 scale was undertaken by Greening Australia as part of their remnant vegetation mapping program of the Litchfield Shire (Brock et al., 1995). This mapping distinguished 3 vegetation communities within the project area (Appendix 2) and indicated the presence of vine-forest or monsoon rainforest on Haycock Hill, a small hill located on the edge of the lease area and completely surrounded by mangrove vegetation (Section 4.3.3)

4.2. VEGETATION AND FLORA OF THE LEASE AREA

Flora data collected during previous vegetation surveys and the current survey, undertaken in October/November 2004, have been collated to produce a description of vegetation communities and flora species that occur within the lease area. In particular, the aim of this section of the report is to describe those communities that will be directly affected by the redevelopment project and to comment on their conservation significance at local and regional scales (Section 4.3). Six (6) vegetation types have been mapped within the project area (Figure 5) indicating the distribution of the major mangrove and upland communities. The characteristics of these vegetation types are summarised in Table 2 and site descriptions and photos of these communities have been compiled for this report.

Table 2 : Summary table of the major vegetation types within & adjacent to the APPL lease

MAP UNIT	CORRESPONDING LAND UNIT (Fogarty et al 1984)	VEGETATION COMMUNITY & DESCRIPTION	KEY FEATURES
MANGROVE COMMUNITIES			
1	9a/b	Tidal Creek Mangrove Zone Mid-high closed forests with <i>Rhizophora stylosa</i> , <i>Bruguiera parviflora</i> , & <i>Camptostemon schultzei</i> . Fringing tidal channels and creeks	Lower intertidal zone (approx 1.0 to 2.3m AHD) on poorly consolidated marine muds, particularly along creeklines
2	9 a/b	Tidal Flat Mangrove Low closed forest often with monospecific stands of <i>Ceriops australis</i> . <i>Avicennia marina</i> is co-dominant on fringes of salt flats	Mid to upper intertidal zone (approx 2.3 to 2.6m AHD) on saline muds. The most extensive mangrove zone
3	9a/b	Salt Flats A mosaic of bare sandy mud, small patches of samphire and stunted mangrove species to 1.5m tall. Occurs as a discontinuous band harbourwide	Hypersaline flats where infrequent inundation, minimal freshwater input and high evaporation causes salinity build up. Numerous salt flats occur from 2.5 to 3m AHD
4	9a/b	Hinterland Margin Mangrove A variable, multi species community at the landward margin of mangroves	Species composition is heavily influenced by the availability of freshwater. Occurs at 2.9 to 3.4m AHD
UPLAND COMMUNITIES			
5	2bl	Mixed Eucalypt Woodland Open woodland, with minor woodland area on low rounded hills and slopes	Typical of savanna woodland around Darwin - influenced by seasonal fire
6	MF	Monsoon Vine- Forest Coastal monsoon vine forest on hinterland 'islands' within mangroves	Isolated, well drained patches fringing mangroves and in fire-protected pockets eg Haycock Hill

§4.2.1. MANGROVE COMMUNITIES

Mangrove vegetation is well developed along the coastline of Northern Australia with particularly extensive mangroves in sheltered embayments such as Bynoe and Darwin Harbours. In these areas, mangroves are notable for both their species diversity and extent, despite being relatively species-poor in comparison with terrestrial habitats. Mangroves of the Darwin region have 38 of the 48 mangrove species known from the Northern Territory (Wightman, 1989). Twelve mangrove and salt flat species were recorded from mangroves within and adjacent to the project area during this survey (Appendix 1).

In areas of macrotidal range and low relief, mangroves typically show distinct patterns of zonation. Within Darwin Harbour, these patterns of zonation, with bands of species aligned roughly parallel to the shore have been mapped by DIPE (Brocklehurst and Edmeades 1995) and occur at particular topographic elevations (Figure 2). This predictable pattern of zonation is a result of the interplay of climatic and geomorphological factors, combined with the frequency and duration of tidal inundation and the availability of freshwater.

The project lease is located south of the Channel Island road on a relatively narrow peninsular fringed to the north and south by extensive mangrove systems. The mangroves to the south of the ponds are over 1.5 kilometres in width (from the landward to seaward margin). However, the re-development associated with the project will require only minimal clearing of mangroves (11.8ha) mainly comprising regrowth and disturbed hinterland margin habitat. Construction will involve 4.1ha of salt flat habitat. Existing mangrove communities downstream of the development may, however, play an important role in bio-filtration and assimilation of release waters from aquaculture ponds and consequently are the focus for a comprehensive mangrove monitoring program (Section 6).

Four distinct mangrove zones have been mapped within the project area (Figure 5) and described below. These zones correspond to floristically distinct mangrove associations that are easily distinguishable in the field and from aerial photographs:

Tidal creek mangrove (Map Unit 1)

This zone characteristically occurs between 1.0 and 2.3 m AHD (Metcalf, 1999). Forest height is variable but ranges between 6 and 12 m. In general, tidal creeks are relatively narrow, with sloping muddy banks prone to bank slump and erosion. This zone receives regular tidal flushing and supports a distinctive mangrove assemblage.

High soil moisture levels in the deep muds of the tidal creek support luxuriant growth of a variety of mangrove species. Common creek bank species include *Rhizophora stylosa*, *Camptostemon schultzei* and *Bruguiera parviflora*. Massive individuals of *Avicennia marina* to 15 m can also occur in this zone (EcoSystems, 1993). The tidal creek has the highest biomass of all mangrove zones and is also the most productive in terms of primary production, as measured by annual leaf litter fall (Metcalf 1999; (Woodroffe et al., 1988).

The tidal creek bank zone is well developed along the main channels of Haycock Reach and the larger tidal creeks in the local area (Figure 5). The seaward margin of the larger tidal channels is typically fringed by *Sonneratia alba* forests, characterised by large, well-spaced trees growing from between -1.0m and +1.0m AHD. This most seaward zone is largely confined to the fringes of Haycock reach and is discontinuous along the smaller channels and so has been mapped here with the tidal creek assemblage.

Tidal creek mangroves also extend along the banks of numerous smaller tributaries and tidal channels. The middle to upper reaches of the smaller tidal creeks within the survey area are fringed by a mixed mangrove association typically dominated by *Rhizophora stylosa* in association with *Camptostemon schultzei*, *Avicennia marina* and *Bruguiera*

parviflora. The *tidal creek* zone is the tallest community, typically forming a closed canopy forest ranging in height from 9 to 14 m. The ground surface is normally a dense tangle of arching proproots and stilt roots to several metres high (see Appendix 2 – photo-monitoring).

The *tidal creek* monitoring sites established during this survey are located on relatively narrow tidal channels, quite high in the tidal drainage system, fringed with characteristic *tidal creek* zone vegetation. At these locations, *Rhizophora stylosa* is most often co-dominant with *Bruguiera parviflora*, the latter forming dense thickets of slender trees 4 to 8m tall on the top of creek banks. Another characteristic of these (minor) tidal creek habitats is extremely abundant seedlings (largely comprising *Bruguiera parviflora*) which are patchily distributed on the upper creek banks.

In the tidal creek habitat downstream from PC2 and PC3, the creek banks have been heavily eroded and in places erosion has cut vertical banks over 1.5m high (Appendix 5 - Photographs). This has occurred where the man-made channel draining the existing pond area exits into a natural mangrove creek. The level of damage from the current small development emphasises the importance of discharge channel erosion control, specifically the need to reduce velocities in discharge channels and protect farm discharge points against scouring

Tidal flat mangrove (Map Unit 2)

The *tidal flat* mangrove zone occurs on the mud flats between approximately 2.3 and 2.6m AHD. As indicated by the very narrow range in topographic elevation, and unlike the *tidal creek* zone, this is a zone of extremely low relief. Surprisingly it is, however, the most extensive zone both within the local area and within Darwin Harbour generally.

In contrast with the deep mud of the *tidal creek* zone, substrates are relatively consolidated and may contain a high proportion of sand and gravel in the noticeably flat terrain. *Ceriops australis* forms almost monospecific closed forests with an average height of between 2 to 6 m. Other associated species include *Bruguiera exaristata* and *Aegialitis annulata*. *Avicennia marina* tends to become locally abundant to co-dominant with *Ceriops australis* as salinity increases towards the salt flats.



Figure 8: The upper *tidal flat* zone is characterised by multi-stemmed *Avicennia marina* and stunted, low-growing *Ceriops australis* fringing numerous salt flats

Tree height in the *tidal flat* zone varies in direct response to soil salinity and freshwater inflow. Low shrubby *Aegialitis annulata* to 1.5 m tall is a widespread ground layer species, tolerant of high salinity levels and is frequently found on the fringes of salt flats.

Hypersaline conditions on the edges of saltflats also influences the habit of *Ceriops australis* which may become extremely stunted. In addition, under these highly saline conditions, *Avicennia marina* typically becomes multi-stemmed and thus shrub-like. Four of the eight permanent monitoring sites are located in this forest type and the multi-trunked habit of the trees in this zone made the measurement of stem density and dbh extremely challenging.

The proposed pond redevelopment indicates that discharge waters from the sedimentation ponds will initially pass directly through this upper *tidal flat* zone – where *Ceriops* and *Avicennia* forests intergrade with saltflat habitat. Consequently the ‘impact’ monitoring sites were situated as close as possible to the location of the proposed pond effluent outlets, in order to document any changes in flora and fauna of these communities (Figure 1).



Figure 9: The *hinterland margin* mangrove community occurs where the mangroves intergrade with terrestrial vegetation at approx. 4m AHD

Hinterland margin mangrove (Map unit 3)

The hinterland margin is a variable, multi-species mangrove community that occurs at the junction of the mangroves and the terrestrial vegetation of the hinterland. Lying roughly between 3.5 and 4.0 m AHD, only the highest spring tides inundate this area. Within the lease area, this mangrove zone has been heavily modified during previous development of the site. Clearing for ponds, bund wall and channel construction has resulted in a mosaic of cleared, regenerating and disturbed *hinterland margin* mangrove areas.

Hinterland margin species composition is heavily influenced by edaphic conditions, particularly the availability of freshwater, on the adjacent hinterland. Sand and quartz gravel is often washed in from the hinterland and is often embedded with mud (Ecosystems 1993). In areas of freshwater seepage, vine-forest and *Melaleuca* (Paperbark) communities typically abut a dense, closed-canopy mangrove forest 6 to 8m high, with *Ceriops australis* dominant.

This is typically the most diverse mangrove zone with associated species including *Lumnitzera racemosa*, *Excoecaria ovalis*, *Bruguiera exaristata*, *Thespesia populnea* and *Scyphiphora hydrophyllacea*. The hinterland margin may be only several trees in width, and is therefore too detailed to map at a small scale, but may be quite diverse and tall, particularly in seepage zones or in areas with abundant seasonal freshwater runoff. *Lumnitzera racemosa* is characteristic of this assemblage, preferring areas with freshwater input. *Lumnitzera* is one of only a few species that occurs almost exclusively in the high tidal zone. A low shrubland of *Ceriops australis* and *Avicennia marina* typically occurs in areas devoid of freshwater input.

Salt flat (Map Unit 4)

Salt flats are typically found on the landward side of the *tidal flat* zone, occurring between 2.5 and 2.9m AHD. Salt flats are either devoid of vegetation or support scattered samphire species including *Suaeda arbusculoides* and *Halosarcia indica*. Infrequent tidal inundation and high evaporation rates during the dry season boost the soil salinity to levels toxic even to mangroves. Consequently hypersaline conditions prevail and salt flats characteristically remain bare of vegetation with only stunted fringing species comprising *Cerriops australis* and *Avicennia marina*.

Visible in aerial photography as a distinctive ring of bare areas in the upper tidal flat, salt flats form a discontinuous band of bare areas varying widely in size and extent. In the project area, several quite large salt flats are located between the development site and the mangroves. Salt flats also form a rough line, extending over 1 km directly south of the prawn farm (towards the Blackmore River) representing not only the highest elevation in this vast *tidal flat* area but effectively demarcating the shared boundary of two small catchments. Networks of salt flats are scattered throughout the mangroves surrounding the lease area at elevations that receive infrequent tidal inundation (Figure 5).

§4.2.2. UPLAND COMMUNITIES

Upland vegetation comprising mixed woodland to open woodland and minor open forests dominated by *Eucalypts* and *Corymbia spp.* occupy 175ha or 60% of the total lease area. Typical of the large parts of Koolpinyah surface around Darwin, these communities are common and have a widespread distribution. Small patches of monsoon vine forest occur infrequently in this community (Leach and Dunlop, 1992) but the vast majority of this vegetation type is characteristic *Eucalyptus* –dominated open woodland. Approximately one third of the remaining area of terrestrial vegetation on the northern and north-western boundary of the existing site will be cleared as part of the proposed future development. The upland vegetation surrounding the freshwater reservoir will be retained.



Figure 10: Eucalyptus-dominated woodlands cover 43% of the 288ha lease area

Mixed Eucalypt Woodland (map unit 5)

Previous terrestrial vegetation surveys report *Eucalyptus miniata* and *E. tetradonta* as the dominant species with canopy height varying from 7 to 15 m. *Corymbia bleeseri*, and *Eucalyptus confertiflora* were common canopy forming species observed during the current survey. Secondary trees including *Erythrophleum chlorostachys* and *Eucalyptus tectifica* are patchily distributed through the woodland area.

Mid-stratum species including *Acacia* spp., *Terminalia* spp., *Buchanania obovata* and *Persoonia falcata* formed a sparse to mid-dense understorey layer. Species dominance was observed to vary according to changes in local topography and drainage. *Lophostemon lactifluus*, *Melaleuca viridiflora* and *Pandanus spiralis* are characteristic species of seasonal waterlogging of low lying terrain, drainage lines and the freshwater seepage zone along the margins of the high ground adjacent to the mangrove communities (Leach and Dunlop 1992). A list of terrestrial plant species observed during the current survey and species recorded from the site during the 1992 PER was compiled as a checklist only, a complete inventory being outside the scope of the current project (Appendix 1).

Monsoon vine thicket (Map unit 6)

A dense monsoon vine-thicket, also containing Eucalypt woodland species, occurs on Haycock Hill, a small low rise situated 70m from the western side of the lease area boundary and 1.5 km from the pond development site (Figure 7). The hill is completely surrounded by mangroves on all sides and thus forms one of only several 'hinterland islets' in Darwin Harbour. These areas are completely fire protected and characteristically support fire-sensitive vine-forest species. The Wickham Point peninsula, prior to development, was another excellent example of this unusual habitat in a savanna landscape that receives frequent if not annual, widespread fires.

Monsoon thicket species recorded from Haycock Hill include *Mimusops elengi*, *Memecylon pauciflorum*, *Antidesma ghaesembilla*, *Premna acuminata*, *Exocarpos latifolius*, *Jasminum aemulum*, *Sterculia quadrifida*, *Croton arnhemicus* and the vines *Adenia heterophylla*, *Parsonsia velutina*, and *Flagellaria indica* (Leach and Dunlop 1992).

4.3. PLANT COMMUNITIES OF CONSERVATION SIGNIFICANCE

The project lease area supports six vegetation communities of varying conservation significance on local and regional levels. However, previous development of the site has led to degradation of several communities, particularly at the interface of mangrove and terrestrial habitats, through the impacts of clearing, miscellaneous earthworks and weed invasion.

The conservation significance of vegetation in natural habitats can be considered on a number of different levels (ie at the level of the individual species, or the plant community) and at several different spatial scales (eg local, regional or national) as follows;

§4.3.1. MANGROVES

The project lease area includes quite a substantial area of mangrove forest covering approximately 112 ha (39% of the lease area). The surrounding very extensive mangroves of Haycock Reach are in relatively intact condition due to limited foreshore development in this part of the harbour. However, aquaculture development in the region is expanding and the long-term and cumulative effects of these developments must be considered. Mangroves are a significant natural resource both locally and globally (Brocklehurst and Edmeades, 1995). Appendix 2 indicates the approximate location of the 2 operational and 2 inactive prawn farms currently on the Blackmore River.

The Oil Spill Response register -formerly the Coastal Resources Atlas (NT Department of Lands Planning and Environment), lists specific mangrove areas in recognition of their ecological and botanical importance and notes the national significance of mangrove stands within Darwin Harbour. The register notes the importance of mangroves in terms of their high primary production, their ecological value as a habitat and their intrinsic social and natural values as a resource. The mangroves of the Darwin region and in particular the 20,000 ha within Darwin Harbour, are notably diverse and are important habitats in terms

of breeding, feeding and nursery grounds for a variety of marine and terrestrial species (EcoSystems, 1993). Indeed, Darwin Harbour mangroves are listed in the Directory of Important Wetlands in Australia (ANCA, 1997) and on the Register of the National Estate (DEH, 2004).

The proposed aquaculture project is primarily located within upland habitat. The small area of mangroves to be cleared for pond expansion (11.8 ha) largely comprises previously disturbed or regenerating hinterland margin mangroves and bare saltflats. Development plans do not involve any further clearing of mangrove communities and a comprehensive monitoring program has been established to monitor the health and status of the surrounding intertidal zone communities. The mangrove monitoring program will focus on the potential impacts of intermittent discharge of pond effluent into mangrove areas.

§4.3.2. UPLAND COMMUNITIES

The proposed project has been designed to redevelop the existing site with some minor expansion into the area of remaining terrestrial vegetation towards the northern boundary. This vegetation is not restricted in distribution and is highly unlikely to contain any rare or endangered species. A species checklist has been compiled for the area (Appendix 1).

Much of the upland section of the project area comprises *Eucalyptus* dominated vegetation communities, either as woodland or open woodland formations. Overall, this vegetation type, where trees co-occur with a more or less continuous grass cover, is commonly known as savanna and occurs across vast areas of northern Australia. Savanna is characteristic of the monsoonal tropics where there is a distinct dry season and where fire is a major factor determining vegetation structure.

However, the presence of cycads (*Cycas armstrongii*) in the lease area is of some botanical importance. These plants are relatively common understorey species in upland Eucalypt communities but a high proportion of cycad species have rare status and are thus generally conferred some intrinsic ecological value. To ensure the conservation and sound environmental management (including harvesting) of this species it is classified by Northern Territory Environmental Legislation as a protected species (Schedule 8, Regulation 15 of the Territory Parks and Wildlife Conservation Act 1994). The implications of this legislation are that *Cycas armstrongii* may not be collected or removed from bushland unless it is part of the lawful use of the land. Thus although cycads are protected species their presence does not preclude development in areas with appropriate development approval.

Minor areas of grassland, *Pandanus* communities and Paperbark also occur within the site, but these communities are common and widespread in the region generally. It follows that the majority of vegetation communities present do not have special conservation significance and are well represented in the Darwin region and elsewhere within the Top End.

§4.3.3. VINE-FOREST

In the Top End, monsoon vine-forest generally only occurs as small, disjunct patches, as islands in a sea of savanna. Vine-forest habitat has declined markedly in area in the Darwin region (Panton, 1993) and fire and feral animals threaten the integrity of over one third of these habitats in the Top End (Russell-Smith and Bowman, 1992).

Recent research stresses the importance of conserving each small area as it forms part of an important network in the landscape (Price et al., 1998; Russell-Smith et al., 1992). Consequently, the conservation of discrete isolates such as that found on Haycock Hill, are important for maintaining the diversity and integrity of the interrelated network of Top End rainforests —particularly as a habitat and resource for frugivorous fauna.

Thus in the regional context, the fire-protected Haycock Hill community and the few scattered areas of vine forest species found within the lease area have considerable ecological and conservation significance. These habitats are not, however protected under any current legislation. Overall, the development is distant from, or does not impinge on vine-forest habitats and therefore is not anticipated to have any negative impacts on these habitats.

4.4. ECOLOGICAL AND CONSERVATION VALUES – FLORA

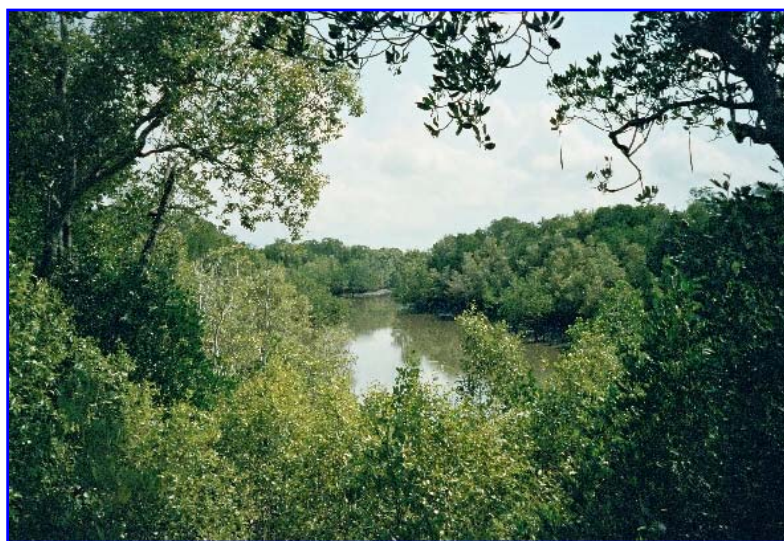
§4.4.1. LOCAL SIGNIFICANCE

Despite its proximity to Darwin and the rural area, the vegetation of the lease area comprises mangrove communities and minor upland areas that remain in a relatively natural condition, except the immediate surrounds of the previously developed area. Consequently the lease area contains a variety of ecosystems with habitats of importance to a range of different fauna (Section 6.2). Healthy natural habitats have an intrinsic conservation significance that is difficult to quantify and not often recognised, but which contributes to important values such as clean air and water, biological diversity and environmental stability.

§4.4.2. REGIONAL SIGNIFICANCE

The terrestrial vegetation communities within the area proposed for development (covering 39.6ha) are typical of *Eucalypt* forest and woodland of the Top End and comprise part of an extensive bioregion (the Top End Coastal bioregion covering 68,072 km²). Thus in the regional context, the conservation value of terrestrial flora found on the site is not significant. Further, 15.8% of the bioregion is currently reserved, predominantly for conservation purposes (Connors et al., 1996) so these woodland habitats are well represented in reserves elsewhere in the region.

In conclusion, the mangroves of the extensive Darwin Harbour system have ecological and conservation significance at the regional and national scale. The surrounding mangroves form part of the extensive Darwin Harbour system (spanning approximately 20,000 ha) and remain in relatively pristine condition. The mangroves within and around the lease area are very similar to assemblages found elsewhere in the harbour; the species present and the general pattern of zonation is predictable and relatively consistent in these tidal systems. Thus in the regional context, the mangroves adjacent to the proposed development area do not have special ecological or conservation significance.



View of tidal creek mangrove assemblage upstream from the APPL saltwater supply jetty

5. ENVIRONMENTAL IMPACT ASSESSMENT

Aquaculture is the fastest growing primary industry in Australia (Productivity Commission, 2004) and environmental impacts from aquaculture vary according to the type of species farmed, type of production system, management practices used, location and number of farms and the environmental carrying capacity of the environment. Potential environmental impacts can be classified as having either site location and construction impacts, or farm operation impacts, local and off-site. Recognising the variation in potential environmental impacts from different types of aquaculture operations is a necessary step in developing and implementing an efficient and effective environmental management regime. In addition, aquaculture may be only one of a number of activities contributing to environmental impacts in a particular area. An understanding is required of both the cumulative impacts from different activities, and the impacts from aquaculture relative to other activities.

Observations by Boyd (1995) have indicated that Australian prawn farmers are amongst the most environmentally sustainable in the world. Accurate levels of environmental impacts in the long term have not yet been adequately defined, although anecdotal reports and preliminary research (Trott, 1996), suggests adverse impacts to water quality and indirect impacts to aquatic flora and fauna by well-planned and managed prawn farms, are yet to be demonstrated.

The most immediate and direct environmental impact of the proposed development will be the earthworks necessary to redesign and reconstruct the existing infrastructure and pond layout followed by subsequent earthworks for the phase 2 and 3 extensions. Construction plans must incorporate control measures for earthworks to prevent and curb erosion and sedimentation, and guidelines for minimal vegetation clearing. Any construction activity within mangrove areas should be minimised and restricted to neap tidal cycles and where necessary earthworks need to comply with strict acid sulphate soil management principles. Acid sulphate soils form when anaerobic marine muds are drained and aerated, causing definite and severe acidification due to the oxidation of sulphides – mainly pyrites FeS_2 (Moormann, 1962).

Potential impacts within intertidal areas are expected to be focussed on the potential for erosion and nutrient enrichment of saltflats and mangroves next to, and downstream of, the two discharge outlets. Approximately 35-45 ML of discharge water will be released on a daily basis, with an upper limit of 66 ML per day. Effluent will flow over a spillway and into lined channels designed to reduce the velocity of flow before being discharged into regularly flushed tidal channels. It is anticipated that some bio-filtration of effluent will occur in the *tidal flat* mangroves and the increase in nutrients may, in fact be of potential benefit to these forests. Indeed, mangroves have been observed to proliferate adjacent to prawn farms in north Queensland (Foster and Robertson, 1999). Depending on the discharge regime, some undiluted pond effluent may also reach tidal creek mangroves further downstream and this mangrove habitat is also under study

Russell Hanley (NT Museum) made an assessment of the potential impacts of the previous 14 ha prawn farm development on mangrove communities (Kinhill, 1992- Appendix B). He likened the farm effluent to nutrient-rich sewage effluent and reported that in studies of the effects of sewage on mangrove invertebrates at Berrimah in Darwin Harbour, there had been no difference between impact sites and control sites (Hanley and Couriel, 1992). However, later studies of mangrove invertebrates downstream of sewage outfalls on Buffalo Creek indicated a decrease in diversity and elevated abundance of some crab species (Hanley Caswell and Associates, 1997). Consequently, the ecological impacts of prawn farm effluent on mangrove communities, is not well understood and this monitoring program should increase our understanding in this area and thereby will assist in future environmental assessment.

The proposed project aims to reduce nutrient and sediment loads in pond effluent via a comprehensive bio-remediation system (involving mullet, crustaceans and molluscs) in a series of ponds (Figure 1). This system should ensure removal of the majority of nutrients and suspended solids, prior to discharge through a lined channel leading to a regularly flushed tidal channel.

Table 3 : Summary table of the potential environmental impacts, safeguards and management strategies for the APPL Aquaculture project

Activity	Potential Impact	Safeguards, Mitigation and Management Strategies
Discharge of pond effluent	• Increased nutrient input to mangrove ecosystem • Shift in flora species composition in mangrove/salt flats in response to alteration in soil chemistry • Change in micro-habitat for invertebrate species from increased water and nutrient levels • Increase growth of algae and possible increase in mangrove primary production • Decreases in biodiversity from increased nutrient/chemical levels • Potential increase in abundance of certain species • Secondary ecological impacts on mangroves due to potential impacts on benthic invertebrates (especially crab diversity and abundance) due to their role in soil aeration and nutrient cycling	• Where possible, releases of pond effluent to coincide with high tides (dry season) or freshwater flooding in (wet season) to ensure discharges are diluted and have rapid residence times • Waste water passes several siltation and bio-filtration ponds prior to discharge • Design of spillway and lined channels will reduce velocities in discharge channels and protect farm discharge points against scouring • Stabilisation of ponds, channels and discharge points to prevent erosion • Installation of comprehensive pond water bio-remediation system • Comprehensive pre- and post impact monitoring of vegetation, fauna diversity and abundance, soil characteristics and water quality downstream of discharge outlets and at distant control sites to detect environmental change resulting from the development
Vegetation clearing	• Potential for increased erosion of cleared areas from higher runoff velocities • Downslope deposition of terrestrial sediments and increased turbidity in water bodies • Compaction of soil and reduced water infiltration • Loss of terrestrial habitat • Introduction and spread of weeds	• Clearing of vegetation should be kept to the minimum required for each stage of development • Road/construction access managed to minimise vegetation clearance • Clearing and disposal shall be in accordance with DIPE guidelines • Relevant permits obtained for clearing of cycads (<i>Cycas armstrongii</i>) • Limit the area of disturbance to immediate construction • Compilation and implementation of a weed management plan in accordance with the NT Weed Management Strategy
Earthworks Reconstruction and extension	• Deposition of terrestrial sediment in mangrove habitats • Siltation of waterways • Alteration to natural drainage lines of freshwater	• Construction in intertidal areas to be kept to the minimum necessary for the proposed project and removal of marine muds to be avoided • Earthworks must be minimised during the wet season • Dust suppression measures implemented during the dry season • Stripped top soil must be stored in bunded area • Any on-site or off -site dumping locations (particularly of marine muds) should be approved by DIPE prior to dumping

Table 3 cont.: Summary table of the potential environmental impacts ,safeguards and management strategies for APPL Aquaculture project

Activity	Potential Impact	Safeguards, Mitigation and Management Strategy
Earthworks cont. Reconstruction and extension	• Acid sulphate soils	• Downstream habitats checked for erosion. Intertidal areas must be managed in accordance with recognised guidelines • Areas where acid sulphate soils have been disturbed and exposed must be rehabilitated
Chemical use, storage and disposal	• Biomagnification in non target species • Pollution from inappropriate disposal practices • Spillage may cause unexpected contamination	• Use, store and dispose as per manufacturers instruction and according to Administering Authority requirements • Risk analysis, hazard management and contingency planning
Operational phase – prawn farming	• Erosion from release of pond water at farm discharge point, along channels & in mangroves • Discharge of pond effluent containing elevated concentrations of suspended solids, nutrients and Chlorophyll a (phytoplankton) • Entrainment of fauna in saltwater intake • Proliferation of exotic species and disease • Discharge of chemicals/additives in pond water into natural habitats • Habitat creation and increased food resources for local wildlife particularly birds • Need for destructive culling of crustacean predators including many native bird species • Contribution to cumulative impact on water quality, environmental stability, pest /disease potential	• Comprehensive on- and off-site operational erosion control program • Development of project- specific Environmental Management Plan incorporating Best Practice program objectives that aligns with national industry standards • Comprehensive, long-term mangrove monitoring program that functions as a trigger for remedial action, should significant negative environmental impacts be detected as a result of the project • Filters attached to saltwater intake to prevent entrainment of fauna • EMP contributes information for local analysis of the cumulative effects and ecological sustainability of the aquaculture enterprises in the Darwin Harbour region • Implement (harmless) laser beam bird deterrent on regular basis • Water quality monitoring program in surrounding mangroves with sites in discharge creek at various downstream locations and at matched control sites (to be undertaken monthly). • Comprehensive water quality monitoring on site, including sampling at the 2 spillways (to be undertaken weekly)

It is anticipated that the mangrove communities adjacent to discharge points will assist in filtering residual nutrients from the discharge water (which may reach these habitats during high tides). Rapid conversion (to chlorophyll a) and assimilation of residual nutrients is anticipated when effluent enters mangrove creeks. Where possible, discharge events will be coordinated with high tides to facilitate the dilution of effluent and to maximise the benefits of tidal flushing. Effluent water will be close to or slightly less than the salinity of seawater (20-35 ppt) during the dry season and less saline than seawater (5-20 ppt) during the wet season. These salinities are unlikely to have a major detrimental effect on mangroves downstream and may result in the expansion of mangrove vegetation into existing bare saltflat areas in the vicinity of the outlets. Table 3 summarises the potential environmental impacts on flora and lists suggested mitigation measures relating to the Aussie Prawns development.

As operations and production increases, environmental management strategies must identify and implement all reasonable and practical measures to prevent any potential negative effect on water quality and the diversity and abundance of flora and fauna, both on-site and off-site. Ongoing research aims to quantify the effects of effluent discharge on the mangrove forest and the suitability of mangrove forests in the biofiltration treatment process. This information will assist in the future assessment of the cumulative impacts of prawn farming on Darwin Harbour.

The redevelopment of this site will increase the number of prawn farms on the Blackmore River to four (see Appendix 2 for locations). However, 2 of these 4 farms are currently inactive. Impacts from the proposed development are clearly not limited to potentially negative effects on the natural environment. Indeed, habitat modifications resulting from the previous development - including construction of the freshwater reservoir and the shallow brackish water habitats provided by the maze of old ponds- has created a rich habitat for birds. Flocks of waterfowl utilise the freshwater dam, which has also become a breeding habitat for saltwater crocodiles (Chris Lim, pers. com.) and the disused ponds are feeding grounds for numerous bird species. Further, it is widely thought that mangroves may benefit from increased nutrients and will proliferate in habitats downstream from pond effluent outlets. Further, the knowledge and baseline data gained from the proposed long-term monitoring of mangrove flora, fauna, soils and water quality will be of benefit for future aquaculture proposals and to coastal management generally.



The existing 33.1ha freshwater dam is a rich habitat for waterbirds



Creek bank erosion from release of pond water into natural mangrove areas

6. RESULTS - MANGROVE MONITORING

Both flora and fauna sampling was focussed in the two mangrove zones that may be subject to potential environmental impacts – the *tidal creek* and *tidal flat* zones. The structure and species composition of these two habitats is described in Section 4 – the Existing Environment. This section summarises the results of the first round of the BACI design mangrove monitoring program representing the pre-impact or ‘before’ baseline data. The raw data, entered into *Excel* spreadsheets and *Access* database format is not included in this report but summaries of the data are presented below.

Results for mangrove flora will be considered first followed by the results for the invertebrate fauna community as a whole. Analysis of invertebrate fauna data was limited to the level of community– analyses of separate taxonomic groups (eg. crabs, molluscs) were not undertaken at this early (pre-construction) stage.

6.1. FLORA

§6.1.1. CANOPY DENSITY

Canopy density was recorded as part of the stand structure inventory for each monitoring site, providing a pre-impact baseline. Canopy density indicates the percentage of the site occupied by the vertical projection of mid and upper vegetation strata. (English et al., 1994). Thus canopy density data may also function as a rough indicator of productivity.

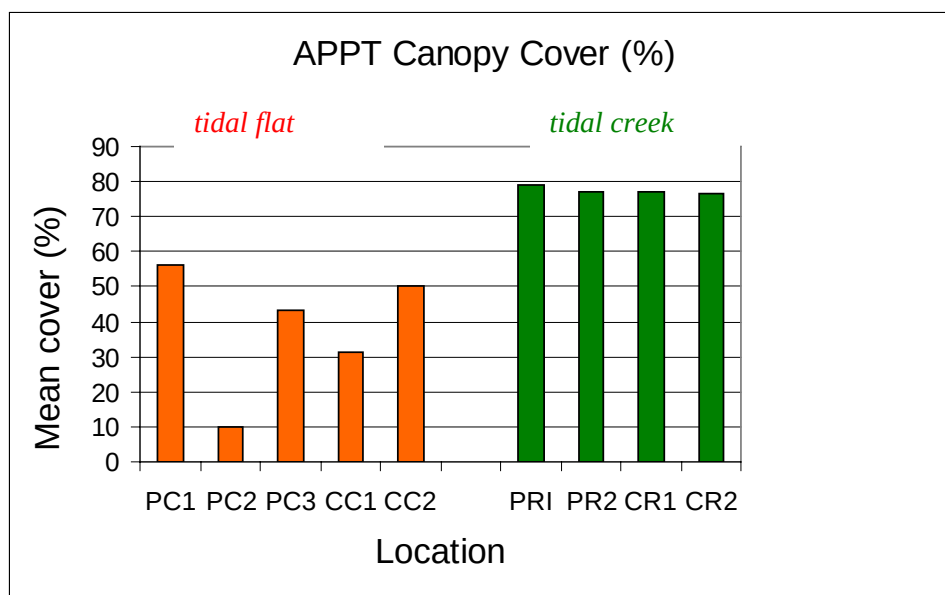


Figure 11: Graph of mean canopy cover for monitoring sites, November 2004

Canopy cover was quite consistent in *tidal creek* habitats with uniformly high values averaging 77%. However more variation was observed in the more open, low-growing *tidal flat* mangroves which had an average cover of 38%.

Site PC2 which was surrounded by saltflats, had very few trees and therefore low canopy cover (Figure 11). Overall, canopy values were similar to those recorded in the same assemblages elsewhere in Darwin Harbour (Metcalf 2004; URS 2004).

§6.1.2. SEEDLINGS/SAPLING DENSITY

Seedling and sapling density was measured to characterise natural recruitment and forest regeneration - another relevant measure of forest health and environmental change.

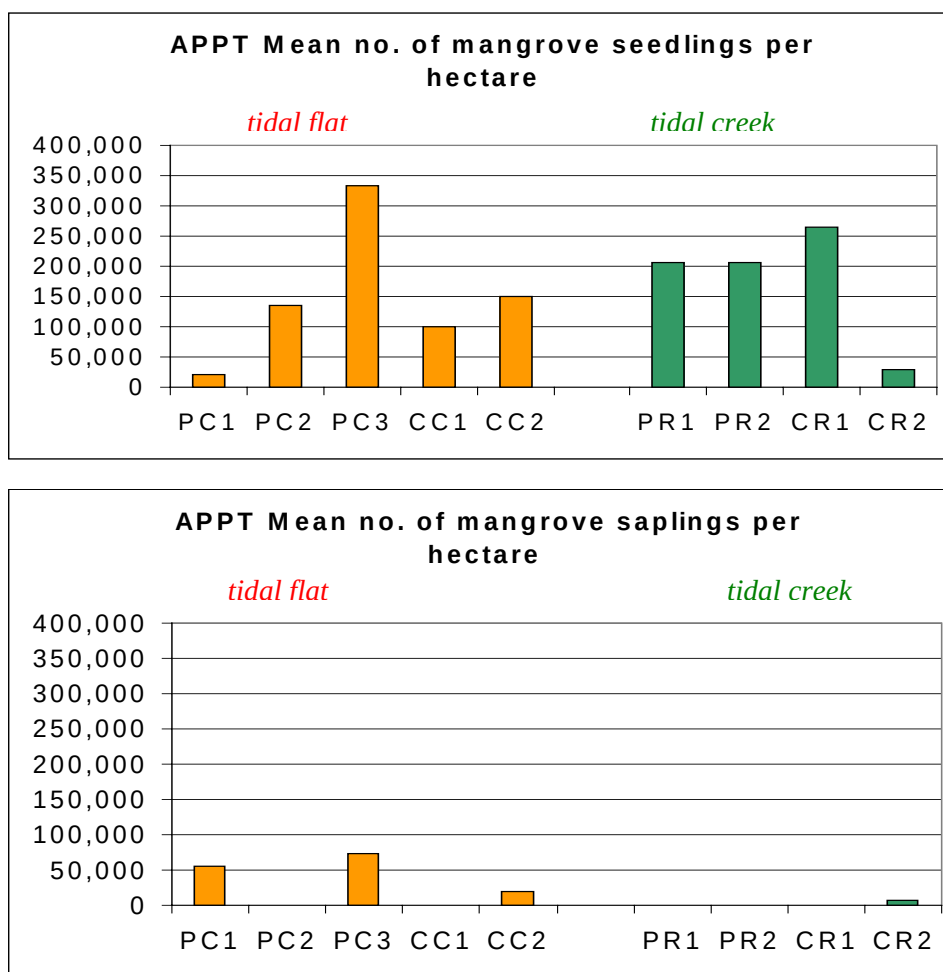


Figure 12: Graphs of mean seedling and sapling density, November 2004

Sapling numbers were low in most plots, particularly in the *tidal creek* habitat but seedling numbers were typically high, the variation shown in Figure 12 reflecting the patchy distribution of often dense patches of seedlings occurring in both *tidal creek* and *tidal flat* forests. Despite the variation in density, natural recruitment is an important ecological indicator of forest health.

§6.1.3. STAND STRUCTURE

Stem density, growth and basal area

The *stand structure* of mangrove forests at key locations was measured using several forestry parameters. Data was typically obtained from within subplots of known area (5m x 5m) rather than using the full-plot method (within 20 x 20m plots) which is excessively time-consuming. Tree *growth* will also be recorded by comparisons of diameter measurements of 30 tagged trees per plot. Table 4 summarises the main stand structure characteristics documented and compares the results with data from elsewhere in Darwin Harbour.

When placed in the harbour-wide context, the monitoring plots appear characteristic and show broadly similar trends. For example, the percentage of dead trees per unit area is typically lowest in the *tidal creek* zone and highest in the high tidal flat of Darwin Harbour (Brocklehurst 1995) where trees are subject to higher environmental stress levels. However, in comparison to other sites, tree diameters were smaller and stem density was higher at the APPL sites probably

reflecting the dense, narrow forests of upper tidal creek habitats sampled during this survey (rather than broad shoreline assemblages sampled in previous studies). The significantly smaller tree diameters support these general observations (Table 4)

Table 4: Summary of stand structure for APPL monitoring sites in Darwin Harbour context

Zone	mean tree diam. (cm)	mean tree diam. Brocklehurst '95	Basal area mean (m ² ha ⁻¹)	Basal area Brocklehurst 1995 (m ² ha ⁻¹)	Species	Relative Density - species %	Stem density (stems ha ⁻¹)	Stem density - Brocklehurst 1995 (stems ha ⁻¹)	Stem density - Comley 2002 (stems ha ⁻¹)
High tidal flat	4.3	5.2	10.5(live) 3.8% dead	8.9 (live) 2.6% dead	<i>A. marina</i> <i>C. australis</i>	63.6 36.3	8,640	21,655.0	17,575
Tidal creek	4.9	13.2	20.8 (live) 3.1% dead	23.9 (live) 1.9 %dead	<i>R. stylosa</i> <i>B. parviflora</i> <i>C.schultzii</i> <i>C.australis</i>	12.4 79.2 4.4 4.0	10,825	7,592.0	7,635

Table 4-1 summarises species composition, relative density and stem density data (Appendix 4) and Table 4-2 summarises data on tree diameter for the 30 tagged trees per plot. Mean dbh values for *tidal flat* species are quite high but *Avicennia* trees in this zone are typically multi-stemmed and/or often the trees are hollow- both factors that tend to increase the diameter values. Tagged trees will be measured annually to document increases in girth.

§6.1.4. PHOTO-MONITORING

The centre of each 20m x 20m quadrat functions as the photo-point and 4 photographs (landscape format) were taken while standing at the centre post and looking toward the 4 corners of each plot. Four (permanent) aluminium stakes were placed 3m from the centre post to assist in accurate relocation of photo-monitoring points.

Appendix 5 contains the photo-monitoring record for the nine monitoring sites- all future images will be compared to these pre-construction images.

§6.1.5. SEDIMENT GAUGES

The four corners and the centre of each quadrat were marked by PVC posts which also function as sediment gauges. 1.5m lengths of PVC were hammered into the mud until exactly 1,000 mm of PVC remained above the surface. Subsequent 6 monthly measurements of exposed PVC (5 gauges per plot) will indicate whether sediment accretion or erosion is occurring within the plots.

Table 4-3 contains the raw data for sediment gauges (Appendix 4).

§6.1.6. SOIL CHARACTERISTICS

The pH and conductivity of mangrove soils within each of the 9 monitoring quadrats was measured from five randomly selected locations. Surface soil moisture and pH was measured with a soil pH meter and then a 1:5 soil to water dilution used to measure conductivity and pH of sediments at 15cm depth with a water quality meter. The results are summarised in Table

5. Sediment sampling of salt flats in the vicinity of spillways was also undertaken to document possible changes in soil salinity at these locations.

Table 5: Sediment sampling results at nine monitoring sites, November 2004

LOCN	ZONE	Soil moisture Mean (7cm)	pH mean (5cm)	Conductivity mean (mS/cm)	mean Salinity TDS (ppt)	Mean pH (15cm)	Temperature mean (°C)
PC1	Tidal Flat	6.1	4.9	11.6	6.3	7.0	34.1
PC2		4.1	6.1	7.8	4.4	7.1	31.3
PC3		4.9	5.4	8.7	4.5	7.0	32.7
CC1		4.5	5.7	12.9	7.0	7.3	30.2
CC2		5.9	5.1	9.7	5.2	7.4	28.5
PR1	Tidal Creek	5.9	4.9	9.5	5.2	6.7	34.0
PR2		5.9	4.8	8.8	4.6	6.8	31.8
CR1		5.3	5.3	11.3	5.2	6.8	33.0
CR2		5.9	4.9	10.8	5.9	7.0	28.9

As expected, the soil salinities in salt flat areas were the highest and tidal creek sites had the lowest mean salinities (Figure 13). Taken in the late dry season, these values are expected to be close to annual maxima – high evaporation rates lead to seasonal increases mangrove soil salinities.

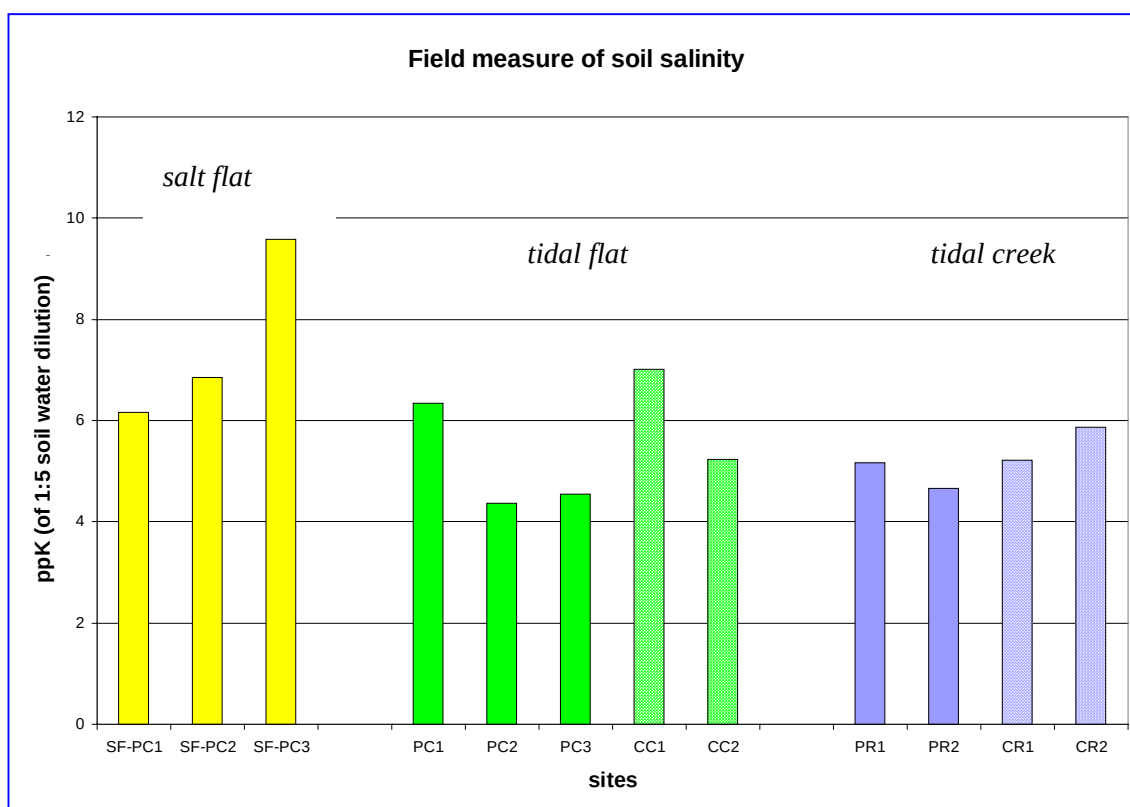


Figure 13: Histogram of mean soil salinity (indicative field data) in 3 main habitats showing pre-construction levels at control sites (texture) and impact sites (plain)

Control sites tended to have slightly higher soil salinities than ‘impact’ sites, in November 2004 (pre-construction). Data for soil pH levels will be examined in future monitoring reports.

6.2. INVERTEBRATE FAUNA

Over 250 records for invertebrates were obtained during initial field surveys in late October 2004. Similar to the findings of previous research and monitoring studies on mangrove invertebrates in Darwin Harbour, the crustaceans (crabs, shrimps, isopods, amphipods, barnacles etc) dominate the fauna with crabs being the most speciose and abundant taxonomic group (Metcalf, in prep). Of a total of 43 species recorded in surveys on 28th and 29th October and 14th November 2004, 51% were crustaceans with a total of 19 species of crabs (Appendix 3). Figure 11 summarises invertebrate fauna data for species richness (NB. The abnormal *tidal creek* impact site PC2 will be dropped from future analyses).

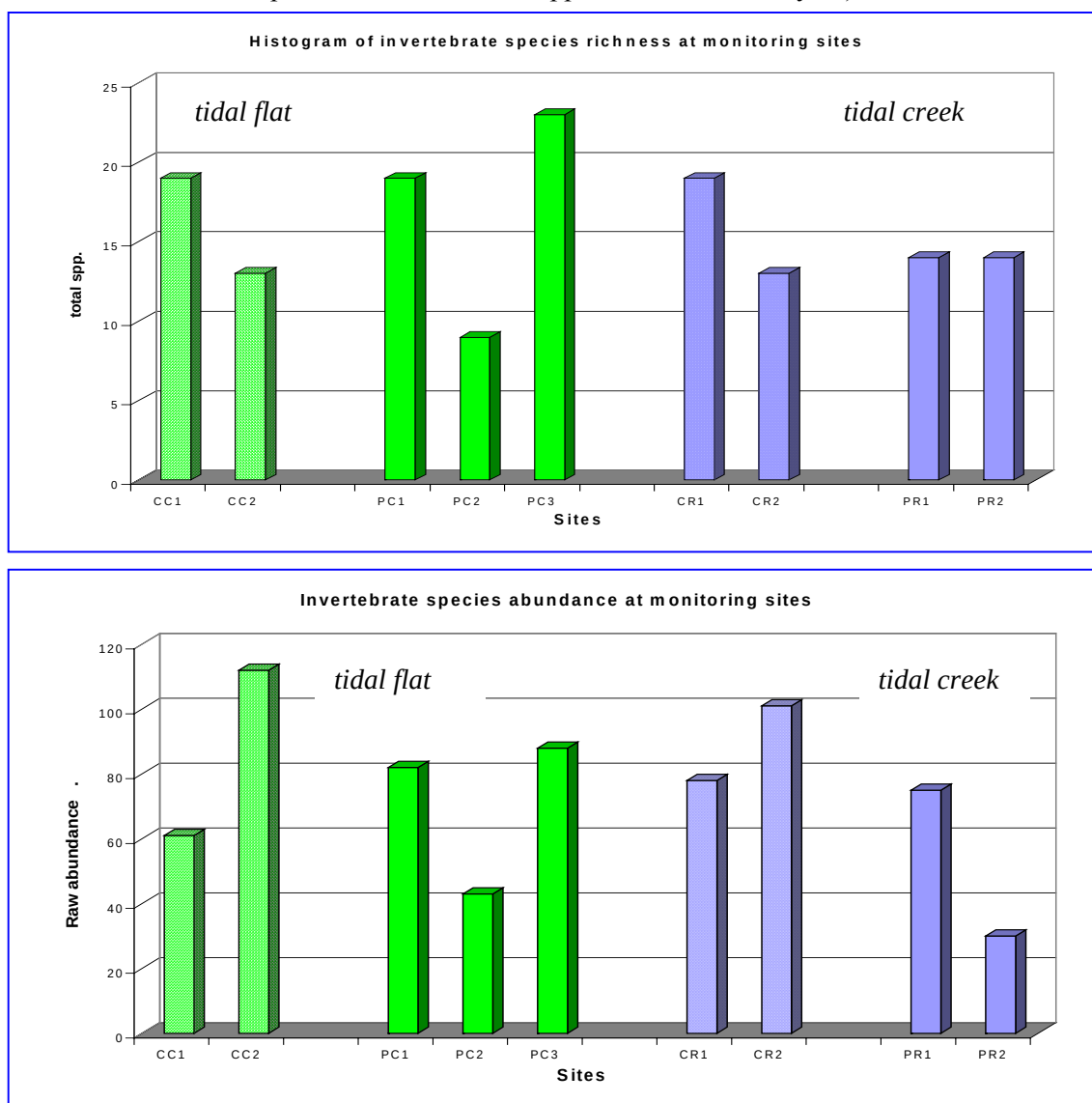


Figure 14 : Histograms of invertebrate species richness and abundance at monitoring sites, November 2004, indicating control sites (texture), impact sites (plain)

To date, 81 species of crustaceans have been recorded within mangroves of Darwin Harbour (URS 2004), but sampling for previous surveys included the highly biodiverse seaward zone and the most landward zone (4 zones in total) and utilised a combination of sampling strategies. The most common crab species recorded during the current survey were *Perisesarma darwinensis*, *P. semperi*, *Parasesarma moluccensis* and the Fiddler crab *Uca signata*.



Figure 15 : Crustaceans were the dominant invertebrate group including 19 species of crab. *Episesarma* sp.(above) is an uncommon *tidal flat* mangrove species

Molluscs were also well represented in the invertebrate fauna with 17 species recorded. The gastropods (82%) were far more common than bivalves, which tend to be more abundant in the softer sediments to seaward. Sampling techniques (quadrat and epifaunal sampling to 2m) also focussed on surface benthic fauna (favouring gastropods) rather than infauna (bivalves).

Similarly, few worm species were recorded (2 species) from within the mangrove mud. Large gastropods from the family Potamidae ('Creepers') were common within the *tidal flat* zone where they move about slowly grazing algae and microorganisms from the mud surface. The large shells of *Telescopium telescopium* (Long Bum), *Terebralia palustris* and *Terebralia semistriata* were common to extremely abundant in the mid-tidal zone. High densities of *Terebralia* and *Telescopium* were also observed in some of the saltwater channels draining the prawn farm where elevated levels of algae may provide favourable conditions for the proliferation of these molluscs.

Epifauna (on the surface of trees and roots) recorded in monitoring plots mainly comprised molluscs with occasional crustacean species. The foliage of *Ceriops australis* in the mid-tidal zone provides habitat for abundant *Littoraria filosa* (Periwinkles). *Nerita balteata* and *Chicoreus capucinus* (Mangrove Murex) are common epiphytic molluscs in the *Rhizophora stylosa* forests found along tidal creeks.



Figure 16: *Nerita balteata* (left) and Mangrove murex, *Chicoreus capucinus* which feeds on mangrove worms (right) are common epifauna the *tidal creek* zone

Invertebrate sampling also included mudskippers, which are actually semi-terrestrial fish (and therefore vertebrates). These unusual water-avoiding fish are mangrove specialists and were included with the invertebrate fauna because represent an abundant and conspicuous group within the mangrove faunal community.

Initial analyses of the invertebrate fauna and soils data indicated that species composition at the second impact site in the *tidal flat* zone (site PC2) appeared substantially different from other *tidal flat* plots, apparently from previous disturbance to surrounding soils arising from drainage channel construction. These observations regarding PC2 were less than ideal for initial 'pre-impact' sampling within a long-term monitoring program - particularly for an 'impact' site (Figure 17).

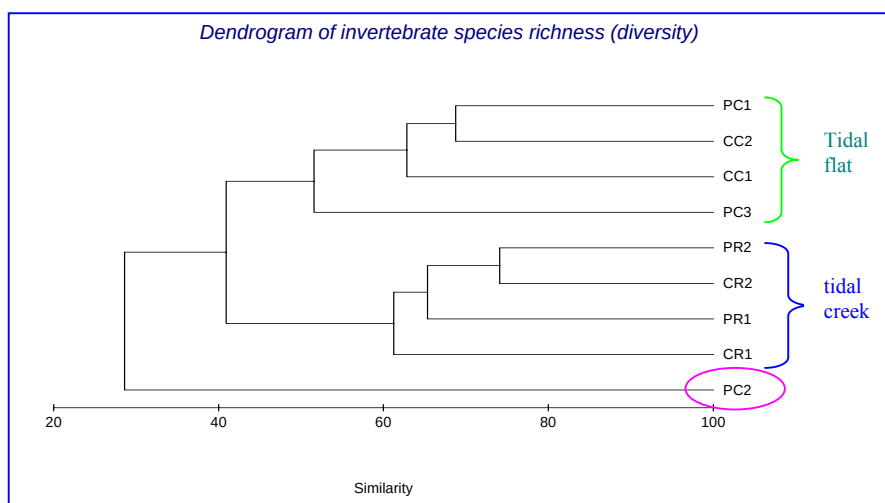


Figure 17: Dendrogram of initial monitoring sites indicating similarity of fauna sites within the two zones and the dissimilarity of site PC2

Consequently, a new, less disturbed quadrat was established (site PC3) on 14th November 2004. For consistency, sampling was undertaken at exactly the same time in the tidal cycle one fortnight after PC2 was established.

Multivariate analysis of **species richness** data for the invertebrate community indicated a clear pattern of zonation with strong similarity between the fauna of sites within the same zone (Figure 18). Sites with high similarity are grouped together, those with differing invertebrate fauna being more widely-spaced on the ordination plot. The strong pattern of zonation observed here has also been clearly demonstrated in mangrove fauna from elsewhere in Darwin Harbour. In fact, intertidal position is the main factor driving variations in species richness and abundance in mangrove invertebrate fauna generally (Metcalf, in prep).

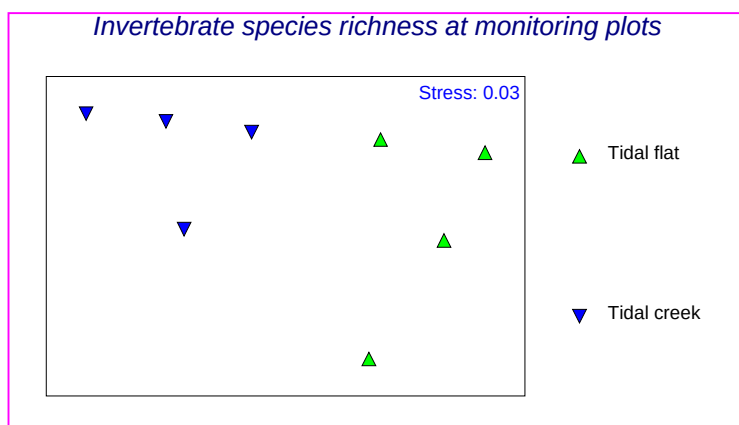


Figure 18: Ordination of nine monitoring sites indicating clear zonation of invertebrates

These results indicate that invertebrates are highly adapted to the particular set of conditions prevailing within each mangrove zone (eg frequency and duration of tidal inundation, salinity, vegetation type etc) and survive there because they have the appropriate specialisations (eg. mouthparts to sieve through a particular sediment particle size). For example, Fiddler Crabs

(*Uca* spp.) appear to proliferate in disturbed mangrove habitats. This suggests that their morphology is better suited to more open areas in which sandy substrates have replaced fine marine muds and clays—conditions that are characteristic of disturbed mangrove sites.

Multivariate analyses of pre-impact invertebrate diversity data indicated no clear groupings or patterns between control and impact sites (Figure 19). This also suggests that the final 8 monitoring sites selected are well matched.

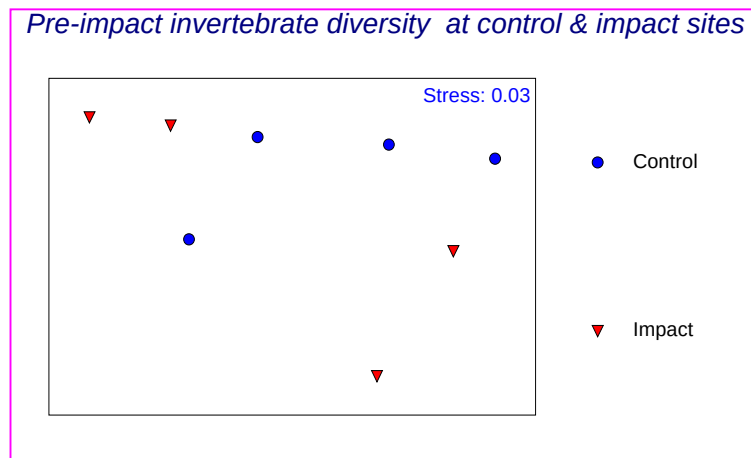


Figure 19: Ordination of 8 monitoring sites indicating no clear grouping of control and impact sites

These trends are more visible when presence /abundance data for individual 1m x1m quadrats was examined in MDS plots (Figure 20). Plots in different zones are similar (left) but no real differences between control and impact sites currently exists (right). Sites appear to be relatively undisturbed although previous cyclone damage and farm operations may have had some effect on faunal communities. However, the overall result shows no clear patterns amongst control and impact locations. Clearly this is a desirable result for site selection at the commencement of a monitoring program).

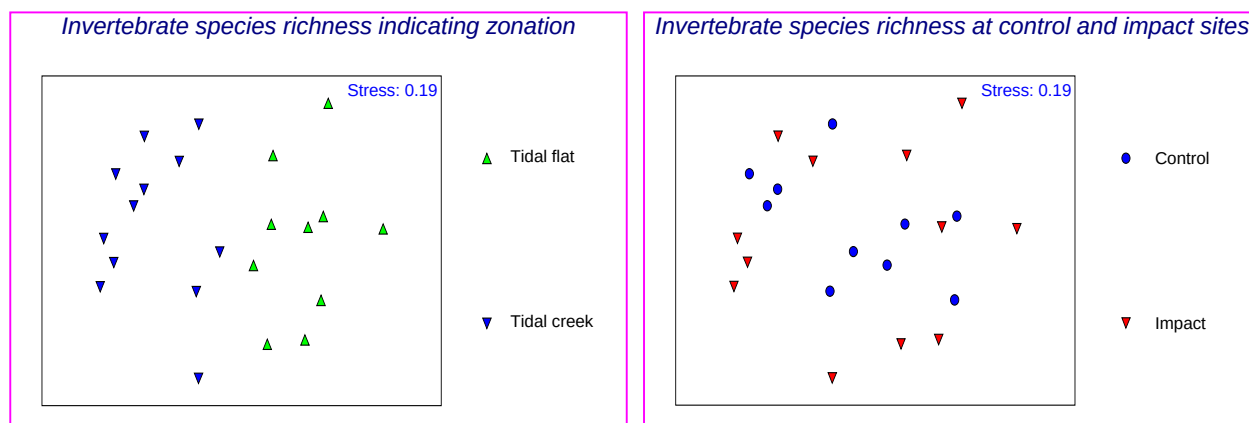


Figure 20: Ordinations of pre-impact species diversity data for 1m² plots indicating clear zonation of fauna (upper) and no clear pattern between control & impact sites

7. SUMMARY

Experimental design, development of methodology, site selection, establishment and pre-construction mangrove monitoring was completed during late October and early November 2004. The monitoring program was designed with a view to practicality and cost-efficiency whilst following the previously trialed methodology of the NT Government's Mangrove Monitoring Program and recent research methodologies. Adoption of previously trialed monitoring techniques will ensure a productive and thorough program is established plus it will allow the mutual interchange of valuable data. Due to the proposed discharge of pond water directly into mangroves rather than into a downstream water body, some site-specific monitoring (soil salinity, conductivity and pH) was added to this program..

The monitoring program was designed in accordance with guidelines for environmental monitoring listed in the *Environmental Code of Practice for Australian Prawn Farmers* (Donovan, 1999). Monitoring conforms with the code by incorporating data from control sites, and by using scientifically accepted sampling techniques that allow comparison of data with baseline background data. Monitoring will be undertaken at an appropriate frequency (6 monthly interim monitoring and comprehensive annual sampling) within an appropriate (long-term) time frame. Once construction is complete, monitoring may be scaled back significantly to an appropriate frequency and level of detail for the operational phase. The project has been designed to provide data that can distinguish between effects of prawn farming and natural levels of variation and natural environmental change.

Interim monitoring will be undertaken by the consultant in April/May 2005 (6 months after initial monitoring) and comprehensive annual monitoring will be repeated in October/November 2005. Interim monitoring will involve photo-monitoring, seedling and sapling counts, soil monitoring, sediment gauging and invertebrate fauna monitoring to examine seasonal change (and to provide data from a second, valuable pre-impact sampling event).

This monitoring program is the most thorough and comprehensive for any aquaculture project established in Darwin Harbour to date and may provide a template for future similar prawn farm proposals of a similar scale in the Northern Territory. Ultimately the results of monitoring will make a significant contribution to our understanding of mangrove ecology and the environmental impacts of aquaculture developments within Darwin Harbour.

The invertebrate fauna sampling will be undertaken again in April/May 2005, at the same time as interim monitoring, to gain a more representative pre-construction baseline. Invertebrate species richness and abundance varies seasonally, with pronounced differences in the upper tidal zones from wet to dry (Metcalf, in prep). Thus late wet season sampling will provide better information on the invertebrate fauna present and a second pre-construction or 'before' data set adds greatly to the strength of the experimental design and statistical analyses.

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APPENDICES

APPENDIX 1: FLORA SPECIES LIST

Checklist of plant species recorded during field surveys of the Aussie Prawns survey area during fieldwork from 18th October to 20th November 2004

MANGROVE COMMUNITIES (12 species)		
Map Unit	Species	Family
1	Tidal creek	
	<i>Avicennia marina</i>	Verbenaceae
	<i>Aegiceras corniculatum</i>	Myrsinaceae
	<i>Bruguiera parviflora</i>	Rhizophoraceae
	<i>Camptostemon schultzei</i>	Bombacaceae
	<i>Ceriops australis</i>	Rhizophoraceae
	<i>Rhizophora stylosa</i>	Rhizophoraceae.
2	Tidal flat	
	<i>Aegialitis annulata</i>	Plumbaginaceae
	<i>Avicennia marina</i>	Verbenaceae
	<i>Ceriops australis</i>	Rhizophoraceae
3	Hinterland margin	
	<i>Avicennia marina</i>	Verbenaceae
	<i>Bruguiera exaristata</i>	Rhizophoraceae
	<i>Ceriops australis</i>	Rhizophoraceae
	<i>Excoecaria ovalis</i>	Euphorbiaceae
	<i>Lumnitzera racemosa</i>	Combretaceae
	<i>Pluchea indica</i>	Asteraceae
4	Salt flat	
	<i>Aegialitis annulata</i>	Plumbaginaceae
	<i>Avicennia marina</i>	Verbenaceae
	<i>Ceriops australis</i>	Rhizophoraceae
	<i>Halosarcia indica</i>	Chenopodiaceae
	<i>Suaeda arbusculoides</i>	Chenopodiaceae

UPLAND COMMUNITIES

**Map
Unit****Species****5****Mixed Eucalypt Woodland**

Upper stratum species:

Acacia auriculiformis
Alstonia actinophylla
Eucalyptus tetrodonta
Eucalyptus miniata
Eucalyptus tectifica
Corymbia bella
Corymbia bleeseri
Corymbia confertiflora
Corymbia polycarpa
Erythrophleum chlorostachys
Lophostemon lactifluus
Melaleuca leucadendra
Melaleuca viridiflora

Mid-stratum species:

Acacia mimula
Acacia holosericea
Acacia latescens
Acacia oncinocarpa
Brachychiton diversifolius
Brachychiton megaphyllus
Bridelia tomentosa
Buchanania obovata
Calytrix brownii
Corymbia foelscheana
Cycas armstrongii
Dolichandrone filiformis
Gardenia megasperma
Grevillea decurrens
Grevillea pteridifolia
Flueggia virosa
Hakea arborescens
Livistona humilis
Melaleuca viridiflora
Pandanus spiralis
Persoonia falcata
Planchonia careya
Pogonolobus reticulatus
Pouteria arnhemica
Syzygium eucalyptoides spp. *eucalyptoides*
Terminalia ferdinandiana
Wrightia saligna
Xanthostemon paradoxus

Ground layer species:

★*Andropogon gayanus*
Ampelocissus acetosa
★*Chloris inflata*
Chrysopogon fallax
Cyperus scariosus
Distichostemon hispidulus
Eriosema chinense
Fimbristylis cymosa
Fimbristylis polytrichoides
Grevillea dryandrii
Heteropogon triticeus
★*Hyptis suaveolens*
Ischaemum australe
★*Passiflora foetida*
★*Pennisetum pedicellatum*
★*Pennisetum polystachion*
Petalostigma quadriloculare
Sorghum sp.
Tephrosia lamproloboides
Xerochloa imberbis

6

Vine-forest (Jungle)

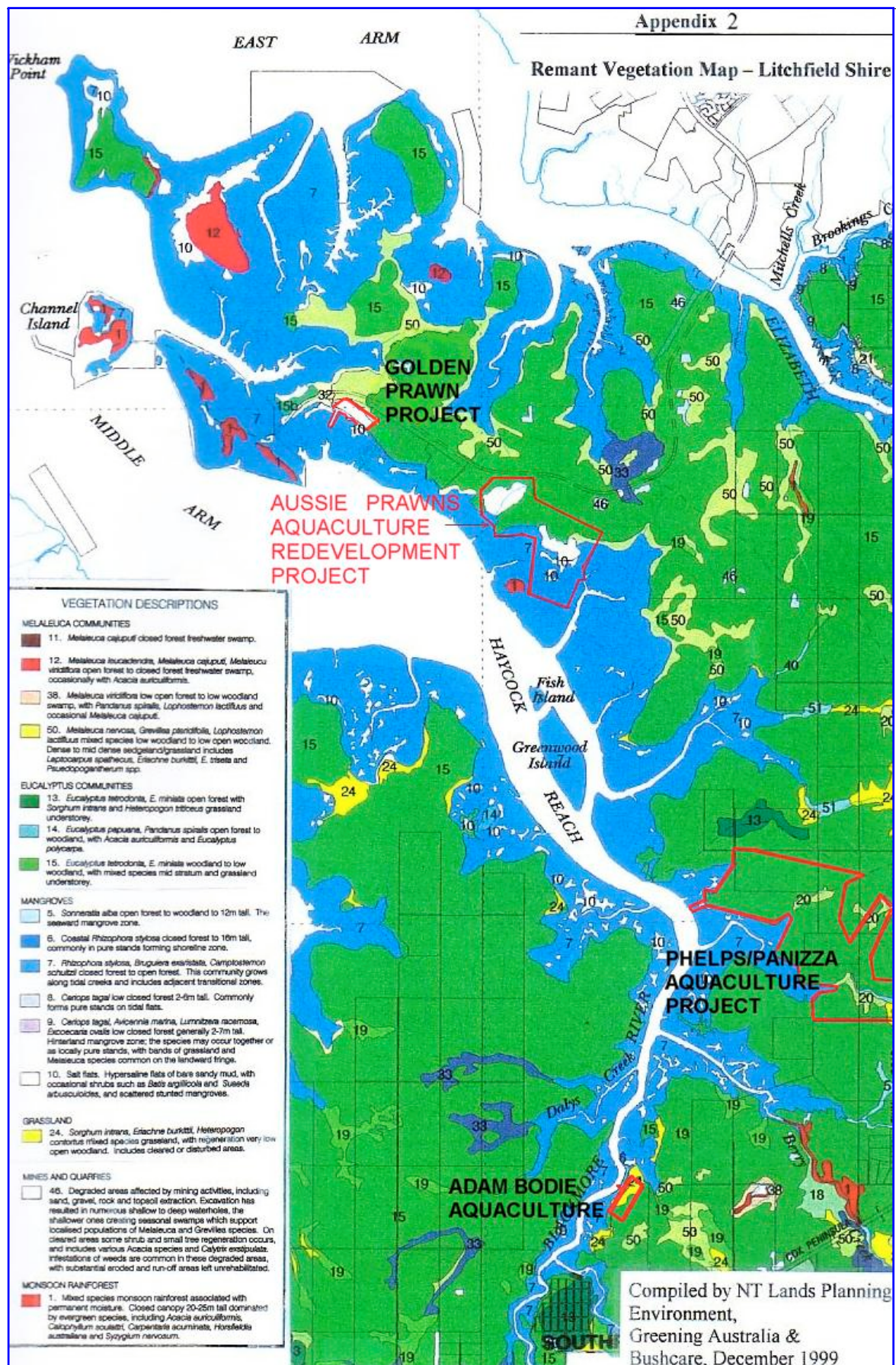
Acacia auriculiformis
Adenia heterophylla
Alyxia spicata
Antidesma ghaesembilla
Croton arnhemicus
Eucalyptus tectifica
Exocarpos latifolius
Flagellaria indica
Gymnanthera nitida
Jasminum aemulum
Memecylon pauciflorum
Mimusops elengi
Parsonsia velutina
Premna acuminata
Sterculia quadrifida

★ denotes introduced weed species

Includes species recorded by Leach and Dunlop within project area for original Haycock Reach Aquaculture Project EIS (1992).

APPENDIX 2: REMNANT VEGETATION MAP - LITCHFIELD SHIRE

Map showing vegetation communities of the local area and the approximate location and extent of prawn farms along the Blackmore River



APPENDIX 3: INVERTEBRATE SPECIES RECORDED DURING INITIAL SURVEYS

Species name	Family	Taxonomic Group
<i>Talitridae</i> unident.sp	Amphipoda	amphipod
<i>Microeuraphia withersi</i>	Chthamalidae	barnacle
<i>Brachidontes maritimus</i>	Mytilidae	bivalvia
<i>Entodesma</i> sp.	Lyonsiidae	bivalvia
<i>Glaucanome plankta</i>	Glauconomidae	bivalvia
<i>Camptandrium</i> sp. nov. 1	Camptandriidae	crab
<i>Cleistostoma</i> sp. nov.	Camptandriidae	crab
<i>Clibanarius longitarsus</i>	Diogenidae	crab
<i>Clistocoeloma merguiensis</i>	Grapsidae/Sesarminae	crab
crab immature	Unknown	crab
<i>Epixanthus dentatus</i>	Xanthidae	crab
<i>Heteranope longipedes</i>	Pilumnidae	crab
<i>Paracleistostoma</i> sp. nov. (cf. <i>wardi</i>)	Camptandriidae	crab
<i>Parasesarma moluccensis</i>	Grapsidae/Sesarminae	crab
<i>Perisesarma darwinensis</i>	Grapsidae/Sesarminae	crab
<i>Perisesarma semperi</i>	Grapsidae/Sesarminae	crab
<i>Sarmatium</i> sp.	Grapsidae/Sesarminae	crab
<i>Scylla serrata</i>	Portunidae	crab
<i>Sesarmoides borneensis</i>	Grapsidae/Sesarminae	crab
<i>Uca flammula</i>	Ocypodidae/Ocypodinae	crab
<i>Uca</i> immature	Ocypodidae/Ocypodinae	crab
<i>Uca</i> indeterminate	Ocypodidae	crab
<i>Uca signata</i>	Ocypodidae/Ocypodinae	crab
Unidentified crab	Unknown	crab
<i>Periopthalmus darwini</i> nsp	Gobiidae	fish
<i>Periopthalmus</i> undet	Gobiidae	fish
<i>Auriculastra subula</i>	Ellobiidae	gastropod
<i>Cassidula</i> aff. <i>doliolum</i>	Ellobiidae	gastropod
<i>Cassidula angulifera</i>	Ellobiidae	gastropod
<i>Cerithidea largillierti</i>	Potamididae	gastropod
<i>Cerithidea obtusa</i>	Potamididae	gastropod
<i>Chicoreus capucinus</i>	Muricidae	gastropod
<i>Littoraria articulata</i>	Littorinidae	gastropod
<i>Littoraria filosa</i>	Littorinidae	gastropod
<i>Melampus</i> sp.	Ellobiidae	gastropod
<i>Nerita balteata</i>	Neritidae	gastropod
<i>Onchidium</i> sp.7.	Onchidiidae	gastropod
<i>Onchidium</i> undetermined	Onchidiidae	gastropod
<i>Telescopium telescopium</i>	Potamididae	gastropod
<i>Terebralia palustris</i>	Potamididae	gastropod
<i>Terebralia semistriata</i>	Potamididae	gastropod
<i>Isopoda</i> unident.sp.	Isopoda	isopod
<i>Polychaeta</i> undet	Polychaeta	worm
<i>Sipuncula</i> sp.	Sipunculidae	worm

APPENDIX 4: FLORA SUMMARY TABLES

Table 4-1: Summary table of vegetation characteristics at monitoring sites, November 2004

Time	Location	Zone	DBH mean (cm)	Basal area mean (m ² ha ⁻¹)	Species	Total stem count (per 100m ²)	Stems /ha	Relative Density (%)
1	PC1	TIDAL FLAT	4.8	18	Am Ca Total	61 16 76	6100 1600 7700	80.3 21.1
1	PC2		4.8	18	Am Ca Total	25 9 34	2500 900 3400	73.5 26.5
1	PC3		3.1	8	Am Ca Be Total	13 160 2 175	1300 16000 200 17500	7.4 91.4 1.1
1	CC1		4.2	14	Am Ca Total	45 23 68	4500 2300 6800	66.2 33.8
1	CC2		4.7	17	Am Ca Total	71 7 78	7100 700 7800	91.0 9.0
1	PR1	TIDAL CREEK	3.8	11	Rs Bp Cs Total	8 138 9 155	800 13800 900 15500	5.2 89.0 5.8
1	PR2		5.1	20	Rs Bp Cs Total	24 78 5 107	2400 7800 500 10700	22.4 72.9 4.7
1	CR1		5.2	21	Am Ca Rs Bp Cs Total	1 15 6 75 6 103	100 1500 600 7500 600 10300	1.0 14.6 5.8 72.8 5.8
1	CR2		5.3	22	Rs Bp Cs Total	11 56 1 68	1100 5600 100 6800	16.2 82.4 1.5

Am – *Avicennia marina*Be – *Brugiera exaristata*Bp – *Bruguiera parviflora*Ca – *Cerriops australis*Cs – *Camptostemon schultzei*Rs – *Rhizophora stylosa*

Table 4.2: Summary table of diameter at breast height (dbh) of 30 tagged trees at monitoring sites

LOCN	ZONE	Mean No. Stems	Mean diameter (cm)
PC1	Tidal Flat	1.8	7.7
PC2		1.4	4.8
PC3		1.2	4.7
CC1		1.6	7.3
CC2		1.2	5.8
PR1	Tidal Creek	1.1	7.6
PR2		1.0	6.4
CR1		1.0	11.5
CR2		1.0	7.3

Table 4.3: Raw data for 5 sediment gauges at each monitoring site

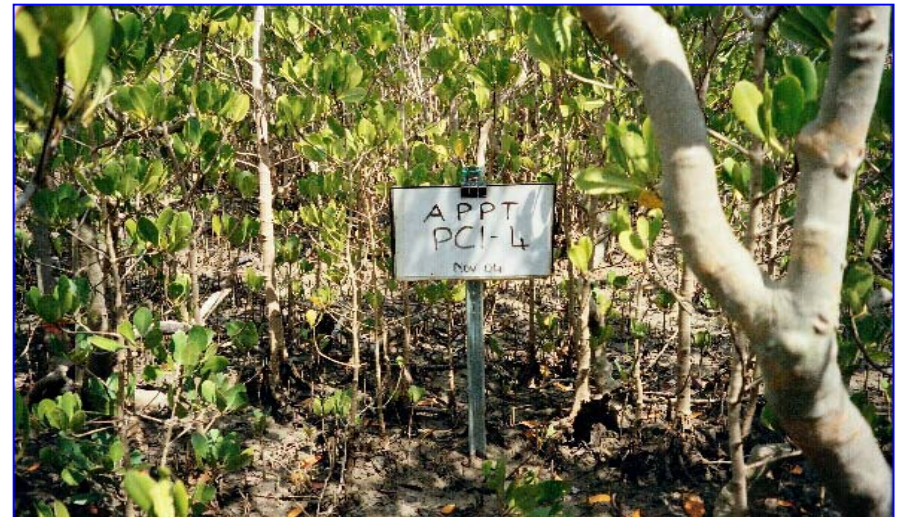
Site	Zone	Gauge 1	Gauge 2	Gauge 3	Gauge 4	Gauge 5	Mean Height (cm)
PC1	TIDAL FLAT	100.7	99.2	99.5	100.0	100.0	99.9
PC2		99.0	100.2	100.3	100.3	99.8	99.9
PC3		79.5	79.0	80.0	77.9	80.2	79.3
CC1		100.5	100.0	99.2	101.3	99.5	100.1
CC2		100.5	100.0	99.8	100.2	95.0	99.1
PR1	TIDAL CREEK	98.3	98.0	98.9	97.7	88.3	96.2
PR2		98.5	100.0	98.6	100.0	99.0	99.2
CR1		99.2	95.8	98.3	99.3	100.6	98.6
CR2		98.5	100.0	99.5	100.0	100.0	99.6

APPENDIX 5: PHOTO-MONITORING IMAGES

CONTROL SITE 1 – TIDAL FLAT ZONE
QUADRAT CCI



IMPACT SITE 1 – TIDAL FLAT ZONE
QUADRAT PCI



CONTROL SITE 2 – TIDAL FLAT ZONE
QUADRAT CC2



IMPACT SITE 2– TIDAL FLAT ZONE
QUADRAT PC2



IMPACT SITE 3 – TIDAL FLAT ZONE
QUADRAT PC3 (to replace PC2)



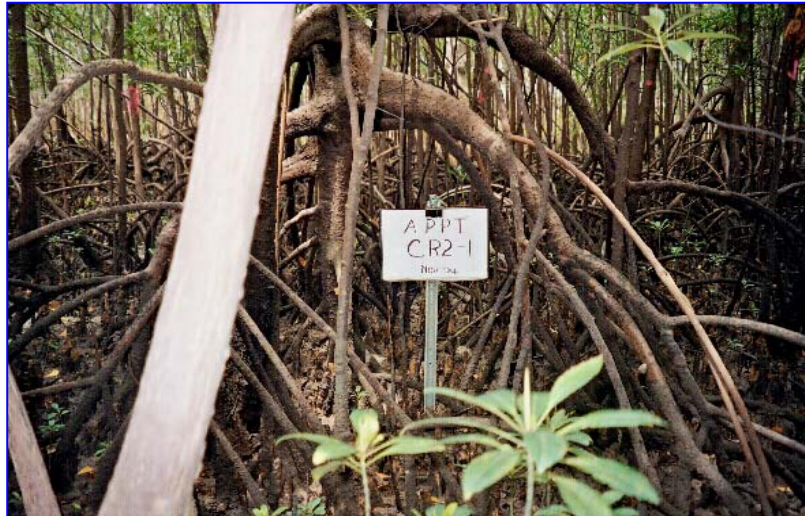
CONTROL SITE 1- TIDAL CREEK ZONE
QUADRAT CRI1



IMPACT SITE 1 – TIDAL CREEK ZONE
QUADRAT PR1



CONTROL SITE 2 – TIDAL CREEK ZONE
QUADRAT CR2



**IMPACT SITE 2 – TIDAL CREEK ZONE
QUADRAT PR2**



APPENDIX 6: SELECTION OF SITE PHOTOGRAPHS

THE EXISTING INTERTIDAL ENVIRONMENT



1. Tidal creek habitat near the saltwater intake jetty (left)
2. *Rhizophora stylosa* & *Bruguiera parviflora* in tidal creek habitat
3. Saltflat in front of tidal flat mangroves and taller tidal creek zone (in distance)
4. Abundant molluscs (*Telescopium telescopium*) in pond drainage channel
5. Tidal flat mangroves with dense *Ceriops australis* (below)
6. Extensive saltflats occur between the development area and the more seaward mangrove communities



EXISTING INFRASTRUCTURE



The APPL site has an existing 33.1ha freshwater dam (left) and a 3.2 ha saltwater dam (right)



The development site has an established saltwater supply jetty and several functional ponds



Existing bund walls and infrastructure will be removed when new ponds are constructed

EXISTING DISTURBANCE TO INTERTIDAL COMMUNITIES



1. Extensive prior clearing of *hinterland margin* mangroves in the lease area
2. The current pond area is fringed with by a complex of disused ponds and regenerating mangroves
3. The pond drainage channel located between sites PC2 and PC2 – near the proposed spillway location
4. Saltflat species (*Sueda arbusculoides*) occur in the saline conditions in old ponds
5. Erosion and debris were observed downstream in the main pond drainage channel

