INPEX

Darwin Harbour –
A Summary of the Ichthys LNG Project Nearshore Environmental Monitoring Program

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The Ichthys LNG Project is a Joint Venture between INPEX group companies (the Operator), major partner Total and the Australian subsidiaries of Tokyo Gas, Osaka Gas, Chubu Electric Power and Toho Gas.

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Executive Summary

The Ichthys LNG Project (the Project) comprises the development of offshore production facilities at the Ichthys Field in the Browse Basin and onshore processing facilities and product loading jetty at Bladin Point in Darwin Harbour, which are to be connected via an 889 km long subsea gas export pipeline (GEP). The Project's dredging programs were designed and approved to safely dredge and dispose of approximately 16.1 Mm^3 of material to create a safe shipping channel and berthing area in East Arm, and 0.466 Mm^3 for a trench to seat the Darwin Harbour section of the GEP. Dredged material was placed at an offshore spoil disposal area in Beagle Gulf, 22 km north of Darwin and 12 km northwest of Lee Point. Dredging for the East Arm program was completed over two 'seasons': Season One from late August 2012 to the end of April 2013 and Season Two from early November 2013 to mid-June 2014. Dredging for the GEP was completed in stages over nine months from late October 2013 to mid-July 2014.

Outside the direct impacts from physical removal and placement of material in the dredging and spoil disposal areas, the primary influence from dredging and spoil disposal activities on the marine environment is from the mobilisation of sediments within the water column and the subsequent dispersal, settlement and accumulation of suspended sediments by natural processes. This can reduce the amount of light penetrating through the water column for photosynthesising organisms such as corals, seagrass and phytoplankton. Accumulation of sediments may also lead to smothering and burial of organisms inhabiting the seabed or intertidal areas, such as mudflats and mangroves. Such impacts may potentially have subsequent flow on effects to other components of the ecosystem.

In order to understand the potential for environmental impacts, sediments released from dredging and spoil disposal activities were modelled to guide predictions of potential influences and impacts to corals, seagrass and mangroves. When assessing the effect of dredging and spoil disposal activities on these communities, water quality (specifically turbidity and light) and sedimentation are important measures to assist in determining both the cause (i.e. relative importance of the dredging-related and natural effects) and the ecological significance of any change.

The Nearshore Environmental Monitoring Plan (NEMP) was developed to monitor for such

potential environmental impacts in the Darwin region. In the case of water quality, corals, mangroves and seagrass, this included the development of triggers that, if exceeded, would initiate a targeted monitoring and management response designed to manage any potential impacts within the limits of acceptable loss. In addition, the monitoring program aimed to gather contextual information to improve the scientific understanding of the environmental impacts of dredging, and it has also resulted in a deepening of our knowledge of Darwin's unique marine environment.

Thirteen environmental monitoring programs have been undertaken for the Project since 2012. Twelve of these form the NEMP, ten of which are reported here (the hydrodynamic model validation and underwater noise monitoring programs were used to collect data for validation purposes). The thirteenth is the Coastal Dolphin Monitoring Program undertaken in collaboration with the Department of Land Resource Management and is reported on periodically. This report presents a summary of the observed influences and impacts of the Project's dredging and spoil disposal activities, as well as some of the interesting findings collected during the course of the monitoring program to date. Post-dredging monitoring is underway and will continue into 2015. This report presents a summary of the observed influences and impacts of the Project's dredging and spoil disposal activities, as well as some of the interesting findings collected during the course of the monitoring program to date.

Darwin Harbour and its surrounds are characterised by large tides (up to 8 m tidal range), and distinct wet and dry seasons, both of which have a unique influence on local water quality. This in turn has shaped the habitats and communities of the region's marine life. The Harbour itself is fringed by thick and impenetrable mangrove forests that give way to the intertidal mud flats and rocky outcrops that delve into the deeper channels, which are partially filled and emptied with the tide. During every tidal cycle, large volumes of water from the Harbour are exchanged with the Beagle Gulf, where key seagrass habitats can be found in shallow intertidal and subtidal coastal areas. Turtles and small populations of dugongs and dolphins have been observed in the region, which is also popular with recreational fishermen targeting iconic species such as barramundi and mud crab.

As part of the monitoring program, water quality was measured adjacent to coral and seagrass communities to provide an early warning of potential elevated turbidity. This formed the basis for assessing the effects of dredging and spoil disposal activities on these communities. While gathering background information, it became clear that turbidity varies predominantly with the spring-neap tidal cycle and waves, with winds and rainfall/runoff also contributing to turbidity variability. Large tidal movements and strong currents in Darwin naturally generate high turbidity, particularly during spring tides when about 50% of Harbour waters are exchanged with the Beagle Gulf. There is also a clear seasonal influence, with turbidity significantly increasing at the onset of the wet season due to the effects from increased wave intensity, wind and rainfall. Turbidity is most extreme during the passage of tropical cyclones or tropical storms near Darwin. During such events, there were times when no light reached the seabed, with blackout (darkness) periods ranging between two and 16 days at some seagrass and coral monitoring sites.

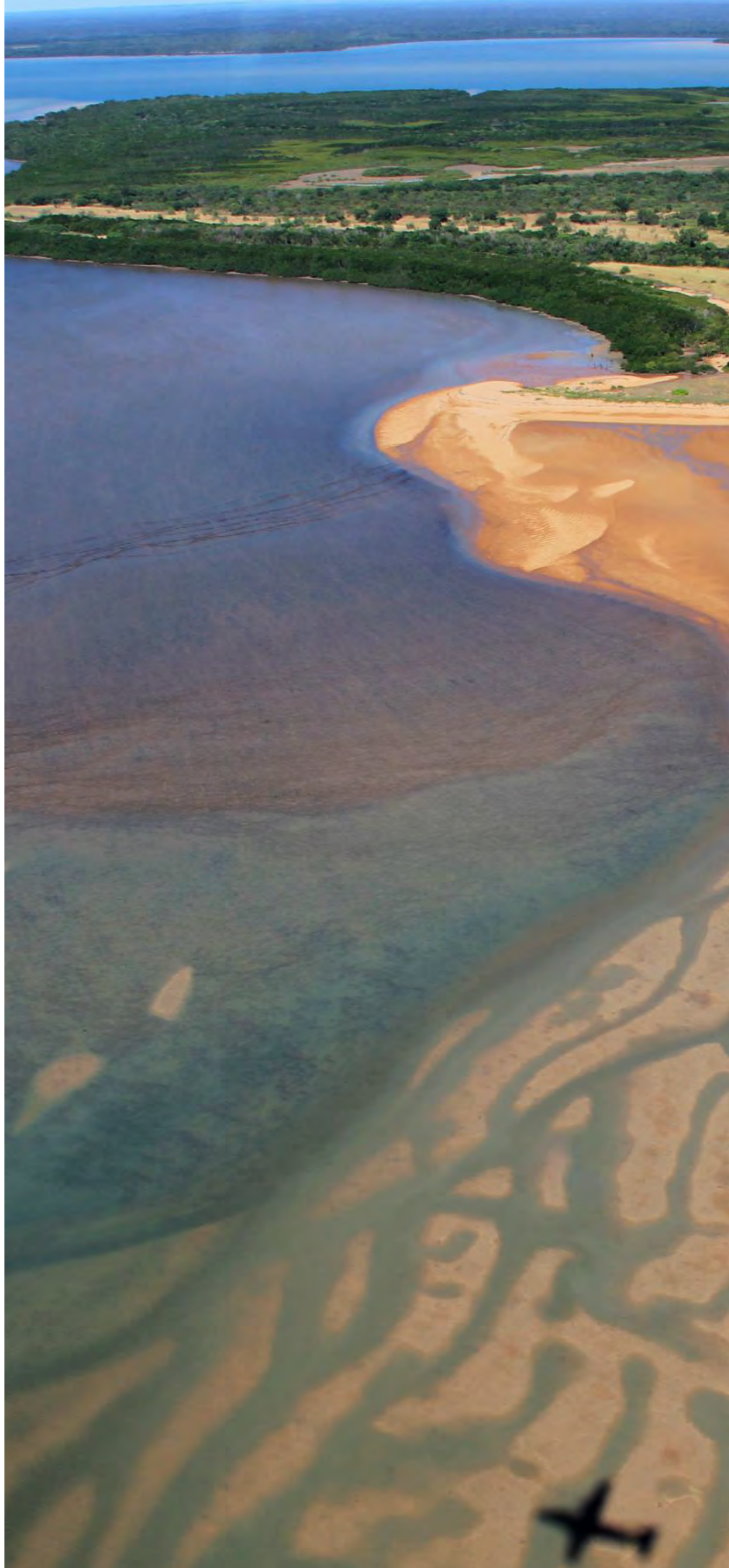
These natural background conditions were important in understanding and contextualising the dredging influence on turbidity and light. With the exception of the sites closest to dredging in East Arm (South Shell Island and Northeast Wickham Point), turbidity remained within the range of natural variation at all other monitoring sites throughout the majority of the monitoring program. Episodic events (tropical cyclones and storms) in the wet season caused elevated turbidity at much higher intensities and across larger areas than anything observed from dredging-excess turbidity alone. During Season One dredging, the spatial extent of the dredging-related suspended sediment plumes were observed to be largely limited to East Arm, and turbidity measurements at all sites outside of East Arm were typical of wet season conditions. During Season Two, dredging plumes were generally similar to Season One and limited to East Arm during neap tides, with a potential minor contribution further afield during spring tides late in Season Two (May/June 2014). Plumes near the spoil disposal area were observed during peak phases of the dredging program, typically associated with peak spring tides when tidal currents were strongest. The magnitude and extent of dredging-excess turbidity (where discernable) returned to background conditions within two weeks following the completion of dredging activities for both Seasons One and Two. In addition, there was no evidence of dredging-related impacts to seagrasses and mangrove communities measured at various locations, while impacts to corals were isolated to one site (South Shell Island) within close proximity to dredging in East Arm.

Hard corals exist in Darwin Harbour despite it being an environment that appears largely unsuitable for their survival. Remarkably, the coral communities survive the combined pressures of the naturally occurring high turbidity, low light environment with a substantial natural sediment load. Additional stressors include strong currents, high water temperatures at times, exposure during spring low tides and sudden changes in salinity from high rainfall events. These hardy corals must also cope with the typical biological pressures that affect all coral communities, regardless of their location, such as disease, predation and competition with other corals and organisms. As predicted, no detectable dredging-related impacts to corals were observed at monitoring sites outside of East Arm, as informed by measurements of bleaching and mortality of tagged corals, and coral cover along transects. Even when turbidity was naturally very high and light levels were very low (such as during and after the passing of tropical cyclones and storms), very little change to corals were measured, suggesting a natural resilience of these communities to such conditions.

Of the two sites in East Arm predicted to be impacted by dredging (Northeast Wickham Point and South Shell Island), there were no distinct changes to corals at Northeast Wickham Point. Some impacts were observed at South Shell Island later in the monitoring program. Monitoring at this site indicated an increase in sediment on coral and a slight reduction in coral cover, potentially as a consequence of dredging.

No dredging-related impacts to seagrass habitats were observed during the program. Turbidity measured at seagrass monitoring sites was within the general range of natural variation. As such, there was no evidence of a subsequent dredging-related decline in levels of light, one of the key mechanisms by which dredging was predicted to affect photosynthesising seagrasses. The seagrass habitat in the Darwin region is dominated by two fast growing, early colonising species that are known to survive well in disturbed environments - Halophila decipiens and Halodule uninervis. Natural fluctuations in the cover and distribution of these species were far greater than predicted dredging-related impacts. Wet season conditions drive natural widespread decline of seagrasses in the Darwin Outer region, while the dry season is generally favourable for seagrass growth. As such, there have been large natural changes in the percentage cover of H. uninervis and considerable and rapid natural changes in the distribution of H. decipiens. In particular, the spatial extent and percentage cover of H. decipiens changed dramatically through time, with complete absence from all surveyed areas during the wet seasons followed by strong recovery and habitat expansion during the dry seasons.

Mangrove forests act as a buffer between the land and the sea. Being intertidal, they are submerged at high tide and exposed at low tide. Mangroves possess the ability to actively and passively trap sediment. However, excessive accumulation of dredged sediments was predicted to potentially impact mangrove health. Measurement of sedimentation levels in mangrove assemblages during the monitoring program were below the level considered to potentially impact mangrove health (>50 mm). Measures of mangrove health, such as canopy cover and seedling growth and survival, indicated no recordable dredging-related changes at monitoring sites. Broad scale measurements of mangrove health captured by remote sensing also found no indications of dredging-related impacts.



During the monitoring program mangroves showed a distinct response to seasonal rainfall. Metocean conditions such as wind and waves were also shown to play a role in affecting the physical processes occurring within the mangroves, particularly in the assemblages adjoining the open water of the Harbour. In addition, Darwin's mangroves were shown to support a high diversity of faunal species, with a total of 393 different species recorded during the program. Of these, 68 are new records for Darwin Harbour mangroves and one species of worm (Dendronereis sp.) had never previously been found in Australia. The main taxonomic groups recorded were crustaceans, molluscs and worms, with the remaining species being predominantly ants and fish.

Estimates of primary productivity for mangroves (measured by leaf litter fall in the Tidal Flat assemblage), water column phytoplankton and microphytobenthos (MPB) on intertidal mudflats at monitoring sites also indicated no detectable dredging-related impacts.

Recreational fishing is a highly popular activity undertaken in Darwin Harbour and surrounding waterways by local residents and visitors to the Northern Territory (NT). The monitoring program found no evidence of dredging-related impacts to fish health and catches. Furthermore, there were no fish kills attributed to Project activities. It was noted that there was some displacement of recreational fishermen from East Arm, mostly due to fishermen having to avoid Project safety exclusion zones around dredging vessels and construction infrastructure. Research fishing activities undertaken for the monitoring program found that recreationally popular finfish such as golden snapper, Moses snapper, javelin, blue tuskfish, grass emperor, stripey snapper and goldspotted rockcod dominated research angling catches, while mud and sand crabs were commonly sampled in pots.

A small proportion of the fish and crabs caught were retained and underwent extensive internal and external scientific examinations to identify and monitor the types of parasites and infections that naturally occur in fish and crab populations in Darwin Harbour and surrounding waters. Five parasite species new to science were identified during the monitoring program, including philometrid nematodes (Philometra australiensis, P. macrochiri and P. zabidii) and dactylogyrid monogeneans (Euryhaliotrema longibaculoides and E. lisae) and have since been scientifically described in peer-reviewed journals.

Dugongs and turtles are iconic species; however, prior to the monitoring program, little was known about their density or distribution around the Darwin region. During monitoring surveys, dugongs were regularly observed in the Darwin Outer area of the Beagle Gulf, presumably foraging on seagrass habitats, their preferred diet, as well as possibly feeding opportunistically on algal-covered rocky reefs. Four turtle species are known to occur around the Darwin region; green, hawksbill, olive ridley and flatback turtles, with green turtles being most commonly sighted around Darwin Harbour. Importantly, there have been no noticeable changes to the distribution of turtles and dugongs within the Darwin Harbour area that would indicate a potential influence of dredging.

Dugong population estimates have remained low and consistent over time, suggesting a relatively

small population that inhabits the Darwin region of approximately 180 to 300 individuals. Population estimates for turtles have been much higher, ranging between 500 and 1,000 individuals. Dugong sightings varied across space and time and this is thought to be due to a number of factors, most likely the inherent behaviour of dugongs being highly mobile and constantly submerging in search of foraging grounds, as well as changes in the distribution of seagrass, which they feed on. Sightings of turtles, however, have remained consistent over time with both juvenile and adult green turtles regularly observed around both reef and non-reef habitats. Green turtles in particular have been sighted in relatively high abundance during the monitoring program, displaying behaviour consistent with foraging, where adults are thought to feed predominantly on seagrass and seaweed, but may also feed on mangrove fruit, jellyfish and sponges.

A particularly exciting aspect of the monitoring program was the satellite tagging of four juvenile green turtles, named Malakai, Chloe, Hendrix and Pepin. A vast collection of data was transmitted from the tagged turtles providing fascinating information about their movements around Darwin Harbour. The turtles remained relatively close to where they were captured and released near Channel Island, with all four turtles staying primarily within a 2.5 km range of this location. This is a unique aspect of juvenile green turtle biology that has not yet been determined in studies elsewhere. On one occasion, Chloe and Pepin travelled briefly up to 10 km outside their home range; however both returned to their home ranges within a week.

Despite being less photogenic than turtles and dugongs and hidden under the ocean, the marine life inhabiting the soft bottom intertidal and subtidal habitats is equally as fascinating. The seemingly barren sediments provide habitat for a rich and taxonomically diverse assemblage of invertebrates that fulfil a multitude of ecological roles. These include polychaete worms, crustaceans (including crabs and prawns), molluscs, echinoderms (sea stars, sea urchins, sea cucumbers) and other worm-like taxa. Monitoring of infauna (animals living within the sediments) in intertidal mudflats indicated no dredging-related impacts.

Potential dredging-related changes to the abundance and diversity of infauna were observed at sampling sites within the deeper, subtidal zone of the Harbour, particularly around East Arm following dredging Season One. The mechanism for the observed changes was unclear as there was no obvious link between measured sediment characteristics (which showed no significant change) and changes in infauna and it is therefore inconclusive whether dredging-excess suspended sediments impacted these infaunal assemblages. It is also possible that naturally occurring hydrographic, or unmeasured physico-chemical or biotic factors may have influenced these changes. The animals living on the surface of the seabed (epifauna), also within the subtidal zone, were not affected by dredging-related activities within the Harbour. As predicted, dredging-related impacts to both infauna and epifauna were observed within the offshore spoil disposal area following Season One dredging, likely to be a result of the direct placement of dredged material on the seabed.

Given the number and type of vessels entering Darwin Harbour as part of the Project, a Marine Pest Monitoring Program was implemented to ensure early detection of potential marine pests

(plants or animals that are not native to a region (usually introduced from overseas) that can have a significant impact on our marine industries and environment). Two species from the target marine pest list were identified during the targeted monitoring program; however their presence was not attributable to Project-related activities as they were identified as being present prior to the commencement of the Project and were also present in other areas of the NT. Neither species displayed invasive pest-like characteristics. A third species was found on the hull of a cargo vessel containing both Project and non-Project related bulk goods during routine maintenance; however, follow-up monitoring found no evidence of establishment of this species in the surveyed areas of Darwin Harbour.

Prior to the commencement of the Project, limited information was available about many of the key processes and ecosystems within the Darwin marine environment, as well as the tolerance of the local plant and animal communities to potential dredging-related influences and impacts. Due to the comprehensive nature of the monitoring program, a vast array of unique and valuable information was collected about Darwin Harbour and its surrounds, subsequently improving the understanding of the environment.

This report provides a description of Darwin's distinctive environmental setting to set the scene for the Project's dredging programs and the NEMP. The setting also provides context for interpreting the predicted and observed environmental influences and impacts of dredging, followed by a summary of the interesting findings. These consolidated findings, along with the detailed technical reports from which they were drawn, represent a valuable contribution to the body of knowledge on Darwin's marine environment.

Table of Contents

1 Introduction

Introduction

The Ichthys LNG Project (the Project) is a Joint Venture between INPEX group companies (the Operator), major partner Total and the Australian subsidiaries of Tokyo Gas, Osaka Gas, Chubu Electric Power and Toho Gas. The Project comprises the development of offshore production facilities at the Ichthys Field in the Browse Basin, some 820 km west-south-west of Darwin, an 889 km long subsea gas export pipeline (GEP) and an onshore processing facility and product loading jetty at Bladin Point on Middle Arm Peninsula in Darwin Harbour (Figure 1).

As part of the construction of its onshore facilities, the Project needed to create a safe shipping channel through Darwin Harbour, along with a berthing area for tanker vessels transiting to the gas processing facilities at Bladin Point, in East Arm. Dredging was also required on the western side of the Harbour to create a trench for the Project's GEP and piling was undertaken for the construction of the product offloading jetty and Module Offloading Facility (MOF).

Cardno, one of the Project's major environmental service providers, has developed the Nearshore Environmental Monitoring Plan (NEMP) (Cardno 2014) and implemented the Nearshore Environmental Monitoring Program. The NEMP monitors for potential environmental impacts arising from the Project's dredging and disposal activities in the Darwin region before, during and after the construction phases of the Project.

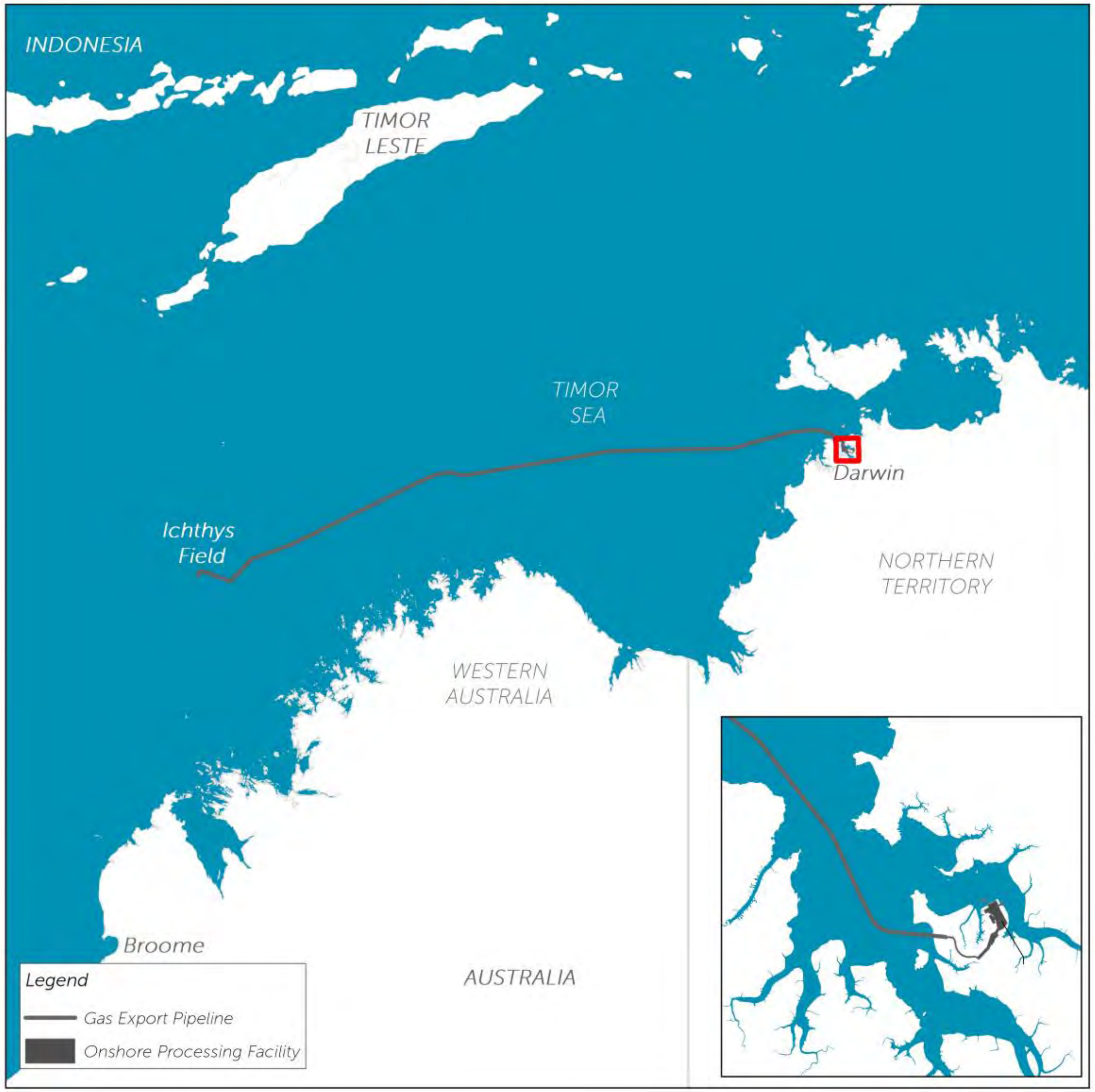


Figure 1 Ichthys LNG Project Location

Objectives and Outline of Report

This report provides an overview and summary of the findings of the Nearshore Environmental Monitoring Program following the completion of the Project's dredging and spoil disposal activities.

A great deal of unique and valuable information has been collected throughout the monitoring program to date, which has led to an improved understanding of Darwin Harbour and its surrounds. By consolidating these findings in one report to complement detailed technical reports, it is hoped that this monitoring program will contribute to the body of knowledge on Darwin's marine environment.

The report begins with an introduction to the Project, dredging and spoil disposal activities and the NEMP (this chapter). Darwin's environmental setting is then described in Chapter 2, Environmental Setting, to provide an overview of the environmental drivers that influence this unique marine ecosystem and that are critical in the management and monitoring of dredging and spoil disposal activities, which are further detailed in Chapter 3, Dredging and Spoil Disposal.

The subsequent chapters provide a broad summary of the findings associated with the influence of dredging and spoil disposal activities on the marine environment (Chapter 4, Nearshore Environmental Monitoring Program). We have also provided a consolidated summary of the findings with regards to the natural history of Darwin Harbour as discovered during the monitoring program. This improved understanding of the Darwin marine environment is described in Darwin Harbour – A Dynamic Environment.

2 Environmental Setting

Environmental Setting

Understanding the environmental setting prior to commencing a dredging program is critical in designing a suitable monitoring program to detect and minimise the potential for environmental impacts beyond acceptable limits. However, knowledge of the environmental context is sometimes limited or incomplete in the initial stages and a monitoring program typically delivers new insights and builds on the existing knowledge base, as the NEMP has done for the Darwin marine environment. The data and information presented in this section focuses on the 2012/13 and 2013/14 wet seasons to provide context for later sections discussing the effects of dredging conducted during these two periods.

This chapter describes the climatic influences on ocean dynamics that in turn determine the key physical drivers of sediment dynamics that result in changes to suspended sediments in the water column (Figure 2). The presence of suspended sediments influences the underwater light climate and biological responses of organisms that rely on light for photosynthesis, like seagrass and corals. The natural processes that contribute to the suspended sediment present in Darwin Harbour include delivery of terrestrial sediment (catchment load) via freshwater inflows (runoff) and resuspension of seabed sediment via currents induced by tides, waves and wind. Of particular interest to this program are the fine sediments that can remain in suspension for long periods of time and which can be transported over large distances, potentially affecting the aquatic ecosystems outside of the immediate vicinity of the dredging and spoil disposal activities.

A significant mass of fine sediments (silt and clay size particles with a diameter less than 63 µm) occur naturally within the waters of Darwin Harbour. When combined with the strong tidal currents that can remobilise bed sediments, this leads to naturally variable suspended sediment concentrations and turbidity. Regional scale climatic and oceanographic processes affecting the northeast Indian Ocean/Timor Sea can propagate into the Beagle Gulf leading to increases in suspended sediments in the Gulf that can subsequently influence water quality in Darwin Harbour primarily through tidal exchange. The cascading of effects from regional scale (1000's km) to the Gulf scale (100 km) to the Darwin Harbour scale (10's km) are important drivers of the suspended sediment dynamics in Darwin nearshore waters.

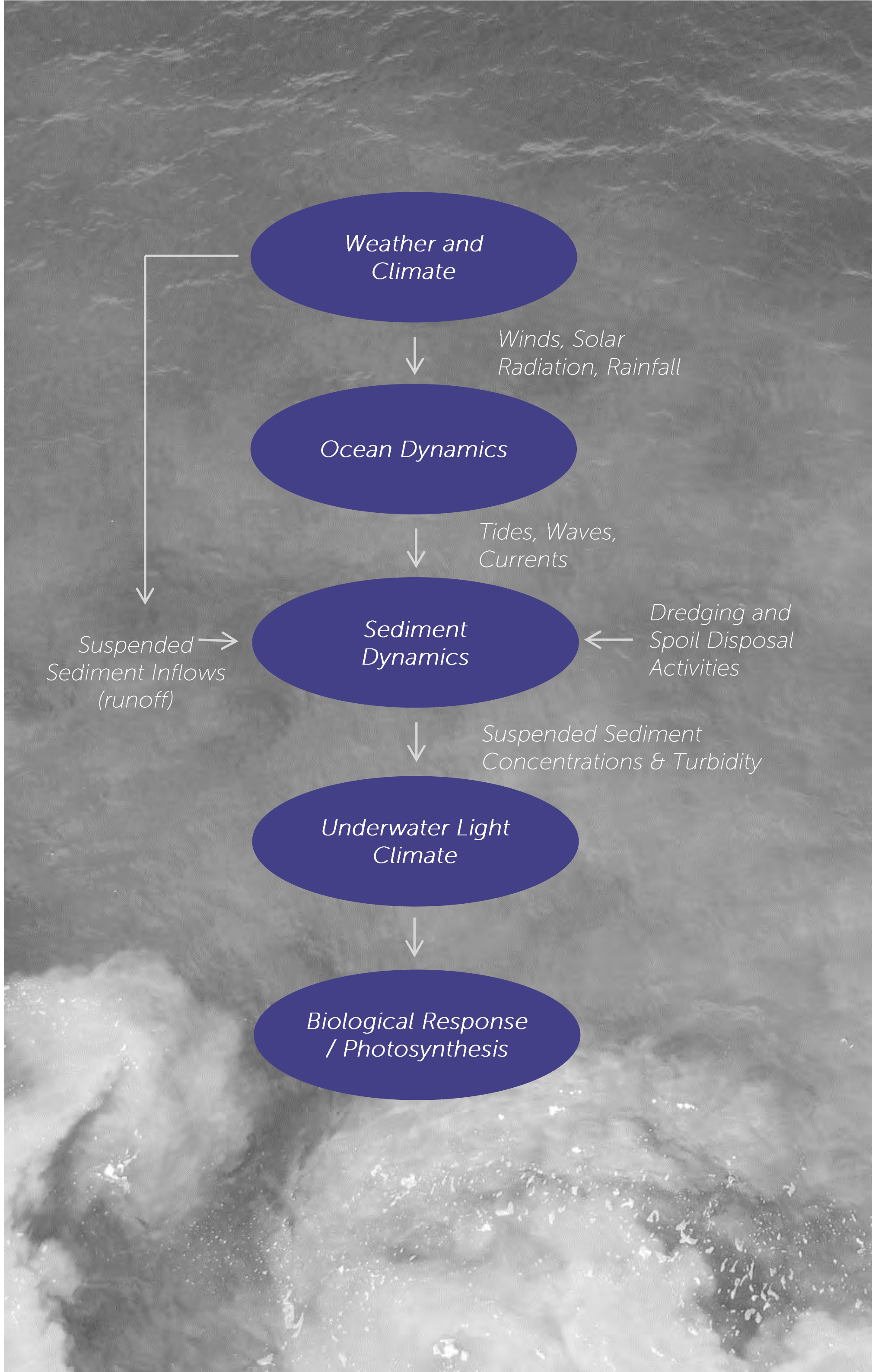


Figure 2 Link between physical forcing influences (weather and climate), ocean dynamics, sediment dynamics and underwater light climate (a key driver of biological response and photosynthesis)

Dredging and spoil disposal activities may also contribute suspended sediment in excess of that generated by natural processes, as indicated in Figure 3. This excess suspended sediment contributes to the natural influence on underwater light (measured as Photosynthetically Active Radiation; PAR) and photosynthesis processes potentially affecting the biological responses of seagrass and corals, as described in Chapter 4 (Nearshore Environmental Monitoring Program). As such, it is important to understand the contribution of both natural (Figure 3a) and dredged (Figure 3b) sources of suspended sediments and mechanisms of how they interrelate in this context.

Three key water quality indicators were used to provide an early warning of potential ecological impacts of natural and dredging-related events during the monitoring program: turbidity, PAR at the seabed and water temperature. Turbidity is a measure of water clarity, and is measured in Nephelometric Turbidity Units (NTU). Turbidity increases when there are large amounts of suspended sediment and other forms of particulate matter in the water column, sometimes collectively referred to as Total Suspended Solids (TSS). Generally speaking there is a complex relationship between turbidity and the suspended sediment concentration (SSC; expressed in mg/L); however, a straightforward relationship between the two can be determined for suspended sediments of relatively uniform particle composition and size. PAR is a measure of the light energy available in the correct form to support photosynthesis and primary production – the primary level food source for an ecosystem. Water temperature was measured to provide an indication of the potential for natural coral bleaching events and is not influenced by dredging.

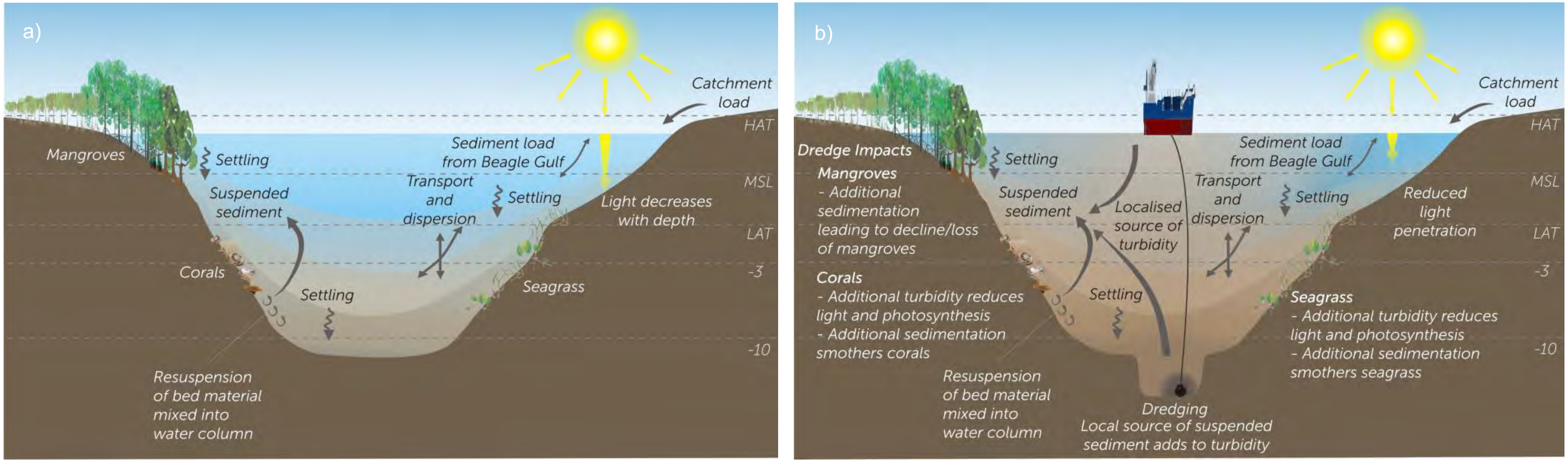


Figure 3 Processes influencing: (a) natural; and (b) dredging-derived sediments and their influence on turbidity, light and sedimentation on corals, seagrasses and mangroves

Darwin's Climate

Darwin is located in tropical northern Australia (12° 27' S, 130° 50' E) and experiences a warm, tropical climate that is characterised by two distinct seasons; the wet season, running from November to April; and the dry season, from May to October.

During the wet season, the northwest monsoon delivers warm, moist air from the equatorial regions leading to unstable weather conditions over Darwin. This instability typically brings tropical storms (lows/depressions) and tropical cyclones (Figure 4), and associated strong winds, high waves and rainfall (Figure 5). The intense seasonal downpours cause the major rivers to deliver significant volumes of fresh water and sediment-laden runoff to the coastal zone. On average over 95% of the annual rainfall occurs during the wet season (Bureau of Meteorology 2014).

During the dry season, Darwin's main climatic driver is the sub-tropical ridge, an extensive region of high pressure situated over southern Australia. The ridge intensifies in the dry season and drives the southeast trade winds that transport warm, dry air from central Australia towards the north and leads to stable weather conditions over Darwin. In general, winds are relatively calm overnight and early morning before an afternoon sea breeze. There is very little cloud cover or rainfall, particularly between May and September (Figure 5), and significant evaporation from the water surface occurs.

The average daily maximum air temperature in Darwin is relatively constant all year round, usually in the range of 30 to 34°C (Bureau of Meteorology 2014). The daily minimum air temperature shows more variation; overnight temperatures are around 20°C during the dry season and increase to 25°C during the wet season. The water temperature in Darwin Harbour reflects the air temperatures and typically varies from 32°C in the wet season to 24°C in the dry season. Relative humidity ranges from typical dry seasons values of 50% to over 70% during the wet season when the mean number of rain days averages over 15 days per month.

Tropical cyclones form over warm ocean waters primarily during the wet season. On average, northern Australia experiences three tropical cyclones per wet season; however, historical cyclone numbers have ranged from zero to as many as five in a season. These cyclones often track close to Darwin, bringing very strong winds and intense downpours.

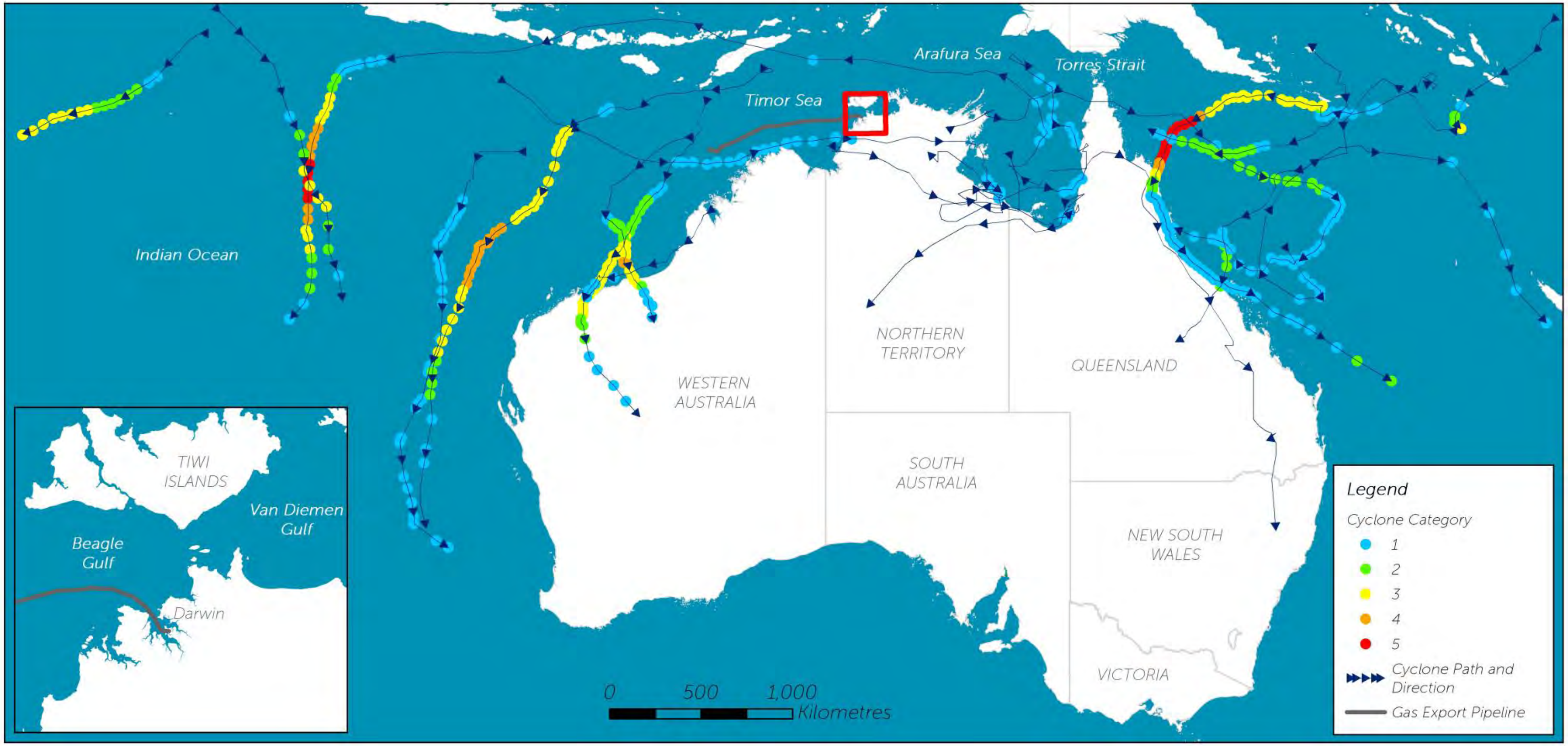


Figure 4 Movement tracks and intensities of tropical cyclones during the 2012/2013 and 2013/2104 wet seasons that coincide with the Project's dredging programs (Note: does not include tropical lows). Source: Bureau of Meteorology Australian Tropical Cyclone Database

Darwin is also indirectly affected by cyclones in the north-eastern Indian Ocean and Timor Sea (Figure 4), which generate large swell waves that propagate eastwards into the Beagle Gulf. Tropical cyclones situated in the Arafura Sea and Coral Sea have less of an influence on Darwin's wave climate due to the protection afforded by the eastern coastline of Van Diemen Gulf. Tropical storms, or moderate-strength low-pressure systems, tend to be more common than tropical cyclones and produce significant rainfall and strong westerly winds. The interannual variability in the cyclone activity and intensity of the monsoonal trough influences the wet season weather. To demonstrate the interannual variability in the environmental conditions, Figure 5 displays tide, significant wave height, rainfall and wind speed from 2012 to 2014, covering the period of baseline and dredge monitoring data collection. The episodic wet season cyclonic activity influences the oceanographic responses at both the seasonal and interannual time scales and is compared with the regular tidal regime (Figure 5).

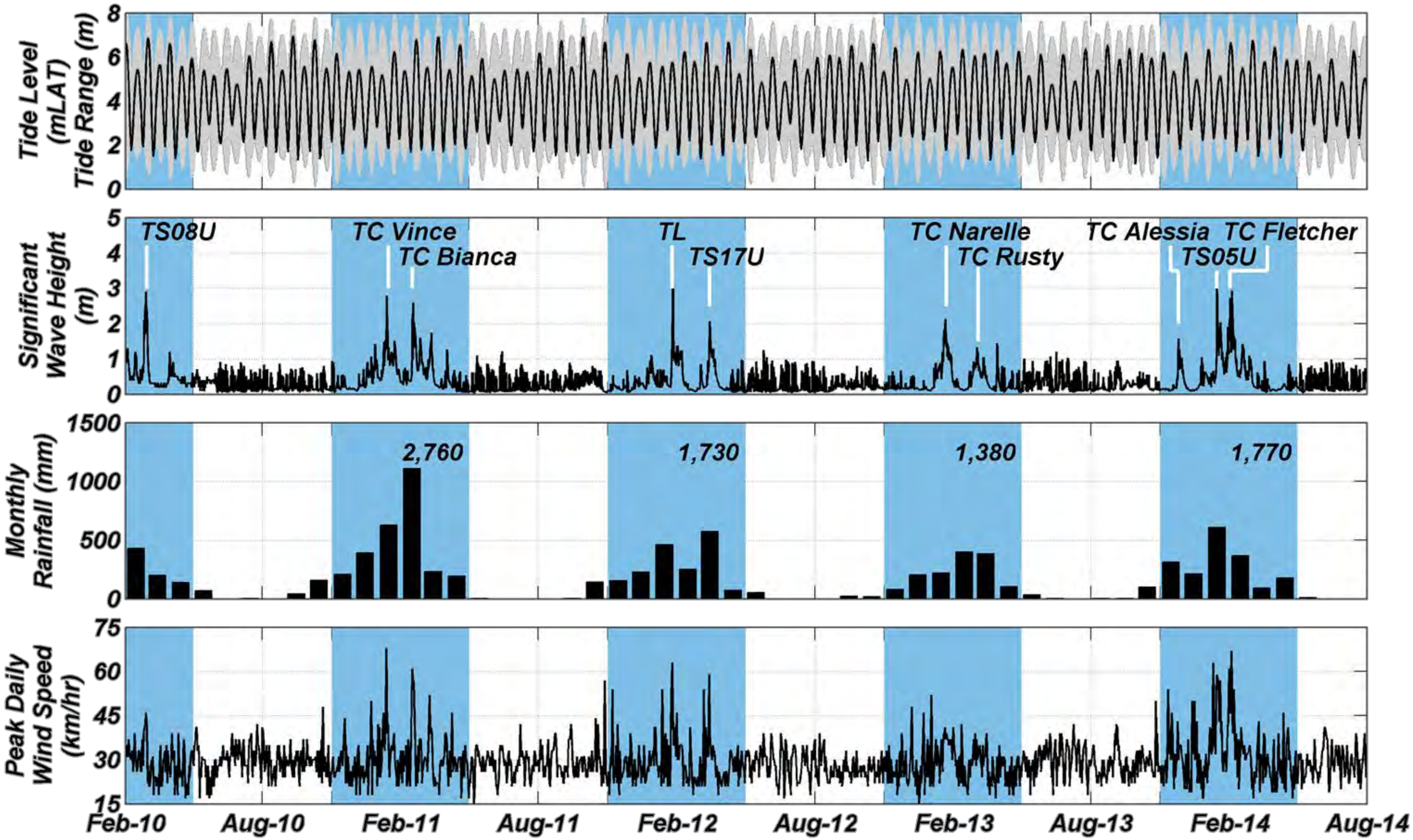


Figure 5 Principal atmospheric and oceanographic drivers influencing turbidity in the Darwin region; tide, significant wave height, rainfall and wind speed. Total rainfall is shown in mm for each wet season (shaded in blue) (data from February 2010 to February 2011 courtesy of URS – URS 2009). Note that tropical low pressure system naming convention is such that names of individual systems are prefixed with their storm designation, such as Tropical Cyclone (TC), Tropical System (TS) and Tropical Low (TL)

Oceanography of the Beagle Gulf and Darwin Harbour

The Darwin region marine environment encompasses the open ocean of the Beagle Gulf (see insert on Figure 4), also referred to as Darwin Outer, and the estuarine-dominated Darwin Harbour (Darwin Harbour Inner). Tidal forces have the greatest control over the sea level and water currents in the Darwin region. Winds are also important and provide fairly regular forcing of the water movements and wave activity, which resuspend sediments on the seabed. Episodic wet season cyclone activity can also lead to vigorous currents that are additional drivers of suspended sediments.

The Darwin region experiences a semi-diurnal tide, meaning there are two tide cycles of highs and lows per day. Darwin Harbour is classed as a macro-tidal estuary, with a maximum water level variation (tide range) reaching 8 m, which is large by world standards. The daily tidal range undergoes a pronounced variation in magnitude, repeating approximately every 15 days (spring-neap tide cycle). The average tide range during 'springs' (spring phase of the tidal cycle) is 6 m and during 'neaps' (neap phase of the tidal cycle) is about 3 m (Figure 5). There is also considerable annual variability, with maximal spring tides occurring in March and September.

The volume of water in Darwin Harbour (outer extent defined by a line between East Point and Mandorah) at mean sea level is approximately 2,100 Mm^3. At high spring tides the volume is approximately 3,400 Mm^3 and at low spring tides is approximately 1,400 Mm^3. The tidal volume (difference between high and low water) represents a significant percentage of the Harbour volume, indicating the importance of the tides for the transport and mixing of waters within it.

The predominant wet season westerly winds also cause the average water level to be higher than in the dry season, when easterly winds prevail. This is a feature of the large scale oceanography of the Arafura Sea through to Torres Strait, in that the water pushed west by the westerly tropical monsoon is trapped by the land mass of northern Australian and Indonesia.

Wave activity is a key driver of sediment resuspension, particularly in the shallow nearshore zone, where wave-generated currents can mobilise the bed sediments.

Wave activity in the Beagle Gulf generally consists of two different types of waves: short-period sea waves that are generated within the Beagle Gulf by local winds, and long-period swell waves that are generated by winds over the Indian Ocean/Timor Sea. These long-period swell waves can propagate into the Beagle Gulf from the west and are more capable of stirring seabed sediments in deeper water than locally generated short-period sea waves.

During the dry season, waves in the Beagle Gulf are predominantly generated by easterly winds. Due to the relatively short fetch distance (distance of water over which a given wind blows) and relatively low wind speeds, these waves are generally small, with a daily average wave height typically below 0.5 m (Figure 5). The daily dry season sea breeze cycle typically leads to calm sea conditions in the mornings. As the wind picks up during the day, the sea state (the general condition of the sea surface) increases and peak wave heights of up to 0.9 m occur briefly late in the day before dropping off again overnight.

The largest waves in the Beagle Gulf occur during the wet season and are associated with tropical storms and cyclones (Figure 4 and Figure 5). When these systems track across this part of the Australian continent close to Darwin they can produce rough seas with very large, short period wind waves (up to approximately 3.5 m wave height and approximately 6 to 8 s periods). Tropical cyclones located in the northern Indian Ocean can also produce longer period swell waves that propagate into the Gulf (up to 2 m wave height and approximately 10 to 12 s periods). At other times during the wet season, daily average wave heights in the Beagle Gulf are 0.8 to 0.9 m, roughly twice the height of those in the dry season, and tend to arrive from a westerly direction.

The overall combination of stronger winds, larger waves, greater rainfall and increased freshwater inflow into coastal waters during the wet season leads to significantly greater suspended sediment load in the water column. This results in greater cloudiness of the water (measured as turbidity) in coastal areas of the Beagle Gulf during the wet season compared with the dry season. During wet season periods of intense cyclonic wave activity, turbidity can increase to more than ten times the typical dry season values (Figure 5). Tidal exchange transports the highly turbid waters formed in Darwin Outer into Darwin Harbour, thereby increasing the turbidity of the waters in the Harbour estuary.

Regional Connectivity - Darwin Harbour and Beagle Gulf (Darwin Harbour Inner and Darwin Outer)

The significance of the strong connectivity between the Beagle Gulf and Darwin Harbour was realised during the monitoring program. As previously described, the exchange of oceanic waters from the Timor and Arafura Seas with the Beagle Gulf is largely driven by seasonal changes in wind patterns and tidal flows. Regular and rapid exchange of waters between the Beagle Gulf and Darwin Harbour is likewise mainly driven by the tides and, to a lesser extent, by winds.

The tides transport large volumes of water between Darwin Harbour Inner and the Beagle Gulf each day. The volume of water occupying Darwin Harbour Inner to mean sea level is approximately 1,800 Mm^3. During spring tides, approximately 2,000 Mm^3 of water flows in and out of the Harbour, which is roughly equivalent to 2.5 million Olympic–size swimming pools, or four times the volume of Sydney Harbour. During neap tides the tidal volume reduces to about 800 Mm^3. Parcels of water within the Harbour can be transported up to 10 km every tidal cycle. This implies that during spring tides a significant volume of water within Darwin Harbour is exchanged with Beagle Gulf water each day.

The volume of freshwater inflow to Darwin Harbour from runoff from the land was estimated to be 90 Mm^3 between 1 January and 30 April 2013. Over the same period, a further 500 Mm^3 of freshwater fell onto the Harbour water area as rain. This means that for these four months of the 2014 wet season, around 4 Mm^3 of freshwater entered the Harbour per day. This is approximately 500 times less than the 2,000 Mm^3 of seawater transported into the Harbour during a single spring tide.

As a result, the sediment-laden runoff entering Darwin Harbour from creeks and rivers is dispersed throughout the Harbour by strong tidal currents. Dispersion of these sediments in Darwin Outer is more variable than in the more confined Darwin Harbour Inner because its exposure to the Beagle Gulf allows for a wider range of influences to act upon the suspended sediment load of the flow rather than the tide alone. For example, local wave activity in the Beagle Gulf promotes stirring of the seabed and mixing of sediments through waves breaking in the shallow coastal zone (Figure 6).

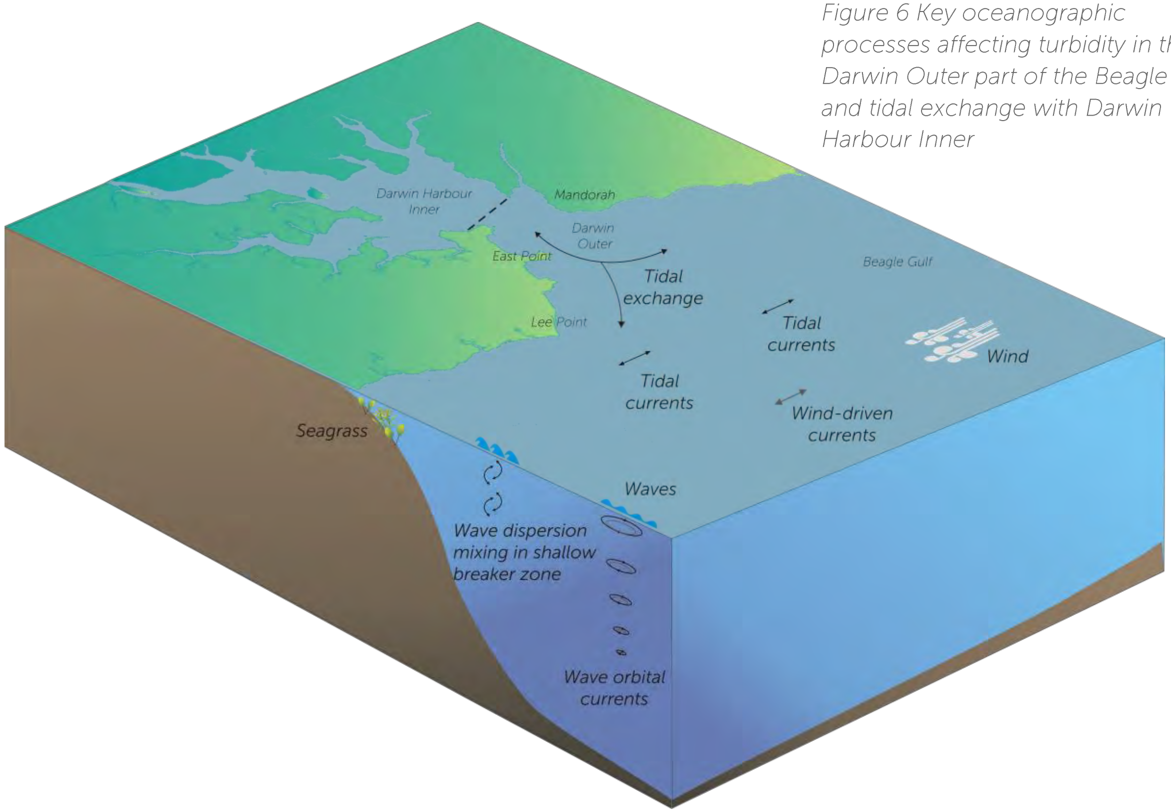


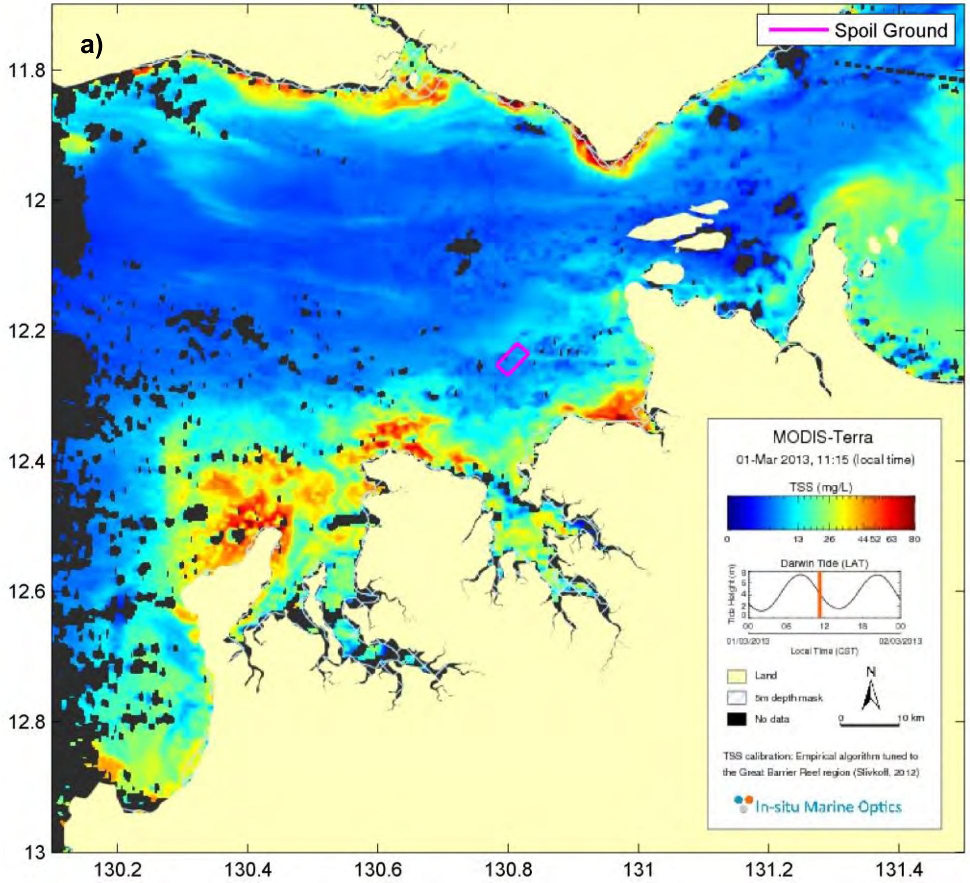
Figure 6 Key oceanographic processes affecting turbidity in the Darwin Outer part of the Beagle Gulf and tidal exchange with Darwin Harbour Inner

In general, large wave events in the Beagle Gulf are short-lived, lasting a few days to a week. However, a succession of tropical cyclones and/or tropical storms observed over the 2012/2013 and 2013/2014 wet seasons lead to weeks of elevated wave energy in the Beagle Gulf. During January and February 2014, the succession of a tropical low, a monsoon trough and Tropical Cyclone (TC) Fletcher led to 34 days of elevated waves (>0.5 m) in the Beagle Gulf (Figure 5). This period was associated with other extreme conditions, such as 108 mm of rainfall in 24 hours on 18 February 2014, extended periods where peak winds exceeded 65 km/hr, and on 2 February 2014, an event that produced the highest tide level in nearly three years. Turbidity generated throughout the Beagle Gulf and Darwin Harbour from these events was the highest and the most long-lived during the monitoring program to date (August 2012 to June 2014).

A consequence of the tidal connectivity described above is that during these events, a proportion of the suspended sediment in the Beagle Gulf is transported into Darwin Harbour, elevating turbidity inside the Harbour as well. At times of elevated wave conditions, turbidity measured at sites in the shallow coastal zone of the Beagle Gulf can reach up to five times more than those measured at sites in Darwin Harbour Inner. For example, during TC Rusty in February 2013 when wave heights peaked at 1.8 m in the Gulf, daily average turbidity at Darwin Outer site Lee Point was 98 NTU, compared with 15 NTU at the Channel Island site located in the more sheltered Darwin Harbour Inner.

The regional variation in turbidity from natural causes, such as the influence of waves on sediment resuspension at a regional scale in the Beagle Gulf, and the subsequent effect of tidal exchange on Darwin Harbour Inner, is shown in Figure 7. Figure 7 shows the surface TSS concentrations calculated from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images. These images provide daily synoptic estimates of the surface TSS concentrations at a spatial resolution of approximately 250 m x 250 m pixels.

Figure 7a shows a snapshot for the month of March 2013 when wet season low pressure systems caused elevated waves (Figure 5), affecting the region's coastal zone. The large westward traveling waves stirred up bed sediments along the coast in the Beagle Gulf. The elevated surface TSS concentrations are generally most prevalent in the coastal wave breaker zone rather than near the rivers and creeks entering the Harbour and Gulf waters. Elevated TSS concentrations inside the Harbour demonstrate the strong connectivity between the Harbour and Gulf waters during such events.



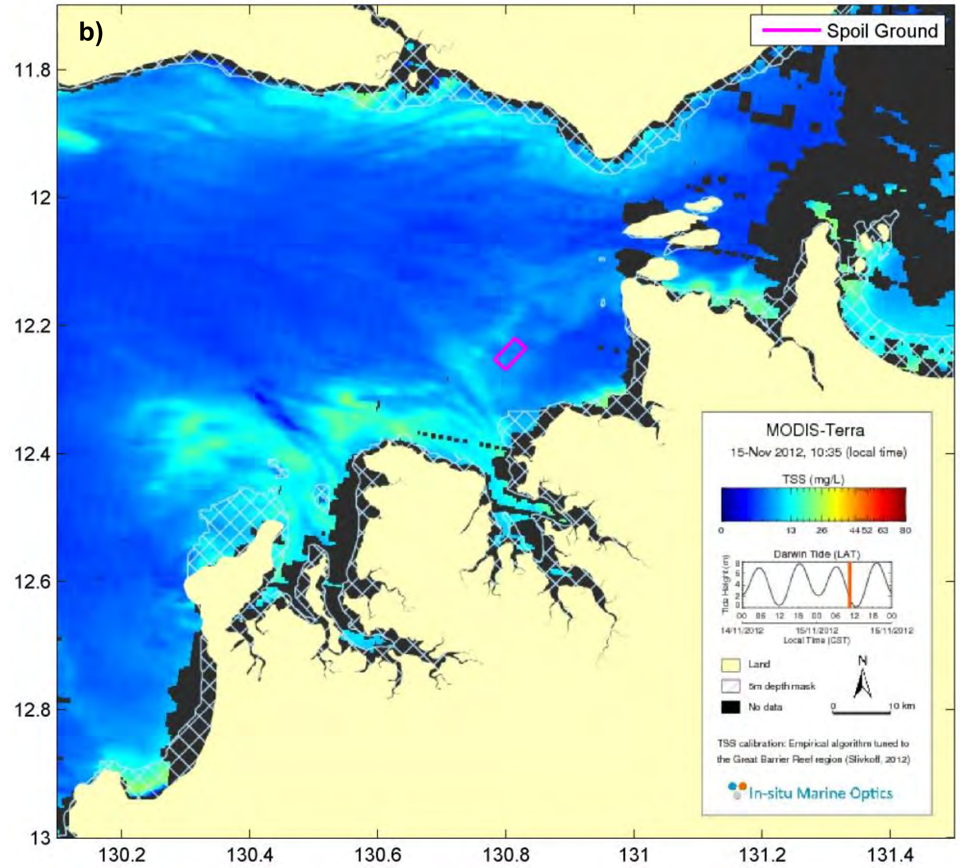


Figure 7b shows the same scene averaged over spring tides through the 2012 dry season. The spatial area of elevated surface TSS is far lower than observed during episodic wet season events but is greater during spring tides than neap tides.

Figure 7 Composite MODIS imagery showing surface TSS in the Darwin marine environment during: (a) episodic wet season events in March 2013; and (b) spring tides during the 2012 dry season

Darwin Water Characteristics

Water Temperature

Water temperature variations in Darwin Harbour are related in part to seasonal variations in ambient air temperature that drive heat exchange between the water surface and atmosphere. They are also related to the mixing of differing water bodies, for example, oceanic waters entering from the Beagle Gulf and freshwater inflow from streams and rivers. During the monitoring program, wet season water temperatures were generally between 30°C and 32°C, whereas dry season temperatures tended to be between 24°C and 26°C (Figure 8).

Temperatures 1°C above the long-term average of the warmest month are considered to cause thermal stress for corals (NOAA Coral Reef Watch 2011) meaning that temperatures of 31°C or greater (NOAA Earth System Research Laboratory 2014) are likely to cause stress to corals in Darwin. During both the 2012/13 and 2013/14 wet seasons, water temperatures temporarily exceeded 32°C, although less so during the latter season when there was greater rainfall and freshwater inflow to Darwin Harbour. Periods of water temperature exceeding this level are usually reduced by a significant rainfall event or influx of cooler water into the Harbour transferred from the Beagle Gulf, such as those during the passage of tropical cyclones or tropical storms.

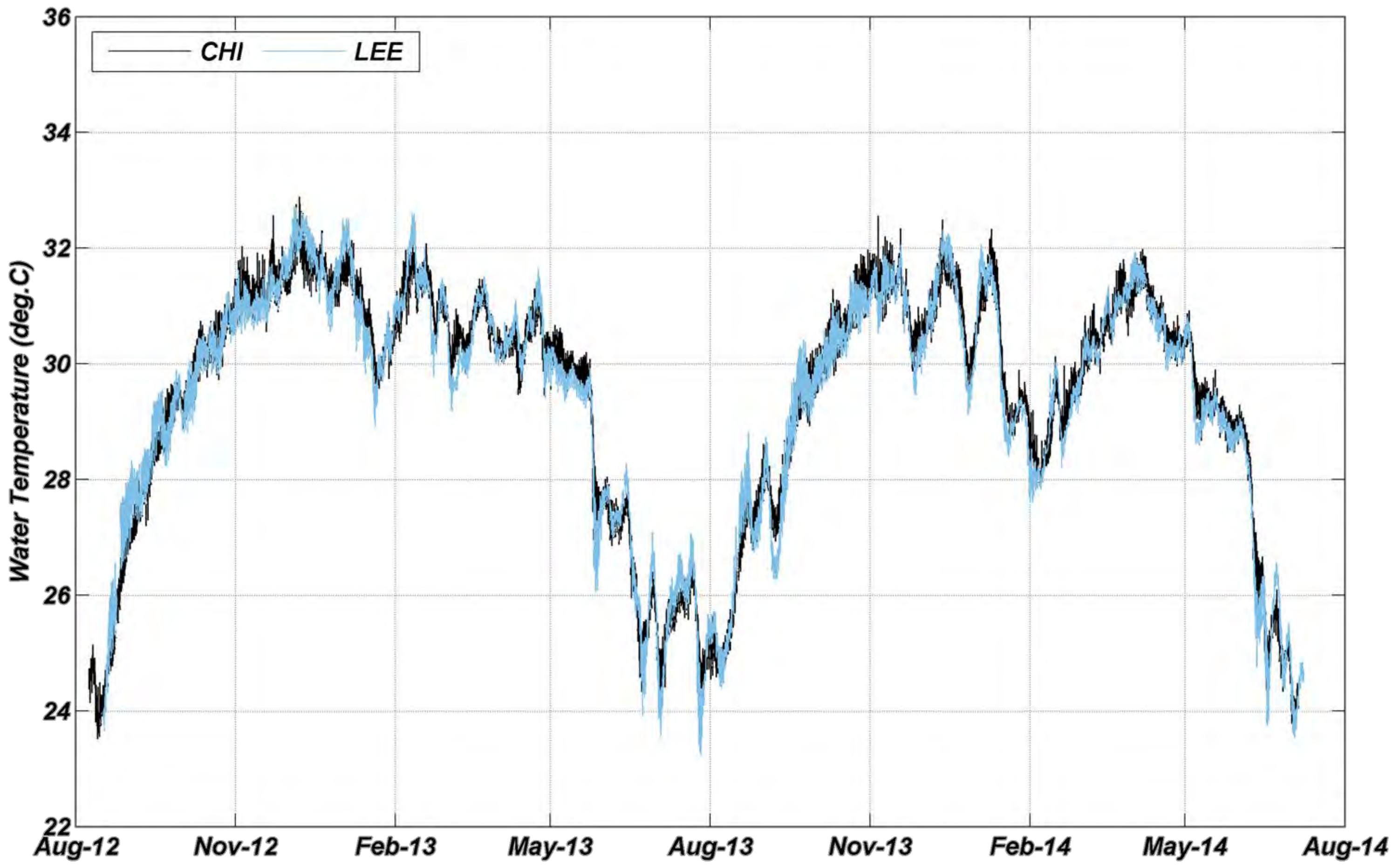


Figure 8 Water temperatures at water quality monitoring sites adjacent to coral and seagrass habitats at Channel Island (CHI) and Lee Point (LEE) respectively in Darwin

Salinity

The salinity of water in an estuary such as Darwin Harbour is affected by the balance between seawater from the ocean and freshwater inputs from river runoff. The salinity of Darwin Harbour is generally a little lower (i.e. fresher) in the wet season when compared to the dry season (Figure 9). For example, the seasonally-averaged salinity during the 2013/14 wet season at the coral monitoring site Channel Island (CHI in Figure 9) was approximately 31 practical salinity units (PSU), compared with 35 PSU in the 2013 dry season. Channel Island is located in Middle Arm in Darwin Harbour Inner and Lee Point is located in Darwin Outer (see location of monitoring sites in Figure 17).

In either season there can be strong local gradients in salinity. During the wet season, salinity can range from approximately 30 PSU in the mid-Harbour down to near 0 PSU further up the rivers where there are significant freshwater inflows from rainfall. As saltwater is more dense (and thus heavier) than freshwater, the Harbour can also become temporarily stratified at locations close to significant freshwater inflow. Under these circumstances, the more saline seawater sinks to the bottom of the Harbour as freshwater delivered from the catchment flows on top of it. The vigorous tidal stirring causes rapid mixing and as such, the stratified waters have minimal effects on the dispersion characteristics within the broader Darwin Harbour Inner waters.

During the dry season, a lack of rainfall and increased evaporation can lead to salinities greater than 35 PSU in shallow waters where there is limited tidal flushing, in Woods Inlet (Figure 17) for example.

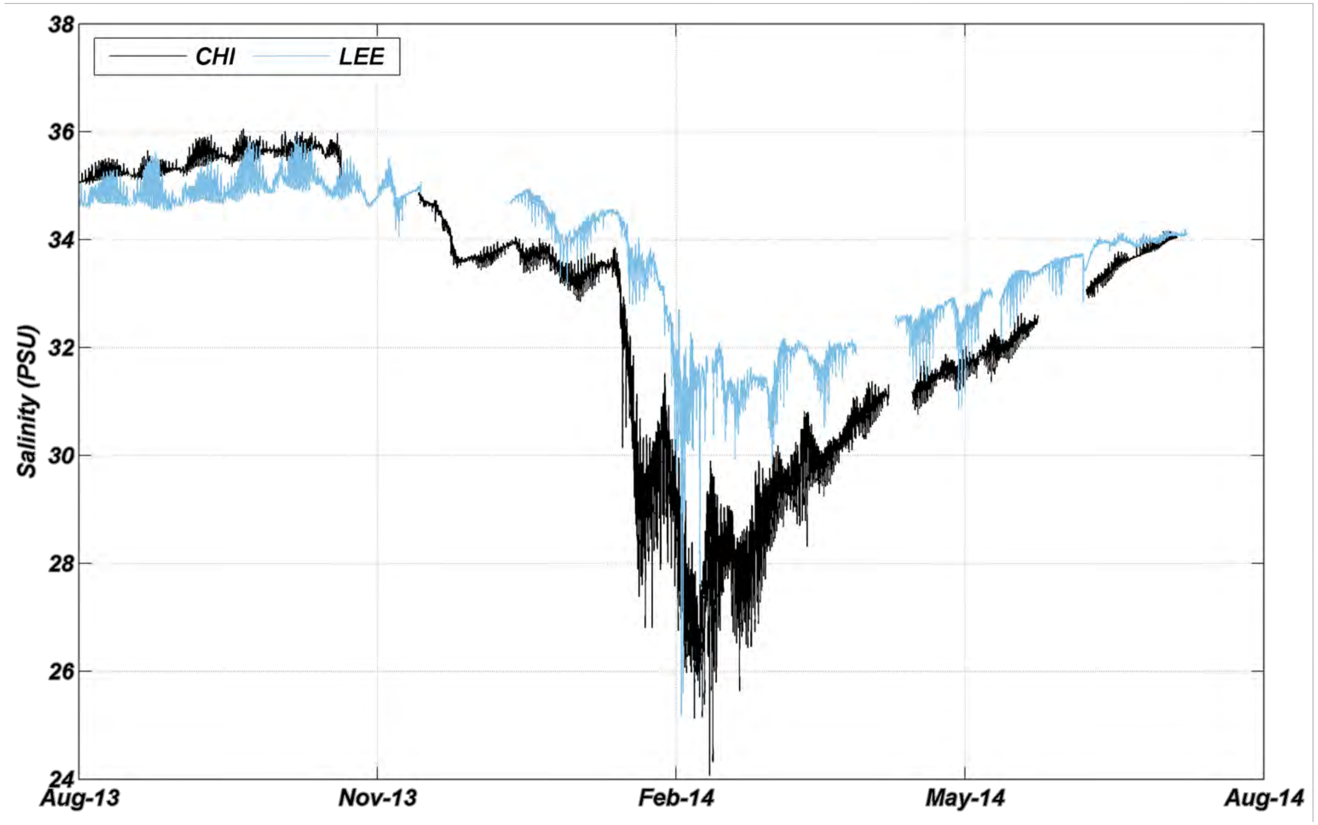


Figure 9 Salinity at water quality monitoring sites adjacent to coral and seagrass habitats (Channel Island and Lee Point respectively) in Darwin

Sediment Mobilisation and Turbidity

As introduced in Figure 2, the key processes controlling sediment dynamics in the Darwin region include resuspension, transport and settling. Turbulent energy generated by waves and currents near the seabed determine the rate at which bed sediments are mobilised, and become suspended in the water column. The critical current speed required to move and suspend sediments decreases as the sediment grain size becomes smaller, at least until cohesive effects (the action of sticking together) become apparent when grain sizes are typically <63 µm diameter (i.e. silt and clay). The cohesive nature of silts and clays occurs by individual particles sticking to their neighbours, a process which results in the sticky character of muds. In addition, a thin layer of biological matter, known as biological film, can grow over the seabed surface also causing the grains to stick together, and thus raise the current speed necessary for resuspension until the film has been disrupted.

The percentages of silt and clay in Darwin's seabed sediments are shown in Figure 10. The high proportion of these particles in the majority of samples indicates that cohesion will have a significant influence on sediment resuspension.

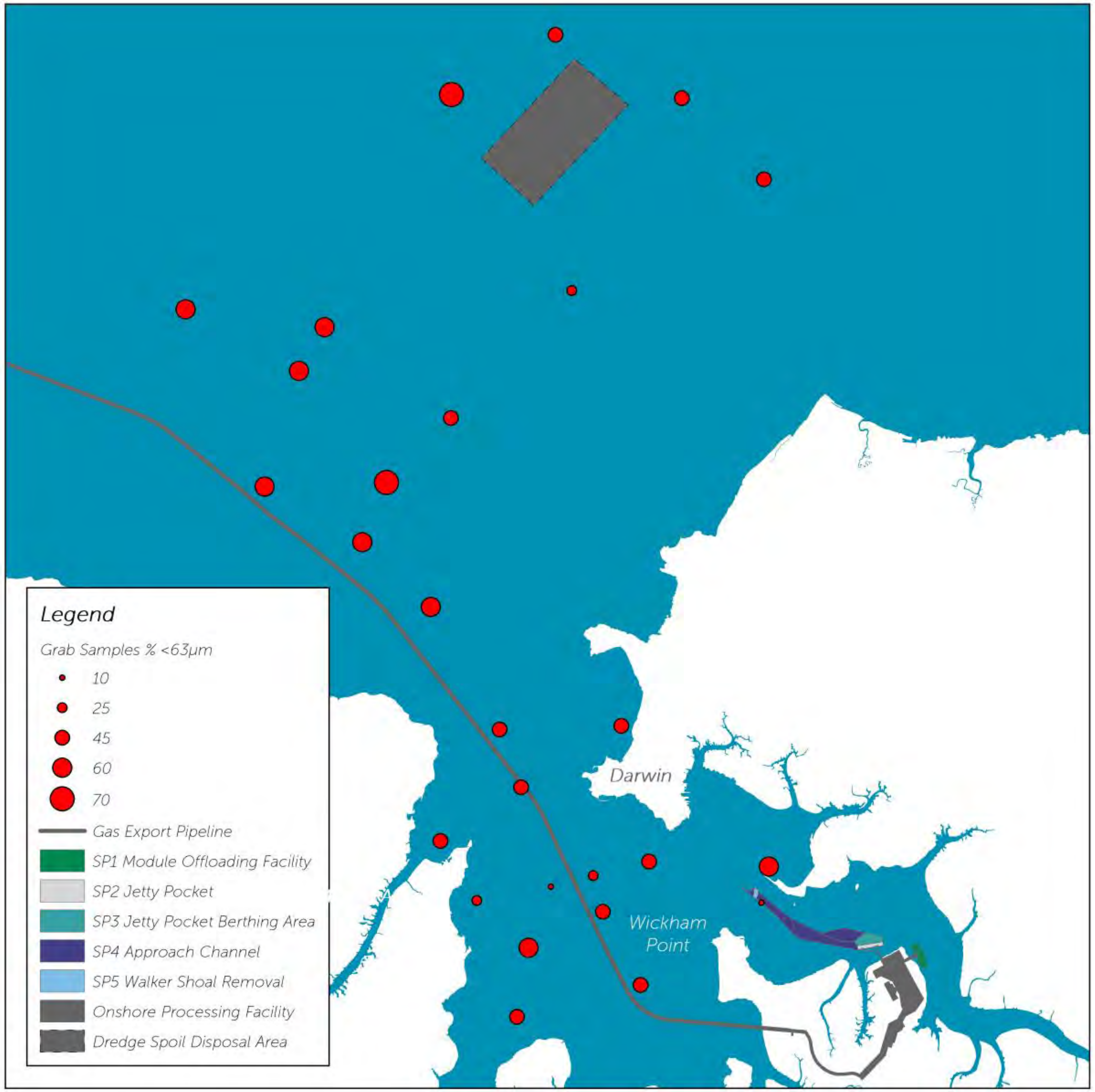


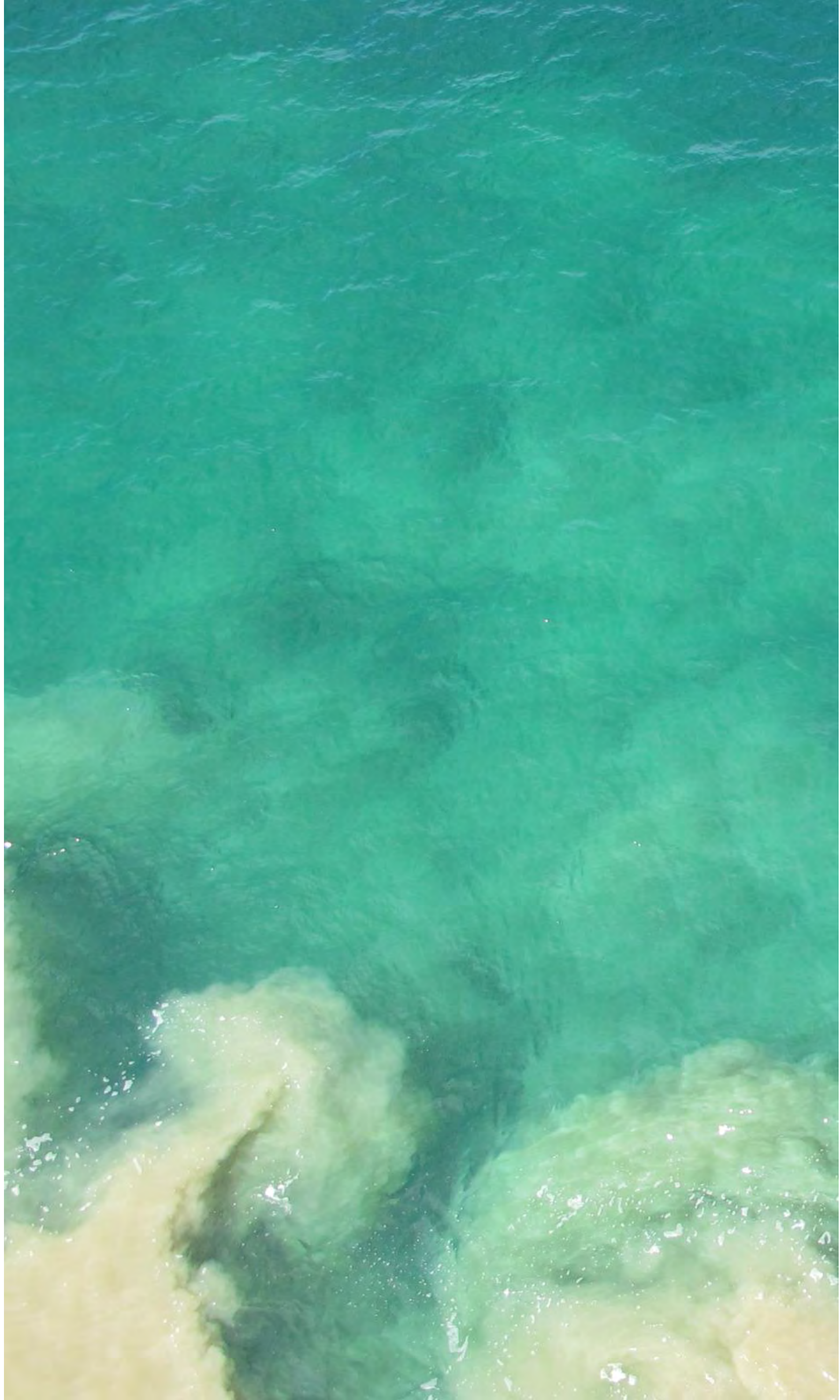
Figure 10 Percentage of fines, silt and clay (<63 µm grain diameter), in the seabed sediments of Darwin. The grain size of sediment in suspension at a particular location reflects both the strength of the currents that resuspended the sediment and the range of available grain sizes on the seabed

When the tide turns and the direction of water flow reverses, current speeds and turbulence reduce (known as 'slack water'), and suspended sediment particles can settle toward the seabed, resulting in sedimentation. The coarser, heavier sand-size particles (>63 µm) settle relatively quickly, while the finer, silt and clay size particles settle more slowly. For example, to settle through a water depth of 10 m, sand-sized particles can take approximately 15 minutes, while silt and clay particles can take a few hours to more than a week for the finest particles to settle. Suspended sediments in Darwin Harbour are predominantly fine silt-sized material.

Consequently, there is a relatively short time lag between both the maximum speed of the currents that mobilise sediments and the occurrence of maximum turbidity and a relatively longer lag between the minimum speed of currents that result in particles settling and causing minimum turbidity levels. The generally fast current speeds and high turbulence levels, relatively short periods of slack water, and abundance of fine sediments in Darwin Harbour Inner means that the water is often very turbid. This is particularly evident during spring tides when currents are strongest. However, the processes driving turbidity in Darwin are associated with three time scales:

- *Periodic tidal time scales (approximately daily, fortnightly and seasonal);*
- *Periodic seasonal time scale (~six monthly wet/dry variation); and*
- *Episodic time scale associated with tropical cyclones and tropical storms during the wet season (annually).*

The relationship between turbidity and short term (e.g. hourly) tidal variations is complex due to the relative timing of processes controlling sediment dynamics – resuspension, transport and settling (Figure 2). Furthermore, the cyclic variation in current speed and turbulence intensity between spring and neap tides (fortnightly) has a strong influence on the turbidity in the Harbour. The daily average turbidity varies with this cycle, with the maximum daily average turbidity coinciding closely with spring tides (maximum tide range) and the minimum coinciding with neap tides (minimum tide range). In the wet season, the situation is further complicated by episodic events of elevated turbidity (Figure 11). Without the influence of episodic events and rainfall, the spring-neap cycle explains approximately 80% of the measured daily average turbidity in Darwin.



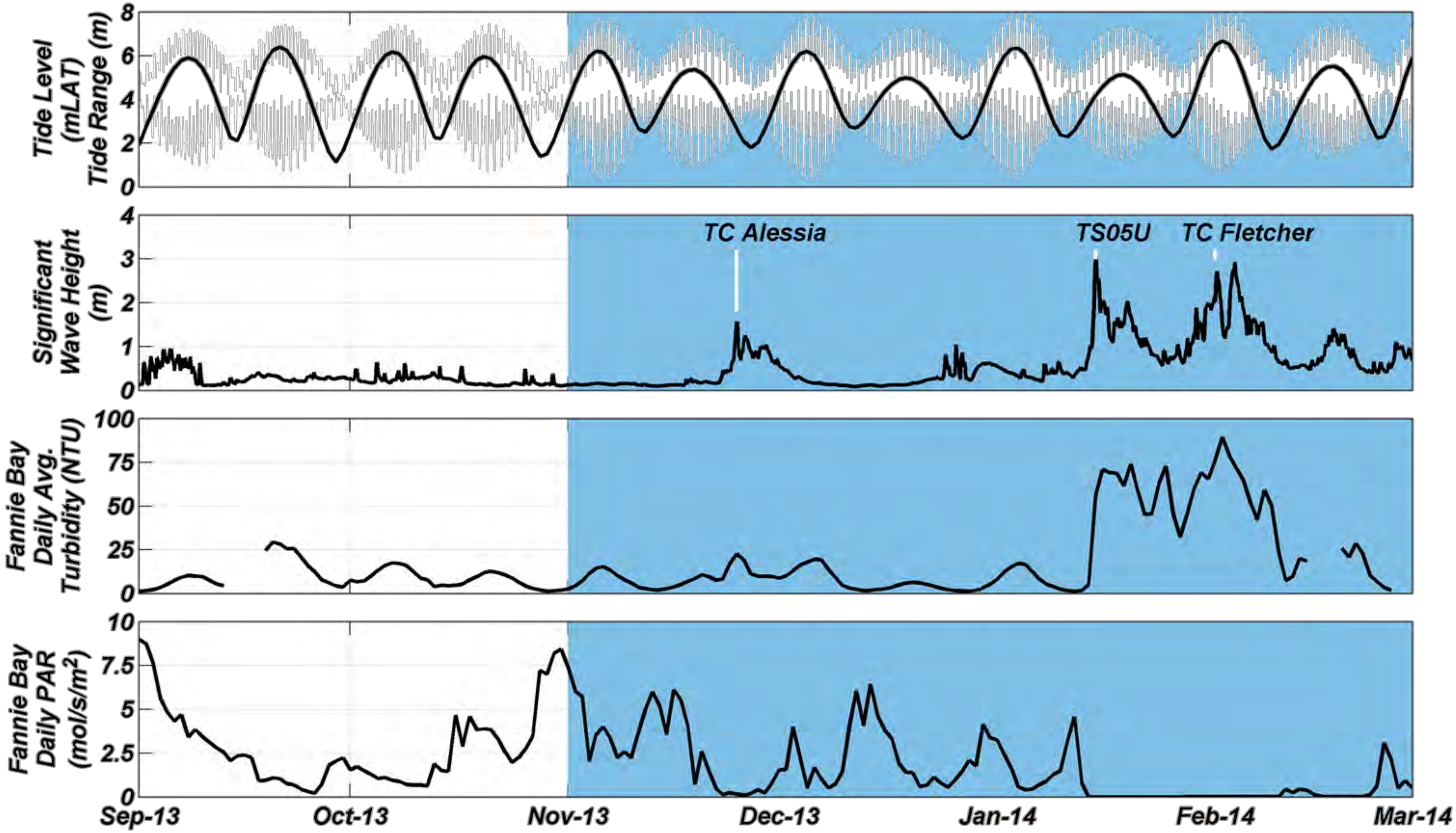
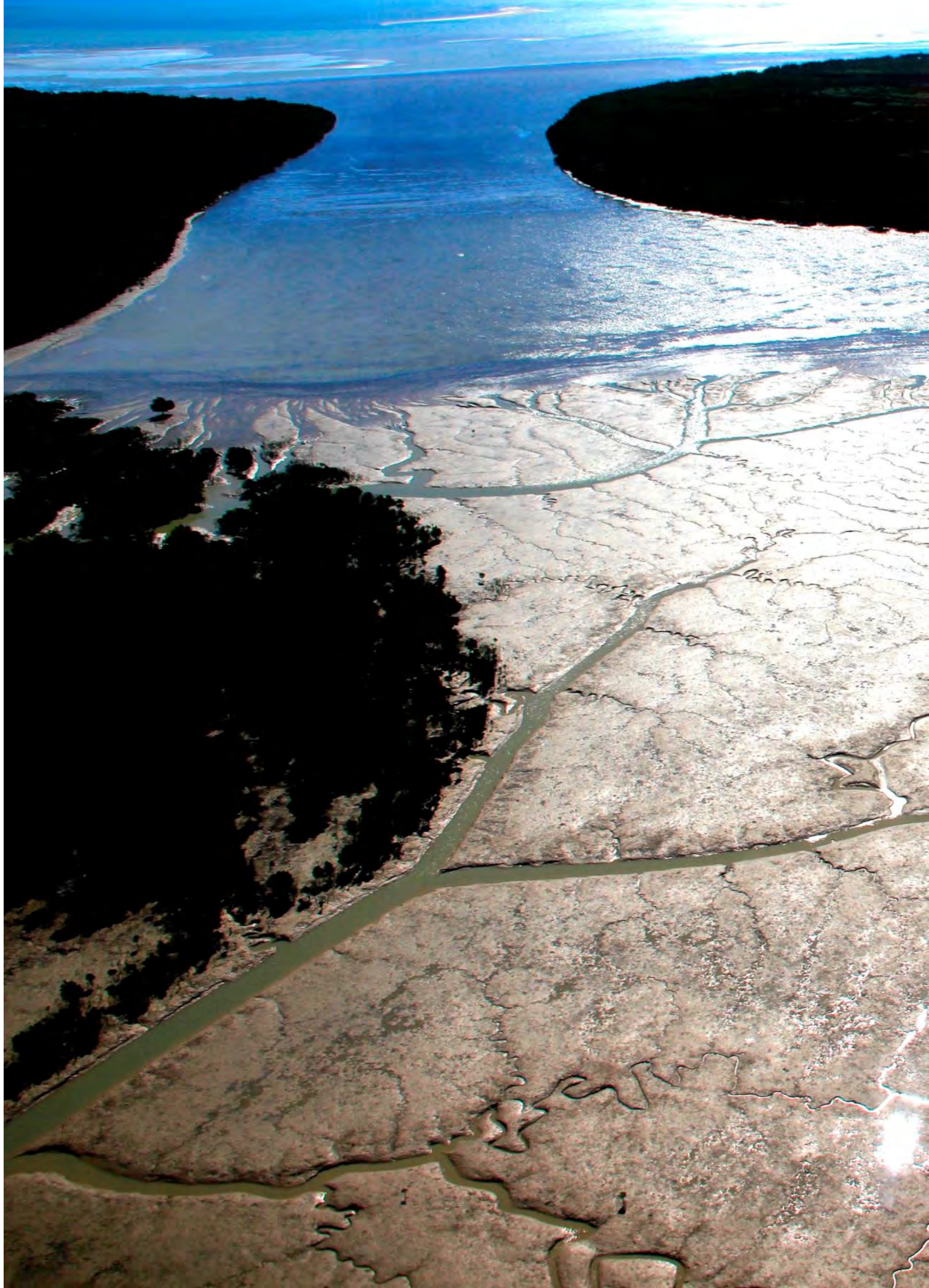


Figure 11 Time series of tide, significant wave height, turbidity and PAR at Fannie Bay in Darwin Outer from September 2013 to February 2014. Note that the highest turbidity during the dry season coincides with the spring tides, but this pattern can be overwhelmed by episodic (elevated wave) events, such as tropical cyclones and storms in the wet season (wet season shaded in blue). Note also the orders of magnitude increase in turbidity and reduction in PAR during episodic events

Interannual and seasonal turbidity variation between February 2010 and July 2014 for the Channel Island monitoring site in Darwin Harbour Inner is demonstrated in Figure 12. The overall differences in turbidity between the wet and dry seasons are clearly evident, as are the seasonal turbidity patterns that vary markedly between years. Over this period, wet season turbidity was typically two to five times higher than dry season turbidity, depending on the year. The most turbid wet season measured at Channel Island during the monitoring period occurred in 2013/14 (Figure 12).

The factors that most influence the magnitude of the difference in turbidity between the wet and dry seasons (Figure 11 and Figure 12) are the number and intensity of episodic tropical cyclones and tropical storms occurring in the wet season. The number of tropical cyclones and tropical storms varies from year to year, but is typically in the range six to ten per season, with one to five of those being tropical cyclones. As discussed previously (see Regional Connectivity - Darwin Harbour and Beagle Gulf (Darwin Harbour Inner and Darwin Outer)*), a series of consecutive episodic events in January/February 2014 led to elevated wave energy in the Beagle Gulf, with significant wave height reaching up to 3 m during each event (Figure 11 and Figure 12). These consecutive events overwhelmed the fortnightly spring-neap turbidity variation and benthic light (PAR) measured during that period. Turbidity remained elevated through two consecutive spring-neap cycles and PAR was almost zero (blackout conditions) over the same period at Darwin Outer seagrass site Fannie Bay (Figure 11). The duration of these naturally driven blackout periods is an important factor in the survival of photosynthesising organisms like corals and seagrass.*



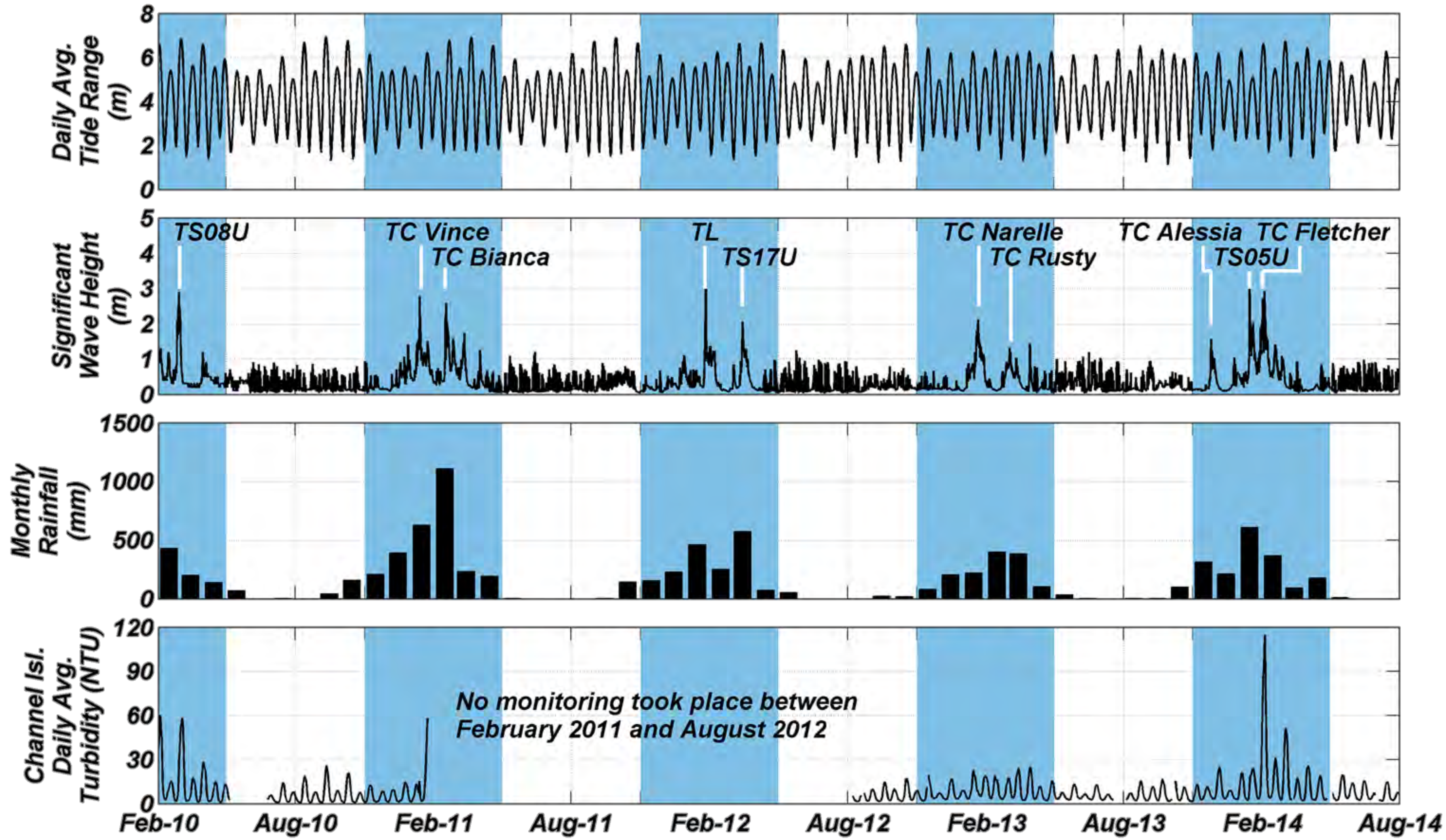


Figure 12 Time series of tides, significant wave height, rainfall and daily average turbidity at Channel Island prior to and during the Project's dredging programs (wet season shaded in blue)

Underwater Light – Photosynthetically Active Radiation (PAR))

Suspended sediment (turbidity) affects the distance through which surface light penetrates into the water column. The intensity of underwater light (measured as PAR) decreases exponentially with increasing depth in the water column. Whether surface light can reach the seabed depends upon the surface light intensity, the depth of water and the clarity (or turbidity) of the water.

In a macrotidal environment such as Darwin Harbour, the timing of the tides with respect to the time of day significantly affects the depth of water through which light has to penetrate to reach the seabed. For example, at low water during spring tides, the water may be only 2 m deep and at high water spring tides the depth may be 10 m. Light levels at the seabed are generally highest when the low water occurs around solar noon and the water depth is at its minimum. Solar noon occurs halfway between sunrise and sunset, which is approximately 12:45 at the longitude of Darwin and is when the sunlight intensity is strongest.

The height and timing of the low water level during spring tides varies across any month and throughout the year (Figure 11 and Figure 12). From April to August, the higher of the two daily low tides during springs occurs around the timing of the solar noon. As such, light has to penetrate a greater depth than for the period from October to February, when the lower of the two daily low tides during springs occurs around the timing of the solar noon, thereby having to penetrate shallower depths. Ignoring turbidity and considering water depth alone, potential light levels at the seabed would generally be largest from October to February, which is also when the sun is highest and most intense, thus further contributing to light penetration. During this period, however, wet season cloud cover is often extensive, which reduces the amount of light at the water surface and hence, underwater light.

The presence of suspended sediments in the water column results in light scattering and absorption, thus reducing the amount of light and PAR reaching the seabed (i.e. for a standard depth and surface light, greater turbidity results in lower light at the seabed). While tidal effects on the water depth tend to work to maximise PAR at the seabed during the occurrence of solar noon coinciding with low water spring tides in the wet season, these effects are counteracted by elevated turbidity driven by strong spring tidal currents, waves and sediment-laden runoff reducing seabed PAR. The relative balance is complex, but overall, turbidity tends to have the dominant effect on seabed PAR in Darwin. Maximum levels of PAR tend to be observed during minor spring tides at the end of the dry season/start of the wet season in October/November.

Spatial differences in PAR between sites (Figure 13a) reflect the relative balance between contributions by waves, runoff and tides to the overall seasonal turbidity (Figure 13b). Tidal stirring of bed sediment and contribution to turbidity is broadly consistent throughout the year, but the tidal currents are greater in Darwin Harbour Inner and hence tidally-induced turbidity is greater at the Darwin Harbour Inner sites than at the Darwin Outer sites. By contrast the wave stirring is significantly greater in the exposed Darwin Outer area than in the more sheltered Darwin Harbour Inner. The stronger winds and wave stirring effects in the wet season dominate the tidal contribution to turbidity at the Darwin Outer sites, while the tidal effects dominate turbidity at the Darwin Harbour Inner sites. Consequently, seasonal differences in light and turbidity levels are most pronounced at the Darwin Outer sites (Figure 13a and Figure 13b respectively).

Low light levels at the seabed can occur throughout Darwin at any time of year due to the coincidence of high tidal water levels and high turbidity. However, extended periods of naturally low light levels and 'blackout' conditions (i.e. no light) are most prevalent during episodic events in the wet season (Figure 11). For example, averaged across all monitoring sites, 10% of the days during the 2013/14 wet season experienced blackouts at a depth of 3 m below Lowest Astronomical Tide (LAT) compared to only 1% of the days during the 2013 dry season. Low light events can extend for periods of around two to 16 (and sometimes longer) consecutive days, which can ultimately influence photosynthesis and subsequent primary production of seagrass and corals.

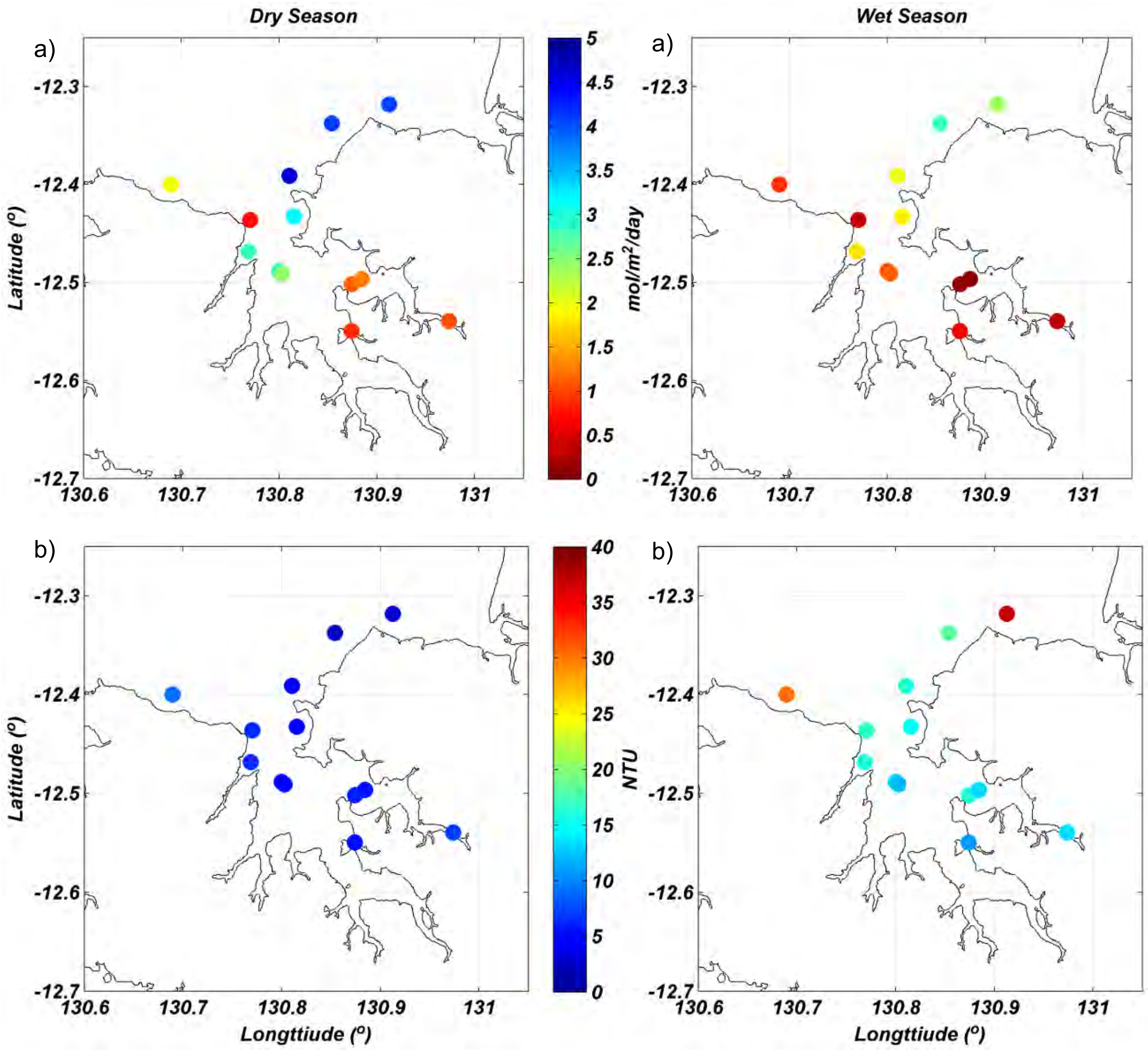


Figure 13 Map of water quality monitoring sites in Darwin showing relative levels of (a) light (PAR, measured as mol/m^2/day); and (b) turbidity (NTU) between the wet and dry seasons during the monitoring program

3 Dredging and Spoil Disposal

Dredging and Spoil Disposal

Dredging Programs

The East Arm dredge footprint is comprised of five separable portions (SPs) as indicated in Figure 14. A total of 16.1 Mm^3 of material was approved to be dredged from East Arm, consisting of fine clays and muds, sands and hard rock. Removal of this material required a fleet of eight dredgers comprising backhoe dredgers (3 x BHDs), trailer suction hopper dredgers (4 x TSHDs) and the most powerful cutter suction dredger (1 x CSD) to work in Australia to date, the Athena. Split hopper barges (SHBs) and TSHDs transported the dredged material ~45 km from East Arm to the dredge spoil disposal area, 12 km north-west of Lee Point.

Dredging for the GEP required the removal of 0.466 Mm^3 of material, which mainly consisted of soft clays/mud and sand. With no rock cutting required, the works were completed using BHDs and a TSHD.

Detailed descriptions of the dredging and spoil disposal methodology are provided in Section 2 of the East Arm and GEP DSDMPs.

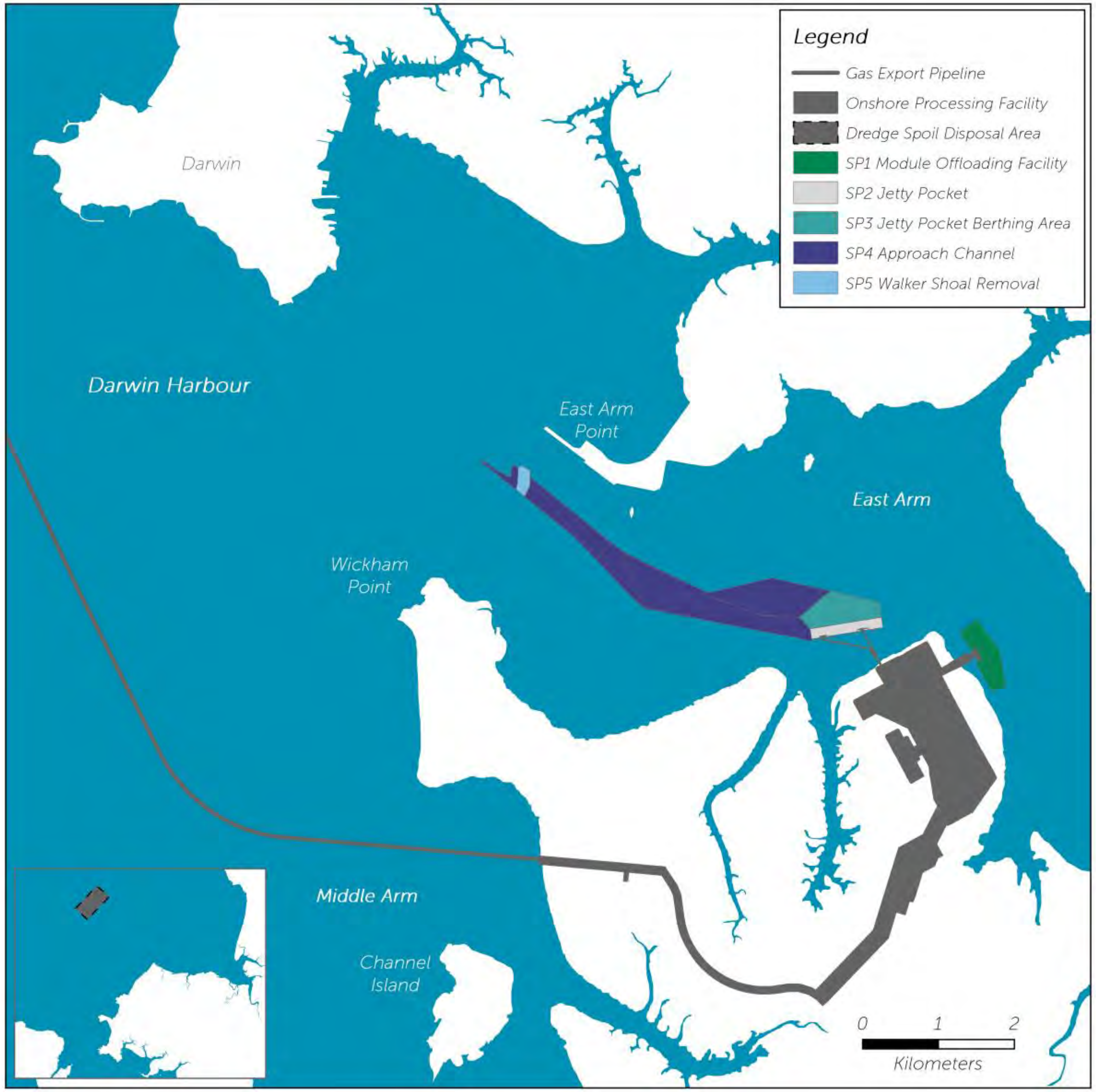


Figure 14 Location of East Arm and GEP dredging and spoil disposal activities

Influence of Dredging and Spoil Disposal Activities

Outside the direct physical impacts at the dredge footprint and spoil disposal area, dredging and spoil disposal activities have the potential to indirectly impact sensitive receptors (e.g. corals, seagrass and mangroves) through the mobilisation of sediments within the water column and the subsequent dispersal, settlement and accumulation of suspended sediments by natural processes (Figure 3b).

As presented in Chapter 2, climatic, oceanographic and sediment transport processes have the potential to disperse, resuspend and allow settlement of suspended material across a range of habitats in Darwin Harbour Inner, as well as offshore areas in Darwin Outer surrounding the spoil disposal area. Potential impacts of the dredging programs followed a range of pathways from the following key mechanisms:

> *Sedimentation effects through the deposition and accumulation of sediments within intertidal and subtidal areas. This has the potential to subsequently affect mangrove health, production and the benthic communities within the mangrove areas. Excessive accumulation of sedimentation within intertidal mudflats and subtidal areas may lead to smothering of benthic communities and a reduction in light.*

> *Increased turbidity within the water column reduces light penetration and therefore the availability of light for photosynthesis, which may affect water column phytoplankton, intertidal microphytobenthos, coral and seagrass, with potential flow on effects to fish, turtles and dugongs that forage on these communities.*

The increase in the number and frequency of vessels visiting Darwin Harbour from overseas to support dredging and spoil disposal activities also has the potential to introduce marine pests that can disrupt ecological communities and interfere with maritime industries.

Impact Predictions

Predictions of potential overall impact from the East Arm dredging program in Darwin Harbour were made in the Draft Environmental Impact Statement (EIS), Supplement (SEIS) and were further refined during the secondary approval process and the preparation of the East Arm DSDMP (Rev 1, INPEX 2012). The dispersion and settling patterns of fine sediments released from dredging and spoil disposal activities were modelled using a sediment transport model (DELWAQ) coupled to a hydrodynamic model (TELEMAC). At the end of the 2012/2013 wet season (i.e. Season One of dredging) additional analyses were undertaken to validate the model and to revise impact predictions for the remainder of the dredging program (Season Two of dredging). The model outputs in Figure 15 represent the predicted sediment deposition at the end of dredging (Figure 15a) and SSC at peak dredging (Figure 15b) contributed by dredging and spoil disposal activities (i.e. outputs present SSC and sedimentation in excess of natural variability).

Further information on the setup, calibration, and results of the modelling and revised impact predictions can be found in the East Arm DSDMP (Rev 4, INPEX 2013).

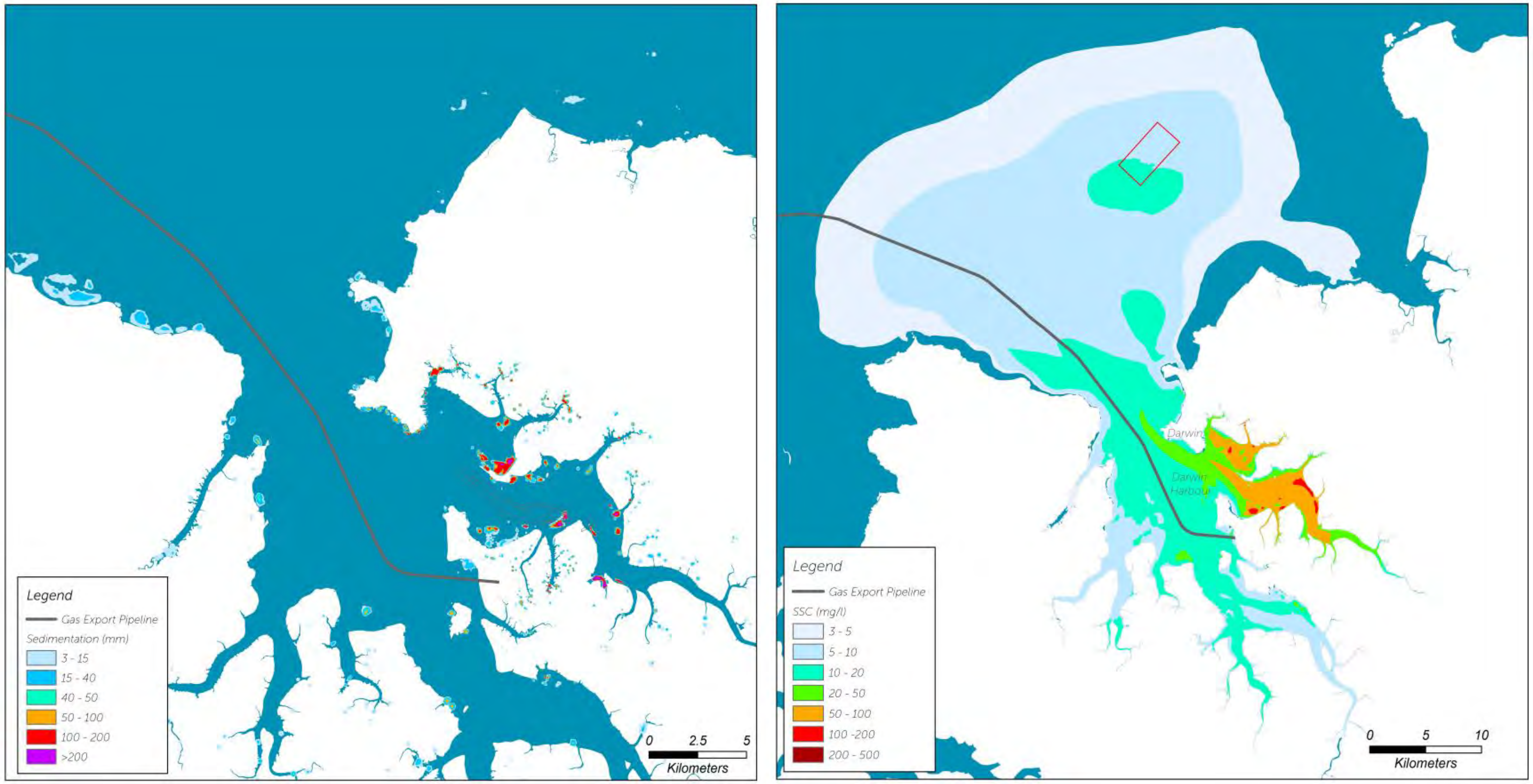


Figure 15 (a) modelled sediment deposition at the completion of dredging and spoil disposal activities; and (b) modelled SSC during peak phase of dredging and spoil disposal activities. Note that these figures relate to East Arm DSDMP (Rev 4) predictions based on the implementation of a one hour overflow for Season Two

To facilitate the assessment of potential impacts from dredging excess SSC and sedimentation, a series of tolerance limits were established for mangroves, seagrass, hard coral, filter-feeders and macroalgal habitats. The tolerance limits for SSC were derived from water quality monitoring data on the premise that resident biota are adapted to the naturally prevailing conditions and variations at each locality, however they would become stressed if exposed to conditions that regularly exceed normally prevailing background concentrations. For sedimentation, the tolerance limits were derived from the scientific literature. These tolerance limits were then compared to the model outputs of excess SSC and sedimentation to determine the extent of these habitats predicted to be potentially influenced and impacted by dredging and spoil disposal activities.

A number of assumptions were used in both the modelling and determination of tolerance limits. Many of these assumptions could be considered conservative and, as such, the Project team were confident that the impact predictions represented a 'worst-case' scenario. These predictions were then used to inform the design of the NEMP.

Detailed information on the method for developing tolerance limits, their values and impact predictions are provided in the East Arm DSDMP (Rev 4, INPEX 2013).

Dredging and Spoil Disposal Activities

The East Arm dredging program was completed over two 'seasons' (Figure 16). Season One commenced with BHDs in late August 2012, with the CSD Athena starting in the wet season on 4 November 2012. Approximately 43% of the material to be dredged was completed by the end of Season One on 30 April 2013. Following a dredging hiatus over the 2013 dry season (May to October 2013), Season Two ran from 1 November 2013 to 11 June 2014. One of the program's key milestones was removing SP5, Walker Shoal, which was dredged by the powerful CSD Athena. This was a significant environmental achievement as the use of the high-powered CSD eliminated the need for drill and blast techniques traditionally used for very hard rock.

Dredging for the GEP was completed in stages over nine months between late October 2013 and 12 July 2014. Dredging for the area of shoreline where the pipeline intersected the mangroves in Middle Arm required careful management of timing the operations with high spring tides to allow vessel access and minimise environmental impacts.

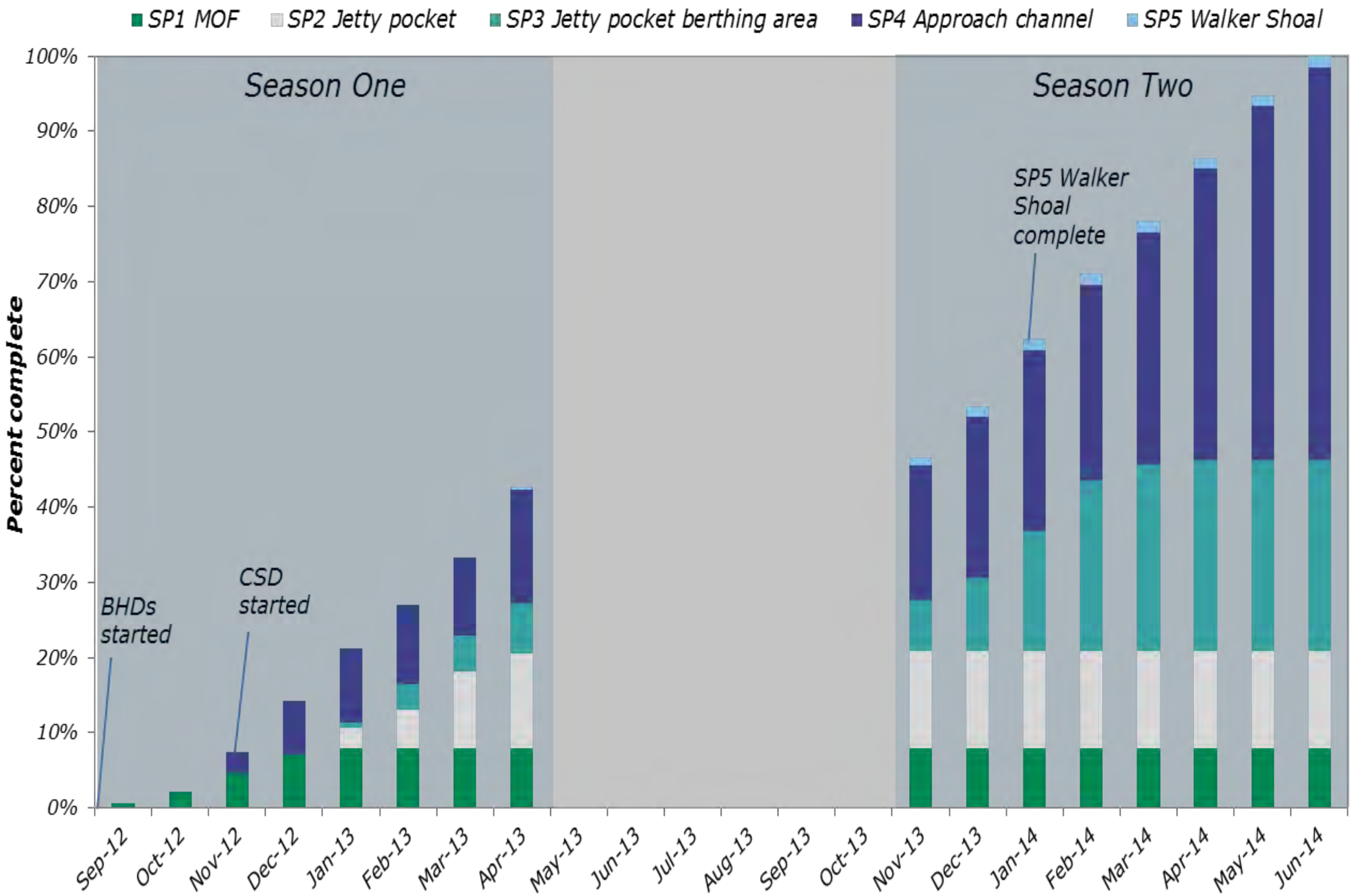


Figure 16 East Arm dredging timeline showing percentage of completion over Seasons One and Two

The Dredging Fleet

The Athena (above) is the most powerful CSD ever to dredge in Australia and was important for the removal of very hard rock at Walker Shoal. The Athena pumped dredged material via a floating pipeline in the THSD Queen of the Netherlands (top right) for disposal at the offshore spoil ground 12 km northwest of Lee Point. The Athena worked ~5,000 operational hours and had over 16,000 cutter head teeth (right) changed over the East Arm dredging program. The teeth on the cutter head weigh over 20kg each.

TSHDs Rotterdam and Vox Maxima on transit to the spoil disposal area, 12 km north west of Lee Point and a ~90 km round trip from East Arm. These two dredgers clocked up over 4,400 operational hours each over the course of the East Arm dredging program and all TSHDs combined traversed the equivalent of over eight trips around the Earth.

The TSHD Queen of the Netherlands receiving dredged material from the CSD Athena via a floating pipeline.

4 Nearshore Environmental Monitoring Program

Nearshore Environmental Monitoring Program

Environmental Monitoring

The NEMP describes 12 monitoring programs that have been designed around predictions of potential overall impact from the Project in Darwin made in the EIS, SEIS and further refined in the East Arm DSDMP (Rev 1, INPEX 2012). The NEMP was specifically designed and implemented to measure and minimise potential impacts associated with dredging and spoil disposal activities. The NEMP includes monitoring of:

> Water Quality and Subtidal Sedimentation;

> Intertidal Sedimentation and Mangrove Community Health;

> Seagrass;

> Corals;

> Marine Pests;

> Recreational Fishing and Fish Health;

> Primary Productivity (Season One only);

> Subtidal Benthos;

> Intertidal Benthos;

> Turtles and Dugongs;

> Model Validation (data collection); and

> Underwater Noise.

Of these 12 programs, ten are reported here (the hydrodynamic model validation and underwater noise monitoring programs were used to collect data for validation purposes).

The NEMP was developed in consultation with the Ichthys Project Dredging Expert Panel (IPDEP), Department of Natural Resources, Environment, the Arts and Sport[1] (NRETAS), Department of Sustainability, Environment, Water, Populations and Communities[2] (DSEWPaC) and scientific experts.

Coastal dolphin monitoring is not detailed in this report but is an additional comprehensive monitoring program undertaken by INPEX in collaboration with the NT Department of Land Resource Management (DLRM) and described in the East Arm DSDMP. The coastal dolphin monitoring program was developed to assess potential dredging-related impacts to the coastal dolphin populations in the Darwin Region.

Results for all monitoring programs are detailed in technical reports that are made available to the community, and provided to various external agencies and authorities. Copies of monitoring reports are available on the Ichthys LNG Project website.

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[1] Department of Natural Resources, Environment, the Arts and Sport has since been changed to the Northern Territory Environment Protection Authority (NT EPA).

[2] Department of Sustainability, Environment, Water, Populations and Communities has since been changed to the Department of Environment (DoE).

Reactive and Informative Monitoring

Two categories of monitoring programs were developed and implemented throughout dredging and spoil disposal activities, comprising:

> Reactive monitoring including triggers that, if exceeded, initiate targeted monitoring and management responses designed to manage dredging and spoil disposal related impacts within the limits of acceptable loss; and

> Informative monitoring designed to measure environmental responses to dredging and spoil disposal activities and provide contextual information on the potential effects of sedimentation and turbidity on (selected) receptors.

Reactive monitoring components are included in the Water Quality and Subtidal Sedimentation, Coral, Seagrass and Intertidal Sedimentation and Mangrove Community Health programs. The East Arm and GEP DSDMPs outline the frameworks for the assessment and management of potential environmental impacts associated with dredging and spoil disposal activities and utilises three 'trigger' levels for the reactive Coral, Seagrass and Intertidal Sedimentation and Mangrove Community Health programs. The trigger levels and assessment frameworks are outlined in the Trigger Action Response Plans of the East Arm DSDMP (Rev 4) and GEP DSDMP (Rev 7). Each trigger level has an associated response based on the perceived risk to the environment.

Level 1 trigger criteria were set to provide an early warning indicator of potential for impact on sensitive receptors. These criteria were based on turbidity for coral and seagrass and sedimentation for mangroves. The exceedance of a Level 1 trigger does not necessarily represent an ecological impact, but is an early warning indicator and acts as a prompt for closer investigation and analysis of measures of the sensitive receptors (e.g. coral mortality or mangrove health measures).

Level 2 and 3 trigger criteria were developed as an estimate of an ecologically relevant change to a sensitive receptor (e.g. significant change in mortality or bleaching of coral communities). They also provided an independent health check of the key sensitive receptors that did not rely on establishing a link between water quality or sedimentation parameters and dredging and spoil disposal activities.

Informative monitoring programs have been carried out on a routine basis and provide contextual information of environmental performance to improve scientific understanding of the potential impacts of dredging on the environment. Data collected on informative indicators were also used for interpretative purposes and were intended to support management response decisions.

Locations of water quality, coral, seagrass and mangrove community health monitoring sites are shown in Figure 17.

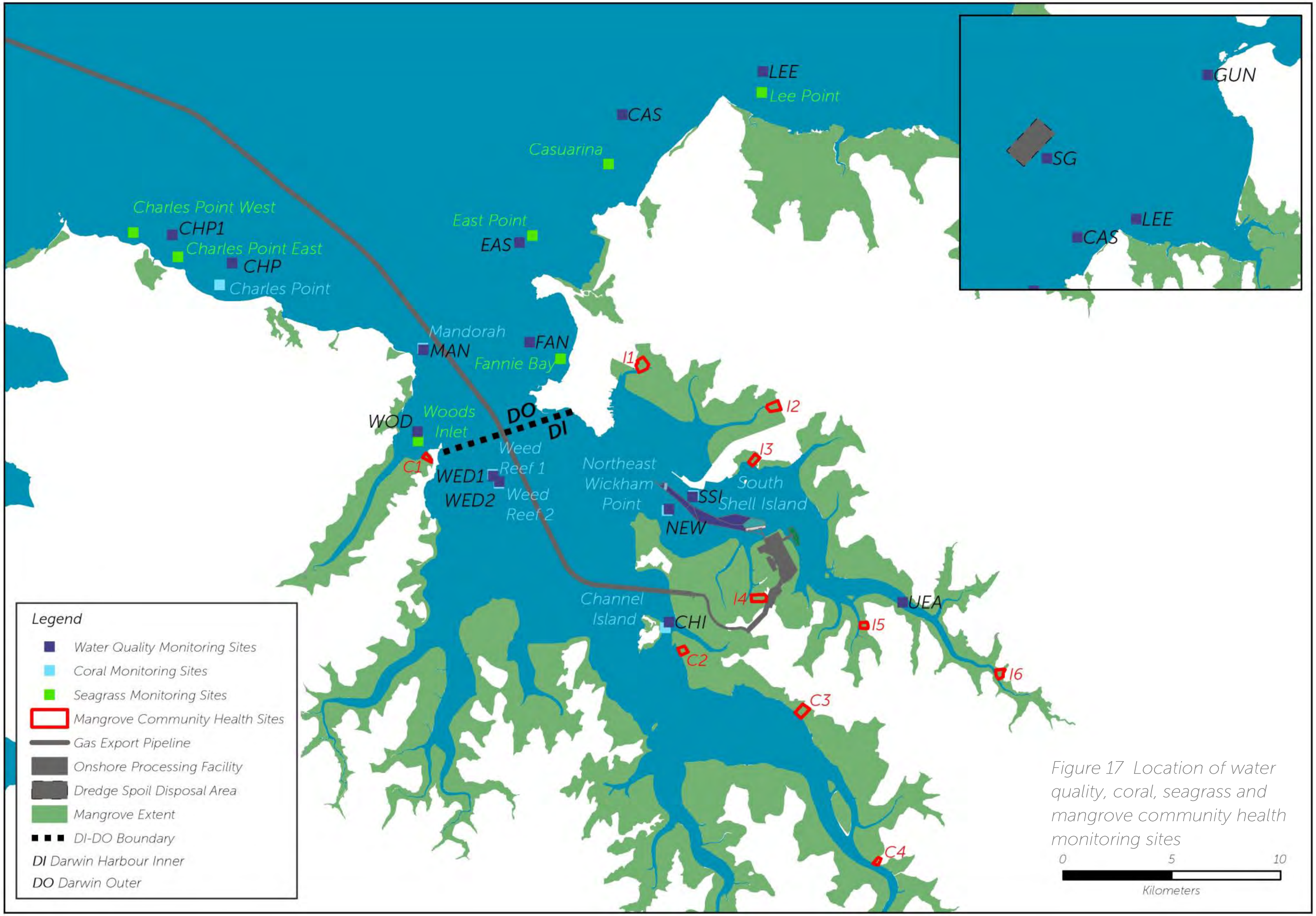


Figure 17 Location of water quality, coral, seagrass and mangrove community health monitoring sites

Snapshot: Observed Effects of Dredging and Spoil Disposal Activities

Environmental monitoring commenced in May 2012 for the baseline (pre-dredging) phase of the Project and continued through Season One of dredging, the dredging hiatus period during the 2013 dry season, and during Season Two of dredging completed in mid-June 2014. A snapshot of the observed effects of dredging for both the reactive and informative monitoring programs described in the NEMP is provided below for the surveys undertaken up to the end of June 2014. Monitoring will also continue post-dredging into 2015 in order to identify any potential delayed effects from dredging and spoil disposal activities. This section provides an overall summary of observed impacts. Specific findings are presented in the relevant technical reports (see list of reports in the Error! Reference source not found.).

Water Quality

Predicted Influence/Impact: Peak dredging-excess SSC and sedimentation predicted to occur in East Arm, in proximity to the dredging footprint. Spoil disposal area and other areas in Darwin Harbour Inner and Darwin Outer predicted to be influenced by excess SSC but at markedly reduced concentrations compared to East Arm[3]

Observed Influence/Impacts:

> With the exception of the monitoring sites closest to dredging in East Arm (South Shell Island and Northeast Wickham Point), turbidity remained within the range of natural variation for the wet and dry seasons

> Episodic events (tropical storms and cyclones) in the wet season caused elevated turbidity at much higher intensities and spread over larger areas than anything observed from dredging-excess turbidity alone

> During Season One, dredging-related suspended sediment plumes (i.e. excess SSC at a discernible level) were largely limited to East Arm and turbidity measurements at all sites outside of East Arm were typical of wet season conditions

> During Season Two, dredging-related suspended sediment plumes and turbidity were generally similar to Season One and limited to East Arm during neap tides, with a minor contribution at some sites further afield during spring tides at the end of Season Two

> Plumes around the spoil disposal area were observed during peak phases of the dredging program, typically associated with peak spring tides

> The magnitude and extent of dredging excess turbidity, where discernible, returned to natural background conditions within a single spring-neap tidal cycle following completion of dredging activities (both Seasons One and Two)

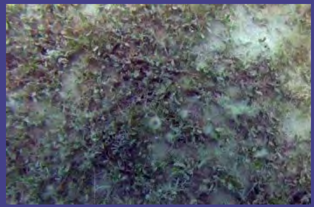
Coral

Predicted Influence/Impact: Impact 36 ha[4] of coral habitat (mostly confined to East Arm, including South Shell Island and Northeast Wickham Point) from excess SSC and sedimentation associated with dredging

Observed Influence/Impacts:

> No detectable dredging-related impacts to coral health at monitoring sites[5] outside of East Arm, as measured by partial mortality of tagged coral colonies and site-wide coral cover

> Probable dredging-related impact at South Shell Island within East Arm, as measured by an increase in partial mortality of tagged corals, a reduction in coral cover on transects and an increase of sediments on corals. However the effects of dredging appear to be confined to this site, with no apparent change at Northeast Wickham Point, and were less than predicted



Seagrass

Predicted Influence/Impact: Impact 2 ha[4] of seagrass from excess sedimentation associated with dredging and disposal activities

Observed Influence/Impacts:

> Turbidity at key seagrass monitoring sites[5] was in the range of natural variation, with no discernable dredging-excess turbidity measured.

> Predictions from seagrass response models also indicated no expected influence of dredging-related excess turbidity on seagrass growth at reactive monitoring sites[5]

> Natural fluctuations in cover and distribution were far greater than potential dredging-related impacts

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[3] Section 6 of the East Arm DSDMP (Rev 4).

[4] As detailed in Table 6-4 of the East Arm DSDMP (Rev 4).

[5] Selected monitoring sites are considered representative of the overall habitat.

Intertidal Sedimentation and Mangrove Community Health

Predicted Influence/Impact: Impact 30 ha[4] of mangroves in Darwin Harbour due to excess sedimentation associated with dredging and disposal activities

Observed Influence/Impacts:

> Net sedimentation levels in mangrove assemblages at monitoring sites[3] were below the level considered to potentially impact mangrove health (>50 mm)

> No dredging-related impacts to mangrove health at monitoring sites[3] as measured by canopy cover and seedling growth and survival

> Broad scale measurements of mangrove health captured by remote sensing found no indications of dredging-related impacts

Recreational Fishing and Fish Health

Predicted Influence/Impact: Low potential for impacts to recreational fishing catches and fish health in Darwin Harbour Inner and Darwin Outer from Project activities

Observed Influence/Impacts:

> No fish kills attributed to Project activities

> No evidence of dredging-related impacts to fish health and catches

>Some displacement of recreational fishermen from East Arm to avoid Project-related activities

Turtles and Dugongs

Predicted Influence/Impact: Potential for displacement of animals in East Arm from Project activities. Potential to indirectly impact through potential loss of foraging area

Observed Influence/Impacts:

> No evidence of displacement of turtles and dugongs from Darwin Harbour

Primary Productivity

Predicted Influence/Impact: Potential impacts to phytoplankton, microphytobenthos on intertidal mudflats and mangrove leaf litter (Tidal Flat assemblage) in East Arm

Observed Influence/Impacts:

> No detectable dredging-related impacts to mangrove productivity (measured by leaf litter fall in the Tidal Flat assemblage), phytoplankton or intertidal microphytobenthos

Marine Pests

Predicted Influence/Impact: Potential for marine pests to enter Darwin Harbour via Project vessels

Observed Influence/Impacts:

> One pest species from the target list was identified on the hull of a cargo vessel unloading break bulk goods (Project and non-Project related) at East Arm Wharf; however monitoring found no specimens and no evidence of establishment of the species to surveyed habitats in the Harbour

Subtidal and Intertidal Benthos

Predicted Influence/Impact: Impacts to infauna and epifauna in East Arm and at the spoil disposal area. Impacts to infauna in intertidal mudflats in East Arm

Observed Influence/Impacts:

> Impacts to infauna and epifauna at the spoil disposal area

> No impacts to epifauna in Darwin Harbour Inner

> Potential impacts to infauna assemblages at sites in East Arm but no such changes in sediment characteristics to link changes to assemblages with dredging, likely to be a result of other natural physio-chemical processes

> No detectable impacts to intertidal infauna

Observed Effects

Water Quality

The Environmental Setting *section (Chapter 2) describes the potential effects of dredging on the natural processes that affect the marine ecosystems of Darwin Harbour. Dredging is known to introduce excess suspended sediments to the water column that are subsequently dispersed, with the potential to reduce underwater light and smother benthic communities (Figure 3b).*

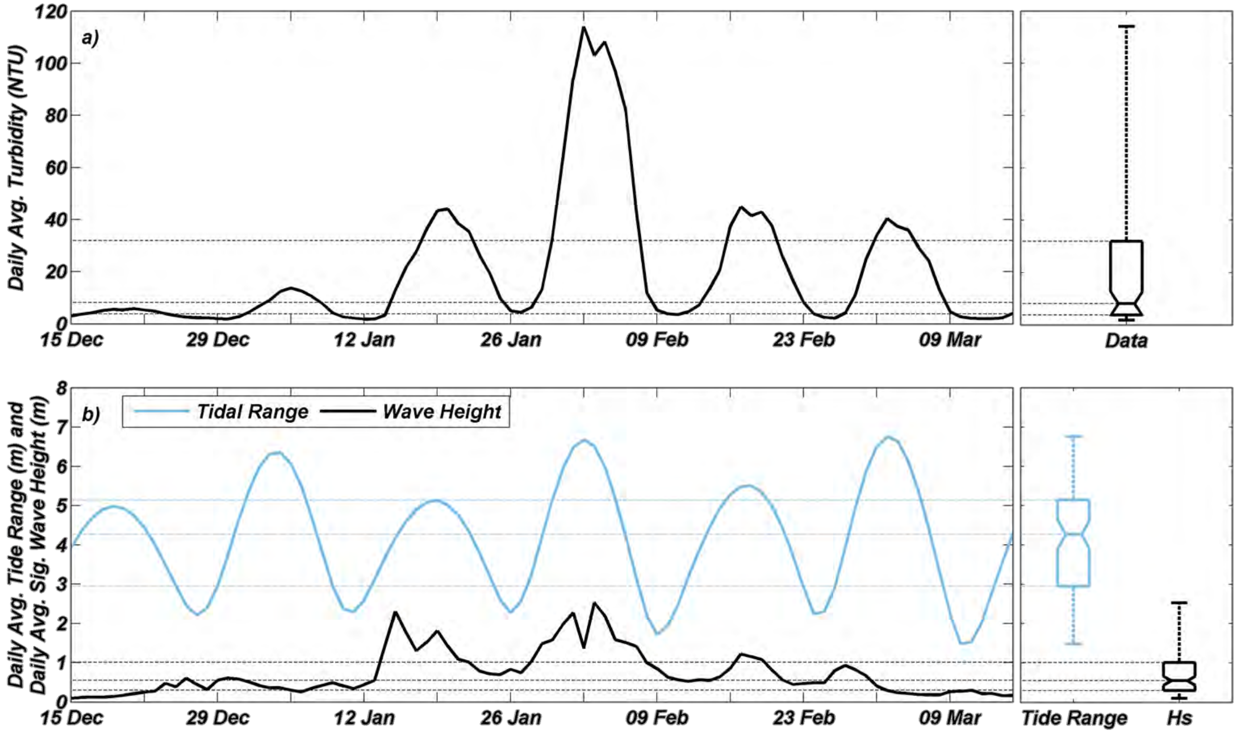
Turbidity and PAR were measured at specific locations adjacent to coral monitoring sites and seagrass survey areas (Figure 17) to provide an early warning of potentially deteriorating water quality. The turbidity measurements formed the basis for inferring deteriorating water conditions that might lead to indirect effects of dredging and spoil disposal activities on seagrass and coral. To assess the influence of dredging and spoil disposal activities, turbidity measurements recorded during the dredging periods were compared with those measured prior to commencement of dredging activities. Comparisons were also made between monitoring sites to understand the spatial influence of different natural episodic events during the monitoring program. In addition, MODIS satellite imagery was obtained on a daily basis (where possible) to provide a broader spatial scale context to assist in distinguishing potential dredging-related turbidity increases above natural background conditions.

As introduced in Chapter 2, the key drivers of turbidity in Darwin Harbour Inner and Darwin Outer are the spring-neap tidal cycle and wet season episodic events that lead to significant waves and stirring of bed sediments in shallow waters (note that winds and rainfall/runoff also contribute to this but to a lesser degree) (Figure 3a). These key drivers of natural turbidity are also presented to distinguish the influence of dredging and spoil disposal activities on turbidity from the natural variations.

An example of the measured daily average turbidity is presented in Figure 18a along with the box and whisker statistical representation of the same data. A box and whisker representation has been used in preference to the mean and standard deviation because (a) it is a more convenient way of graphically depicting and comparing groups of data, particularly where the data for individual variables is skewed or contains outliers; and (b) it makes no assumptions about the form of the underlying statistical distribution of the data.

The daily average tidal range and daily average significant wave heights are shown in Figure 18b and highlight the strong correlation between turbidity, tidal range and wave height. Notwithstanding this strong linear correlation, there is evidence that the physical relationship that it represents is complex.

At times when the significant wave height is greater than 1 m there is a significant increase in turbidity in addition to the tidal influence. In the example shown in Figure 18, a daily average tide range of approximately 6.5 m and a daily average wave height of 0.25 m is associated with a daily average turbidity of approximately 40 NTU, whereas the same tide range and a 2.5 m daily average wave height is associated with a daily average turbidity of 120 NTU. This substantial increase in turbidity is due to the interaction of waves and tides, with waves being a very effective mechanism for resuspending sediment in the littoral (shallow coastal) zone.



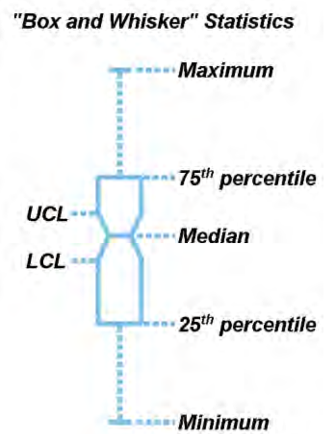


Figure 18 Example of measured time series data and box and whisker representations of the same data for: (a) turbidity; and (b) tidal range and significant wave height for the same period as (a) (UCL: Upper Confidence Limit; LCL: Lower Confidence Limit)

Turbidity, tidal range and significant wave height time series data and "box and whisker" figures are used in the following sections to assess the effects of the dredging and spoil disposal activities on turbidity measured at monitoring sites. Turbidity comparisons are between dredging Seasons One and Two and baseline (non-dredging) periods to gain an understanding of the relative magnitude of dredging-related turbidity against natural background levels and between sites.

There is a further division of results into wet and dry seasons because the majority of dredging occurred during the wet season, except for a nine week period at the start of Season One (27 August 2012 to 31 October 2012) and a six week period at the end of Season Two (1 May 2014 to 11 June 2014) (Figure 16). Wet season turbidity data were available from 2010 at four sites as part of the EIS baseline data collection period. These data provided a useful comparison for the Season One and Season Two wet seasons, which experienced different forcing conditions reflective of the interannual variability of episodic events.

Wet and dry season data also highlight spatial variation in turbidity, such as that observed between Darwin Harbour Inner and Darwin Outer sites. These are also compared to MODIS imagery to contextualise the surface TSS (turbidity) at a regional scale.

Wet Season Turbidity

*The majority of dredging occurred in the wet season (Figure 16), when episodic events generate greater forcing conditions that influence turbidity (***Environmental Setting***). To highlight the variability in the key turbidity drivers, box and whisker plots of tidal range and wave height are included in Figure 19 for the Baseline 2010-11, dredging Season One (2012-2013) and Season Two (2013-2014) wet season datasets. Daily average turbidity is also presented for four Darwin Harbour Inner coral monitoring sites; Weed Reef, Channel Island, Northeast Wickham Point and South Shell Island, as measurements are available at these sites for all three time periods (Figure 19). The locations of these sites are shown in Figure 17. It should be noted that the baseline period is labelled 2010-11 for convenience and is actually a composite of data from months over two wet seasons: 1 February 2010 to 30 April 2010 and 1 November 2010 to 31 January 2011. For this reason caution is required in comparing data with this time period.*

The sites Northeast Wickham Point and South Shell Island, nearest the dredging in East Arm (within ~1 km), show a relatively small increase (5 to 10 NTU) in the median of daily average turbidity for both dredging seasons when compared to the Baseline 2010-11 dataset (Figure 19). At Weed Reef and Channel Island, some 15 km from the dredging activity, the turbidity is within the range of natural (2010-11) variability for both the Season One (2012-13) and Season Two (2013-14) dredging seasons. The higher turbidity values in Season Two may be in part due to the increased wave conditions and rainfall during this period when compared to Season One.

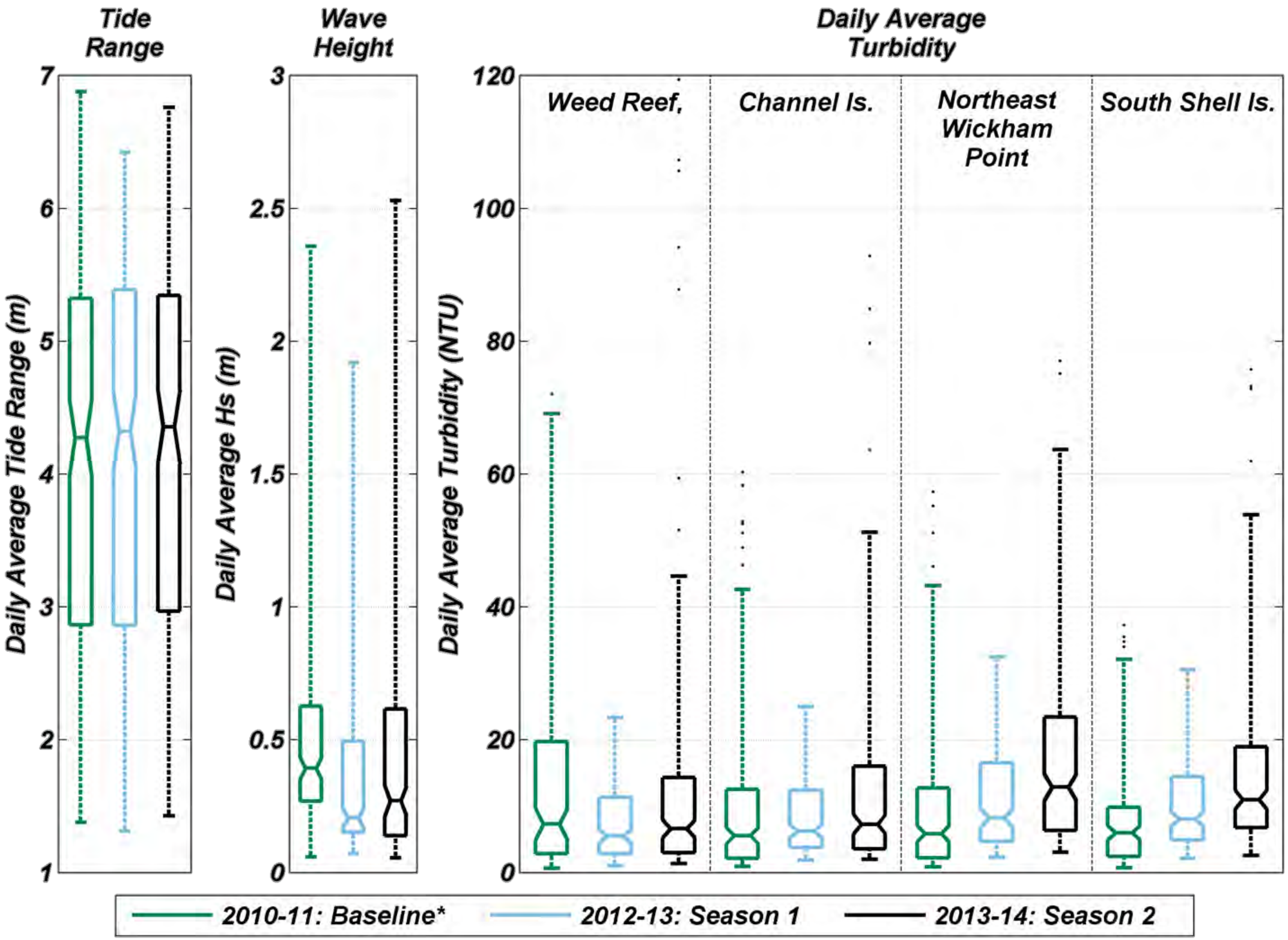


*Figure 19 Comparison of wet season turbidity variability during Baseline (2010/11), dredging Seasons One (2012/13) and Two (2013/14) at four Darwin Harbour Inner sites. Locations of sites are shown in Figure 17. *composite of data from months over two wet seasons – 1 February 2010 to 30 April 2010 and 1 November 2010 to 31 January 2011*

Although the forcing conditions for tide are generally comparable across the three time periods, the wave height shows significantly higher values recorded in Season Two (2013-14) and 2010-11 when compared to Season One (2012-13). This suggests that turbidity would be naturally higher in Season Two, compared to Season One, which is reflected in the turbidity data for the sites unaffected by dredging (Channel Island and Weed Reef) (Figure 19). Daily average rainfall (for the periods that turbidity data are available) was also greater in the 2010-11 (15 mm/day) and 2013-14 (10 mm/day) wet seasons compared to 2012-13 (7 mm/day) (Bureau of Meteorology 2014). Overall, results indicate that even close to dredging, the relative contribution of dredging to turbidity is small (5 to 10 NTU increase in the median of daily average turbidity) and negligible at key coral sites Weed Reef and Channel Island further away from dredging activity (≥15 km).

A comparison of the daily average turbidity measured at sites during the wet season of dredging Seasons One and Two also highlight the effects of natural forcing conditions on turbidity (Figure 20). As evident in Figure 19, the median of daily average turbidity was generally higher for Season Two compared to Season One for the majority of sites, as a result of higher tidal range and greater monsoonal activity (Figure 20). Some regional patterns were also evident, with those sites in Darwin Harbour Inner showing lower median daily average turbidity than more exposed sites in Darwin Outer, such as Charles Point (CHP), where westerly swells cause localised wave stirring of bed sediments. In the case of Charles Point, this elevates turbidity to median daily average of around 15 to 20 NTU compared to 5 to 10 NTU at sites inside the Harbour.

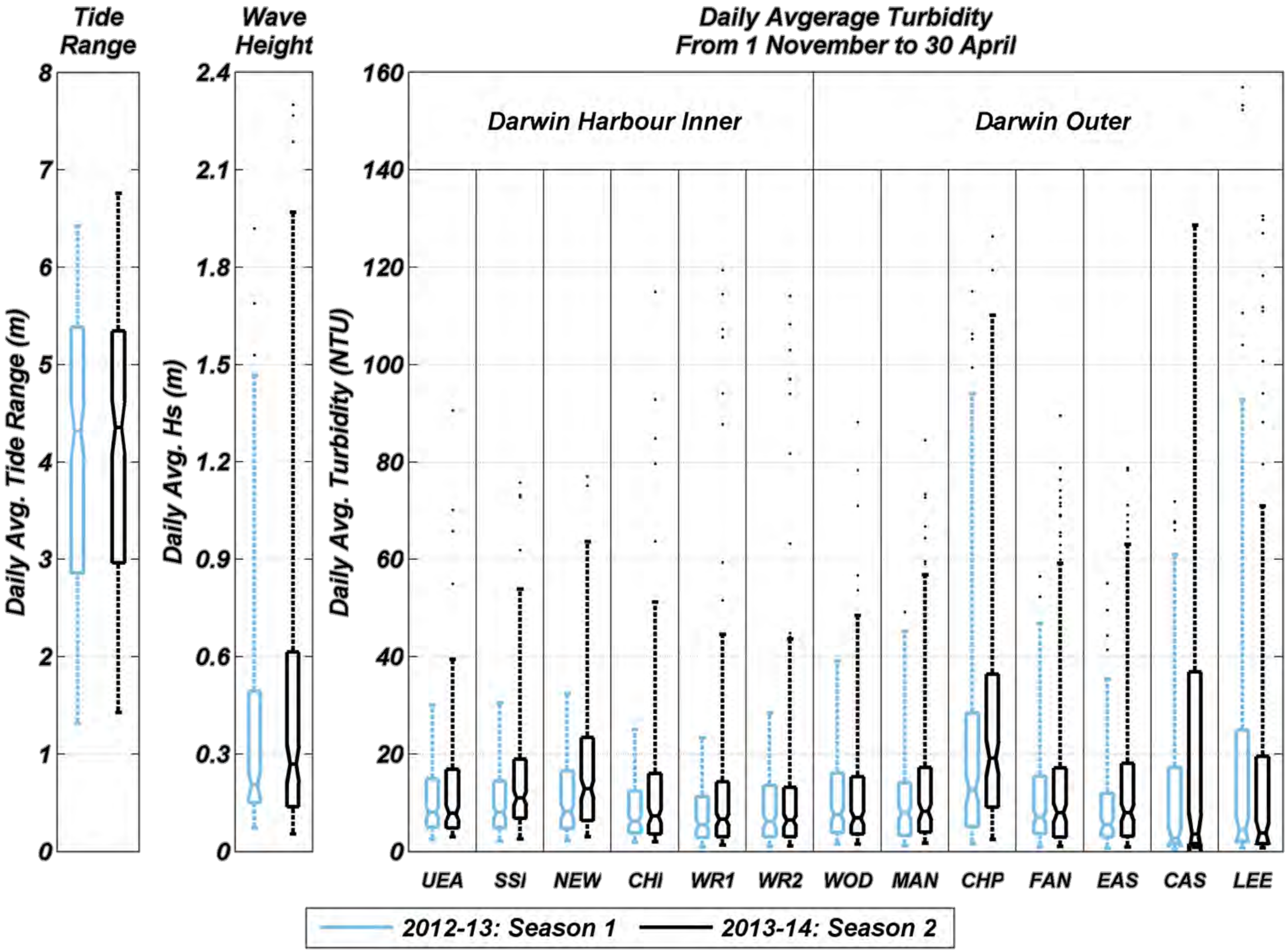


Figure 20 Comparison of wet season turbidity variability during dredging Seasons One (2012/13) and Two (2013/14) at 13 Darwin Harbour Inner and Darwin Outer sites. Locations of sites are shown in Figure 17

Darwin Outer sites exhibit a much greater range in turbidity because of this episodic exposure to wind/wave swells in the Beagle Gulf compared to those sheltered in Darwin Harbour Inner, where wind fetch and wave energy is limited.

To assess turbidity at a regional scale, surface TSS values were extracted from MODIS imagery along two transects; from the spoil disposal area to Lee Point/Shoal Bay (i.e. Point A to B; Figure 21) in Darwin Outer and from the dredging area in East Arm to mid-Harbour, near Weed Reef (Point C to D; Figure 21) in Darwin Harbour Inner. Wet season averages for the years ending 2009, 2010, 2011 and 2012 represent the natural background conditions along these transects, and those for 2013 and 2014 represent data captured during Season One and Season Two dredging respectively.

Transects show that during the wet seasons of dredging Seasons One and Two, elevated turbidity (measured as surface TSS) from the spoil disposal area attenuated to background levels within 5 km from the source (Figure 22a).

From dredging activities in East Arm moving westward to mid-Harbour (Point C to D), elevated turbidity returned to background within ~8 km of the dredge source (Figure 22b). This is well before reaching coral monitoring sites at Weed Reef and Channel Island, approximately 15 km and 18 km from dredging activities respectively. However, coral monitoring sites within in close proximity to dredging (<1 km) at South Shell Island and Northeast Wickham Point have been exposed to elevated turbidity for dredging Seasons One and Two (Figure 19). All dredge plume extents were well within the model predictions.

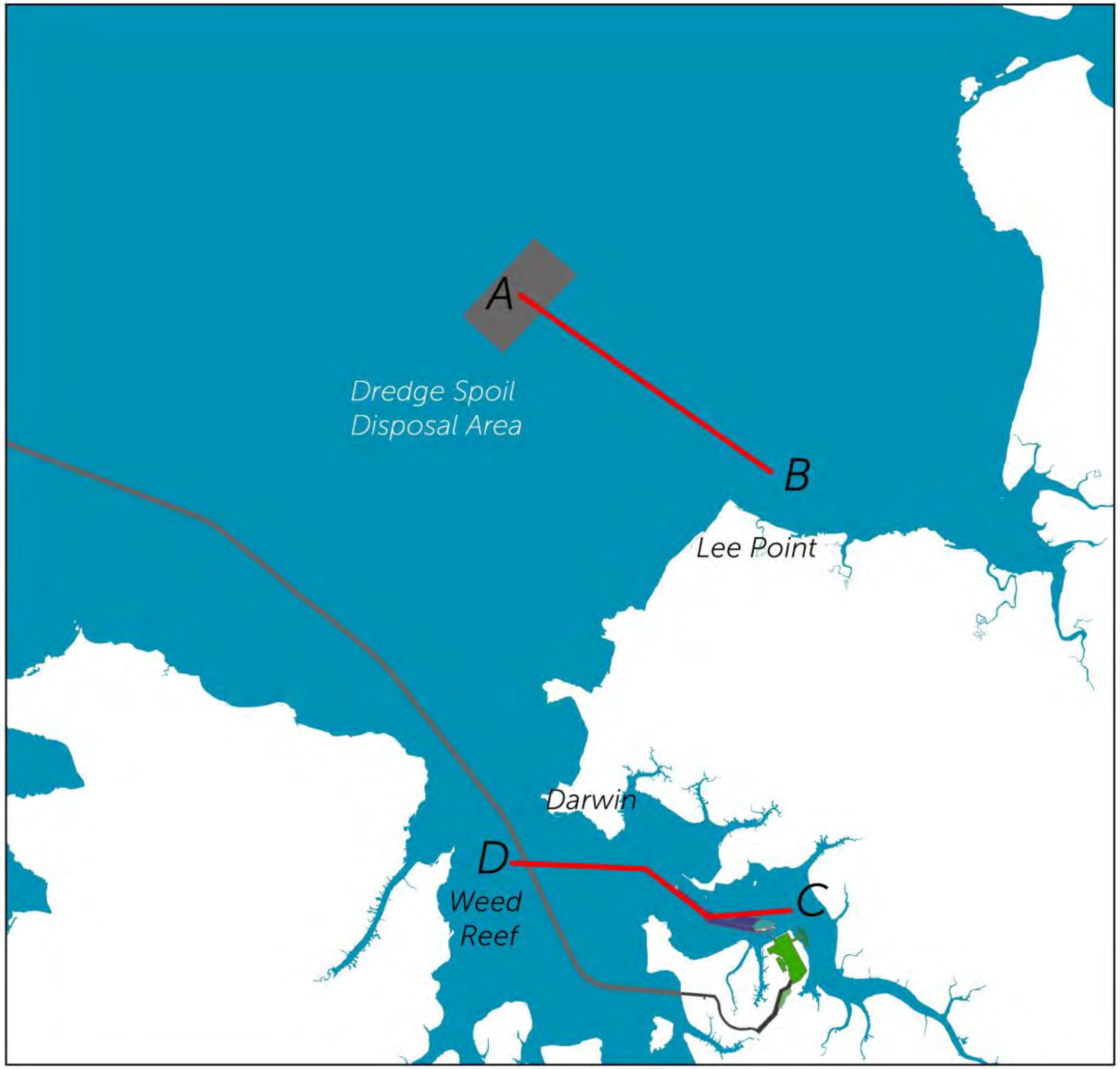


Figure 21 Locations of transects used to extract surface TSS values from the MODIS satellite images

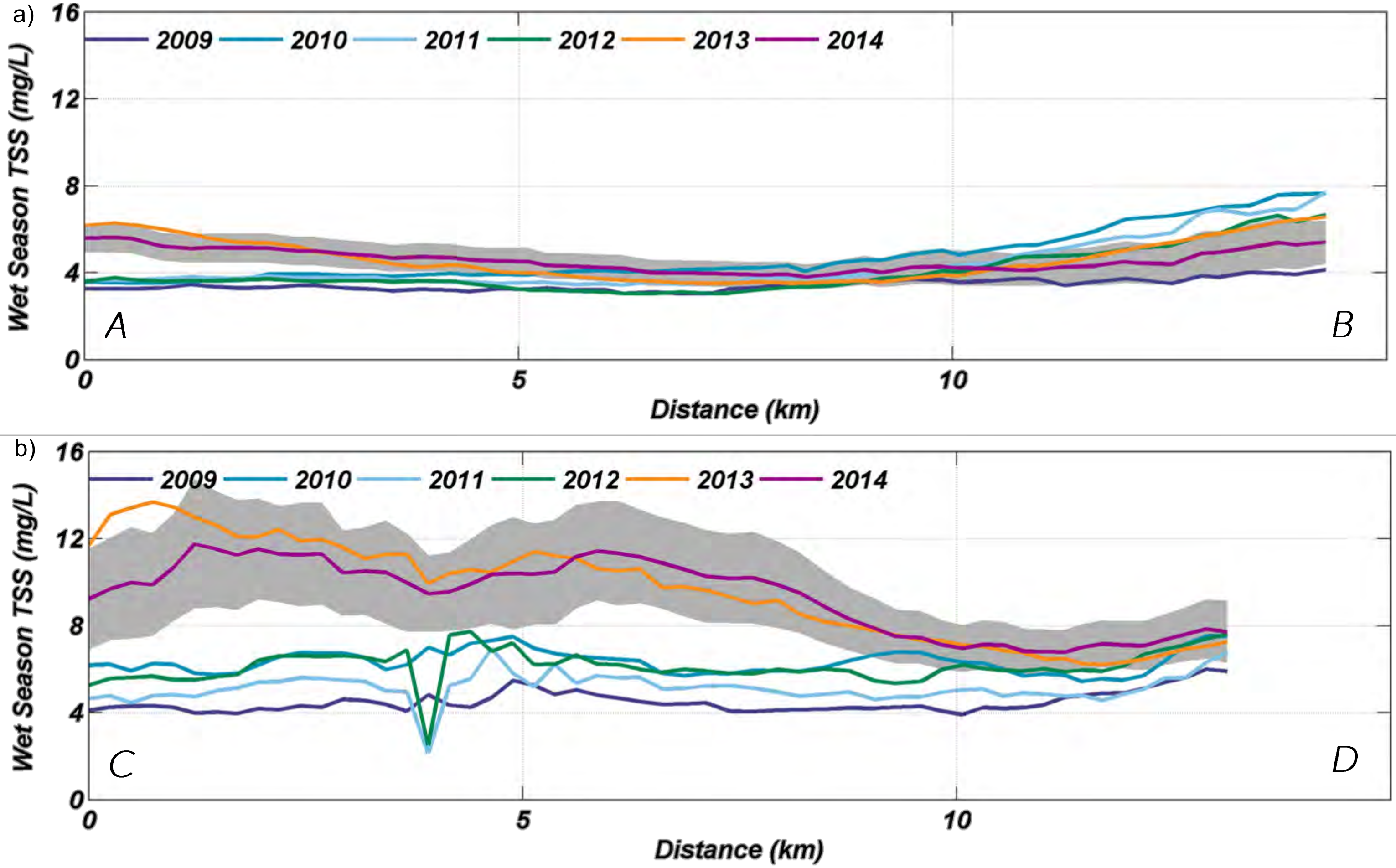


Figure 22 Wet season surface TSS concentrations along transects extending downstream from: (a) the spoil disposal area (Point A) to Lee Point (Point B); and (b) from upstream of the dredging area in East Arm (Point C) to Weed Reef in the mid-Harbour (Point D). The years 2009 to 2012 reflect natural baseline conditions and 2013 and 2014 refer to Season One and Season Two dredging conditions respectively. Grey shading indicates 95% confidence intervals

2014 Dry Season Dredging

East Arm dredging during the dry season of Season Two dredging from 1 May 2014 to 11 June 2014 (Figure 16) saw four weeks of CSD dredging activity followed by two final weeks of TSHD clean up dredging. The initial four week period of dredging was carried out in areas that allowed relatively high dredge production rates when compared to the overall dredging program. A composite map of surface TSS estimates from daily MODIS satellite images for May 2014 shows elevated surface TSS values near the spoil disposal area in Darwin Outer and the dredging area in East Arm (Figure 23).

Turbidity data collected during May-June 2014 dry season show elevated turbidity levels of between 5 and 10 NTU at some monitoring sites when compared to the equivalent period in May-June 2013 (Figure 24). In Figure 24, sites are aligned from upstream Upper East Arm (UEA) in Darwin Harbour Inner to offshore Darwin Outer and demonstrate the effects of East Arm dredging at Northeast Wickham Point (NEW) and South Shell Island (SSI), as well as the spoil disposal area dispersion at Darwin Outer sites Charles Point (CHP), Fannie Bay (FAN) and East Point (EAS).

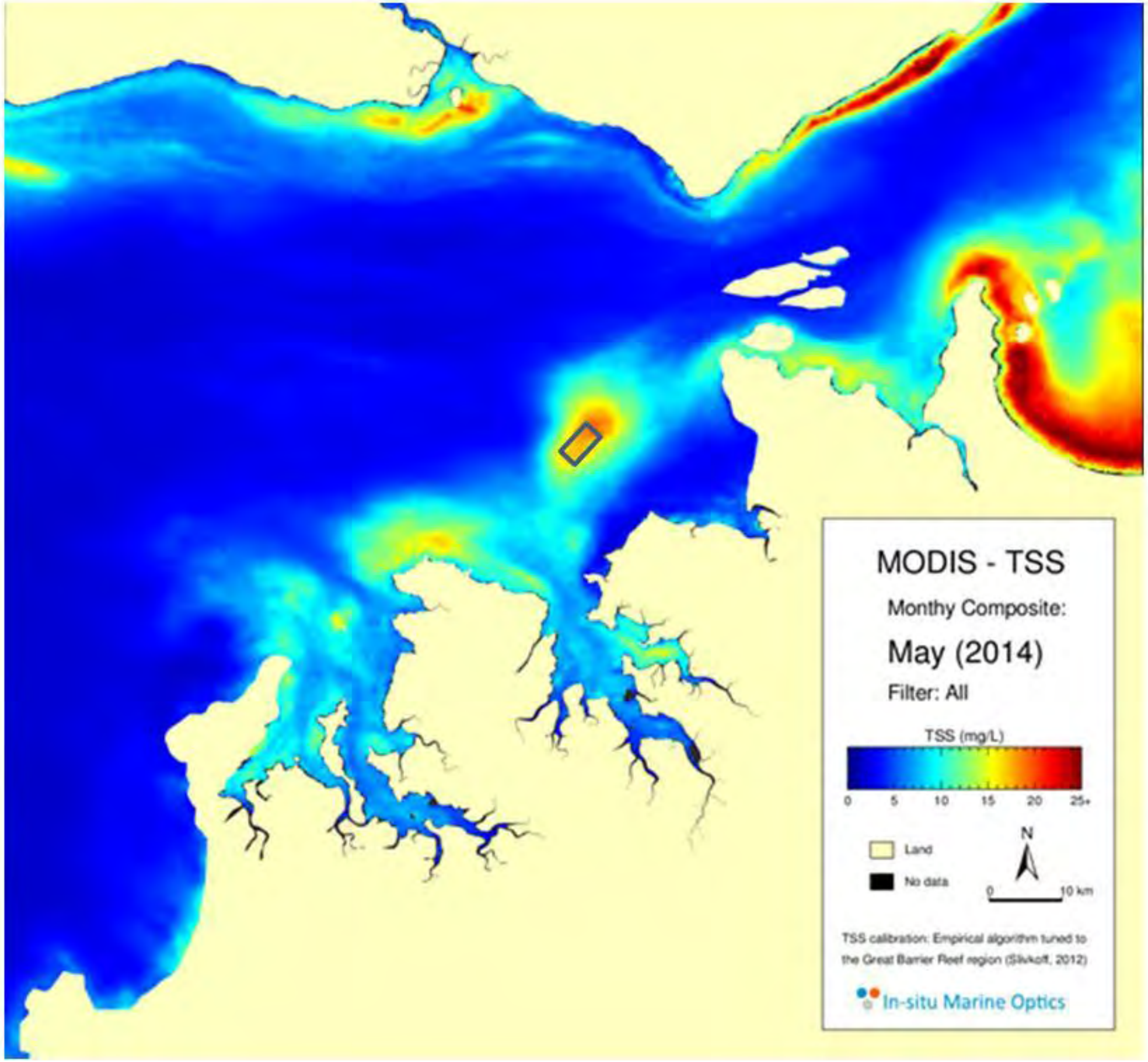
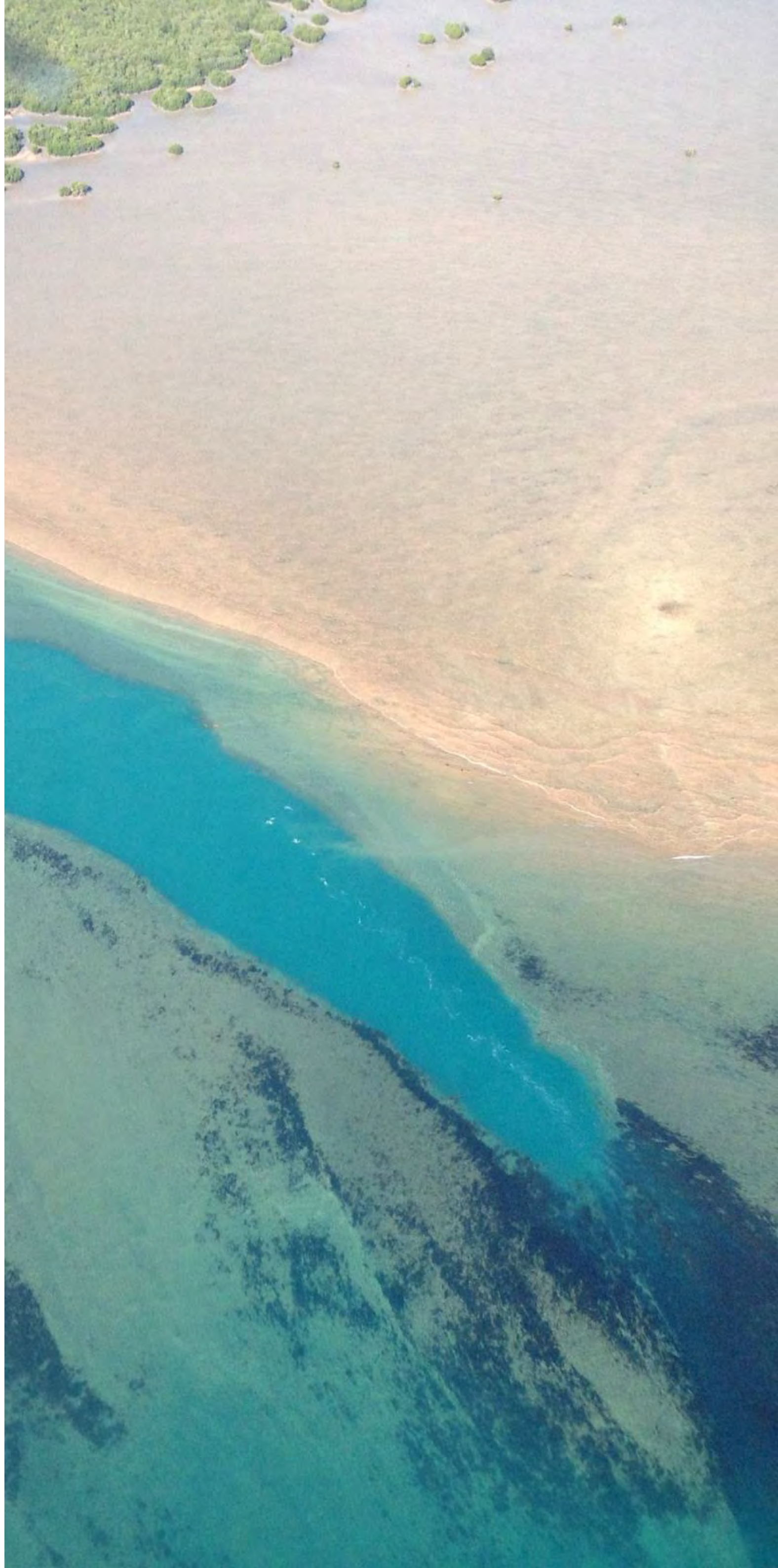


Figure 23 Composite of surface TSS estimates derived from daily MODIS images for May 2014 (box shows spoil disposal area boundary)

Turbidity within the Harbour at Channel Island (CHI) and Weed Reef (WED) is generally higher in May-June 2014 than the same period in the preceding year (May/June 2013) (Figure 24). The variability in the median of daily average turbidity at these two sites is still within the longer term dry season variability. Interestingly, turbidity at Darwin Outer sites near Shoal Bay, Lee Point (LEE) and Casuarina (CAS), indicate that dispersion of turbidity from spoil disposal activity has not influenced these sites, whereas turbidity at the sites further west (EAS and FAN) may have been influenced by the spoil disposal and/or dredging activities. These slight elevations in turbidity varied with tide and were typically recorded during spring tides only, when stronger tidal currents caused increased turbidity and dispersion of sediments away from the spoil disposal and dredge areas over this short period. Naturally elevated surface TSS estimates were also observed in Bynoe Harbour (estuary system to the west) and near Adelaide River to the east (Figure 23), which were naturally driven and considered unrelated to dredging and spoil disposal activities.

The surface TSS transects compiled for the six week dry season component of dredging Season Two (1 May to 11 June 2104) indicate a larger dispersion from the dredging footprint and spoil disposal area (Figure 25) than during the preceding wet seasons (Figure 22), with surface plumes extending to around 8 km downstream from either source. The surface TSS estimates are slightly higher than background at this distance and may have contributed a small amount to background turbidity at Channel Island and Weed Reef 1 during spring tides in late May 2014. As discussed above, the variability in turbidity measured at these sites during the May/June 2014 dry season dredging period was within the long term range natural variability. The elevated turbidity values were recorded over short-lived periods only during the higher spring tides. However, shortly following the completion of dredging, turbidity reduced to within natural variability with one spring neap tidal cycle (see *Post-dredging Turbidity**).*



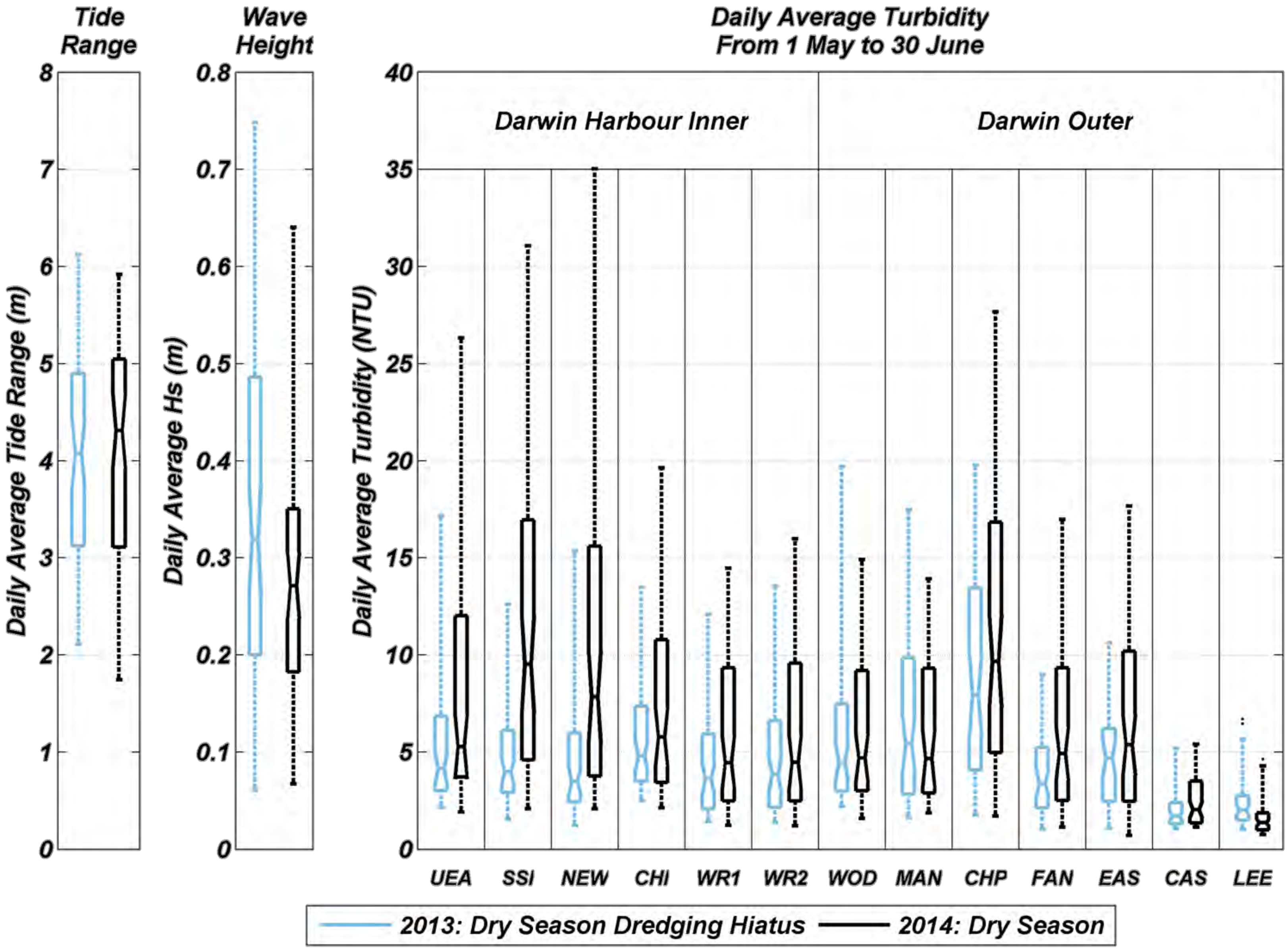
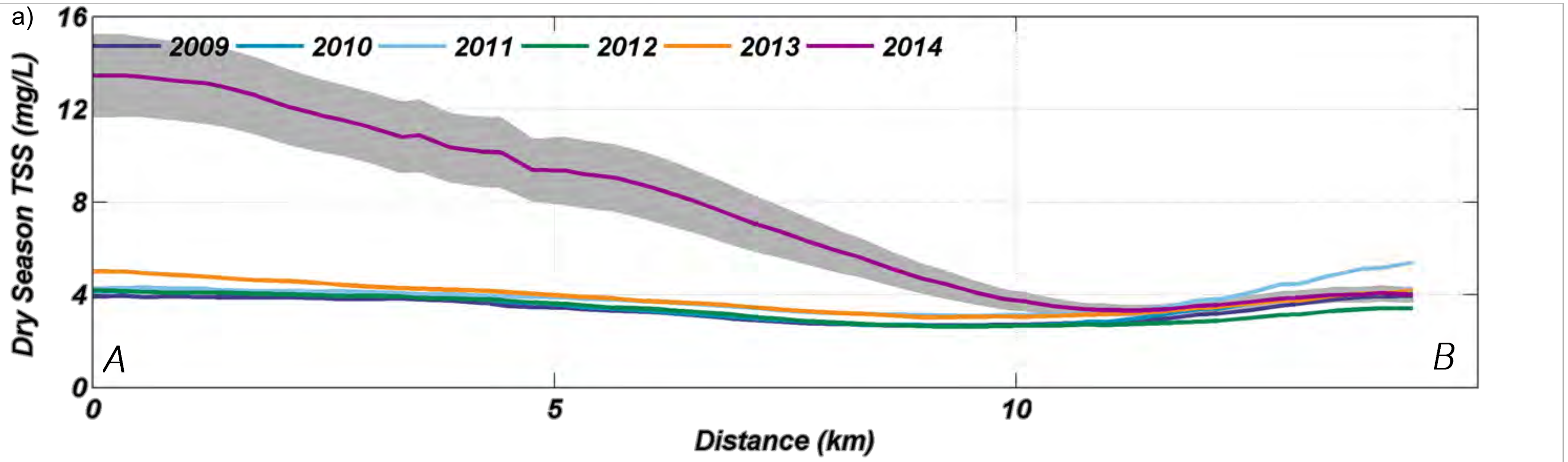


Figure 24 Comparison of dry season turbidity variability for 1 May to 30 June for the 2013 dredging hiatus period and dredging Season Two (2013-14). Note - Season One dredging was completed on 30 April 2013. Locations of sites are shown in Figure 17



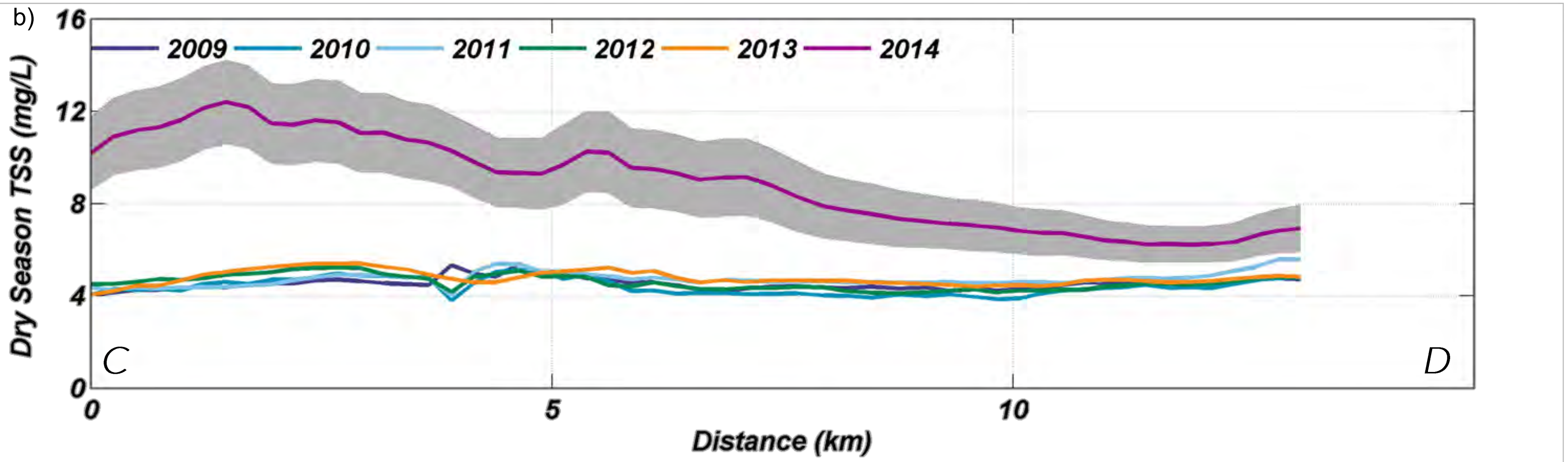


Figure 25 Season Two dry season (May/June 2014) surface TSS concentrations along transects extending downstream from: (a) the spoil disposal area (Point A) to Lee Point (Point B); and (b) from upstream of the dredging area in East Arm (Point C) to Weed Reef in the mid-Harbour (Point D). 2009 to 2012 reflect natural baseline conditions and 2013 and 2014 refer to Season One and Season Two dredging conditions respectively. Grey shading indicates 95% confidence intervals

Post-dredging Turbidity

Elevated turbidity measured at monitoring sites closest to dredging rapidly returned to natural conditions following the completion of dredging activities for both Seasons One and Two. This rapid return to natural turbidity conditions (represented by 2010 turbidity data) following Season Two dredging occurred within a single spring-neap tidal cycle at Northeast Wickham Point (Figure 26) and South Shell Island, located less than 1 km from the East Arm dredge footprint (Figure 17). The same occurred within a matter of days at Channel Island (Figure 26) and Weed Reef, where a minor dredging contribution was observed in the final six weeks of Season Two dredging (Figure 24).

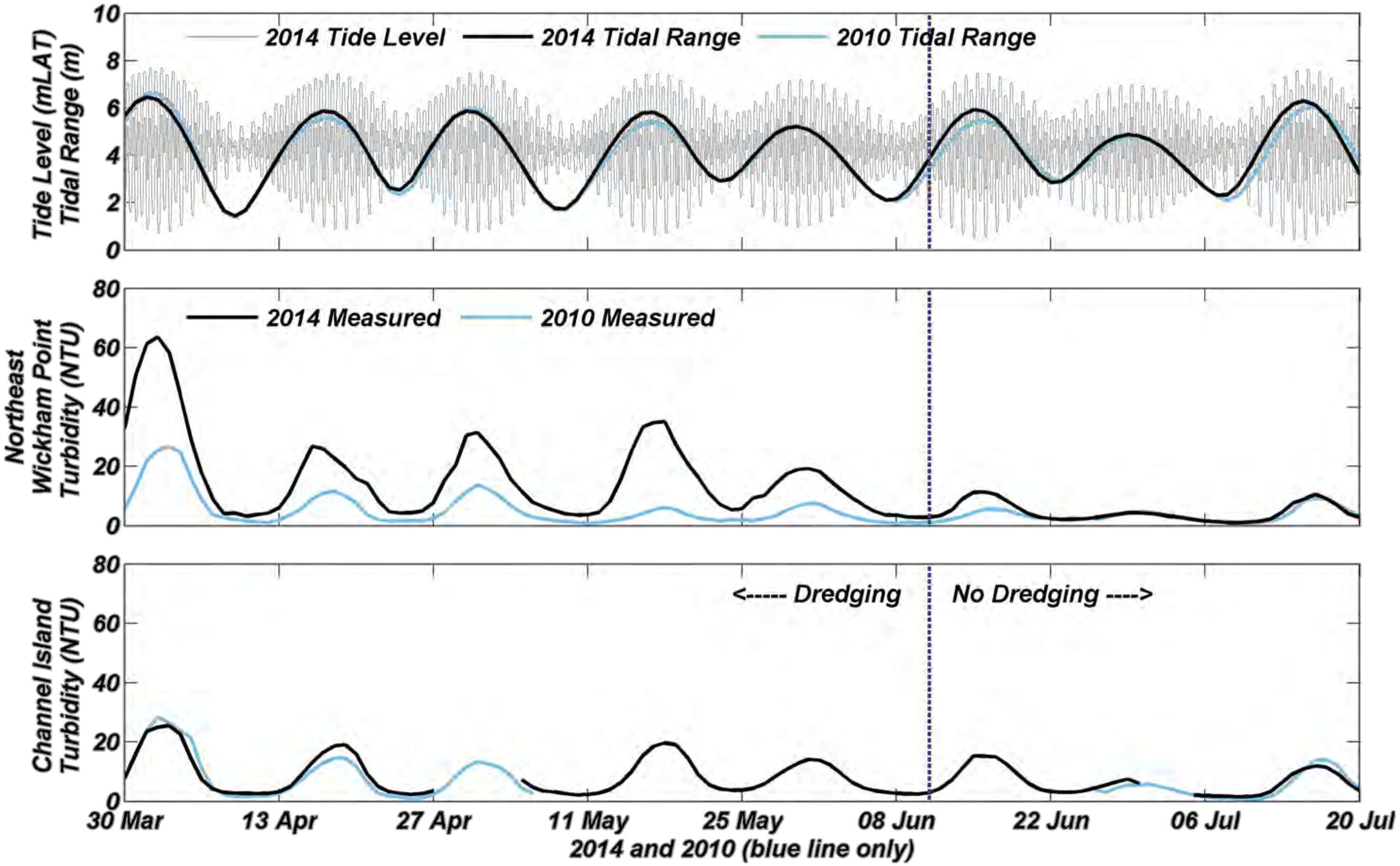


Figure 26 Time series of turbidity and tidal range at Northeast Wickham Point (NEW) and Channel Island (CHI) demonstrating the return to natural conditions (represented by 2010 data) after the end of Season Two dredging on 11 June 2014

Summary of Turbidity Observations

In summary, turbidity (and underwater light climate) in the Darwin region are influenced by regular tidal stirring and regional climatic and oceanographic processes (Figure 2; Environmental Setting*). The macrotidal environment exerts a strong influence on turbidity and light, particularly in Darwin Harbour Inner. Overprinted on this regular tidal influence are the wet season episodic events during which turbidity levels can increase by an order of magnitude and blackout conditions occur.*

The influences of dredging and spoil disposal activities on turbidity in the wet and dry seasons were considered in this natural context. Turbidity measured during the wet seasons of dredging Seasons One and Two was within the range of natural variability for all water quality monitoring locations beyond 8 km from dredging activities and beyond 5 km from the spoil disposal area. Coral monitoring sites within 1 km from dredging activities in East Arm (South Shell Island and Northeast Wickham Point) showed a relatively small dredging-related increase (5 to 10 NTU) in the median of daily average turbidity for the wet seasons of both dredging seasons when compared to natural baseline conditions. Dredging in the dry season of Season Two (1 May 2014 to 11 June 2014) contributed to elevated turbidity at some sites in both Darwin Inner Harbour and Darwin Outer (5 to 10 NTU), particularly during spring tides. The relatively low contributions of dredging-excess turbidity measured at times over the course of the dredging programs did not appear to cause measurable environmental impact to seagrass or coral habitats at monitoring sites, with the exception of corals at South Shell Island (see Observed Effects – Corals*). Furthermore, turbidity returned to natural background levels within one spring-neap tidal cycle following completion of each dredging season and as such, longer term lag-effects from dredging-excess turbidity are likely to be minimal.*

*Monitoring also highlighted the strong influence of episodic events (tropical storms and cyclones) in the wet season, which caused naturally elevated turbidity at much higher intensities over large areas than anything observed from dredging excess alone. Such events influenced the distribution and cover of seagrass in Darwin Outer (*Observed Effects - Seagrass*) and the catchability of finfish from Darwin Outer reefs during research angling activities (*Darwin Harbour – A Dynamic Environment – Research Fishing and Fish Health*).*

The influence of these natural and dredging-related turbidity patterns on ecological receptors are discussed in the following sections.

Corals

Hard corals (corals with a calcium carbonate skeleton) exist in patches of the shallow, rocky areas of Darwin Harbour where the seabed and water quality are suitable for their growth and survival. Corals generally occupy less than 20% of the seabed in these areas. They must also cope with naturally high levels of turbidity caused by the resuspension of sediments generated by the strong spring tidal currents, wind, waves and runoff associated with episodic wet season events (see Sediment Mobilisation and Turbidity*). Increased turbidity and sedimentation from dredging has the potential to affect corals in Darwin Harbour (Figure 3b), particularly those communities at Northeast Wickham Point and South Shell Island, within 1 km from the East Arm dredge footprint (Figure 17).*

As most corals obtain some of their nutrition autotrophically (i.e. from photosynthesis of their symbiotic microscopic algae - zooxanthellae), prolonged levels of elevated turbidity and reduced light may affect the health of corals. Sedimentation can also cause stress in corals, as they may need to invest energy removing sediment from their surface to prevent partial mortality and eventual colony death.

As part of the monitoring program, divers took photos of permanently tagged coral colonies at seven sites within Darwin (Figure 17) and interpreted these for changes to coral health (bleaching and mortality). Of these, two sites in East Arm were predicted to be impacted by suspended sediment mobilised during dredging activities (South Shell Island and Northeast Wickham Point) and the remaining five sites were not predicted to be impacted (Weed Reef 1 [North], Weed Reef 2 [South], Channel Island, Mandorah and Charles Point).

As tagged coral colonies only represent a small proportion of the total coral cover at sites and the methodology does not take into account growth or recruitment, coral health was also assessed on a site-wide level from photos taken along permanent transects. Using this approach it was possible to assess whether coral mortality was at a level that:

- *Exceeded the replacement rate through recruitment and growth, so that the net result was a reduction in coral cover at a site-wide level; or*
- *Caused changes in the dominance of certain coral families or growth forms due to varying sensitivity to the potential effects of dredging-excess turbidity and sedimentation.*

Over time, mortality in coral colonies occurs naturally and this natural attrition results in a gradual increase in tagged coral mortality at all sites over the Baseline and Dredging phases of the program (Figure 27). Increases to the average mortality at sites were in part driven by the complete mortality of a few colonies, as well as slight increases in partial colony mortality (i.e. mortality of a portion of a coral colony).

Natural rates of tagged coral mortality at the monitoring sites were modelled so that potential increases in rates of mortality above these could be investigated for potential effects of dredging. Data from all surveys up to October 2013 were used to generate predictions of natural mortality. At most sites, there were no indications that tagged coral mortality reached levels outside of the range of natural variation during dredging activities, and this was supported by measurements of the cover of corals in the communities, which showed no observable decreases.

Turbidity at the coral monitoring sites outside of East Arm was generally in the long-term range of natural variability and, as such, no dredging-related impacts were anticipated or measured at these sites during the monitoring program (see Observed Effects – Water Quality*). Natural changes to tagged coral mortality and coral cover along transects at Weed Reef 2, located outside of East Arm in the mid-Harbour, were observed due to temporarily high water temperatures (i.e. >32°C) that led to a bleaching event at this site in February 2013. This caused the eventual death of some of the tagged coral colonies and a slight reduction in coral cover (Figure 27).*

As expected, dredging-excess turbidity in the range of 5 to 10 NTU was measured at times at South Shell Island and Northeast Wickham Point (see Observed Effects – Water Quality*), where coral impacts were predicted. Of these two sites, probable dredging-related coral health impacts were only observed at South Shell Island.*

At about 300 m from the nearest section of the dredge footprint, South Shell Island was the closest of the coral monitoring sites to East Arm dredging operations. In addition to partial mortality (Figure 27), sediment on coral, which constitutes up to half of the partial mortality of tagged corals, generally increased throughout the monitoring program at this site (Figure 28). South Shell Island also showed slight increases in sediment cover at a site-wide level (i.e. along the transects), particularly from March 2014 onwards, during Season Two dredging. These increases are consistent with observations from tagged corals, although when temporal and spatial variability (error) is considered this increase is generally indistinct.

Increasing sediment cover on tagged corals over time (on average) is expected, similar to the expected average increase in mortality, as areas of dead coral gradually become covered in sediment with no active removal by the coral itself. However, during the monitoring program, the increases to sediment on coral (and mortality) at South Shell Island appeared elevated compared to the other monitoring sites (Figure 28). Given there has also been a slight decrease (non-significant) to the cover of hard corals in this community (Figure 27), the close proximity of this site to dredging operations and the fact that dredging has increased turbidity above natural levels, it is likely that turbidity and/or sedimentation from dredging has affected corals at South Shell Island. However, South Shell Island has also shown substantial losses of tagged colonies due to coral instability (e.g. dislodgment and overturning from tidal currents and wave action), which may also be influencing coral cover measurements along the transects.

General findings from the coral monitoring program are discussed in more detail in Darwin Harbour – A Dynamic Environment*.*

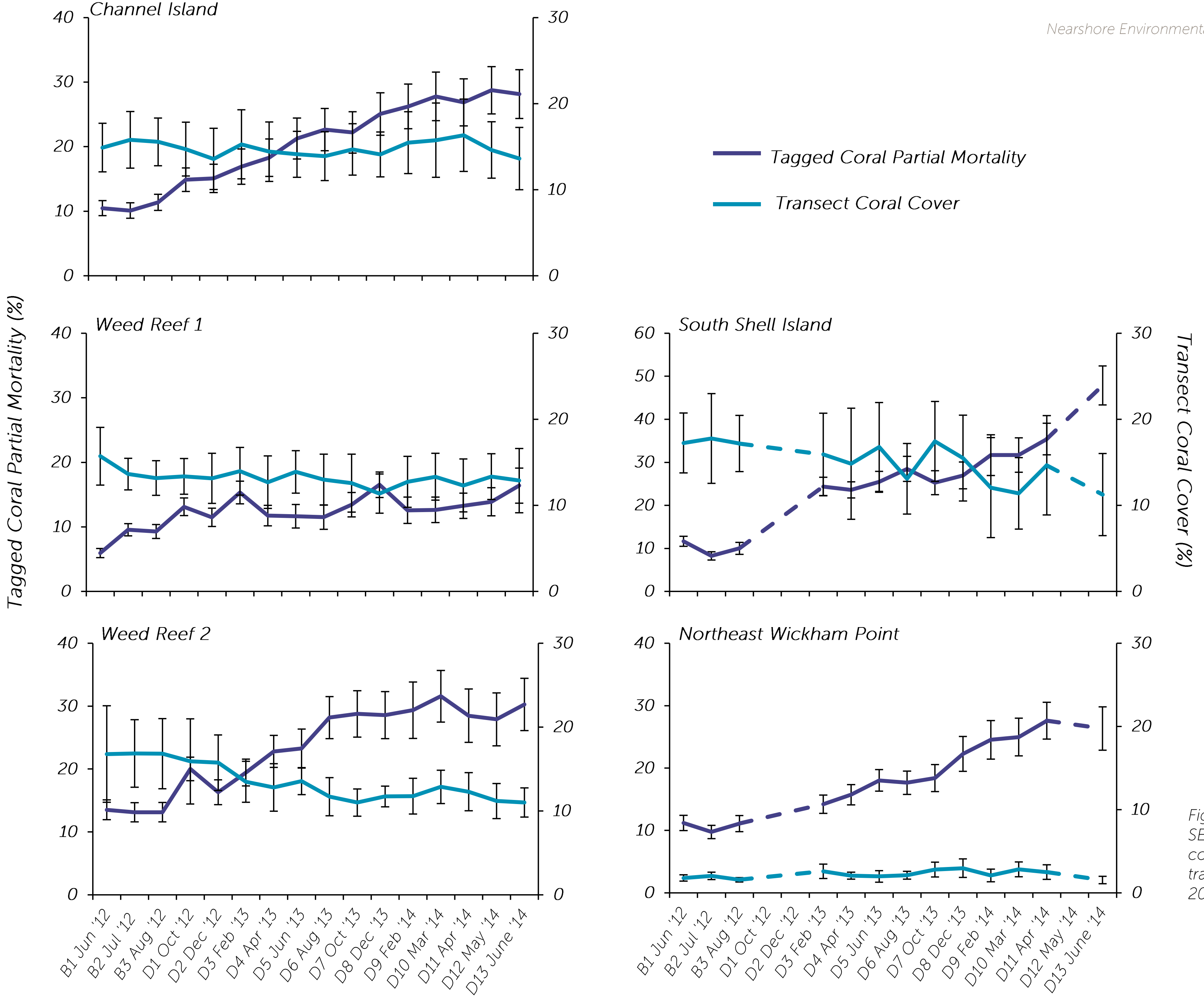


Figure 27 Mean (± Standard Error; SE) partial mortality of tagged corals and coral cover along transects from June 2012 to June 2014

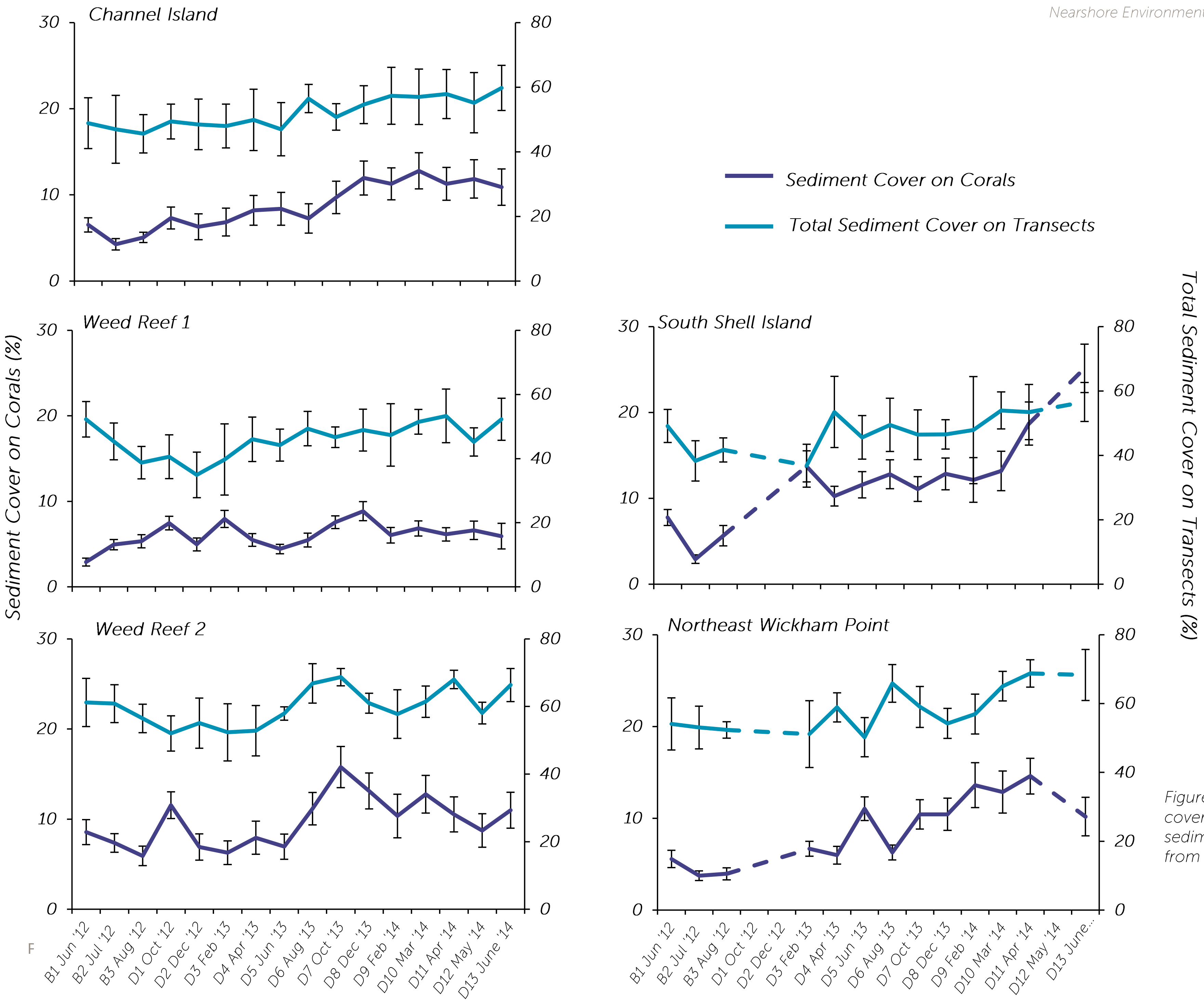


Figure 28 Mean (± SE) sediment cover on tagged corals and total sediment cover along transects from June 2012 to June 2014

Seagrass

Seagrasses are important primary producers providing food for dugongs and turtles and provide habitat for fish and other organisms. Two seagrass species occur in the coastal of Darwin Outer; Halophila decipiens and Halodule uninervis.

Two main impact pathways were identified by which the Project's dredging and spoil disposal activities may affect key seagrass habitats in Darwin Outer: suspended sediment in the water column reducing light availability and causing a reduction in photosynthesis, and smothering and burial of seagrass by sedimentation (Figure 3b). A range of monitoring techniques were adopted to assess the condition of seagrass habitat and detect potential influences from dredging activities. High-definition underwater drop camera surveys were initially conducted within permanent sites, and were replaced with the more suitable large scale towed-video mapping surveys to better assess changes in seagrass distribution over large spatial scales.

The drop camera surveys were initially conducted within a 'Before-After-Control-Impact' framework, whereby changes in percentage cover within Impact locations (Fannie Bay, Woods Inlet, and Lee Point) were compared with Control locations (East Point, Casuarina Beach and Charles Point) (see locations in Figure 17). This design was initially chosen to detect small levels of change in seagrass percentage cover and density, and compare these to management trigger values of 20% and 30% change above natural variability.

Baseline surveys conducted between June 2012 and August 2012 revealed that these trigger values were far too conservative when compared to the large natural spatial and temporal variability in distribution and abundance of both seagrass species (H. decipiens and H. uninervis). During June 2012, mean (± Standard Error; SE) seagrass percentage cover was low, ranging between 1.9 ± 0.3% and 4.5 ± 0.5% at all locations, and by August 2012 had increased by a factor of two to three at Fannie Bay, Woods Inlet and Charles Point (ranging between 4.8 ± 0.8% and 11.7 ± 1.0%). A tenfold increase was recorded at Lee Point during the same period, reaching 18.6 ± 1.0% in August 2012. This high level of natural variability revealed that the trigger levels set in the East Arm DSDMP (Rev 1) did not represent ecologically significant change in such a dynamic system and could not be used to assess the small and localised potential impacts from dredging activities. As a result of these early findings, a new monitoring approach was adopted to map changes in seagrass distribution and health over large spatial scales, and to investigate the relationship between light and seagrass distribution.

Seagrass mapping surveys commenced in June 2012 to map the distribution and extent of seagrass habitat over large spatial scales in the Darwin Outer region. Survey maps showed that H. uninervis was generally found in the intertidal zone between approximately +2 m and -1 m LAT, while H. decipiens dominated deeper habitats in the shallow subtidal zone between 0 m and -3 m LAT.

Consistent with natural seasonal cycles of decline and recovery of seagrasses in the wet tropics, the distribution of H. decipiens habitat changed considerably through time. For instance, the extent of H. decipiens habitat mapped near Lee Point changed from approximately 600 ha in June 2012 to 2,700 ha in October 2012, before complete absence in February 2013 and strong recovery to approximately 1,800 ha in May 2013. H. uninervis was generally found in the same areas in all surveys but showed changes in percentage cover between approximately 5% and 10-20% cover, declining in the wet season, and this was also consistent with expected seasonal growth dynamics. The declines observed in percentage cover and habitat extent of H. decipiens and H. uninervis observed in February 2013 and February 2014 were associated with conditions of naturally elevated turbidity and reduced light during both wet seasons (see example provided for Fannie Bay in Figure 11), which were attributed to episodic events causing energetic metocean forcing conditions including strong winds and elevated waves.

Turbidity at the seagrass monitoring sites in Darwin Outer was generally in the long-term range of natural variability (see Observed Effects – Water Quality*) and as such, no dredging-related impacts were anticipated or measured at these sites during the monitoring program. Survey results were also used together with water quality monitoring data to investigate the relationship between seagrass growth and light and turbidity conditions. A set of light and turbidity variables was identified that best correlated to changes in seagrass distribution and used to develop seagrass response models. A depth-independent model included the 14-day, 28-day and 84-day average turbidity was complemented by a depth-dependent model based on light variables (including the proportion of days receiving less than 1 mol photons/m^2/day). These seagrass response models were then used to estimate the potential influence of dredge excess turbidity on seagrass growth. The variables that were found to best explain changes in H. uninervis cover were the 14-day and 28-day average turbidity values. For H. decipiens, a two-model format was used, consisting of a turbidity (depth-independent) model, which accounts for most of the variability in H. decipiens cover, complemented by a depth-dependent model (based on light variables) to resolve possible depth-related differences in the growth of H. decipiens.*

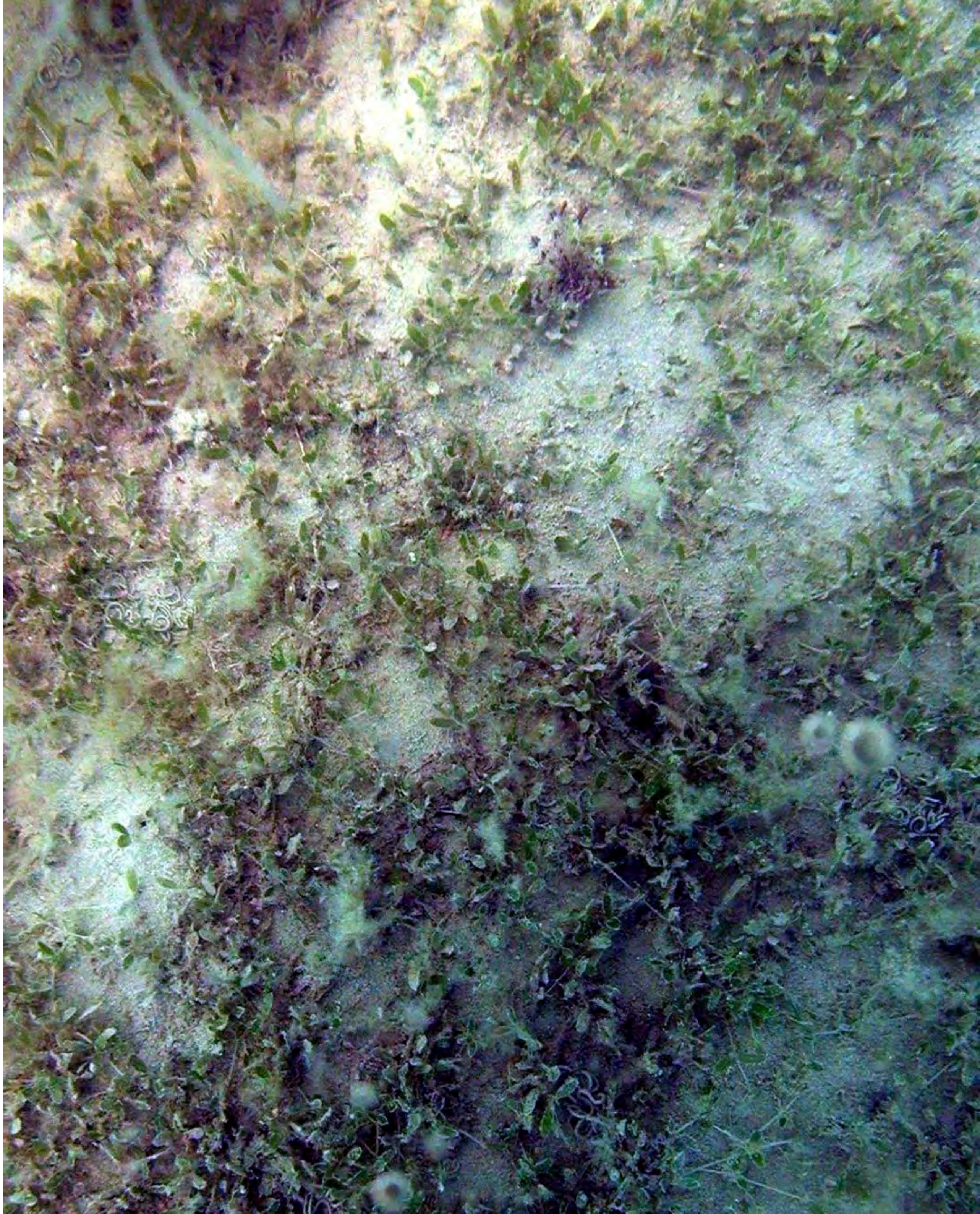
Predictions of dredging-excess turbidity were used to estimate potential dredging-related impacts on the light history at the seabed and the seagrass response models were used to estimate potential

effects on seagrass growth. The possible growth response of each species was predicted using measured turbidity (assumed to potentially include a dredging contribution) and estimated background conditions. Model outcomes were generally similar between turbidity scenarios (i.e. measured and estimated background), indicating that changes in percentage cover and distribution of H. uninervis and H. decipiens observed throughout the monitoring program can be considered representative of natural variability.

The species-specific growth response models were associated with prediction uncertainties for both species. In particular, the model fit for H. uninervis remained poor even with the inclusion of all data to May 2014 (pseudo-R^2 =0.16), indicating that most of the variability in H. uninervis cover remained unexplained by the light-related variables tested here. This may be due to spatial variability in turbidity not accounted for in the model, or the influence of additional factors influencing these species, such as nutrient availability, temperature, salinity, shifting sediments, wave action and episodic exposure to air at low spring tides.

Results from large-scale mapping of seagrass habitats, together with predictions from seagrass response models, indicated no expected influence of dredging-related excess turbidity on seagrass growth at reactive monitoring sites.

General findings on the seagrass monitoring program are discussed in more detail in Darwin Harbour – A Dynamic Environment.



Intertidal Sedimentation and Mangrove Community Health

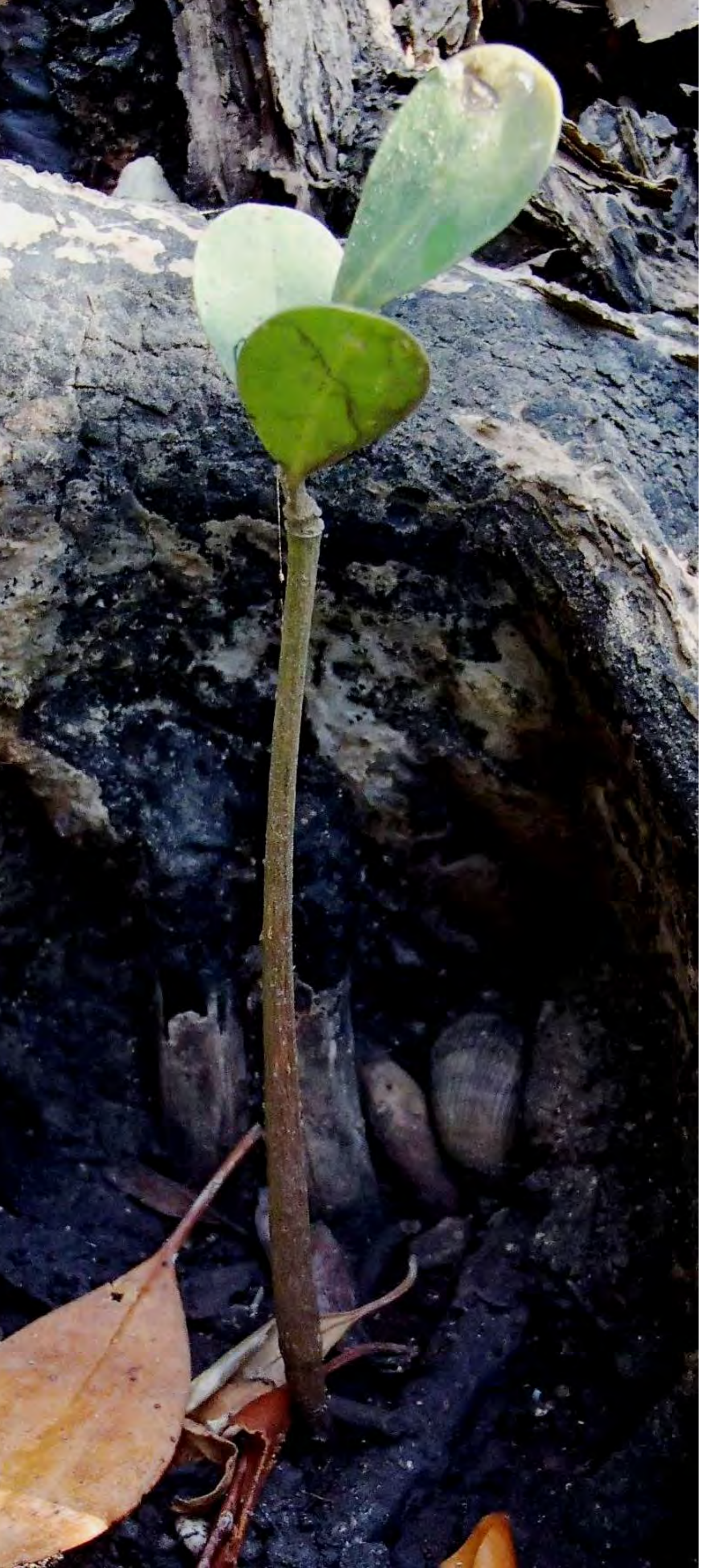
Mangroves act as a buffer between the land and the sea. They are intertidal, being submerged at high tide and exposed at low tide. Mangrove communities possess the ability to actively and passively trap sediments. However, excessive accumulation of dredging-derived sediments has the potential to impact mangrove health. The level of sedimentation that could potentially impact mangroves was established as 50 mm for the program.

It was predicted that approximately 30 ha of mangrove habitat could potentially be impacted by the deposition of >50 mm of dredge-derived sediments. During dredging, water quality monitoring showed that dredging-excess turbidity was largely restricted to East Arm in both dredging seasons (see Observed Effects – Water Quality*), so if there were any dredging-related impacts on mangroves, this is the likely area they would manifest in the short term.*

Potential dredging-related impacts to mangroves were monitored using a number of techniques. Sediment deposition was measured at field monitoring sites (Figure 17) to determine if dredging-derived sediments were accumulating in the mangroves. Mangrove health indices (including canopy cover and seedling survival) and fauna (abundance and species richness) were also measured at these sites to detect potential impacts that could manifest from excessive sedimentation. At a broader scale, satellite imagery was obtained on a regular basis and closely examined to measure mangrove health and detect potential impacts to mangroves both within and outside of the field monitoring sites, extending across all the mangroves in Darwin.

The most robust and practical method of measuring sedimentation in Darwin proved to be the monitoring of the sediment bed level using a series of simple stakes installed in each of the five key mangrove assemblages at ten sites (Figure 17). Levels of net sedimentation at all monitoring sites and assemblages were lower than the level considered to potentially impact mangrove health (Figure 29a). The highest mean net sedimentation measured over the monitoring period was 27.4 mm in October 2013, measured in the Seaward assemblage at Site I3 in East Arm. While this site was closest to the dredging, it is also immediately adjacent to the recently constructed East Arm boat ramp and industrial land reclamation, which is likely to have influenced localised sediment dynamics because of the construction of a groyne at the ramp. No dredging-related effects on mangrove community health were observed at any of the field monitoring sites

One of the key mangrove health indicators monitored was canopy cover (as measured using a densitometer), which is a useful indicator of change in health over time. Leaf shedding and leaf growth are sensitive to a wide range of environmental factors and may be indicative of environmental stress. Net change in canopy cover was calculated by obtaining the difference between each dredging survey and baseline canopy cover percentage. No monitoring sites or assemblages showed decreases in net canopy cover close to the level considered to be



reflective of ecologically significant change (30%). Seasonal patterns in canopy cover were also observed, generally increasing in the wet season and declining in the dry season.

There was an overall slight trend of decreased canopy cover over the monitoring period (Figure 29b), regardless of the site's proximity to dredging. Furthermore, there was no evidence of a relationship between the observed levels of net sedimentation and change in canopy cover. As such, dredging is not considered to be a cause of the slight decline in canopy cover observed at monitoring sites during the monitoring program.

Mangrove seedling survival and growth were also unaffected by the Project's dredging activities. Random sampling techniques were used to work out the overall density of seedlings and saplings, and individually identified seedlings were tracked over more than two years to detect changes in survival and growth. A high level of natural seedling mortality was recorded at all sites; however the surviving seedlings showed similar levels of growth at all sites and there were no overall changes in density of seedlings and saplings of concern. Seasonal patterns in seedling ecology were observed, as detailed in Darwin Harbour – a Dynamic Environment*. Similarly to mangrove health indices, there was no evidence of impacts to mangrove fauna, as there was no decline in species richness or abundance during dredging surveys when compared to baseline surveys.*

Harbour-wide satellite monitoring of mangroves using remote sensing also showed no areas of mangrove decline that could be associated with dredging. Mangrove health was quantified using a measure of 'greenness' shown in satellite imagery called the Normalised Difference Vegetation Index (NDVI). A range of analyses were used to detect where potential changes in mangrove health were occurring. Approved clearing of mangroves was clearly visible; however, there was no change outside of natural variation or indication of reduced health in mangroves close to the dredging, such as East Arm. This was corroborated by detecting change in NDVI between the baseline survey and each dredging survey across a range of scales; from small 20 m x 20 m plots within monitoring sites, to large 'catchment'-sized areas up to ~2,000 ha.

Similarly to canopy cover, there was no evidence of a relationship between the observed levels of net sedimentation and seedling survival, seedling growth or NDVI. Thus, there is no evidence for a dredging-related impact occurring. This is not surprising considering that the level of sedimentation at monitoring sites was below that which may start to cause impacts on mangroves. Changes in all mangrove community health indicators appeared to be related to seasonal and longer term variability in naturally occurring factors such as rainfall and salinity, as discussed in Environmental Setting*.*

Findings of the intertidal sedimentation and mangrove community health monitoring program are discussed in more detail in Darwin Harbour – A Dynamic Environment*.*

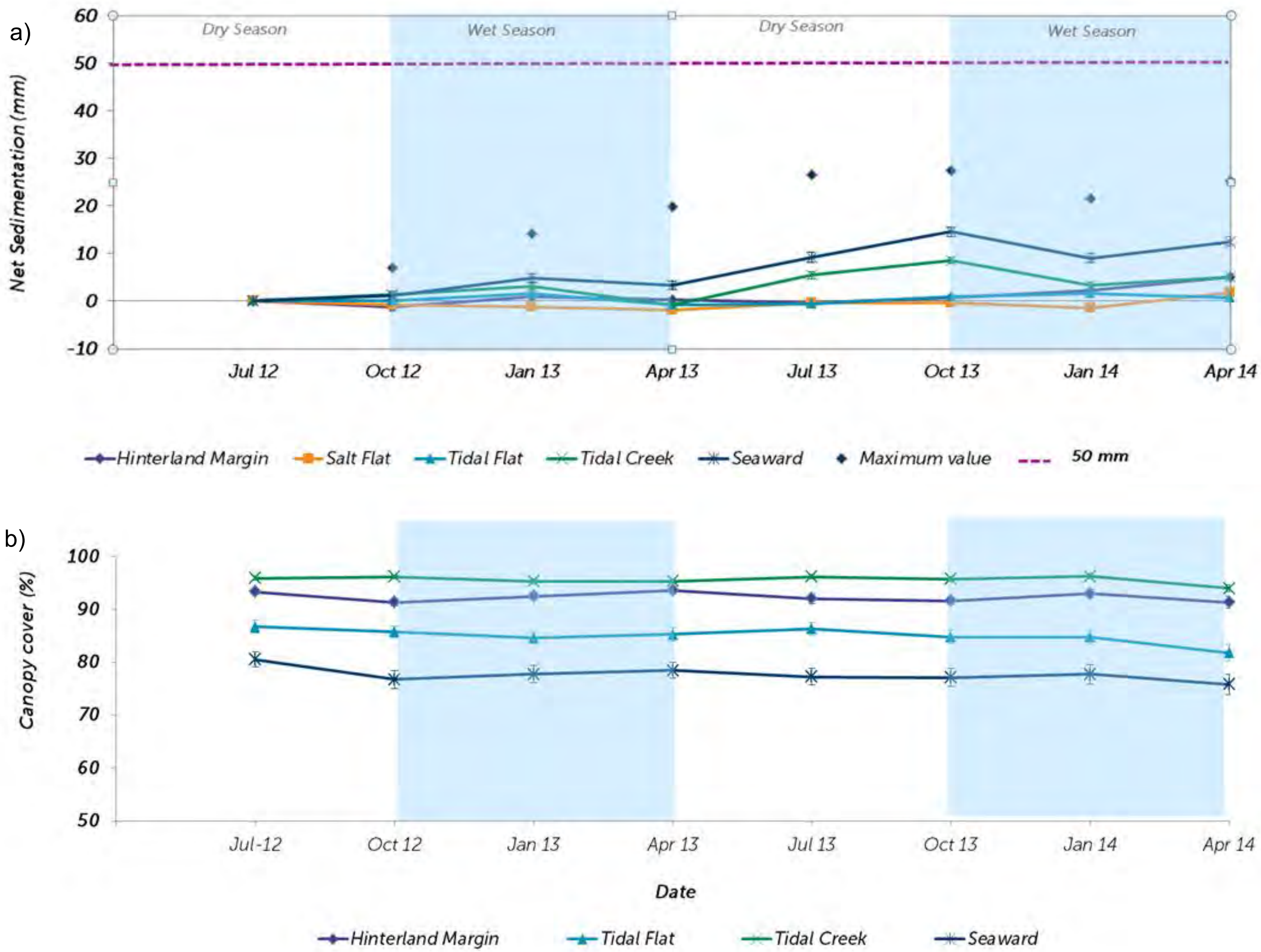


Figure 29 (a) Net intertidal sedimentation; and (b) mangrove canopy cover in each assemblage averaged over all sites for all dredging surveys. For each survey the maximum net sedimentation value recorded for any one site in any assemblage is shown. The dashed purple line represents the level considered to potentially start impacting mangrove health (50 mm). Blue shading represents the wet season

Primary Productivity (Season One only)

The Primary Productivity Monitoring Program has been developed to detect potential dredging-related changes in marine plant productivity indicators: mangrove leaf litter fall, microphytobenthos (MPB) biomass in intertidal mudflats and phytoplankton biomass within the water column.

Mangrove Productivity

Mangrove leaf litter fall (biomass, measured in the Tidal Flat, Ceriops assemblage) is an indication of the quantity of detritus that enters the marine food chain and is known to vary seasonally. Mean daily litter fall measured at mangrove monitoring sites (Figure 17) ranged between 0.4 ± 0.0 g m^{-2} day^{-1} and 4.5 ± 0.5 g m^{-2} day^{-1} between July 2012 and April 2014. Temporal variations in Tidal Flat mangrove productivity have shown an increase in leaf litter fall from October to December (2012 and 2013) compared to the rest of the year. This is consistent with seasonal dynamics in leaf litter fall reported previously between 1997 and 2000 (Metcalfe et al. 2011) for comparable mangrove assemblages throughout Darwin Harbour. A similar seasonal pattern was found for stipule counts, where the lowest stipule counts occurred in July 2013 and August 2013, and were similar to those recorded for the same months in 2012 during Baseline sampling (June 2012 to August 2012).

Some differences were found in the rate of leaf litter fall and the count of stipules between sites. However, as described previously, intertidal sedimentation measured in the Tidal Fat mangrove assemblage at monitoring sites in East Arm and Middle Arm have been below levels that may start to cause impacts to mangrove health (Figure 29a). These results suggest that dredge-derived sediments have not contributed to sedimentation at levels that may influence primary production in mangroves in this assemblage at monitoring sites, and that there may be natural differences in productivity in this assemblage between sites.

Microphytobenthos Productivity

Chlorophyll-a (Chl-a) and pheophytin concentrations (a proxy for MPB biomass) in intertidal sediments were quite variable both spatially and temporally throughout the monitoring program. Values for Chl-a and pheophytin ranged between 0.3 $\pm$ 0.1 and 12.0 $\pm$ 2.4 mg Kg^{-1} dry weight and between 1.2 $\pm$ 0.1 and 20.1 $\pm$ 1.5 mg Kg^{-1} dry weight respectively, and there were no obvious seasonal or spatial trends. Although statistical analyses revealed there were differences in Chl-a and pheophytin levels at some of the Impact sites between Baseline and Dredging monitoring, there were also instances of Control sites showing similar patterns. This suggests that these differences were most likely a result of natural variability within the system and unrelated to dredging activities within Darwin Harbour.

Phytoplankton (Water Column) Productivity

The Chl-a fluorescence measured at Woods Inlet, Weed Reef, Northeast Wickham Point, Channel Island and Upper East Arm water quality monitoring sites (Figure 17) indicated that Chl-a concentrations in the water column were low and generally remained below 4 μg L^{-1}. There was no clear link between turbidity and surface Chl-a fluorescence, thus no indication of impacts from dredging-related turbidity on phytoplankton biomass at these sites. In addition, there was no indication of elevated concentrations potentially associated with algal blooms. There was no clear pattern with the spring-neap tide cycle and all sites exhibited diurnal fluctuations in Chl-a fluorescence.

Findings of the primary productivity monitoring program are discussed in more detail in Darwin Harbour – A Dynamic Environment.

Recreational Fishing and Fish Health

The activities required to construct the Project's facilities had the potential to affect recreational fishing in Darwin Harbour in a number of ways. First, the presence of construction activities, including increased vessel movements and exclusion zones associated with construction, could have deterred some recreational fishers from using parts of Darwin Harbour. Second, there may have been measurable temporal and spatial changes to recreational catch profiles or catch rates associated with Project activities in Darwin Harbour. Third, there could have been temporal and spatial changes to the incidence of ill-health in finfish and crabs associated with dredging activities.

Access Point Surveys (APS) were conducted, which involved interviewing recreational fishing parties at boat ramps in Darwin Harbour, Bynoe Harbour and Adelaide River at the end of their fishing trips. Information compiled from these interviews was used to identify potential changes through time in the distribution of recreational fishing effort, general profiles of recreational fishing activities and/or catch rates in Darwin Harbour that may have been attributed to Project activities. In addition, Research fishing activities (research angling and potting) were undertaken in Darwin Harbour, Bynoe Harbour and Adelaide River by a team of scientists in collaboration with the Fisheries Division of the Territory's Department of Primary industry and Fisheries (NT Fisheries) to collect and monitor catch rates of fish and crab species independently of the recreational fishing sector. The team also monitored for any instances of ill-health among fish and crab species sampled, including characterising and monitoring a range of parasites and diseases that naturally occur in fish and crab species within Darwin Harbour and surrounding waters.

Around half (~48%) of the approximately 2,600 recreational fishing parties interviewed as part of the APS monitoring launched their vessels from ramps in Darwin Harbour Inner (i.e. south of Darwin city) and typically remained in those waters to fish.

Compared to spatial patterns of fishing effort recorded during Baseline surveys, slight but clear small-scale spatial shifts in fishing effort within Darwin Harbour were recorded during dredging surveys. The proportion of fishing parties interviewed at Darwin Harbour ramps during Baseline APS that reported fishing around lower East Arm (21%) decreased to between 13% and 16% for surveys completed during Project dredging activities. These decreases were accompanied by slight increases in other areas around Darwin Harbour, such as further up East Arm, across to the western side of the Harbour and to open waters outside the Harbour. Beyond the disturbances directly associated with dredging, dredging-related factors such as navigational issues due to commercial traffic, restrictions on access to fishing spots due to observing Project safety exclusion zones and an unattractive environment for fishing were also likely to have contributed to this observed small-scale spatial shift in effort. Other than these minor shifts in fishing effort within the Harbour, Project dredging activities had little measurable effect on recreational fishing within Darwin Harbour.

Catch rates of individual fish and crab species in Darwin Harbour Inner estimated from interviews with recreational fishing parties and independently via standardised research fishing monitoring were generally similar throughout the monitoring program. Based on standardised research angling sampling techniques, the average catch rates of golden snapper, grass emperor and stripey snapper during Baseline sampling were 1.6 $\pm$ 0.3, 0.4 $\pm$ 0.3 and 1.0 $\pm$ 1.0 fish per hour respectively. Sampling during dredging showed similar results, with the average catch rates of golden snapper, grass emperor and stripey snapper ranging from 1.1 to 4.2, 0.3 to 0.4 and 0.3 to 0.8 fish per hour respectively. In addition, the average catch rate of mud crabs was 0.2 crabs per pot during Baseline sampling and ranged between 0.2 and 0.3 crabs per pot during dredging sampling.

A range of naturally occurring infections were identified in association with specimens examined from Darwin Harbour and surrounding waters, including 66 finfish parasites and 29 crab parasite species. Flatworms on the gills of fish and parasitic barnacles attached to the gills of crabs were the most commonly recorded parasites. Examining the prevalence and intensity of these parasitic and other infections provided a means by which to monitor spatial and temporal changes in fish health indicators possibly associated with factors such as changes in environmental conditions, immune suppression and stress, which could result in ill-health. The prevalence and intensity of parasites and bacterial infections identified among the finfish and crabs examined in the laboratory during the program have not indicated any areas of particular concern in terms of abnormalities or health problems. The results have also provided no indication that the proportion of abnormal finfish in the potential impact locations (Darwin Harbour Inner and Darwin Outer) during the Dredging phase have substantially changed from levels recorded during Baseline sampling or in reference (Bynoe Harbour and Adelaide River) locations beyond the influence of dredging.

While no dredging-related changes were observed, seasonal variability in the prevalence and levels of parasitic and bacterial infections were detected in fish and crabs across Darwin and reference locations throughout the monitoring program. For example, in Darwin Harbour Inner, rust spot, which is a common disease found on the shell of mud crabs was present on 7% of crabs sampled during the Baseline phase (dry season) and on 33% of crabs sampled during a wet season Dredging (March 2014) sampling event. Similarly, rust spot was recorded on 4% of mud crabs sampled from Bynoe Harbour (reference location) during the Baseline phase and 25% of mud crabs sampled during the March 2014 Dredging sampling event. This variability was most likely related to species-specific responses to naturally driven changes in environmental conditions.

Overall, there has been no evidence of conspicuous signs of immuno-suppression or ill-health in fish and crab specimens examined from Darwin that could be attributable to Project dredging activities. In addition, there have been no instances of fish kills attributable to these activities.

The recreational fishing and fish health monitoring program is discussed in more detail in *Darwin Harbour – A Dynamic Environment*

Prepared by Cardno

Marine Pests

Six-monthly surveillance for potential marine pests has been conducted in Darwin Harbour since August 2012 to identify potential marine pests that may have entered as a result of Project activities. Additional information was also collected as part of the coral, research fishing, and subtidal and intertidal benthos monitoring programs.

One pest species, Perna viridis (Asian green mussel), from the target list was identified on the hull of a cargo vessel unloading bulk goods (both Project and non-project related) at East Arm wharf during routine maintenance; however, environmental monitoring found no specimens and no evidence of the establishment of the species in surveyed Darwin Harbour habitats.

Two additional target pest species were identified during the targeted monitoring program, the ascidians Didemnum perlucidum and Botrylloides leachi, which did not display invasive pest-like characteristics. As B. leachi was recorded during the Baseline survey, its presence cannot be attributed to Project-related activities. The presence of D. perlucidum in Darwin Harbour at Fort Hill Wharf and from marker buoys in the vicinity of Charlie Anchorages 2 and 7 (in the mid-Harbour, approximately 2.5 km south of Fort Hill Wharf), and was confirmed through Deoxyribonucleic acid (DNA) analysis. However this species may have been present for an extended period in Darwin Harbour as previous surveys (the Golder (2010), Baseline, and March 2013 surveys) did not specifically include this species on the target list as it was not listed as part of the National System for the Prevention and Management of Marine Pest Incursions (National System). The target list was developed and updated based on marine species known to display invasive characteristics that have the potential to survive conditions in Darwin Harbour and was based on previously targeted species and recent advice from taxonomists. D. perlucidum was recorded (based on morphological analysis) in the two surveys (August/September 2013 and March 2014) following its inclusion on the target species list.

Green algae that may potentially be the pest species Caulerpa racemosa and C. taxifolia, and tubeworms with potential to be a Hydroides dianthus/ H. sanctaecrucis and Sabella spallanzanii, have been observed in photographs collected for the coral monitoring program. Potential specimens of C. taxifolia were collected during coral surveys in August 2012 and April 2014; however these were subsequently identified by a specialist to be a native species. Further analysis revealed no pest species of tubeworms. The marine pests monitoring program is discussed in more detail in Darwin Harbour – A Dynamic Environment*.*

Turtles and Dugongs

The abundance and distribution of turtles and dugongs were monitored via aerial surveys along approximately 3,500 km of pre-defined linear transects. This equated to around 2,700 km^2 of surveyed area across three geographical blocks, representing approximately 20% of the total available area within the three blocks. Sightings of turtles and dugongs were then used to derive population estimates around the Darwin region, including Hope Inlet (referred to as 'IM' block), Bynoe Harbour ('C1') and from the Vernon Islands across to Melville Island ('C2') (see Figure 75 and Figure 77 in ***Darwin Harbour – A Dynamic Environment****). Land-based observations were also carried out to examine finer-scale aspects of dugong and turtle populations and behaviour at two identified 'hotspots' within Darwin Harbour, namely Channel Island Bridge and the rock wall at Cullen Bay. Satellite tagging of turtles was undertaken during late 2012 and 2013 to examine patterns of movement of turtles in Darwin Harbour.*

During the monitoring program, temporal and spatial variation in the abundance and distribution of dugongs and turtles was observed, with no evident seasonal patterns. Population estimates of dugongs within the Darwin Harbour area, derived from the number of animals sighted, were generally higher in the IM block, compared to the C1 or C2 blocks. During the Baseline surveys, a total of 263 dugongs were sighted over three survey periods (from May to October 2012), while 288 dugongs were sighted across four Dredging surveys. Despite considerable variation in the mean number of turtles sighted over time, mean sightings per survey (replicate flights and blocks combined) were similar between Baseline and Dredging surveys, with a mean of 634 turtles sighted per Baseline survey and 699 turtle sightings per Dredging survey.

In May 2013, there was a decline in the densities of turtle sightings within the Darwin region, specifically around Hope Inlet, across 60% of the total area surveyed compared to 2012. This was probably a result of natural variation such as short-term movement of turtles in and out of specific areas due to feeding preferences, nesting activities or the need to maximise foraging opportunities in variable environmental conditions, for example, with shifting seagrass habitats. Dredging had ceased for the 2013 dry season hiatus period (Figure 16) prior to this survey and it is unlikely that dredging or spoil disposal activities influenced turtle distribution and abundance in this region. In October 2013, however, turtle density increased in the same area when compared to the same time period the previous year.

Although turtles and dugongs were sighted throughout the whole survey area, animals were more commonly observed in shallower waters. In the IM block during Baseline surveys, 47% of dugongs and 65% of turtles were sighted in waters less than 5 m depth. Similarly, during the Dredging surveys, 52% of both dugongs and turtles were observed in these shallow waters around the Darwin region. The areas of greatest dugong densities often corresponded to areas of seagrass habitat (H. decipiens and H. uninervis). As detailed in **Observed Effects – Seagrass**, no dredging-related impacts to key seagrass habitats in Darwin Outer were observed during the monitoring program, which presented no flow-on risk of potential impacts to dugongs foraging in these areas.

Turtles appeared to have less preference for a particular habitat, although juvenile green turtles tagged at Channel Island displayed remarkably small home ranges (within 2.5 km) in the mangrove areas and rocky reef areas east of the island. As such, there was no evidence of displacement of the tagged juvenile turtles during dredging and piling activities. Importantly there have been no noticeable changes to the distribution of turtles and dugongs within the Darwin area that would indicate a potential influence of dredging.

The turtle and dugong monitoring program is discussed in more detail in Darwin Harbour – A Dynamic Environment.

Subtidal Benthos

The mechanisms by which infauna (animals living within the sediments) and epifauna (animals living on top of sediments) are affected by dredging and spoil disposal activities include direct removal (from within the dredge footprint), smothering (through spoil placement), indirect changes to the physico-chemical composition of the sediments and/or elevated levels of suspended sediments mobilised and dispersed by dredging. Elevated levels of suspended sediments have the potential to damage and block feeding or respiratory organs and in turn, may affect feeding efficiency, growth and reproduction in benthic invertebrates. Results of sampling within Darwin Harbour Inner following dredging Season One did not indicate that dredging within East Arm had a significant impact on subtidal epibenthic assemblages, which have continued to be relatively sparse and limited in diversity.

Potential dredging-related impacts were observed in relation to the benthic infaunal assemblages in East Arm of Darwin Harbour Inner (significant changes in relative abundance, taxon richness and assemblage structure); however the mechanism for the observed changes was unclear as there was no obvious link between measured sediment characteristics (which showed no significant change) and changes in infauna. Maximum turbidity (used as a proxy for SSC) during Season One also did not exceed baseline levels at sites within East Arm (see Observed Effects - Water Quality*) and it is therefore inconclusive whether dredging-excess suspended sediments impacted these infaunal assemblages. It is likely that the majority of infauna (particularly those found in relatively high abundances) are well adapted to the naturally high levels of suspended sediments experienced in Darwin Harbour Inner during the wet season. It is also possible that naturally occurring hydrographic, or unmeasured physico-chemical or biotic factors may have influenced these changes rather than the indirect influence of dredging activity. Post dredge monitoring in Season Two may provide additional information to help determine possible causes of change. As expected, results of sampling at Darwin Outer after dredging Season One suggest that spoil disposal activity has had significant impacts on the epibenthic and infaunal assemblages at the spoil disposal area, with decreases in mean abundance of commonly occurring taxa. The physical properties of the sediments also changed, with a greater percentage of fines and small changes in sediment pH and oxidation reduction potential (ORP). A lack of correlation between physical parameters and infaunal assemblages indicates that the changes in infaunal assemblages observed are likely to be from the direct physical impact of dredge spoil placement, rather than indirect changes to sediment characteristics.*

Intertidal Benthos

Infaunal assemblages and physico-chemical characteristics of intertidal soft sediments within Darwin Harbour Inner did not change significantly between August 2012 and June 2013, indicating that Season One dredging did not have a significant or lasting impact on the intertidal assemblages sampled. While there was an overall reduction in the total number of individuals recorded across all sites in June 2013, this was not significant and several new taxa were recorded that had not previously been recorded in the Baseline sampling. The subtidal and intertidal benthos monitoring programs are discussed in more detail in Darwin Harbour – A Dynamic Environment*.*

5 Darwin Harbour – A Dynamic Environment

Darwin Harbour – A Dynamic Environment

Coral Communities

Hard coral communities in Darwin Harbour fringe some of the short, rocky slopes of the Harbour's channels and reefs, down to approximately -5 m LAT. Within these sparse communities, corals exist as a patchy arrangement of individual colonies occupying up to 20% of the seabed. The communities in Darwin appear most comparable to those of the inner-shelf coral communities of the Great Barrier Reef (Done 1982, in Wolstenholme et al. 1997). Growth forms are predominantly low-relief (i.e. encrusting, small massive, submassive and low-profile foliose types), with branching corals conspicuously absent. Wolstenholme et al. (1997) reported 123 species of hard corals from 45 genera and 15 families in the Darwin region. In this monitoring program, 48 species of hard corals from 34 genera and 13 families were recorded in the Harbour itself, with a maximum of ten families at any one site.

Shallow water tropical corals form a symbiotic relationship with microscopic algae of the genus Symbiodinium. This mutualism allows corals to obtain some of their daily energy requirements from the photosynthates produced by the algae. Corals growing in high underwater light environments can obtain all their energy needs by this means but corals living in low light environments can obtain up to 60% of their energy requirements from heterotrophic feeding (i.e. they actively catch food in the water column using their tentacles) (Falkowski et al. 1990, in Wolstenholme et al. 1997).

Hard corals exist in Darwin Harbour despite it being an environment which appears largely unsuitable for their growth and survival. Indeed, one of the key sites in the monitoring program, Channel Island, has been officially recognised on this basis.

Channel Island was first listed on the Commonwealth Register of the National Estate (RNE) under the Australian Heritage Commission Act 1975 (AHC Act). The AHC Act has now been repealed but Channel Island remains on the RNE, which is a now a non-statutory archive. It is also listed on the Northern Territory Heritage Register (NTHR), established under the Northern Territory's Heritage Conservation Act 1991 (since repealed and replaced by the Heritage Act 2011).

The listings were made on the basis of the significance of the diverse coral community at Channel Island, which is not consistent with its location well inside a large estuarine system characterised by a substantial decrease in salinity during the wet season, high turbidity, and deep, fine muds over much of its area (AHPI 2012).

The coral communities in Darwin Harbour must be able to cope with the combined pressures generated from the strong tidal currents in a highly turbid, low light environment with a substantial sediment load. These can also be combined with other stressors including: high water temperatures at times, exposure to air during spring low tides and changes in salinity during high rainfall. In addition to these specific environmental pressures of Darwin Harbour the coral communities must also cope with the typical biological pressures that naturally affect all coral communities, regardless of their location, such as predation, disease, and competition with other organisms, including corals.

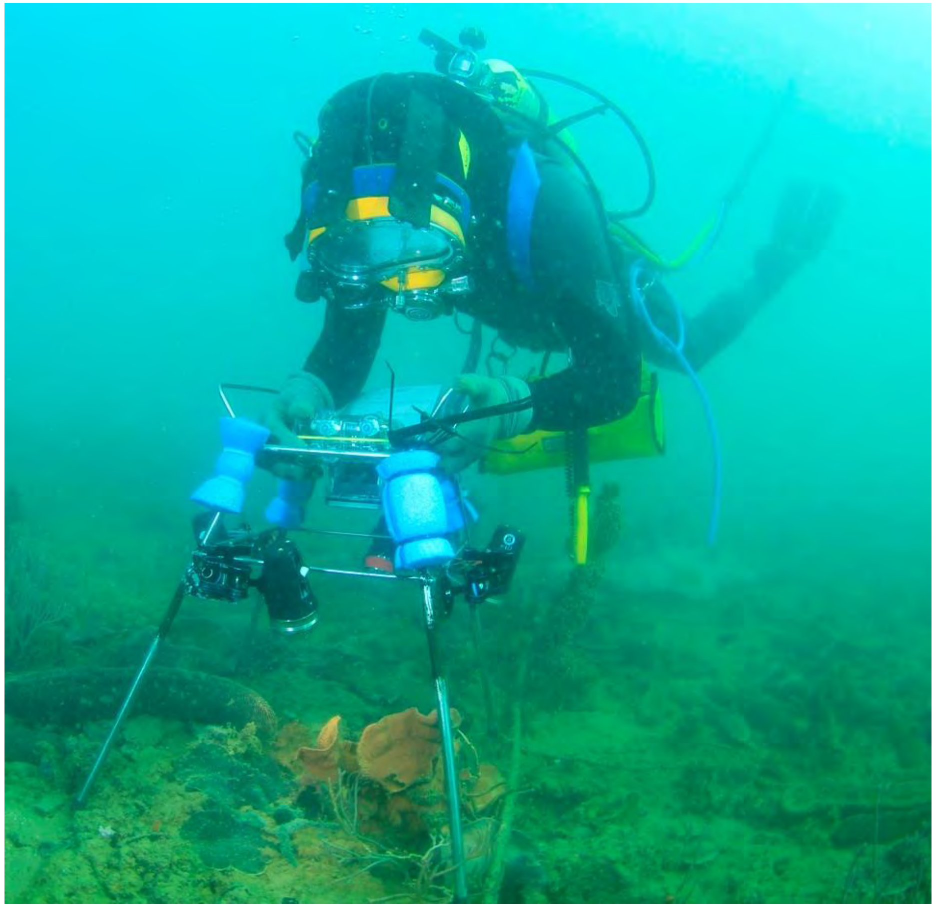
High Turbidity and Low Light

Turbidity can affect coral by reducing the amount of light available for photosynthesis. Within the Harbour, turbidity is generally greater and photic depth (depth at which light is sufficient to permit photosynthesis) shallower over the spring tides, due to the large tidal movements and strong currents at these times; these generate substantial natural turbidity in the water column through the resuspension of sediment (Figure 30). During the monitoring program peak daily average turbidity for spring tides during the wet season were typically between 20 and 30 NTU at the Darwin Outer site Charles Point and between 10 and 20 NTU at Weed Reef 1 located mid-Harbour (see location of monitoring sites in Figure 17).

There is also a seasonal influence on turbidity which increases at the onset of the wet season due to episodic events that increase wave intensity, winds and rainfall. Turbidity is at its most extreme during the passage of these episodic tropical cyclones or tropical storms near Darwin (Figure 5; Environmental Setting). During these times, the greatest daily average turbidity for any of the coral monitoring sites was far greater than values recorded during spring tides, with up to 169.2 NTU recorded at Charles Point and the greatest values within Darwin Harbour Inner recorded at Weed Reef 1 (119.4 NTU).

In general, the maximum daily average turbidity in the more sheltered parts of Darwin Harbour Inner (such as East Arm and Middle Arm) does not get as high as for the sites in the mid-Harbour and Darwin Outer. During times of increased wind and wave action in the wet season turbidity reached levels as high as 75.8 NTU and 77.0 NTU at South Shell Island and Northeast Wickham Point respectively. During these episodic wet season events, there were times when no light reached the corals and there were blackout periods at sites that ranged between two days (Channel Island) and 16 days (Weed Reef 1). Interestingly, when extreme low tides occurred in the middle of the day during the wet season, light recorded at the seabed was greater than for the dry season (see Underwater Light – Photosynthetically Active Radiation).

Even when turbidity was very high and photic depth very shallow, very little change in coral health was measured at monitoring sites, suggesting that they obtain enough energy through photosynthesis during periods of sufficient light or that they are obtaining energy through heterotrophic feeding when light is not available, or through a combination of the two.



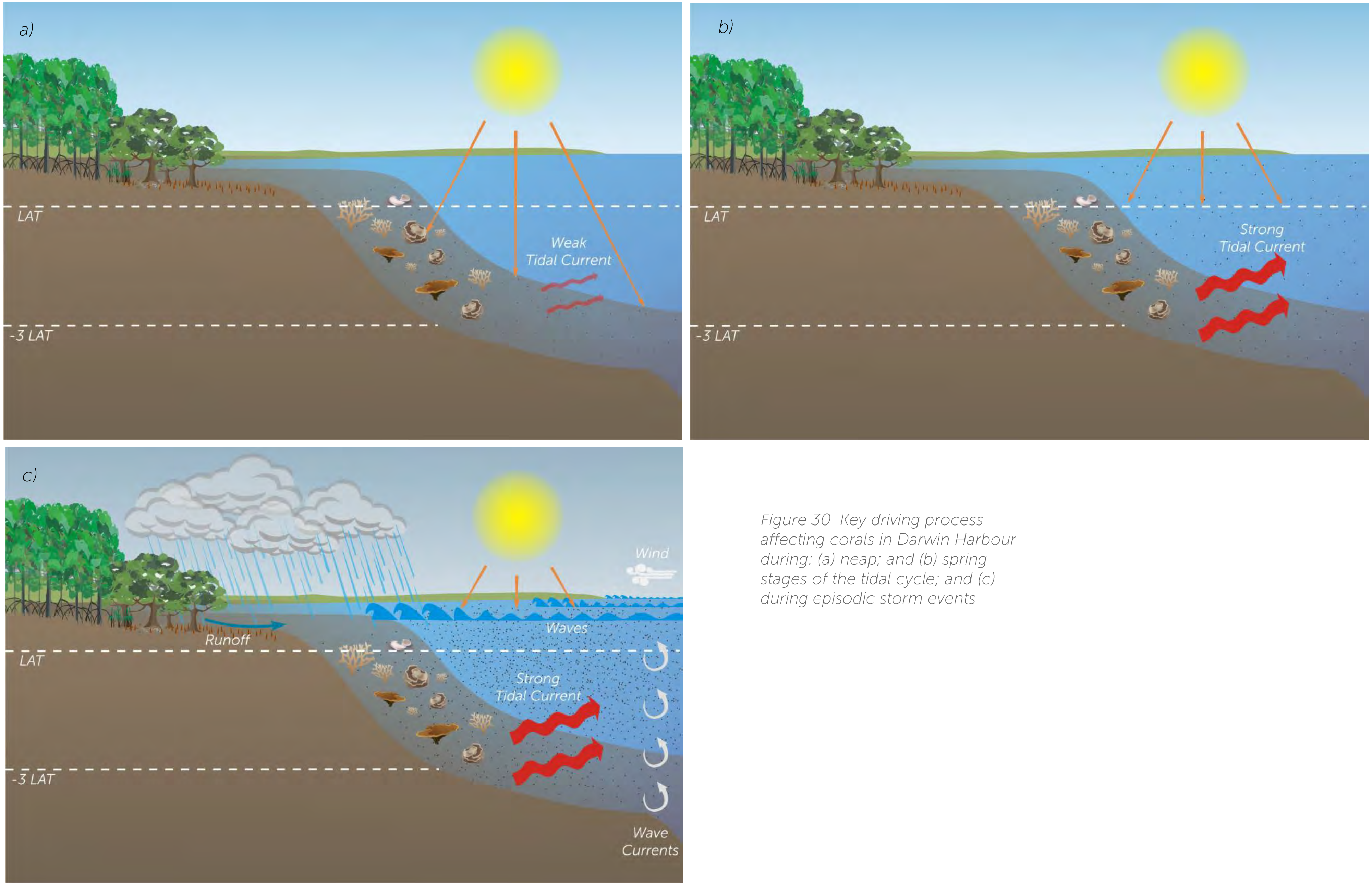


Figure 30 Key driving process affecting corals in Darwin Harbour during: (a) neap; and (b) spring stages of the tidal cycle; and (c) during episodic storm events

High Rates of Sedimentation

The large spring tidal movements and associated strong currents in Darwin Harbour resuspend sediments, which increases the potential for sediments to settle and accumulate on corals when currents weaken during neap tides or periods of slack water (see ***Sediment Mobilisation and Turbidity****). This can ultimately lead to gradual burial and mortality if the sediment is not resuspended naturally or the coral is unable to remove it. In order to survive in Darwin, corals must be physically tough to cope with complete or partial burial.*

Sediments that accumulate on corals can be removed by both passive and active means. Passive removal of sediment occurs when sediment that settles on coral is then removed by water movement, such as tidal currents and wave action. The growth forms of coral in Darwin probably facilitate efficient removal of sediment by tidal currents but it is likely the strength of the current that is more important. Passive removal of sediment by the strong currents is potentially the main reason why corals can exist far up in the Harbour reaches at places such as Channel Island, which is adjacent to extensive mangroves and muddy tidal flats that provide a large source of sediments available for suspension.

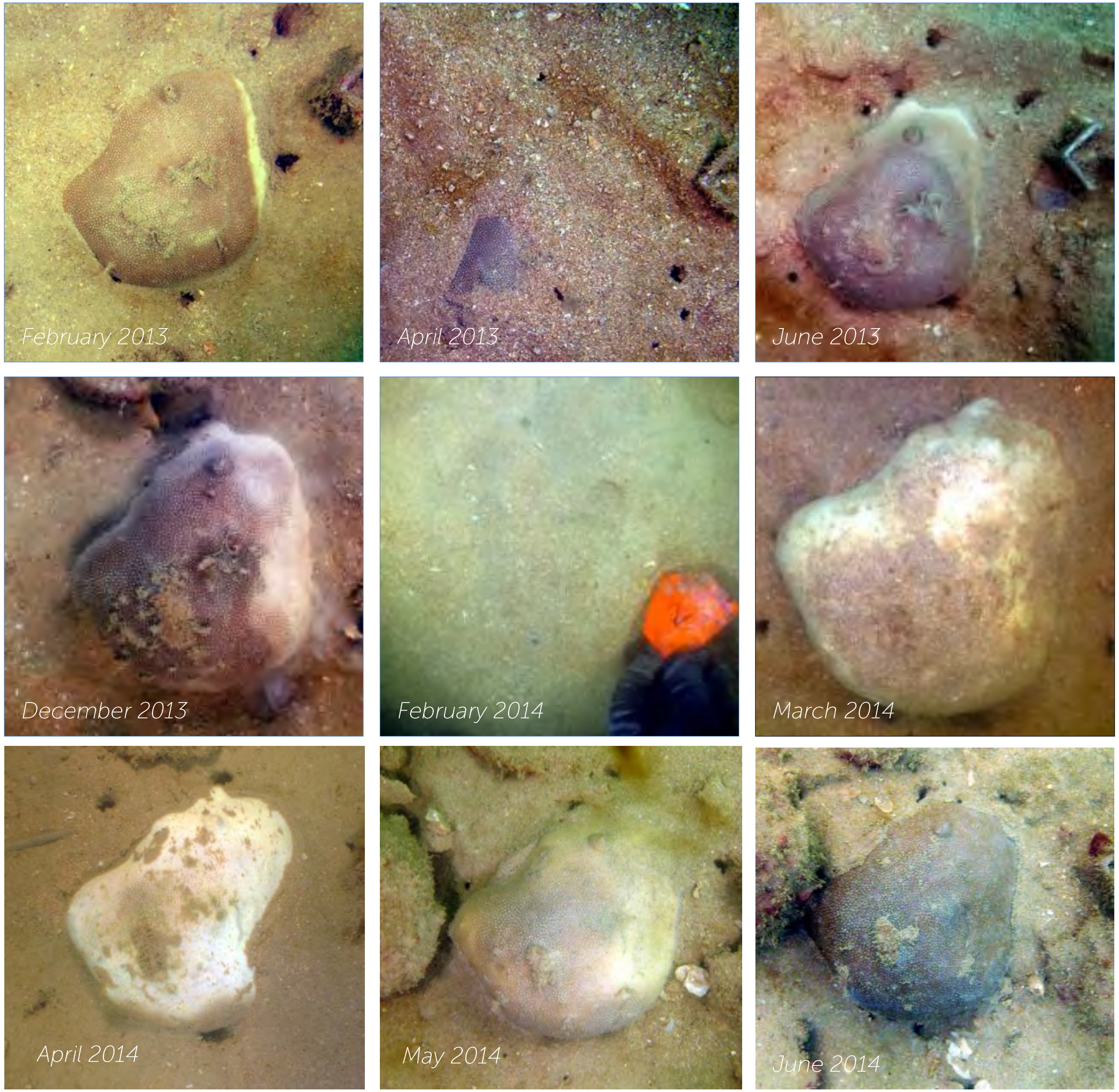


Figure 31 Time-series photos of a tagged Porites sp. showing the natural resilience of Darwin Harbour corals to sediment burial. Burial initially observed in April 2013, with emergence by June 2013, and subsequent reburial in February 2014, followed by emergence by March 2014, then recovery from April to June 2014. Sediment removal is likely to have been by a combination of both active and passive means

Mucus production and tentacular action are two ways in which corals can actively remove sediment. Coral colonies can produce copious amounts of mucus that collects and binds sediment, which is then removed from the colony during strong currents and wave action. Sediment can also be removed from the colonies by the corals' tentacles, which can move the sediment to the edge of the colony.

Although sediment has completely buried coral colonies in Darwin in some instances, substantial removal of sediment has also been observed (Figure 31). Burial and subsequent removal of sediment from colonies can happen over a very short period (days or less), once deposition is no longer occurring (Figure 32).

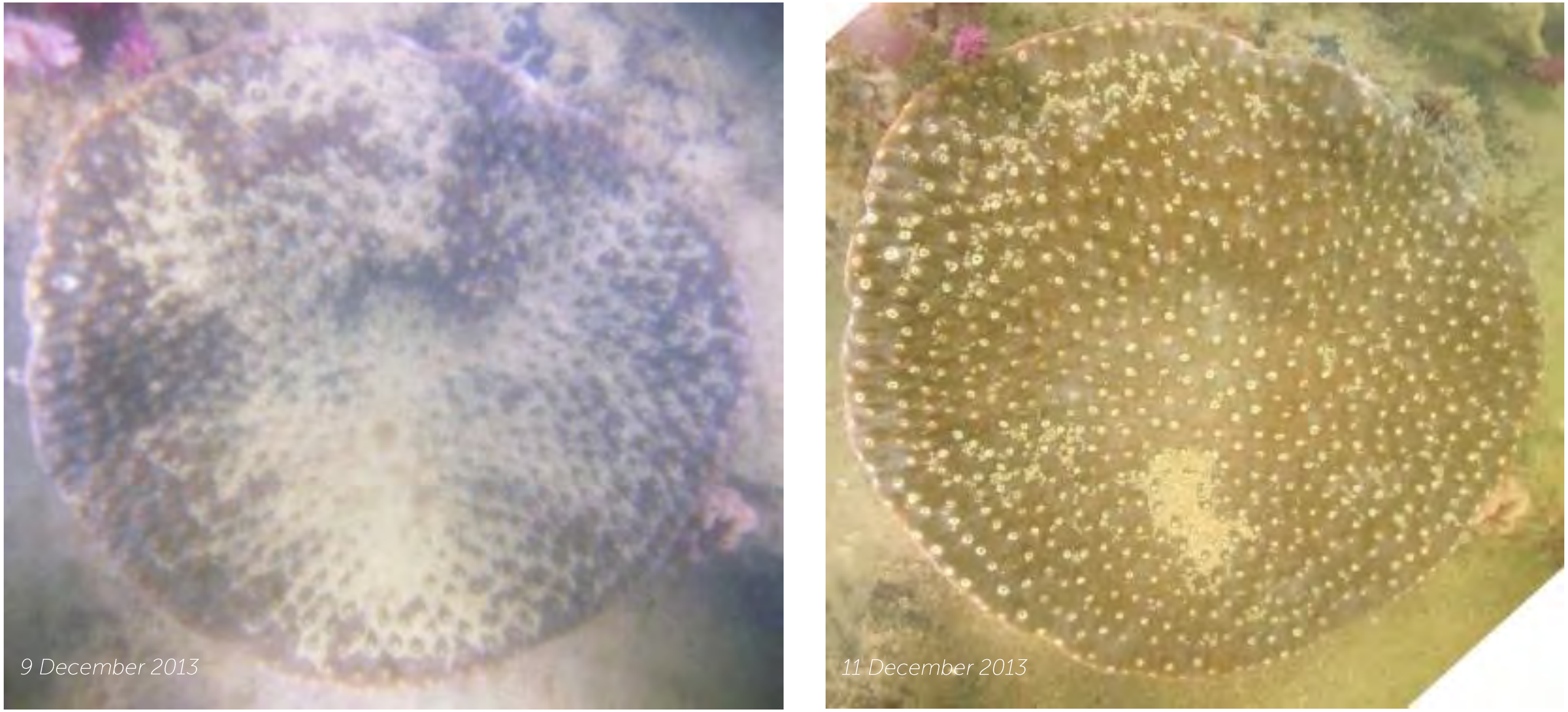


Figure 32 A tagged Turbinaria sp. Coral showing sediment removal over a two day period

Elevated Water Temperature

Above average water temperatures are known to cause stress to coral colonies and can cause coral bleaching to occur. Bleaching is a stress condition that involves a breakdown of the symbiotic relationship between corals and their photosynthetic algae that causes colonies to expel the algae and turn completely white. This can be problematic to the coral colony, as the photosynthates from the symbiotic algae may provide a large proportion of the colony's energy needs. The low latitude of Darwin Harbour, close to the equator, means that warm water temperatures of up to 32°C occur during the wet season each year (Figure 8). Given that Darwin corals are exposed to water temperatures of over 30°C for days to weeks, they probably exist close to their upper thermal limits and are potentially vulnerable to bleaching. Temperatures exceeding 1°C above the maximum of the monthly mean (MMM; i.e. long-term average of the warmest month) are considered to cause thermal stress for corals (NOAA Coral Reef Watch 2011). The MMM for Beagle Gulf occurs in December and is approximately 30°C (NOAA Earth System Research Laboratory 2014) meaning that temperatures of 31°C or greater are likely to cause stress to corals and a small amount of coral bleaching appears to be a regular wet season event.

A thermal bleaching event was recorded in February 2013, which occurred between surveys (December 2012 and February 2013) when the water temperature in Darwin Harbour temporarily exceeded 32°C (Figure 8). Importantly, this bleaching event was primarily restricted to one of the two monitoring sites at Weed Reef (Weed Reef 2). Only certain types of coral (Alveopora spp. and Goniopora spp.) were affected (Figure 33). These types are more common at Weed Reef, where the bleaching occurred, than at other coral monitoring sites in Darwin. Interestingly, Goniopora spp. and Alveopora spp. have elsewhere been observed to be more resilient to temperature bleaching than many other coral types (Ammar et al. 2011, Marshall and Baird 2000, Wilson et al. 2012, Yeemin et al. 2001).

Many of the corals first observed to have bleached in the February 2013 survey, particularly Alveopora sp., remained bleached for a long period (between four to six months). Some of the bleached coral colonies had recovered from the bleaching by August 2013, however a substantial number of colonies also died, thereby contributing to measures of mortality at Weed Reef 2 (Figure 27). This prolonged period of bleaching is unusual, and further supports the hypothesis that corals in Darwin may not be entirely dependent on photosynthesis for their survival and can obtain adequate energy by alternative means (i.e. heterotrophic feeding on suspended particles), at least for periods of darkness (such as blackouts) or when the corals are bleached and are unable to obtain photosynthates.

Figure 33 Extensive bleaching of Alveopora sp. in February 2013 at Weed Reef, Darwin Harbour. Bleaching occurs when the colourfully pigmented symbiotic microscopic algae are expelled from the coral tissue. Bleaching of some colonies was observed for four to six months, before recovery was measured

Extreme Low Tides

The large tidal range of Darwin Harbour means that the corals growing in the shallowest parts of the communities can become exposed during extreme low tides (Figure 34). The lowest spring tides of the year, dropping to around 0.2 m LAT, occur at night in the dry season and in the middle of the day in the wet season. Emersion from water during low tides can stress corals as a result of desiccation (drying out from exposure to air), intense sunlight (if this happens in the middle of the day), high temperature and exposure to freshwater runoff and rain (if rainfall occurs during this period). Despite the potential stress that this can cause to corals, they persist in depths where such exposure occurs. Previous monitoring programs of Darwin Harbour coral communities indicate that when extreme low tides coincide with intense sunlight events or significant rainfall, coral bleaching and subsequent mortality may occur (HCA 1996). Coral monitoring was conducted below the lowest astronomical tide level to ensure that such exposure stress would not confound mortality estimates at the monitoring sites.

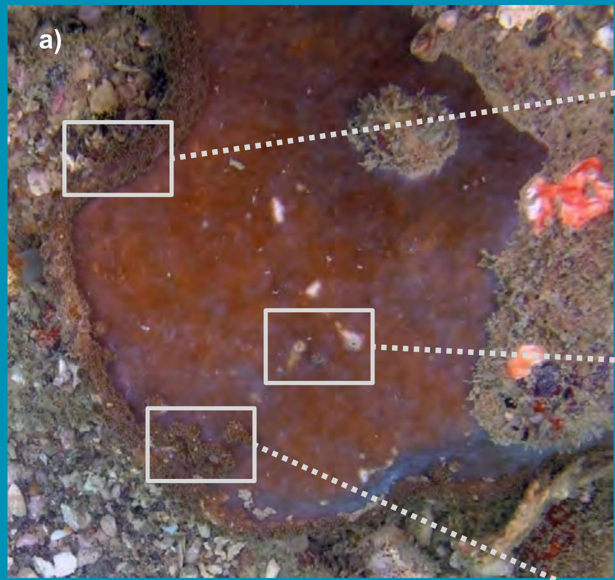
Figure 34 Exposure of coral to air during an extreme low tide at Channel Island, Darwin Harbour

Strong Currents

Darwin's strong tidal currents and waves during episodic wet season events can affect corals directly, by destabilising the substratum on which corals grow or moving/overturning colonies, and also indirectly, by mobilising and resuspending the sediment.

During the monitoring program, between 7% and 35% of corals at each site were moved from their original position by strong tidal currents and wave action in shallow waters. The effects of the tidal currents on the corals are magnified by the unconsolidated nature of the substratum of Darwin Harbour, which is inherently unstable at most monitoring locations.

In many cases, when colonies move, this is likely to result in mortality. This is especially the case when colonies are overturned so that the individual coral organisms (the polyps) that make up the colony no longer face the light, which their symbiotic algae need for photosynthesis. Other movements may also be problematic if, for example, a coral is relocated to an unsuitable position, such as in deeper water with lower light availability. However, many of the corals in Darwin Harbour show considerable ability to adapt to physical disturbance and can survive if moved to new positions. Some of the corals in Darwin have shown plasticity in the way they grow and, when partially or fully overturned, can change their shape as they grow. Figure 35a-b shows an example of where the edge of such a colony has continued to grow, folding back onto itself so that the new polyps are facing upwards. In some colonies of Turbinaria spp. that were observed to have completely overturned, new polyps developed on the underside of the coral (Figure 35c-e).



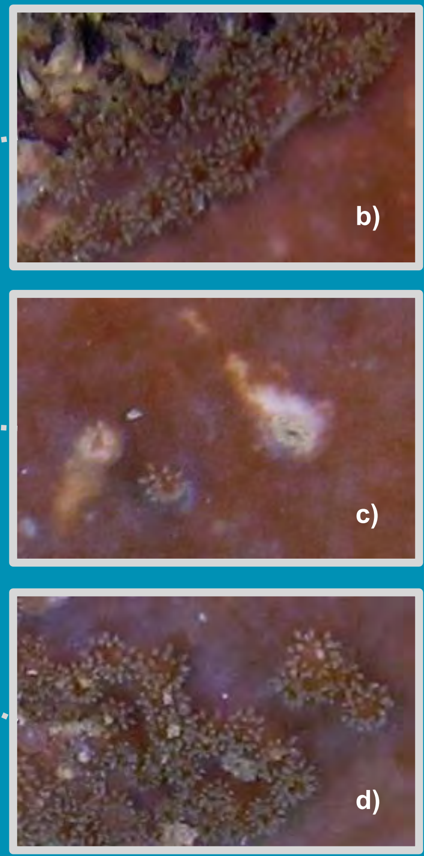


Figure 35 (a) Overturned Turbinaria spp. showing (b) the leading edge growing back over the underside of the colony; (c) and (d) new polyps forming directly on the underside of the colony; and (e) developing polyps on the underside of an overturned Turbinaria sp. allowing the colony to continue surviving

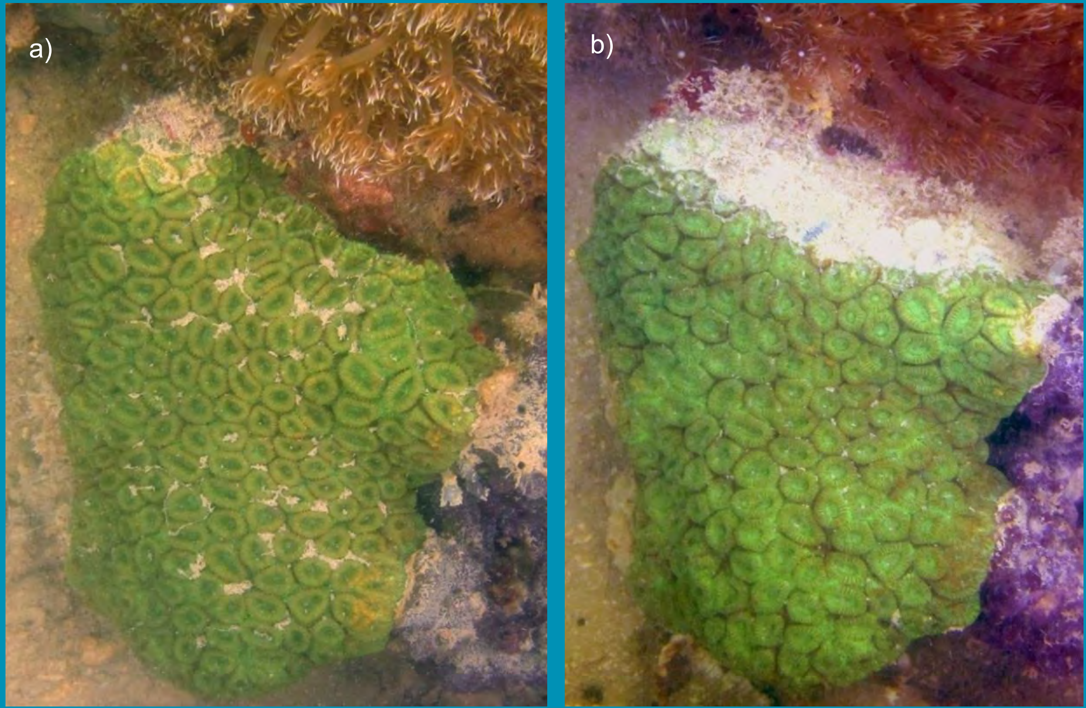


Figure 36 Inter-species competition between Goniopora sp. (top right) and Favia sp. (bottom left) colonies: (a) healthy Favia sp.; and (b) partial mortality of Favia sp.

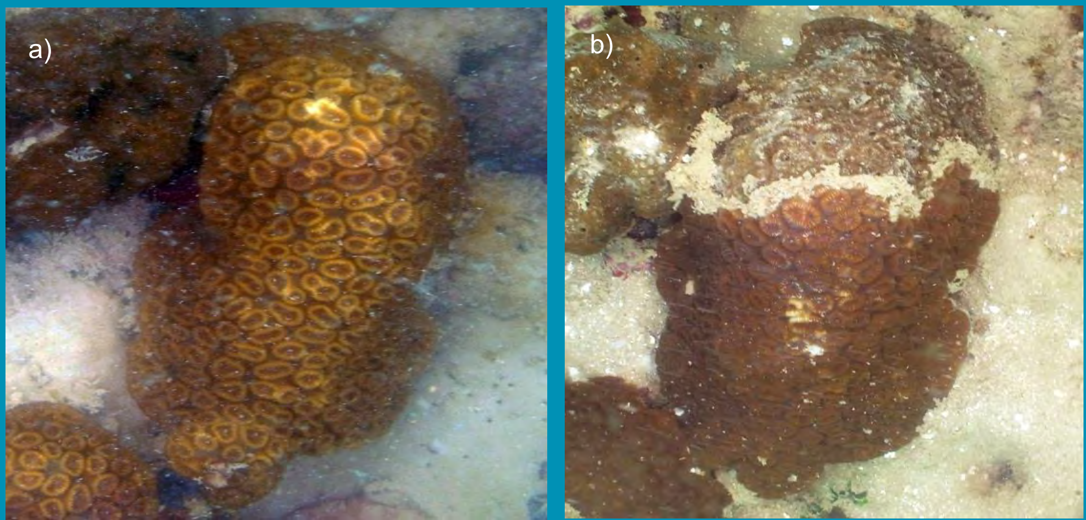


Figure 37 Faviid colony being colonised by bio-eroding sponge: a) healthy colony; b) sponge colonisation (top)

Competition

Competition between corals for space is an important factor that can cause stress and mortality. As corals grow and expand into new areas they will often encounter other corals colonies. At this point of interaction, the corals will compete with each other by either direct overgrowth, or by attacking with stinging cells contained in the coral polyps, often leading to tissue death (Figure 36).

As well as competing with other coral species, the coral colonies have to contend with competition from other types of organisms. The two main competing organisms observed during the monitoring program were turf algae, which partially or fully colonised some colonies, and sponges (Figure 37), which are particularly prevalent in the coral communities at Charles Point and Mandorah.

Disease and Syndromes

Diseases and other syndromes are prevalent in corals throughout Darwin. In a number of cases where complete coral mortality occurred, there were pre-existing signs and symptoms of disease, such as bioeroding sponges, white syndrome and turf algae. In many cases the disease was a precursor to mortality and the subsequent rapid colonisation by turfing algae (Figure 38). However, in a number of cases, the presence of a disease or syndrome did not cause deterioration of health of the host coral, indicating that the corals are able to fight off disease. Also, where disease caused substantial but not complete mortality, the affected corals have in some cases shown surprising regenerative ability. An example of this can be seen in Figure 38 where a Turbinaria sp. underwent almost complete mortality, being reduced to two solitary surviving polyps. Subsequently the two polyps have developed into two new colonies on the old dead skeleton.

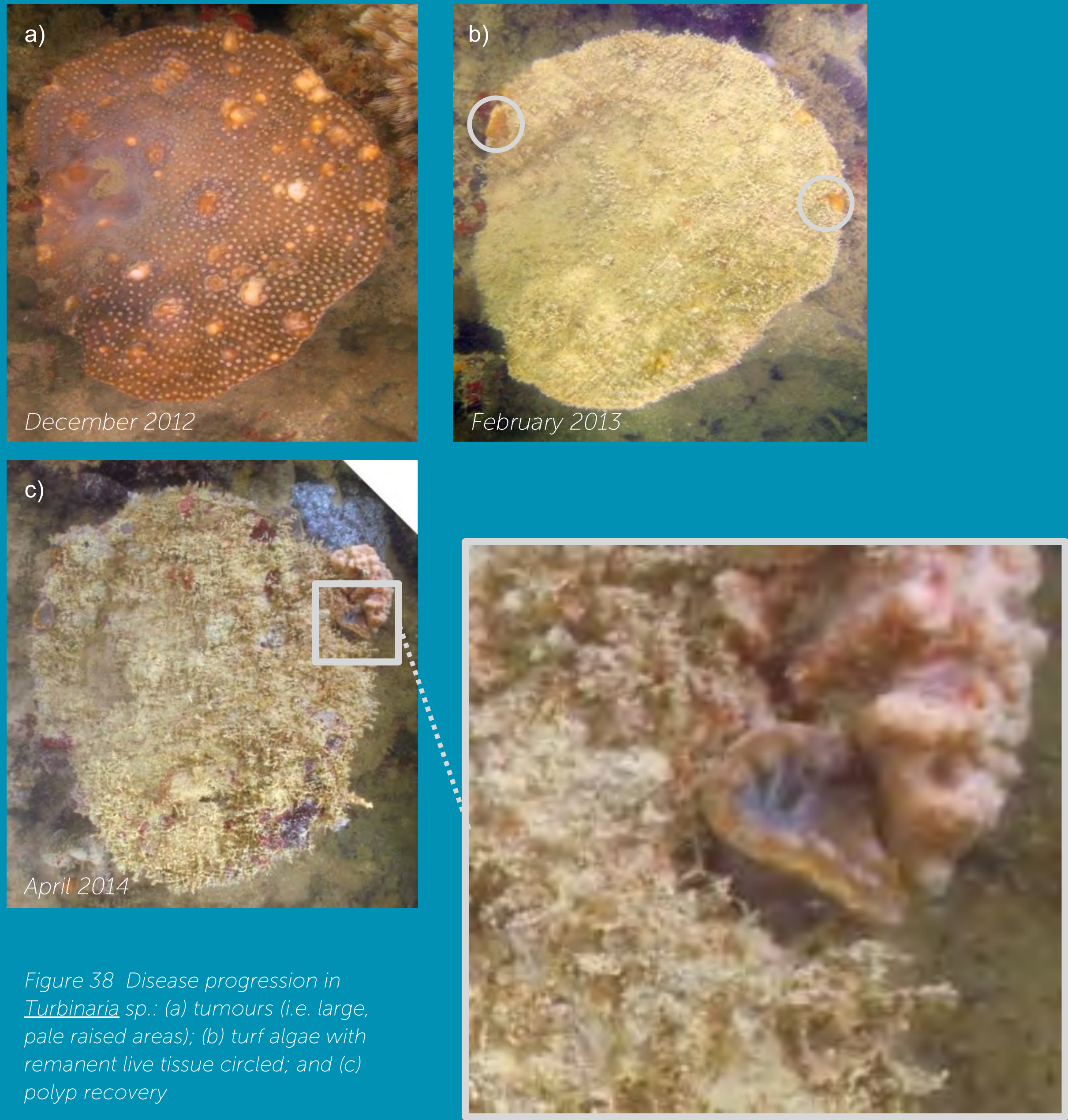


Figure 38 Disease progression in Turbinaria sp.: (a) tumours (i.e. large, pale raised areas); (b) turf algae with remanent live tissue circled; and (c) polyp recovery

Coral Mortality

The hard corals of Darwin live in an extreme environment where they are presented with pressures that challenge their existence on a seasonal, and sometimes daily, basis. Despite these challenges, the communities persist with great resilience along a narrow depth-band whose upper bound is determined by frequency and duration of exposure and whose lower bound is determined by the frequency and duration of available light. Given all of the pressures outlined above, it was expected that some corals would die or show partial mortality during the monitoring program. Surprisingly, few of the tagged corals in the monitoring program suffered complete mortality (Figure 27) and even when a temperature-induced bleaching event was observed at one of the monitoring sites, many of the affected colonies completely recovered. The natural heritage listing of the Channel Island coral community is a recognition of its unique ability to persist in such an extreme environment.

Case Study: Coral Reproduction in Darwin Harbour

The vast majority of corals are hermaphrodites, that is, they contain both male (testes) and female (oocytes) reproductive structures within the same coral (Figure 39). Most of these also broadcast spawn - releasing both eggs and sperm into the water column synchronously over a few nights. A few corals have separate sexes with some colonies being male and others females, while others are sequential hermaphrodites with the colony usually first acting as a male and then as a female once all the sperm has been released. These latter strategies are thought to help avoid self-fertilization. Whatever the case, sexual reproduction provides the opportunity for corals to adapt to environmental change as sexual reproduction allows for the rearrangement of genetic material. In contrast, asexual reproduction via clones or fragmentation does not allow for genetic adaptation to a changing environment.

Currently there is no published information about the timing of coral spawning in Darwin Harbour. Predicting when corals are likely to spawn is difficult, given the uncertainty regarding the environmental cues that initiate spawning. On the Great Barrier Reef (GBR) corals mass spawn primarily during October and November. On other hand, on the Western Australian coast coral spawning occurs predominantly in March and April, although a second spawning period has been reported for many reefs in the Northwest (e.g. Scott Reef and the Bonaparte Archipelago) (Rosser and Baird 2008), albeit of a much lesser magnitude. Spawning of corals in Darwin Harbour may be aligned with the east or west Australian coasts, or both.

For many decades it was thought that spawning was linked to maximal sea surface temperature because of the strong correlation of mass spawning on the GBR with peak seasonal sea surface temperature. However, this hypothesis was negated when corals at Ningaloo in Western Australia were observed to spawn in March and April when water temperatures were not the highest (Simpson 1991). Another theory was that sea surface temperatures have to be the optimal 28 to 30°C, which would fit the pattern for the GBR and Ningaloo reef corals. This would make spawning in Darwin likely in June and/or September. More recently studies of coral reproduction have revealed further variation in the timing and duration of coral spawning including some locations such as Kenya and the Galapagos having 7-month spawning seasons (Glynn et al. 1991; Mangubhai and Harrison 2008). A novel hypothesis has been proposed that corals spawn when wind speeds are minimal (<20 km/h) resulting in a calm sea state (van Woesik 2010). In Darwin this would mean spawning would be likely to occur during the dry season (approximately May to October).

To determine when spawning occurs in Darwin Harbor, coral cores have been collected from coral colonies between April 2013 and July 2014.

Currently, histological analysis has only occurred on the initial samples collected in April 2013, which indicated that 9 of the 10 coral cores collected contained reproductive tissue. Some of these contained only male or female reproductive structures, while one sample contained both male and female gametes that were mature. This coral belongs to the genus Favites (Faviidae) and the presence of mature gametes indicates that it is likely to be a simultaneous hermaphrodite and have an autumn or dry season spawning. The vast majority of Faviidae corals are hermaphroditic and broadcast spawn (Baird et al. 2009). These results are preliminary, and histology of samples from subsequent surveys will help determine the timing and nature of spawning more precisely.

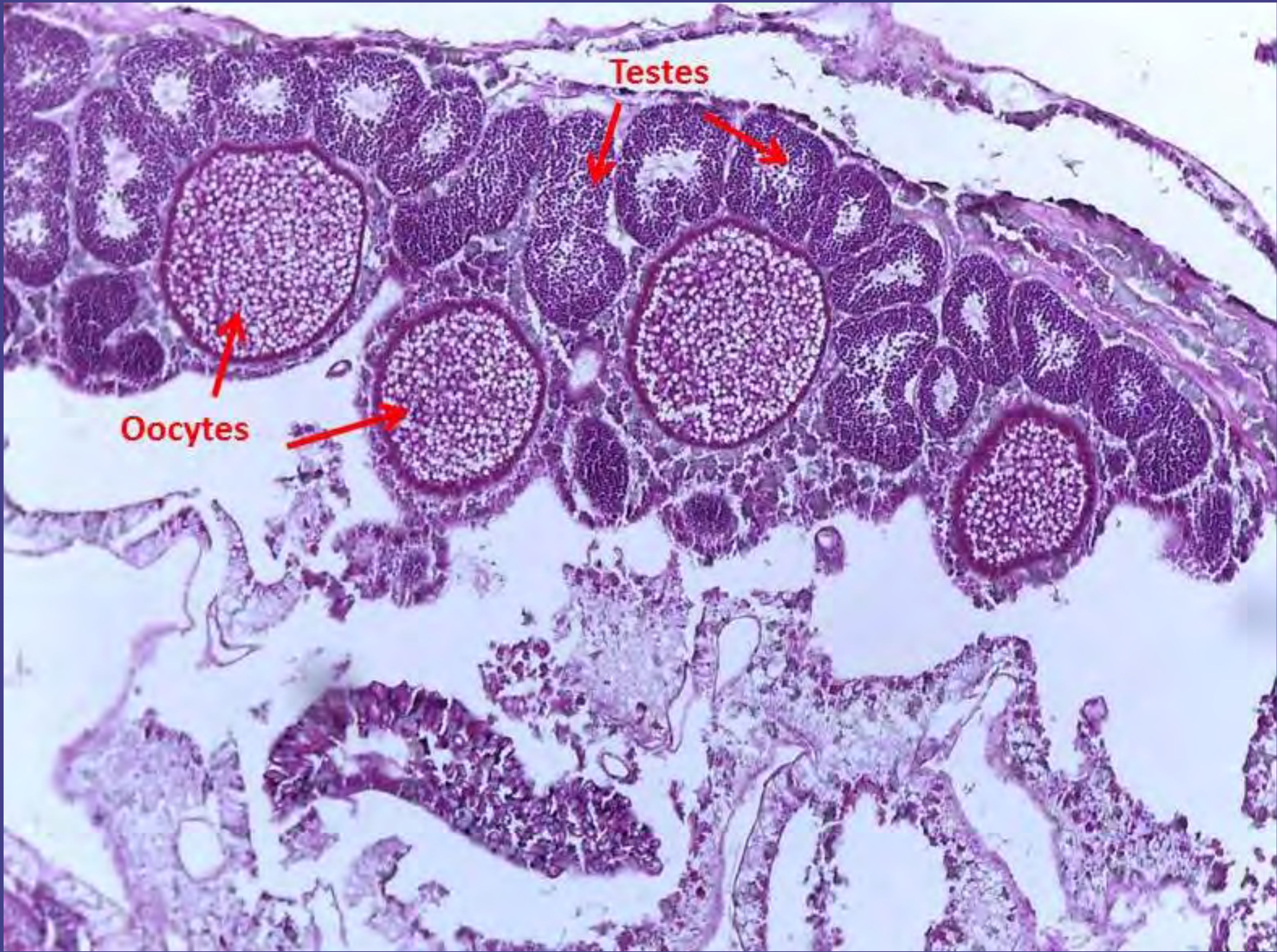


Figure 39 Transverse section through Favites sp. coral at Weed Reef (April 2013) showing mature male (testes) and female (oocytes) reproductive structures

Seagrass Habitat

Darwin Seagrasses

Seagrass habitat in the Darwin region is dominated by two fast growing, early colonising species that are known to survive well in unstable (shifting sediments) or depositional (subject to sedimentation) environments (Green and Short 2003). These are Halophila decipiens (commonly called "paddle grass") and Halodule uninervis (commonly called "needle grass") (Figure 40).

Figure 40 Illustration of the dominant seagrass species found in Darwin; Halodule uninervis and Halophila decipiens

The seagrass habitat has been found to occur mostly along the foreshore of Darwin Outer, including patches along the Cox Peninsula near Charles Point and Woods Inlet, and along the eastern shoreline from Fannie Bay to Lee Point (Figure 41). Six survey areas were defined within these general areas and used to monitor the distribution and condition of seagrasses every three months. Within these survey areas, H. uninervis has been found mostly in the intertidal zone of each survey area between 2 m and -1 m LAT. Halophila decipiens has been observed in deeper habitats, dominating the shallow subtidal zone between 0 m and -3 m LAT. It was even observed down to -10 m LAT in October 2012.

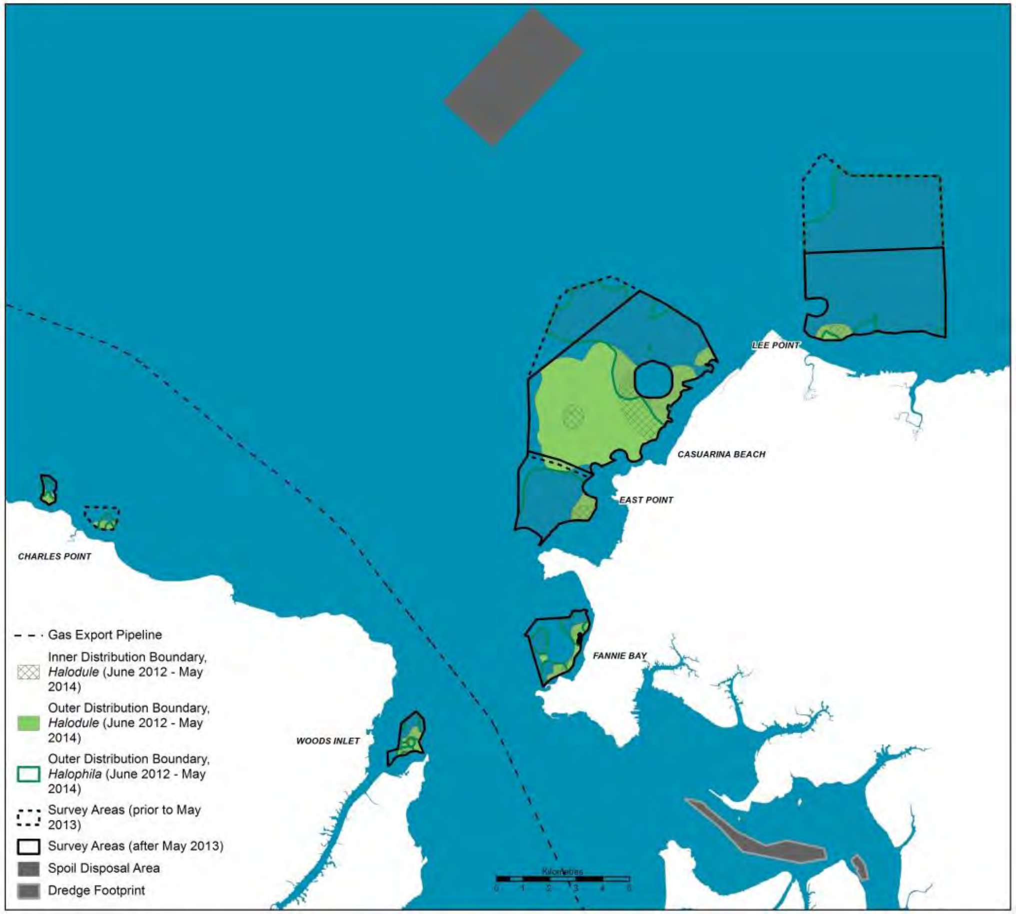


Figure 41 Seagrass distribution variability in surveyed areas in Darwin Outer showing the maximum (outer boundary) and minimum (inner boundary) extent of Halodule uninervis, and maximum extent of Halophila decipiens mapped during the monitoring program. Note that Halophila decipiens was absent from all surveyed areas during the 2013 and 2014 wet seasons and as such, there is no minimum extent shown

A Highly Dynamic System

Increased rainfall and runoff in the wet season together with strong wind and waves create highly turbid conditions that reduce light availability at the seabed. Episodic weather event such as tropical cyclones and storms during the wet season cause very strong winds and waves that further increase turbidity along the coast, and can directly damage or physically remove seagrasses.

As discussed in **Environmental Setting – Underwater Light***, the amount of light at the seabed is driven by changes in surface light, water depth and turbidity, with turbidity having the overall dominant effect. As all these factors vary over a range of timescales from daily, fortnightly, seasonally and inter-annually, so does the light available for seagrass photosynthesis. There is a general spring-neap variation in turbidity and hence in benthic light, with greater levels of light generally occurring during neap tides (Figure 11).*

During the wet season, the spring / neap tidal cycle still drives changes in turbidity and light at the seabed but there is the addition of more energetic wind and wave forcing conditions. These generate greater turbidity, particularly in shallow areas, where seagrass habitat occurs. These conditions limit the penetration of light to the seabed and can even lead to periods of prolonged darkness during severe weather events, such as tropical cyclones. Since the start of monitoring, seagrasses at a depth of -1 m LAT near Lee Point have been exposed to one to two week-long periods of darkness on several occasions. These occurred following the passage of TC Narelle in January 2013, TC Rusty in March 2013, TC Alessia in November 2013, and TC Fletcher in February 2014 (see example from Fannie Bay in Figure 11).

Breaking waves during such weather events can also physically damage and remove seagrass habitats, and the large loads of sediments resuspended in the water column can also bury or smother seagrasses. Immediately after these events, seagrass debris (wrack) can be seen occasionally washed up along beaches.

Seasonal Variability of Seagrass Habitat

Characteristics of the wet season drive widespread decline of seagrasses in Darwin Outer, while the dry season is generally favourable for seagrass growth, as observed since the start of monitoring in June 2012. There have been large natural changes in the percentage cover of H. uninervis and considerable and rapid natural changes in the distribution and extent of H. decipiens habitat (Figure 41).

The spatial extent and percentage cover of H. decipiens in Darwin has naturally changed quite dramatically through time: there was a complete absence of H. decipiens from all surveyed areas during the wet season, and this was followed by strong recovery and habitat expansion during the dry season (Figure 42).

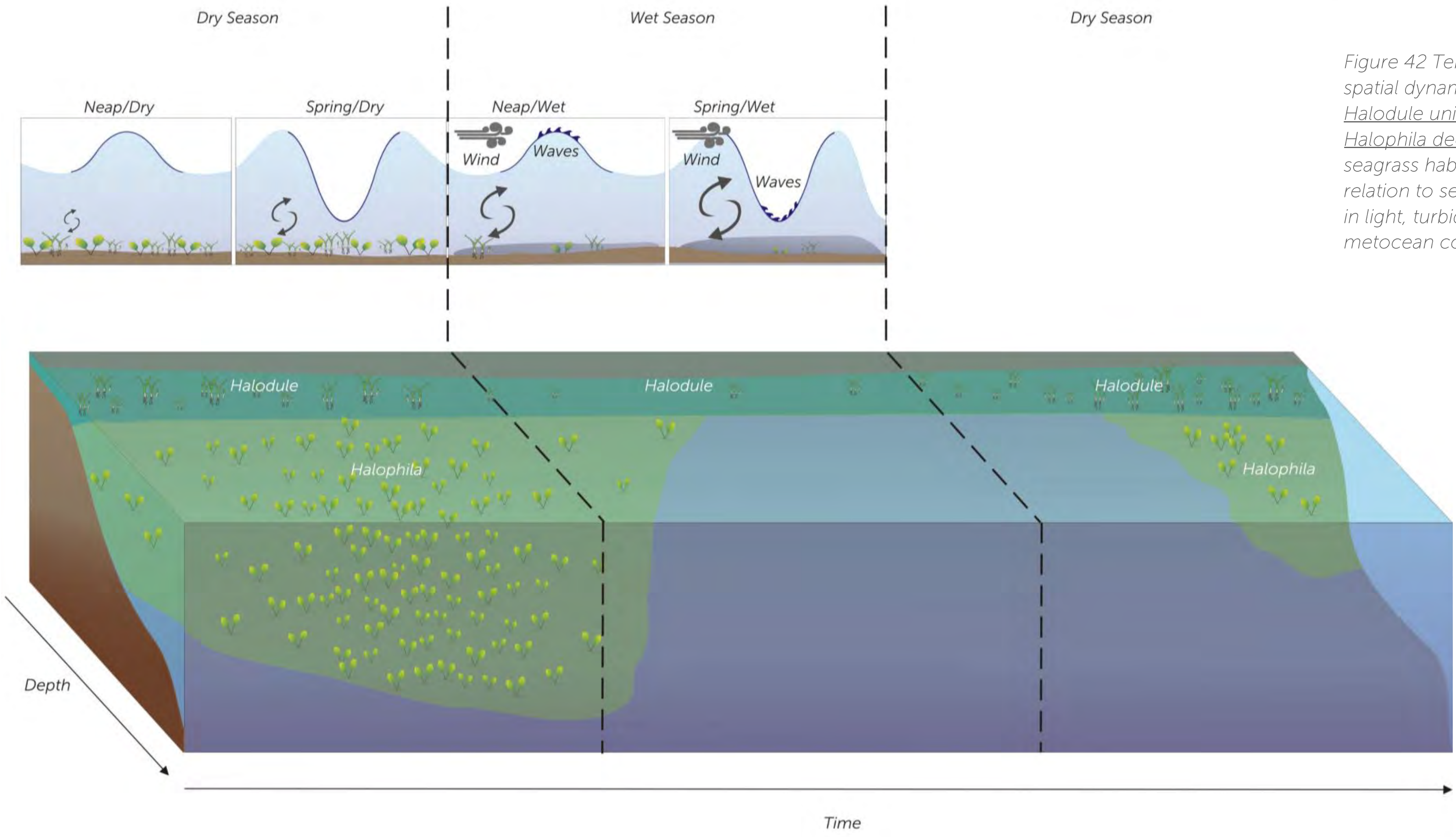


Figure 42 Temporal and spatial dynamics of Halodule uninervis and Halophila decipiens seagrass habitat in Darwin in relation to seasonal changes in light, turbidity and metocean conditions

For example, the extent of the H. decipiens habitat near Lee Point exceeded 2,700 ha in October 2012 and this was followed by a complete decline by February 2013 and rapid renewal and expansion in May 2013 to approximately 1,800 ha (Figure 44). In addition to changes in the extent of H. decipiens habitat through time, there were also considerable changes in its percentage cover. This reached 10% to 40% cover during the dry season surveys of October 2012 and May 2013 with patches of up to 80% cover found at Lee Point in October 2013.

By comparison, the spatial extent of H. uninervis habitat has remained relatively stable throughout monitoring (Figure 44), but has recorded some shifting of patches and overall changes in percentage cover. For example, percent cover ranged from approximately 5% cover during the wet season (surveyed in February 2013) to approximately 10% to 20% cover in the dry season (surveyed in October 2012 and May 2013).

These processes are typical of highly dynamic seagrass habitats in the wet tropics, with cycles of natural decline and recovery (Figure 42). Both H. decipiens and H. uninervis are known to recover rapidly after disturbances, as they often establish large seed reserves (Figure 43) in the sediment and/ or grow and expand rapidly from remaining patches (Short et al. 2010a and 2010b).

In addition to natural seasonal patterns, the monitoring program also highlighted some interannual differences in water quality that can influence the dynamics of seagrass habitat over longer timeframes. The 2012/2013 wet season started late and was atypically dry, while the 2013/2014 wet season started early with above average rainfall (Figure 5). There were differences in the distribution of seagrass between these two years, in particular near Lee Point, H. decipiens habitat considerably expanded towards the end of the 2012 dry season (October 2012) before declining during the wet season (by February 2013). By contrast at the end of the 2013 dry season, the decline in H. decipiens habitat was already noted by November 2013 (Figure 44). Due to adverse weather conditions experienced during the February 2014 survey, the majority of survey areas were unable to be mapped. As such, a comparison with this survey cannot be made.

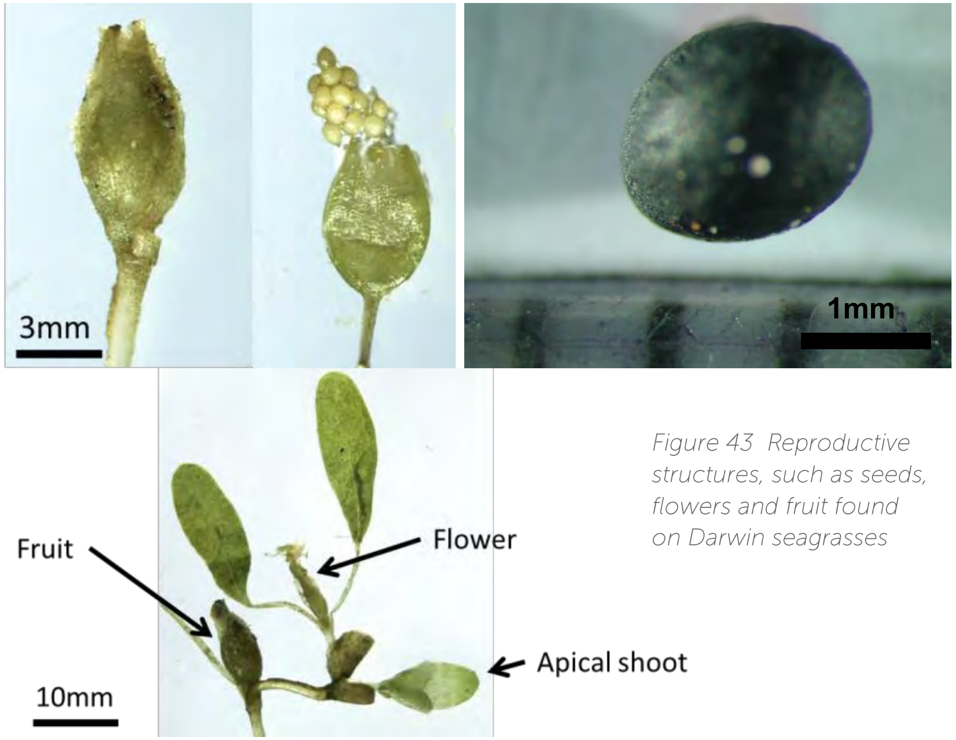


Figure 43 Reproductive structures, such as seeds, flowers and fruit found on Darwin seagrasses

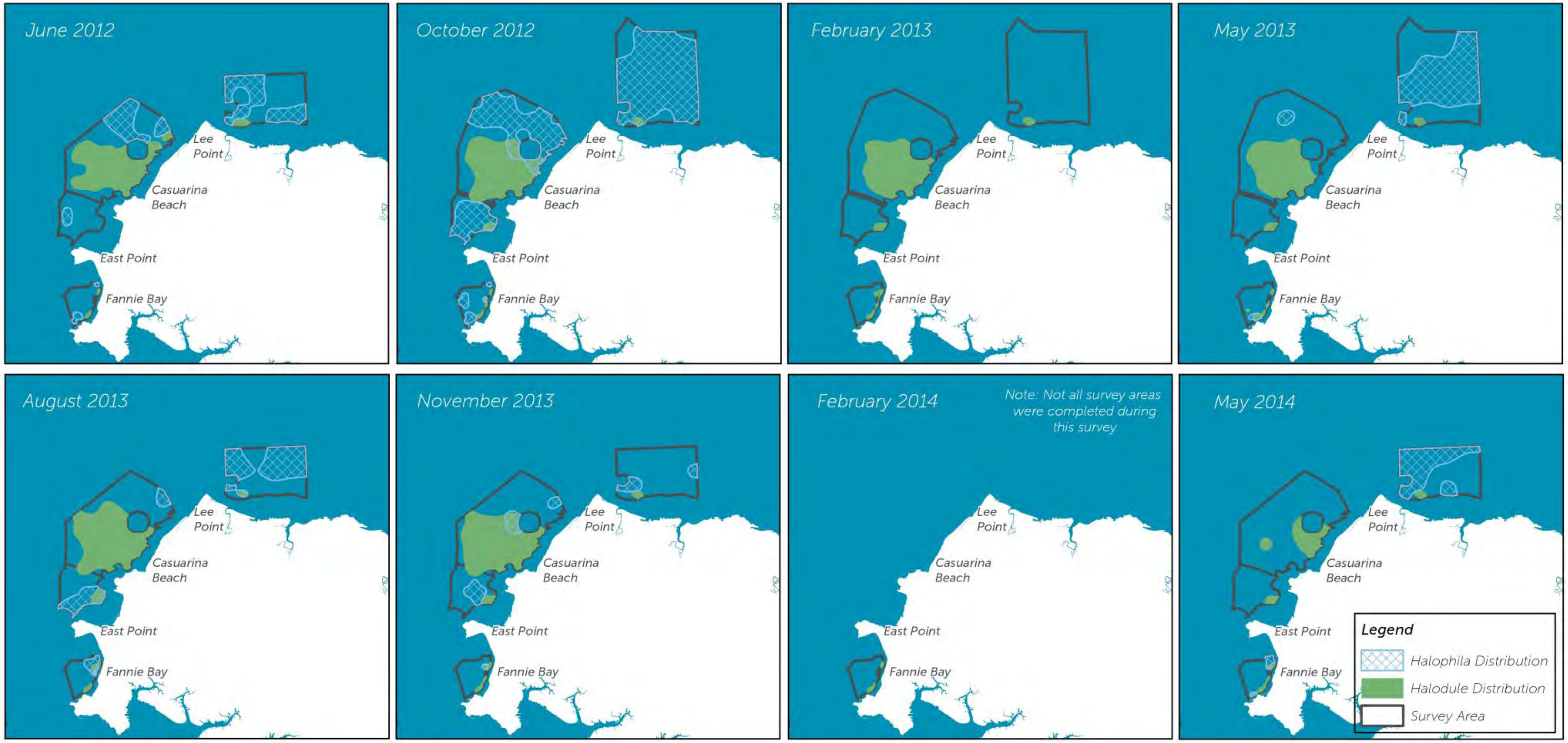


Figure 44 Changes in the distribution of Halophila decipiens and Halodule uninervis in Darwin Outer during the monitoring program. Note that not all survey areas were completed during February 2014 due to adverse weather conditions during the survey period

Investigating the Influence of Light and Turbidity on Seagrass Growth Patterns

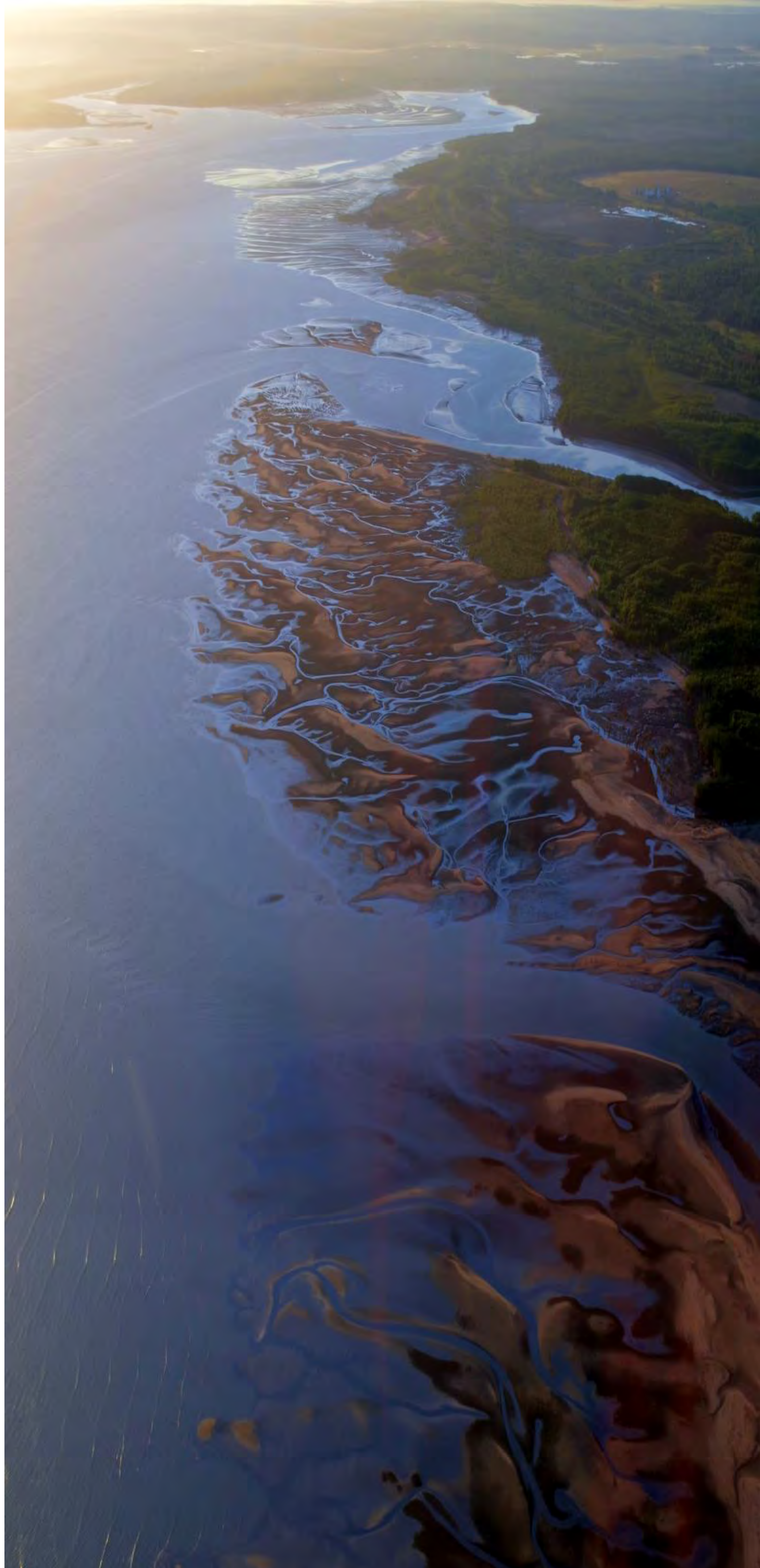
The monitoring program has provided two years of data on the distribution and density of seagrass in Darwin Outer, together with continual records of turbidity and underwater light conditions. Seagrass and water quality results were combined to help improve our understanding of the response of seagrasses to changes in light and turbidity.

Over the first year of monitoring, decreases in the percentage cover of H. decipiens generally coincided with periods of elevated turbidity (10 to 15 NTU on average) over the previous month, while increases in cover generally coincided with reduced turbidity levels (below approximately 5 NTU). For H. uninervis, decreases in percentage cover were less pronounced over time, and occurred over a wider range of turbidity between 5 and 15 NTU.

Changes in seagrass cover over time were also compared to the light (PAR) history at various depths. Halophila decipiens cover mostly decreased within a PAR range of 4 to 8 mol photons/m^2/d over a 28-day period, while for H. uninervis this occurred at PAR levels of 10 to 15 mol photons/m^2/d. The higher PAR values for H. uninervis suggest that it may have greater light requirements compared to H. decipiens, which may in part explain why H. uninervis frequents shallow intertidal habitats (Figure 42 and Figure 44).

Unlike H. decipiens, H. uninervis persisted throughout the wet season and its distribution did not appear to be greatly influenced by the extreme seasonal changes in light and turbidity. Consequently the relationship between light history and changes in H. uninervis cover was not as strong as for H. decipiens. Other factors such as nutrients, salinity, temperature, sediment grain size, sedimentation and seasonality, could also play an important part in structuring seagrass distribution in the Darwin region. With a primarily intertidal distribution, H. uninervis may be more affected by factors such as wave action, increased mixing in shallow areas and episodic exposure to air at low spring tides. It may also respond to changes in light over longer timeframes than considered here.

Seagrass habitats in Darwin have a generally low biomass, particularly when compared to dense temperate seagrass meadows. This limits the ability to define and interpret relationships between seagrass health and physical variables, and posed a particular challenge for monitoring anthropogenic change in the tropical marine environment in the Darwin region.



Mangrove Ecosystems

Largely undisturbed tracts of mangrove occupy an area of over 25,000 ha in and around Darwin Harbour, representing approximately 5% of the Northern Territory's and 0.1% of the world's mangrove area (Brocklehurst and Edmeades 1996). With approximately 30 mangrove species occurring naturally within Darwin Harbour alone, these are among the most diverse in Australia and are considered a significant natural resource of local and regional importance.

Mangrove Assemblages – Defined by the Tides

As a result of the macrotidal environment of Darwin Harbour, a range of intertidal habitats have evolved that are defined by daily and seasonal inundation patterns. There are four key mangrove plant communities or assemblages, each occurring in close succession along the tidal profile and with different sediment characteristics, tree species and fauna.

Closest to the water is the Seaward assemblage, which grows between 3 and 4 m LAT and gets inundated twice every day at high tide. The next assemblage is the Tidal Creek, inundated at least once every day and sometimes twice by high tides. Further up the bank, the Tidal Flat assemblage is only inundated during spring high tide, and contains hyper saline salt flats. Furthest up the tidal profile is the Hinterland Margin assemblage, inundated only a few times a year by the highest spring tides (Figure 45).

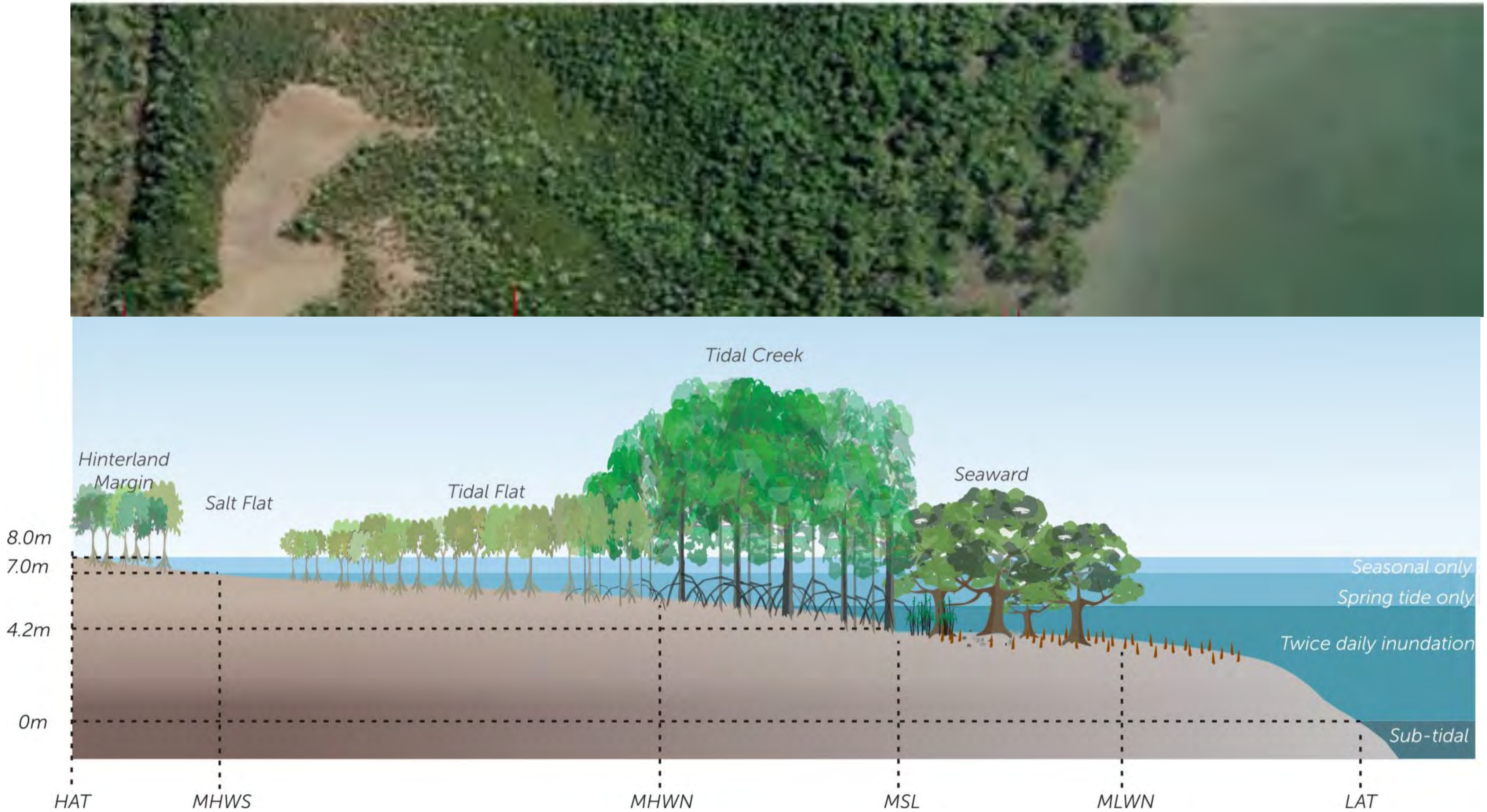


Figure 45 Major mangrove assemblages of Darwin Harbour and their position in the tidal profile (adapted from Brockelhurst and Edmeades 1996). Showing relevant tidal profiles that contribute to defining the mangrove assemblages: highest astronomical tide (HAT), mean high water springs (MHWS), mean high water neaps (MHWN), mean sea level (MSL), mean low water neaps (MLWN) and lowest astronomical tide (LAT)

Seaward Assemblage

Covered by up to 4 m of water at high tide, the Seaward assemblage is inundated twice each day. It is most commonly found adjacent to the open Harbour next to expansive mud flats rather than in riverine or creek system settings. These areas are truly part of the marine environment and are subject to wave action and currents. In some locations there is a small step of up to 1 m in height at the boundary with the Tidal Creek assemblage, indicative of a change in shoreline processes between these two zones. It is dominated by open woodland of mature Sonneratia alba trees that typically grow to heights of 8 to 10 m (Figure 46). In many places there is an understorey of the river mangrove Aegiceras corniculatum that tends to colonise in dense patches. Canopy cover in this assemblage is patchy and ranges from around 60% to 90% (Figure 29b).

Sedimentation has been found to be greatest in this assemblage (Figure 29a), with net accretion rates in the order of 8 mm per year. This is broadly comparable to rates cited in the literature for both sedimentation (Sanders et al. 2010) and estimates of annual sea level rise over the last 20 years (BOM 2014).

Figure 46 (a) and (b) show mature Sonneratia alba trees which dominate the Seaward assemblage, spending nearly half their lives submerged by up to 4 m of water

Sediments have a high moisture content (verging on the consistency of mousse). They consist of very fine particles with up to 40% of particles with a diameter of less than 1 µm. Navigating this habitat on foot is only made possible by the extensive cable root system to which pneumatophores are attached, which spreads out for a great distance from each mature S. alba tree, shown in Figure 46b. These roots are an important part of the trees' ability to obtain oxygen in a water-saturated environment and may also make them resilient to changes in sediment levels. Studies have shown that S. alba seedlings are the most tolerant species to burial (Thampanya 2006).

Tidal Creek Assemblage

The Tidal Creek assemblage is dominated by dense closed Rhizophora stylosa forests 5 to 12 m tall. The Tidal Creek assemblage is often found fringing creeks that lack a Seaward assemblage; however it is ubiquitous around Darwin Harbour at its specific height in the tidal profile. The environment is characterised by large stilt root systems that make moving through this assemblage challenging (Figure 47). With lush dark green foliage and sometimes very tall canopies (up to 16 m in height), these forests are highly productive ecosystems. Canopy cover is generally around 95% with little seasonal variability (Figure 29b).

Inundation occurs daily throughout the year and sediments also have a high moisture content. Sedimentation rates are lower than in the Seaward assemblage but greater than assemblages higher in the tidal profile (Figure 29a). Sediments are very fine and extensive bioturbation is evident with mounds and holes indicating that a diverse range of fauna (including mud crabs and mud lobsters) are hiding below. Pools of standing water support some resident fish, such as mudskippers and other free-swimming species stranded by the retreating tide.

Figure 47 (above) The stilt root system of Rhizophora stylosa form a dense tangle at ground level, reducing current flow and promoting the accumulation of sediments

Tidal Flat Assemblage

The tidal flats support a low closed but patchy forest dominated by Ceriops australis trees 2 to 6 m tall (Figure 48). Tidal inundation of much of this generally broad assemblage only occurs during spring tides. The reduced frequency, duration and depth of inundation, combined with the flat topography makes this assemblage prone to the accumulation of salt in the sediments and ultimately the formation of unvegetated salt flats in the upper part of the tidal zone. Mangroves surrounding the salt flats are often stunted and in poor condition, with individuals of the salt tolerant species Avicennia marina commonly occupying the margin (Figure 48).

Away from the salt flats, the vegetation can be very dense with C. australis of an even height crowded together to make an impenetrable stand, with canopy cover ranging from around 80 to 85% (Figure 29b). Sedimentation in this assemblage was found to be minimal (Figure 29a), with sediments generally having a coarser sediment particle size and higher pore-water salinity than in the Tidal Creek and Seaward assemblages.

Figure 48 The Tidal Flat assemblage includes dense stands of Ceriops australis and salt flats fringed with Avicennia marina

Hinterland Margin Assemblage

At the landward edge of the mangroves lies the generally narrow Hinterland Margin assemblage. Inundation of this assemblage only occurs during the highest of the spring tides, which mostly occur during the wet season. Although this habitat is commonly dominated by large C. australis trees up to approximately 5 m in height, there is a greater variety of mangrove species than in other assemblages, including Lumnitzera racemosa and varieties of the deciduous Excoecaria sp. (Figure 49). Other species more typical of freshwater habitats such as Melaleuca (paperbark) spp. are often in mixed associations with the mangroves.

This is the most variable of the assemblages, both spatially and seasonally, being strongly influenced by the hydrology, biogeography and land use of the adjoining terrestrial environment. Canopy cover is generally high, fluctuating seasonally from around 90 to 95% (Figure 29b).

The forest floor is commonly covered with a layer of 'wrack' consisting of leaves, twigs, sticks and other materials deposited at the high tide mark.

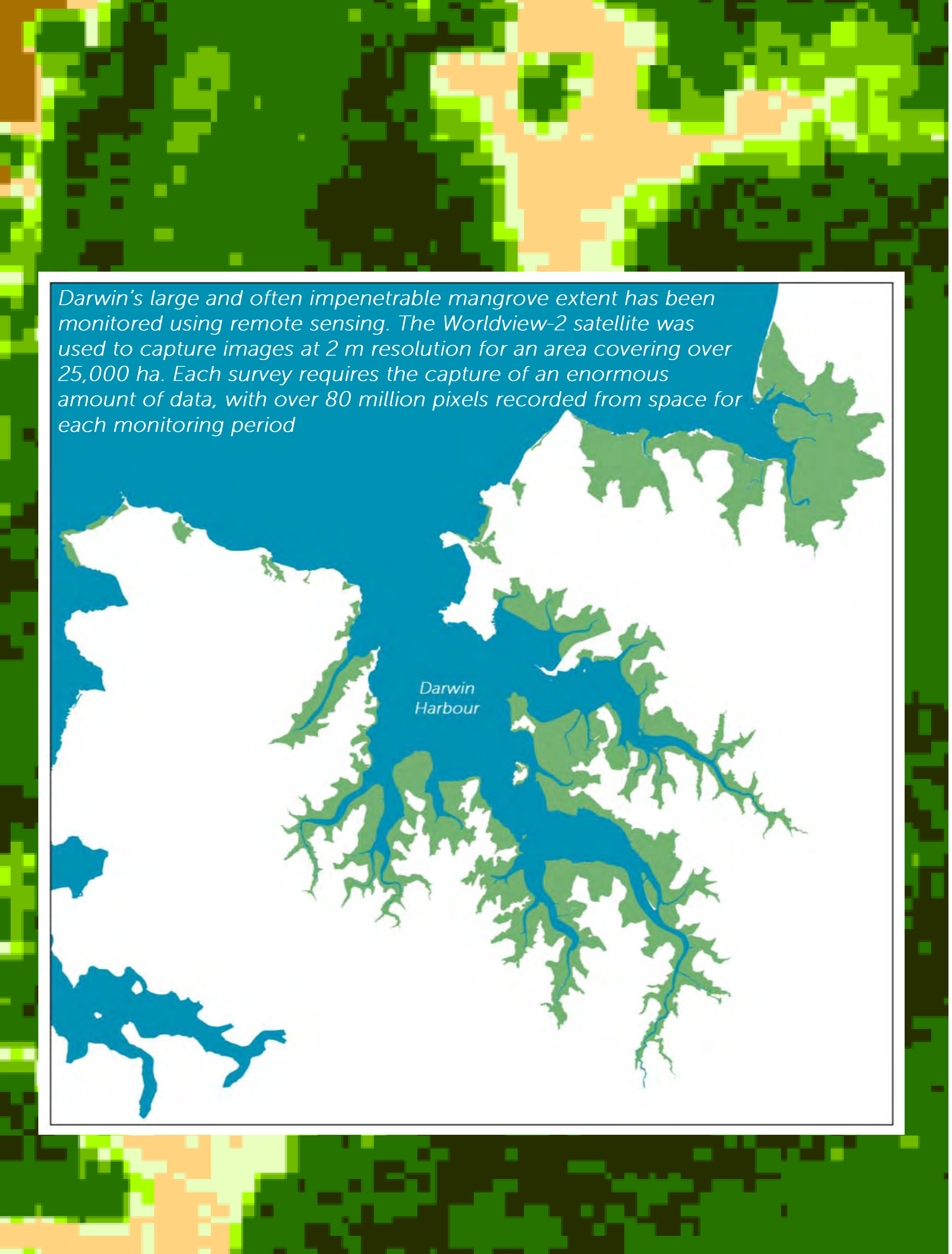
Figure 49 The Hinterland Margin assemblage is commonly dominated by Ceriops australis and often supports a variety of mangrove species, some of which are deciduous

A Matter of Scale

The overriding challenge for monitoring mangroves in the Harbour is the vast and inaccessible nature of the environment and inherent spatial variability at a range of scales. The monitoring of mangrove community health occurred at selected scales ranging from the millimetre scale used for recording sedimentation (Figure 50) to hundreds and thousands of hectares used for assessing broad scale changes in mangrove condition. During the monitoring program evidence was collected showing that there are factors operating at different spatial and temporal scales, some may be considered normal, everyday influences and others are the more extreme metocean conditions.

Field studies were essential for the monitoring of sedimentation and sediment characteristics, forest regeneration, fauna and the ground-truthing of remote sensing surveys. Simple methods were found to be the most robust and effective with sufficient replication essential for dealing with small-scale variability.

Figure 50 Field surveys of intertidal sedimentation in Darwin's mangroves found that simple and robust methods were most applicable in this challenging environment



Remote Sensing – The Big Picture

The NDVI (first introduced in Observed Effects – Intertidal Sedimentation and Mangrove Community Health) is commonly used as a measure of mangrove health as it is indicative of leaf chlorophyll content, and green leaf density and biomass. Remote sensing of NDVI allows for the assessment of mangrove health by detection of change in canopy condition over large spatial scales across selected time periods (Figure 51). It also enables monitoring of mangrove habitat that is largely inaccessible to field-based surveys.

Figure 51 The intensity of the different wavelengths of light reflected from plants to a satellite can be used to assess the health of a plant and in this case, Darwin's mangroves

The remote sensing imagery allows clear detection of variability in NDVI over Darwin's entire mangrove area, from small assessment scales that tie in to the fieldwork component of the monitoring program to large assessment areas used for quantitative analysis. Qualitative change detection techniques facilitate the identification of areas exhibiting change in excess of natural variation that occurs seasonally and inter-annually across Darwin's mangrove extent. This allows for detection of potential impacts in areas where they may not have been expected and areas of mangroves where access is inhibited.

Drivers of Natural Variability in Mangrove Heath

Rainfall patterns and associated surface and groundwater hydrology have been confirmed as the primary driver of temporal and spatial variability in mangrove health in the Harbour. The different mangrove assemblages show a distinct response to seasonal rainfall and interannual rainfall variability across the region. Seasonal variability in tidal height and the reduced inundation of mangroves high in the tidal profile also appear to be significant factors affecting the condition of both Tidal Flat and Hinterland Margin assemblages.

Wind and wave energy also play a part in affecting the physical processes occurring within the mangroves, particularly in the assemblages adjoining the open water of the Harbour such as the Seaward and Tidal Creek assemblages. In these areas, sedimentation rates show seasonal patterns with accretion during the calmer dry conditions and erosion at some sites during the high energy wet season (Figure 29a).

Wet Season Processes

The wet season presents optimum conditions for the growth of mangroves in Darwin. The onset of the wet season brings freshwater from increased rainfall (Figure 52) and increased tidal inundation to the mangroves. During the monitoring program there was found to be a lag effect in the general improvement of mangrove condition across the mangrove assemblages with the wet season. The Hinterland Margin assemblage showed the most immediate improvement in condition in response to rainfall when compared to assemblages more seaward and distant from groundwater sources.

Seedling recruitment and survival, new leaf production on trees, canopy cover and NDVI all increased during the wet season and reached a maximum in the late wet / early dry season. By the end of each wet season, all assemblages showed a distinct increase in NDVI indicative of increased condition and productivity (Figure 54 and Figure 55).

Increased wave energy during the wet season appeared to lead to the erosion of sediments in the Seaward assemblage at some sites and potentially deposition at other sites and assemblages (Figure 29a).

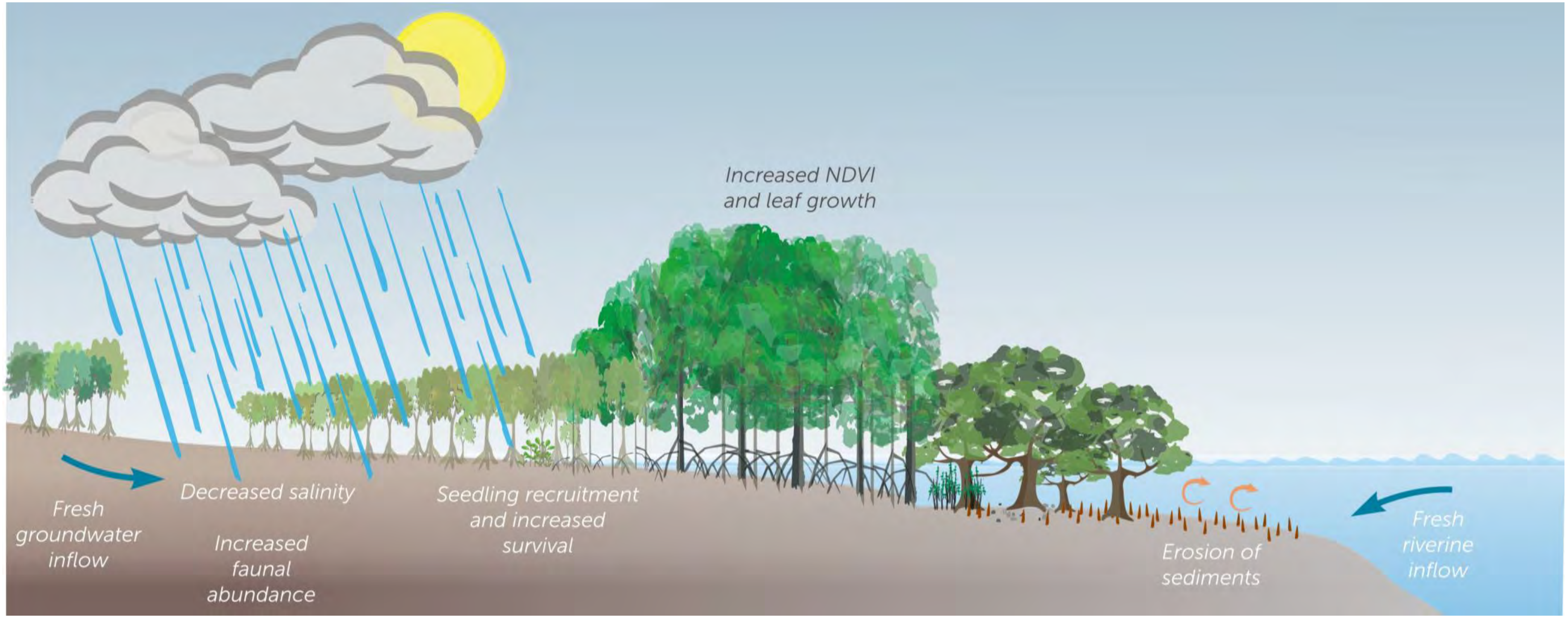


Figure 52 Wet season processes affecting Darwin's mangrove communities

Dry Season Processes

Little to no rainfall combined with warm dry easterly winds during the dry season lead to harsh conditions for mangroves, including high salinity and heat stress from evaporation (Figure 53). During this period, the monitoring program found that the canopy cover decreased in all assemblages (Figure 29b), with decreased leaf initiation and increased shedding of leaves, probably associated with mechanisms for the reduction of transpiration and removal of salt. There was also less seedling recruitment, lower seedling survival and lower NDVI (Figure 54 and Figure 55) during this period.

Sedimentation was greatest at the end of the dry season, particularly in the two assemblages lowest in the tidal profile (Seaward and Tidal Creek assemblages) (Figure 29a). This may be due to the calmer metocean conditions increasing settling and reducing resuspension of sediments.

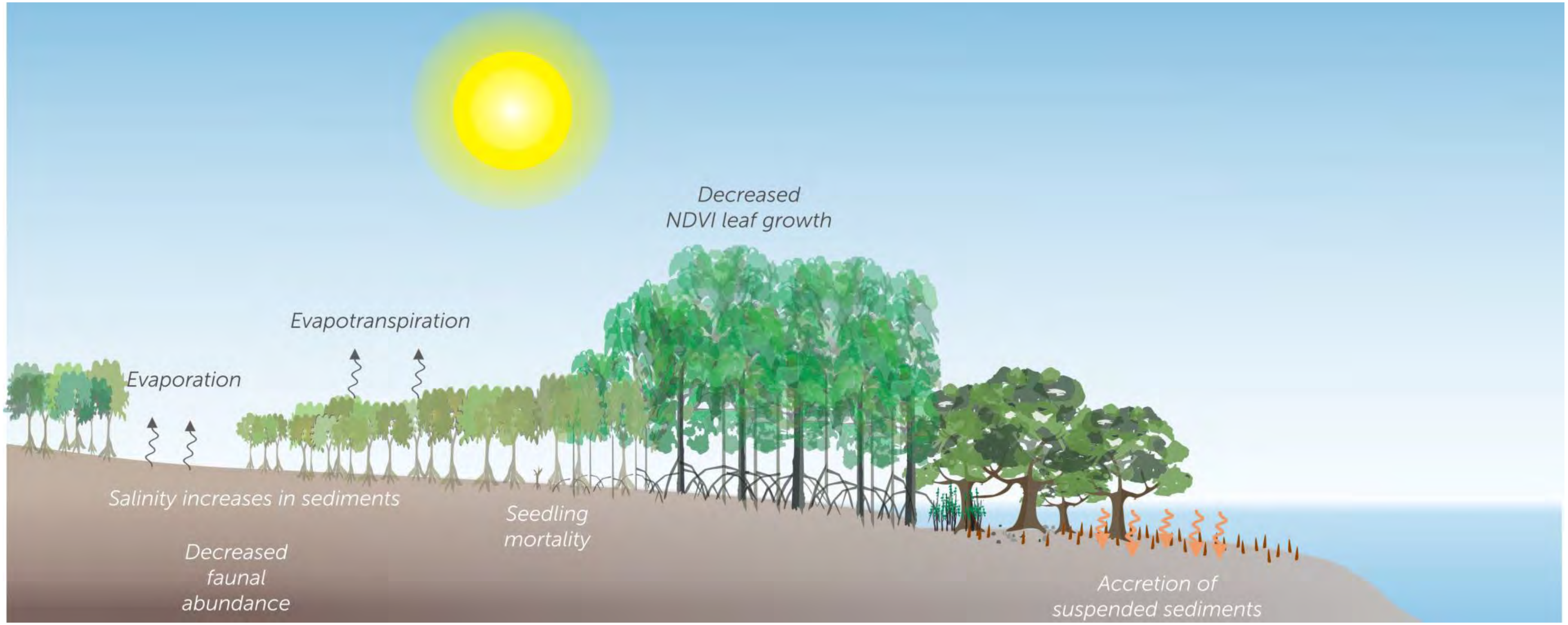


Figure 53 Dry season processes affecting Darwin's mangrove communities

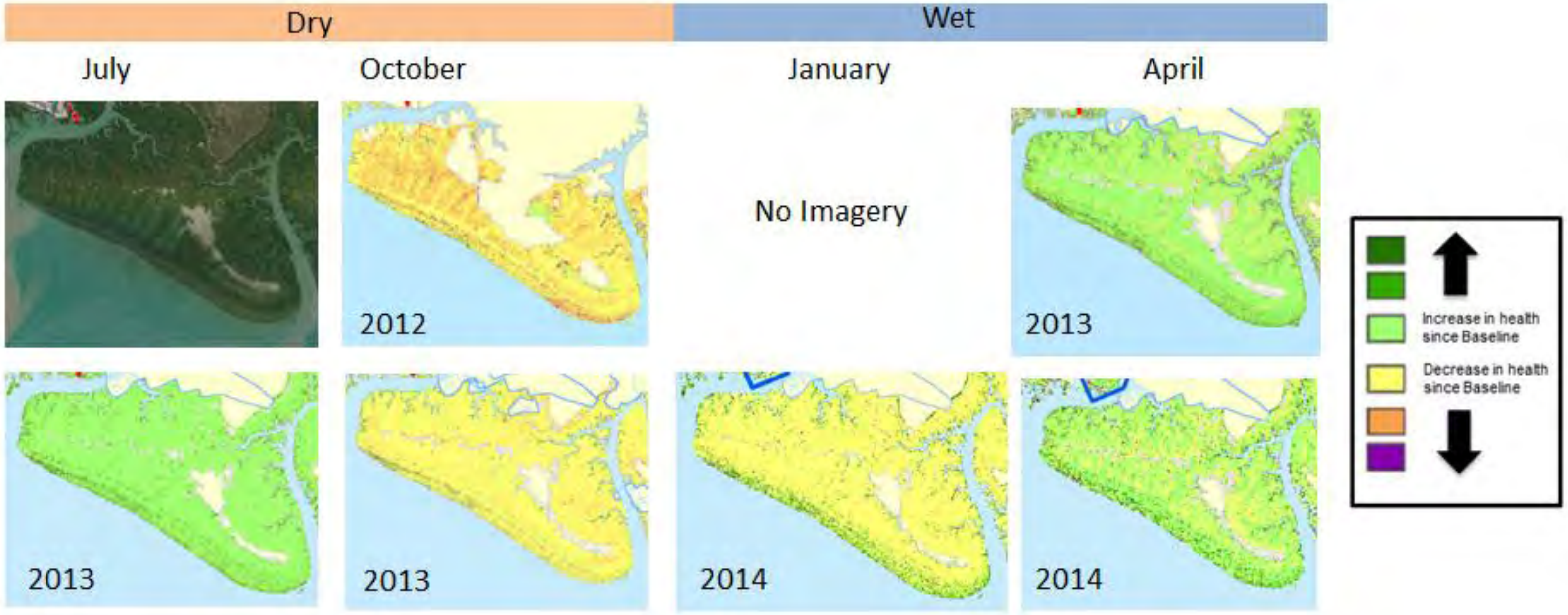


Figure 54 Time series example of NDVI difference between the baseline survey (July 2012) and each dredging survey (from October 2012 to April 2014) using Worldview-2 imagery of a section of mangroves in Charles Darwin National Park collected over the monitoring program. Images demonstrate general seasonal patterns of an increase in NDVI of mangroves in the late wet/early dry and a decrease in late dry/early wet seasons

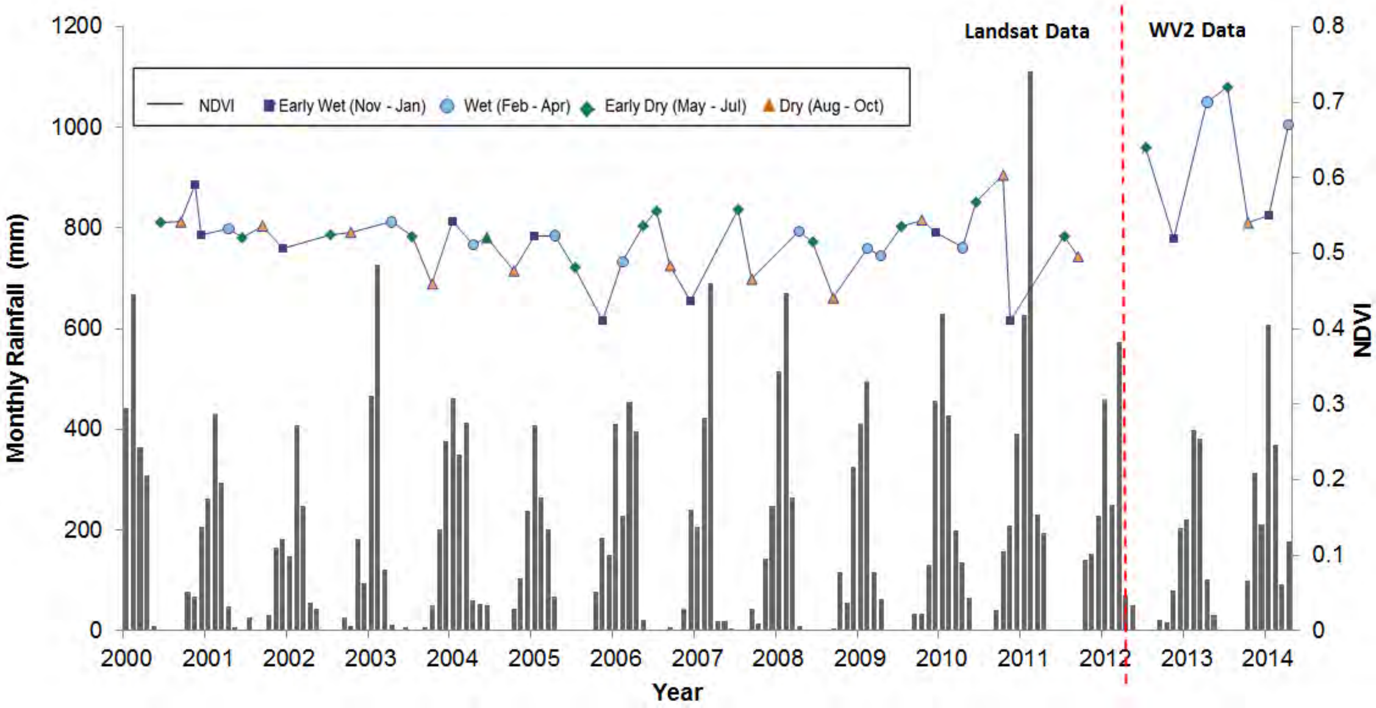


Figure 55 Mean NDVI values for Darwin's entire mangrove area for more than 10 years of Landsat data analysed as part of the baseline dataset and Worldview-2 imagery collected over the monitoring program. Note that the NDVI range is different for the two satellite types but shows general seasonal patterns of increase in the late dry/early wet and decrease in late dry/early wet seasons

Forrest Regeneration

The process of mangrove forest regeneration relies on the recruitment, survival and growth of seedlings. Predation, competition, the frequency and duration of tidal inundation, salinity and the availability of light are primary factors influencing the survival of mangroves, and mortality is naturally high during the first year after seedling establishment (Krauss et al. 2008).

Seedling density (a measure of forest regeneration) was found to be greatest in the Tidal Flat assemblage followed by the Seaward assemblage, and lowest in the Hinterland Margin and the Tidal Creek assemblages (Figure 56a). The overall density of seedlings was found to be highest in the early to mid-dry season, and lowest at the end of the dry season and early wet season. Recruitment was greatest in all assemblages in the period prior to April, coinciding with the end of the wet season (Figure 56b). There was little or no recruitment at all in the period leading up to the October-November surveys at the end of the dry season.

Seedling survival was found to be highly variable across the different assemblages and sites with no survival in some areas. After 21 months, seedling survival was lowest in Hinterland Margin and Seaward assemblages (close to 50%) and greatest in the Tidal Creek assemblage (66%) (Figure 56c). In general, assemblage-specific recruitment, survival and growth patterns were also reflected in seasonal changes in density.

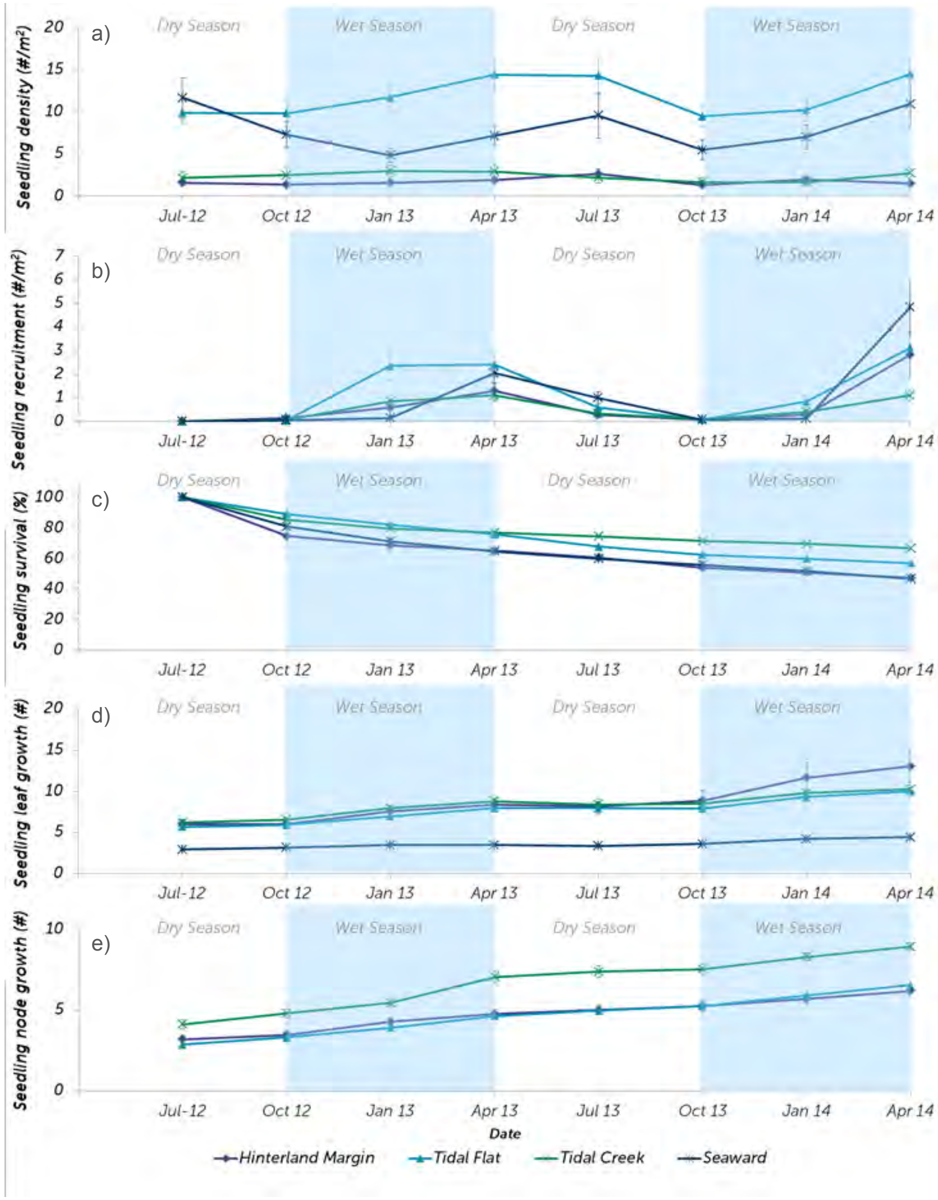


Figure 56 Patterns in: (a) average mangrove seedling density throughout the 20 m x 20 m monitoring plots; (b) mangrove seedling recruitment within 1 m x 1 m monitoring plots; (c) individually monitored mangrove seedling survival and growth indicated by: (d) leaf; and (e) node counts. Blue shading represents wet season

Seedling recruitment and survival process leading to forest regeneration are likely to be assemblage/species-specific. Each species is adapted to the microenvironment and broader physical environment in which they inhabit. It is well known that one of the main factors effecting survival of mangrove recruits is the presence of 'canopy gaps' that provide the seeding with a chance of reaching maturity (Duke 2001, Clark 2004).

In the Seaward assemblage, seedlings tended to have fewer leaves than in other assemblages (Figure 56d), suggesting that many of the seedlings were recent arrivals. This is consistent with the observed pattern of high recruitment and low survival rate in the physically dynamic environment of the Seaward assemblage.

The Tidal Flat exhibited a more extended recruitment period, greater survival and growth, and thereby a high overall number of seedlings. This is suggestive of a higher turnover rate in this assemblage, consistent with the lowest overall size (canopy height and trunk diameter) of the dominant species C. australis.

Seedlings in the Tidal Creek assemblage had the greatest survival and had the greatest number of nodes (Figure 56e), however recruitment was relatively low, as was overall density. Seedlings and saplings were most apparent in canopy gaps.

In the Hinterland Margin, despite average recruitment rates and high growth rates in the wet season of 2014, this assemblage appears to be prone to low survival rates and low overall seedling density.

For some sites, the recorded seedling species composition was often not representative of the typical saplings or mature tree species present. For example, A. corniculatum accounted for 100% of seedling and saplings records within the Seaward assemblage, including sites dominated by S. alba. Failure of seedlings is a natural process in the maintenance of the zonation pattern of mangroves in Darwin Harbour.

Fauna

Darwin's mangroves support a high diversity of animal species. The monitoring program used a variety of methods to quantify the species abundance and richness of fauna (living in and on the mud, in refuge pools and on the trees) in each assemblage. A total of 393 different species were recorded during the program. Of these, 68 are new records for Darwin Harbour mangroves (see examples in Figure 57) and one species of worm (Dendronereis sp.) had never previously been found in Australia.

The main taxonomic groups were crustaceans, molluscs and worms, each accounting for approximately 25% of the total species recorded. The remaining species were predominantly ants and fish. The crustaceans included crabs, lobsters, shrimps and smaller species such as isopods and amphipods.

Molluscs were mainly bivalves and gastropods, and included the bush-tucker gastropod known colloquially as the 'longbum' (Telescopium telescopium). The worms included annelids and other worm species. The most common types of fish recorded were blennies and gobies.

Seasonal variability in fauna abundance and richness was evident in the Hinterland Margin and the Tidal Flat, where overall species richness and abundance was highest during the wet season and lowest at the end of the dry (Figure 58a and Figure 58b respectively).

Figure 57 Three of the 68 new taxonomic fauna records sampled in Darwin Harbour mangroves: (a) Scintilla sp.; (b) Camponotus crozeri; and (c) Gymnodoris sp.

Overall, species richness and abundance was greatest in the Seaward assemblage and decreased towards the Hinterland Margin (Figure 58). In contrast to this overall pattern, ant species richness was greatest in the Hinterland Margin and molluscs were more abundant and diverse in Tidal Flat assemblage (Figure 59).

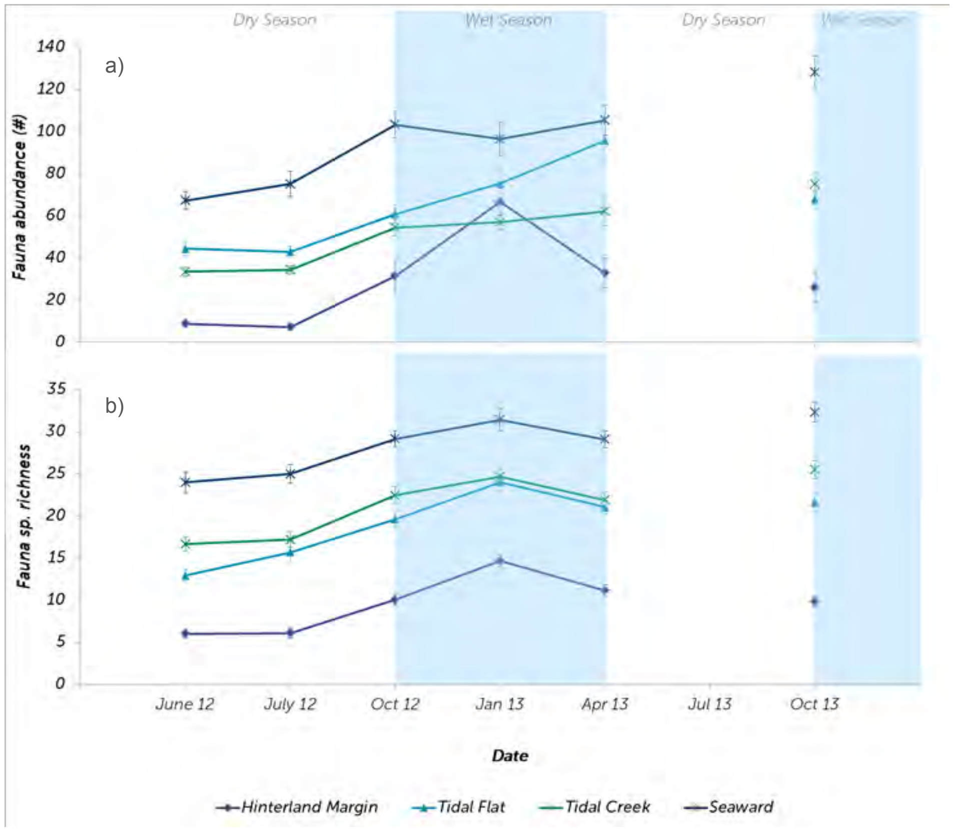


Figure 58 Mean fauna: (a) abundance; and (b) diversity for each mangrove assemblage recorded at monitoring sites during the monitoring program. Blue shading represents wet season

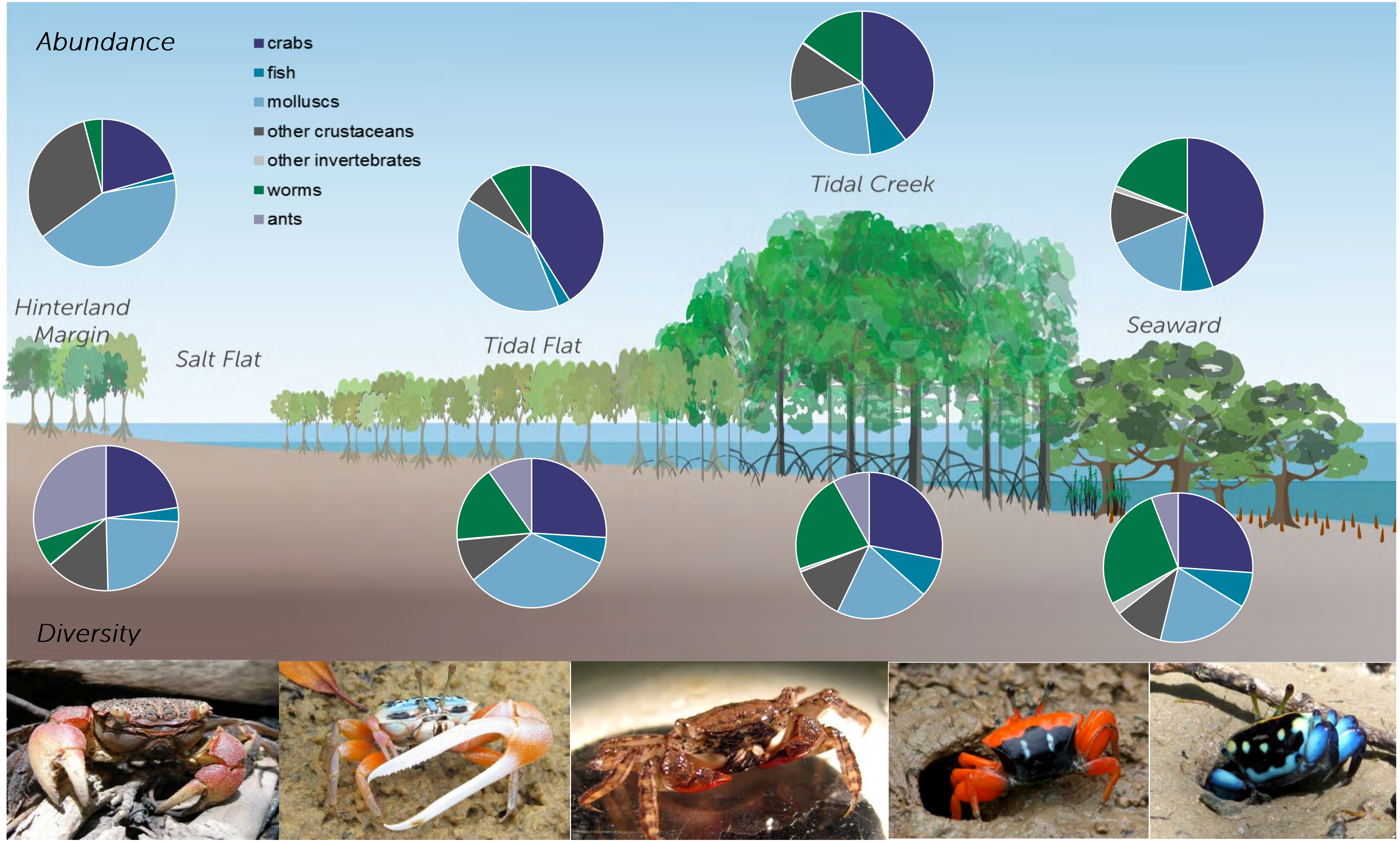


Figure 59 Relative fauna abundance (top) and diversity (bottom) for the major taxonomic groupings are shown for each mangrove assemblage recorded at monitoring sites in Darwin Harbour during the monitoring program (note that ant abundance was not recorded). Representative crab species by assemblage are also shown. L-R: Hinterland Margin and Tidal Flat (Neosarmatium australiense), Tidal Flat and Salt Flat (Uca elegans), Tidal Flat (Perisesarma darwinensis), Tidal Creek (Uca flammula), Seaward (Uca capricornis),

Primary Productivity

Primary production is the fixation of sunlight energy by photosynthesising organisms such as plants and algae. The organic material produced through the growth of these plants and algae forms the basis of an ecosystem's food web and therefore initiates the flow of energy through all subsequent levels of consumers. For this reason primary productivity is commonly used as a measure of the ecological value or function of a vegetation community (Saenger et al. 1983).

As is typical in many tropical estuaries, Darwin Harbour has three main primary producers: the extensive area of fringing mangroves, the microscopic algae found in the mudflats of intertidal and subtidal zones (microphytobenthos or MPB), and the free floating algae suspended in the water body of the Harbour (phytoplankton) (Figure 60).

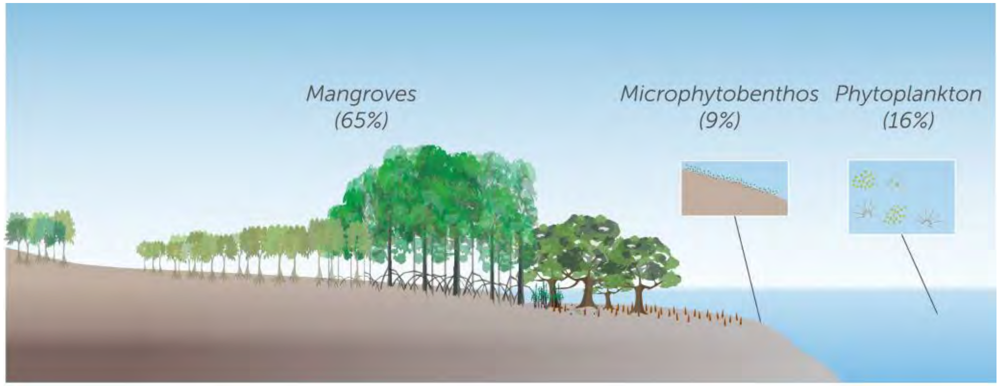


Figure 60 The three main contributors to primary production in Darwin Harbour; mangroves, microphytobenthos and phytoplankton (numbers in brackets represent the relative contribution of the three components to primary productivity in Darwin Harbour. Source: Burford et al. 2008)

Mangroves

Of the three contributors to primary production in the Harbour, mangroves carry by far the largest standing stock of carbon and contribute about 65% of Harbour-wide carbon production (Burford et al. 2008). Mangroves produce large amounts of litter in the form of leaves, flowers, fruits, twigs and bark (Figure 61). These are consumed by detritus feeders such as bacteria and fungi, which are in turn eaten by molluscs, crustacean and fish.

Figure 61 (a) Typical Tidal Flat (Ceriops) mangrove assemblage site in Darwin; (b) Leaf litter trap installed in a Tidal Flat assemblage; and (c) collected leaf litter accumulated over one month (leaves, flowers, fruits, twigs and bark)

During the two years of monitoring, the productivity of Ceriops trees in the Tidal Flat assemblage has varied seasonally. There was an increase in productivity and growth of new leaves during the wet and early dry season months of October to June, broadly coinciding with increases in canopy cover within that assemblage (see canopy cover trends in Figure 29b). A decrease in productivity occurred with the decrease in rainfall during the dry season months of July to August/September, with indications of more leaf shedding coinciding with the start of dry season declines in canopy cover (Figure 62a and Figure 62b).

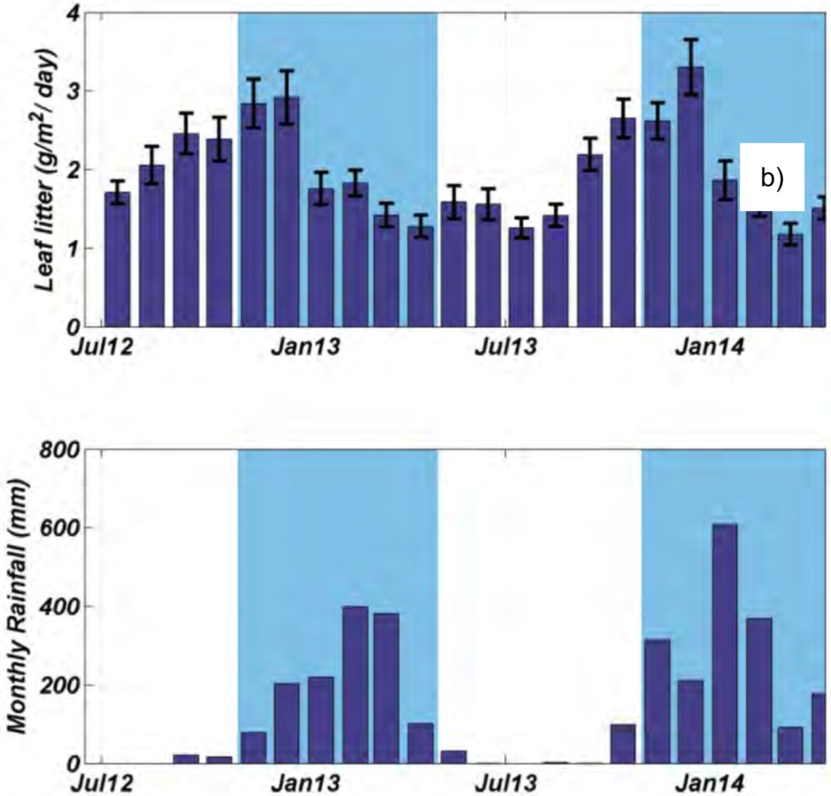


Figure 62 Monthly: (a) mangrove leaf litter fall in the Tidal Flat (Ceriops) assemblage; and (b) rainfall during the monitoring program. Blue shading represents wet season

Microphytobenthos in the Tidal Mudflats

The main benthic primary producers in most intertidal or shallow subtidal soft sediments are benthic microalgae (microphytobenthos) that use light penetrating the water column to grow and reproduce. They are dominated by diatoms and generally occupy the top few millimetres of the sediment (Figure 63). They are an important food source for micro- and macrobenthic organisms such as molluscs, worms, small crustaceans such as amphipods, and herbivorous fish. The latter are, in turn, important food sources for carnivorous fish and larger mobile invertebrates such as prawns. The standing stock of MPB was used as an indicator of primary productivity in the intertidal mudflats, and was evaluated from samples collected once a month throughout the Harbour.

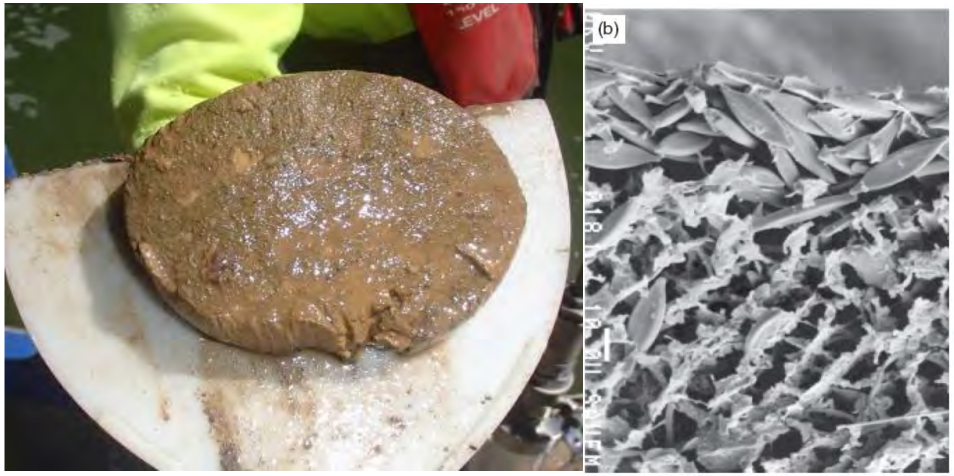


Figure 63 (a) Mud sample from Darwin Harbour showing the thin surface layer of MPB; and (b) a scanning electron microscopy (SEM) view of a benthic diatoms assemblage clustered at the surface of the sediment (Vertical cut of a sediment surface at low tide photographed in a low temperature SEM. Photograph by A. Miles, Sediment Ecology Research Group, University of St. Andrews, Scotland)

The biomass of MPB has been extremely variable both spatially and temporally. The concentration of Chl-a pigment was measured as a proxy for MPB biomass, and values found in individual samples ranged from approximately 0.1 to 27 mg of Chl-a per kilogram of dried sediment. The MPB biomass varied by a factor of three to four between individual samples collected only a few metres apart. The biomass of MPB also varied substantially between surveys. For example, Site 7 located in East Arm had a Chl-a concentration of 12 mg/kg of dried sediment in June 2012, and this decreased to a range of 3 to 4 mg/kg of dried sediment between July and October 2012; it increased again briefly to 10 mg/kg in December 2012, and decreased again to below 4 mg/kg during the 2013 surveys. Similar changes were seen at other sites located throughout East Arm and Middle Arm. However there was no seasonal pattern to these changes.

Pigments in mud samples contained a large proportion (50% to 90%) of pheophytin, which is a detrital product of Chl-a. Such proportions indicate that sediments contained either a large amount of dead microalgae or large inputs of organic detritus from the fringing mangroves. Some sites located upstream of the Harbour and in creeks have had consistently higher levels of pheophytin compared to other sites generally downstream. This might also be related to differences in sediment types between sites, whereby upstream sites generally had higher proportions of clay and silt, while downstream sites generally had a greater proportion of sand.

Phytoplankton in the water column

The biomass of phytoplankton was generally low throughout the monitoring program, as indicated by low Chl-a fluorescence (generally below 5 µg/L). Darwin Harbour Inner is generally classified as 'oligotrophic' due to the low concentrations of bio-available nutrients, and high turbidity and low light levels that limit the growth of phytoplankton. The large tidal range also ensures that the Harbour is well flushed with significant exchange of Harbour and oceanic water during each tidal cycle, as described in the Environmental Setting. There was a slight increase in phytoplankton biomass during the wet season compared to the dry season, possibly due to additional nutrient sources from increased rainfall and runoff.

Variations in the biomass of phytoplankton in the water column (indicated by Chl-a fluorescence) did not follow the large fluctuations in turbidity between spring and neap tides. Instead there was a marked diurnal pattern with a peak in Chl-a fluorescence during the day. The timing of this peak changed through time and was not consistent between sites. These complex patterns indicate that multiple factors may influence phytoplankton productivity in the Harbour, such as diurnal changes in light together with transport by tidal currents throughout the Harbour including the main channel mangroves and mud flats.

Figure 64 Phytoplankton diatoms (photography by Richard Kirby, Plymouth University, UK)

Research Fishing and Fish Health

Recreational fishing is a highly popular activity in Darwin Harbour and surrounding waterways by local residents and visitors to the NT. Waterways around Darwin collectively account for ~37% of NT-wide recreational fishing effort, with Darwin Harbour alone accounting for ~29% (Coleman 2004). Previous research conducted by the NT Government has found that the types of fish most commonly caught and retained by anglers in Darwin Harbour for purposes other than to use for bait were golden snapper and other tropical snappers, barramundi, threadfin salmon, bream, trevally and grunters, while mud crab was by far the most popular crustacean targeted using pots (Figure 65).

Monitoring of recreational fishing activities and recreationally popular fish and crab species in Darwin Harbour and surrounding waters as part of the monitoring program has been undertaken at regular intervals from late 2012 until early 2014 with monitoring scheduled to continue into 2015. These monitoring activities involve extensive scientific sampling to investigate and compare catch rates of popular fish and crab species, examine aspects of aquatic animal health as well as to detail and characterise recreational fishing activities and catches.

Figure 65 A selection of the species commonly caught and retained by recreational anglers in Darwin Harbour and surrounding waters: (a) golden snapper; (b) goldspotted rockcod; (c) mud crab; (d) barramundi; (e) king threadfin; (f) stripey snapper; (g) grass emperor; and (h) Moses snapper

Research Fishing

Research fishing activities have been undertaken by scientists in collaboration with NT Fisheries to gather catch rate information independently of the recreational fishing sector and to collect specimens for laboratory health assessments. Recreationally popular finfish such as golden snapper, Moses snapper, javelin, blue tuskfish, grass emperor, stripey snapper and goldspotted rockcod have dominated research angling catches, while mud and sand crabs have been commonly sampled in pots during the 136 boat days of research fishing undertaken to date. Although not caught during research fishing activities, species including barramundi, queenfish and threadfin salmon have been regularly collected using alternative scientific sampling methods such as cast netting and gill netting. All specimens sampled in the field undergo an external examination by trained scientists looking for any abnormalities, with most released immediately following examination. Around 2.9% of all finfish sampled were assessed upon capture as having at least one visible abnormality (parasites, lesions or other deformities), while 24.5% of crabs sampled were found to have common parasites and/or subtle shell infections or deformities. Fish and crabs retained by the research fishing team were taken to a laboratory to undergo further external and internal examinations.

A consistent feature of the fishing in and around Darwin Harbour and surrounding waters during the monitoring program has been the substantial variability in catch rates among fishing days for each species caught (i.e. between 0 and 11 fish per hour across all species). This variability was mirrored by similar variability in catch rates among recreational fishing parties interviewed at boat ramps throughout the Darwin region as part of the monitoring program (see below). Such variability in the catchability of fish may be influenced by changes in habitat characteristics as well as in species-specific behavioural and ecological requirements.

Most of the frequently-caught reef fish species captured were found throughout the waters in and around Darwin Harbour and surrounding areas. In Darwin Harbour, however, golden snapper, javelin and Moses snapper were more frequently caught upstream of Darwin city, while blue tuskfish, stripey snapper and grass emperor were more frequently caught on reefs in more exposed coastal waters around Darwin. Similarly, survey results showed that pelagic fish such as various mackerel and trevally species were most frequently caught outside of Darwin Harbour (Figure 66).

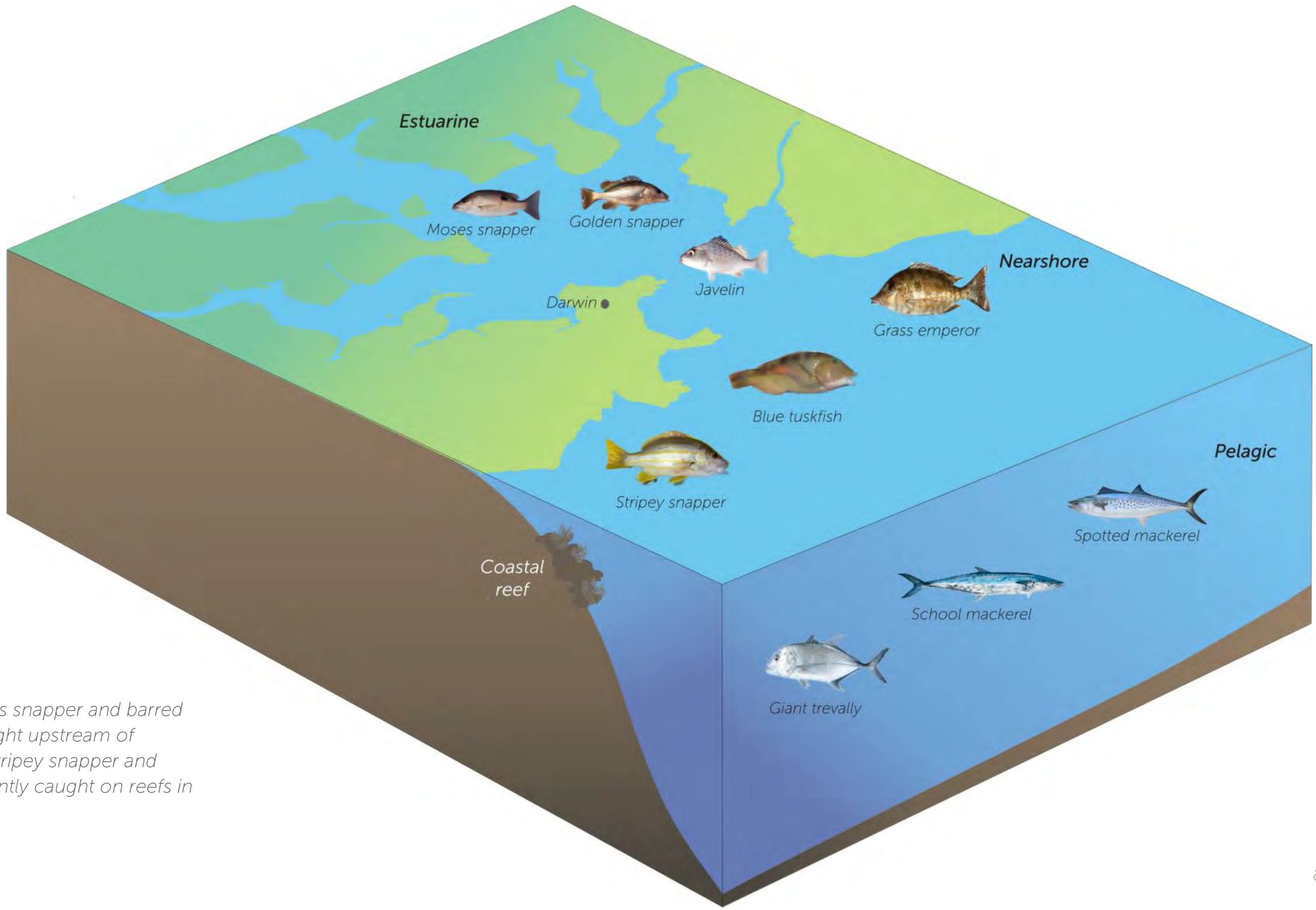


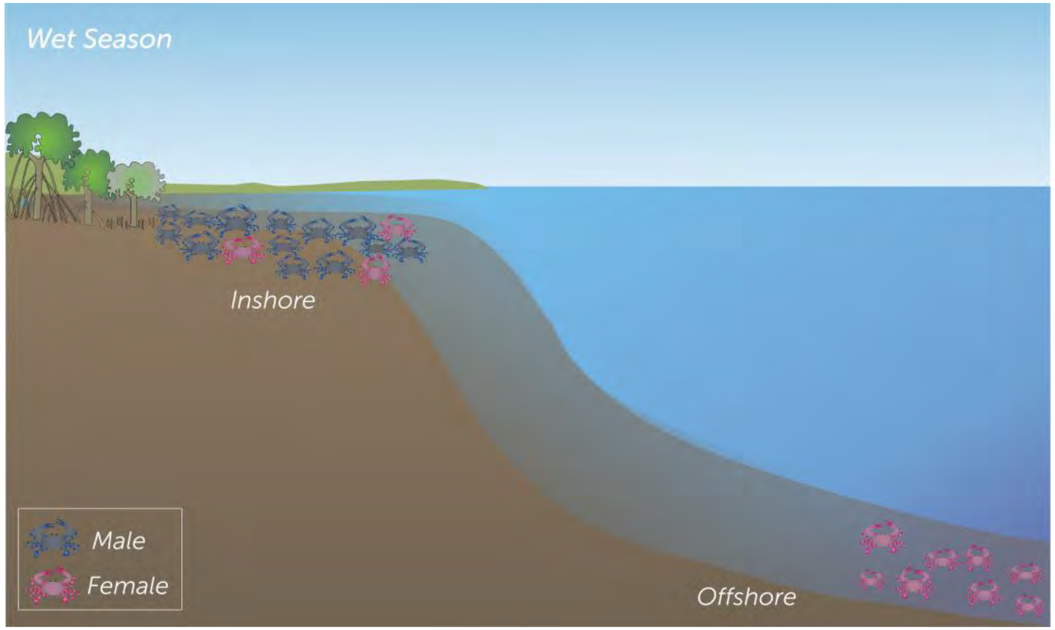
Figure 66 Golden snapper, Moses snapper and barred javelin were more frequently caught upstream of Darwin city, while blue tuskfish, stripey snapper and grass emperor were more frequently caught on reefs in more exposed coastal waters

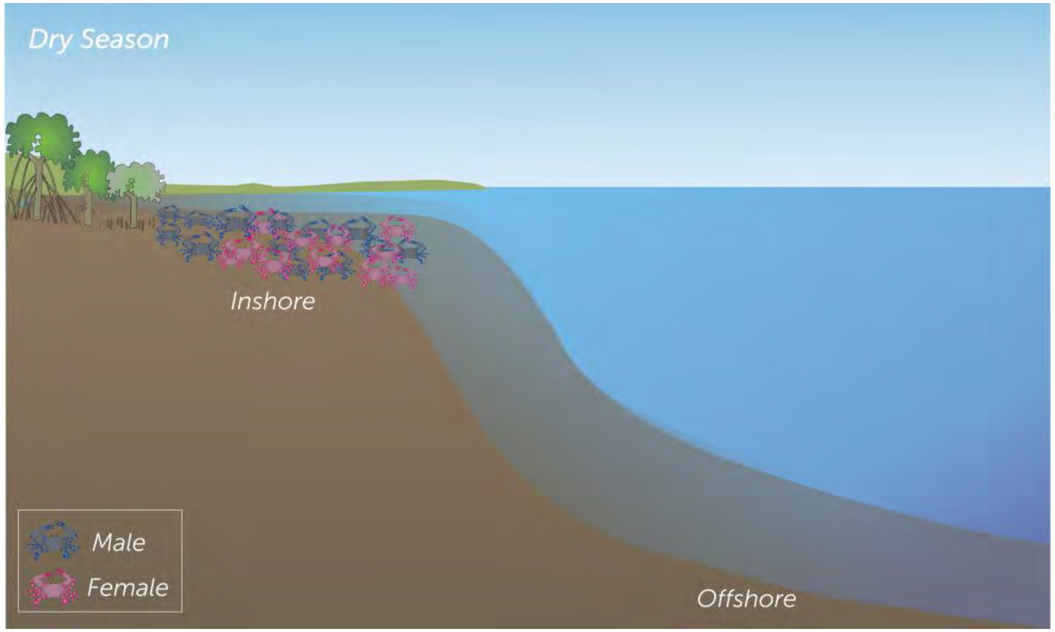
Differences in catch rates of these species between these areas are likely to be associated with different environmental and bathymetric characteristics. Darwin Inner is primarily characterised by tidally influenced estuarine, mangrove, rocky reefs and mud habitats, whereas more exposed coastal reefs and pelagic habitats in Darwin Outer are primarily deeper, open-ocean habitats more susceptible to extreme meteorological influences such as tropical cyclones.

Substantial changes in the conditions at research fishing sites along the more exposed, seaward coastline of Darwin Outer occurred in early 2013 following the transit of TCs Narelle and Rusty along the Kimberley coast. Large swells and increased turbidity were recorded around reefs in Darwin Outer's more exposed waters following these extreme meteorological events. During this period, a clear reduction in the catchability of fish (measured by the catch rate; number of fish caught per hour) on those reefs was detected. This was temporary and, once oceanic conditions returned to a pre-TC state, the catchability of fish returned to levels consistent to those recorded prior to the TCs. It is likely that, while fish remain on these reefs during periods of oceanic instability caused by TCs, these climatic events may have short term effects on feeding, habitat selection and refuge seeking behaviours of fish, thereby influencing their overall catchability during those times.

Catch rates of mud crabs and sand crabs in research pots have also varied from area to area around the Darwin region. Catch rates of mud crabs have been generally higher in the creeks around Shoal Bay than other areas, while the catch rates of sand crabs have been highest in creeks within Darwin Harbour. The sex ratio (the proportion of males to females) of mud crab catches varied according to the time of year. Around the end of the wet season (i.e. March 2013 and March 2014) catches of mud crabs were dominated by males, while female mud crabs dominated catches during the dry season. Mud crabs are reproductively active mainly during the wet season. During this time, reproductively active female mud crabs, including those carrying eggs (i.e. 'berried' females), commonly migrate to offshore spawning habitats where they shed their eggs (Figure 67), with some individuals reported to have migrated 95 km seaward (Brick 1974; Hyland et al. 1984; Heasman et al. 1985; Moser et al. 2002; Grubert and Phelan 2007). The departure of these females from the creeks and estuaries in the wet season in turn reduces the mud crab catch in pots.

Figure 67 Changes in the sex ratio of mud crab catches during different seasons throughout the year are potentially influenced by the offshore spawning migration of females offshore during the wet season





The fish and crabs retained during research fishing activities underwent extensive internal and external scientific examinations to identify and monitor the types of parasites and infections that affect fish and crab populations in Darwin Harbour and surrounding waters. Parasites are organisms that gain benefit by connecting themselves to the outside surface or getting inside the body of the host species. Virtually all wild aquatic animals, including those targeted by recreational fishers, are infected with at least one type of parasite, the majority of which are harmless to humans. Relationships between natural parasites and their hosts have evolved over long periods of time. In the majority of cases this relationship results in co-existence without significant harm to the host under natural environmental conditions. In general, there has been very little documented information regarding natural levels of infection of parasites and other diseases (and natural fluctuations in those levels) in finfish and crabs inhabiting Darwin Harbour and its surrounding waters. Examining the prevalence (proportion of a population infected) and intensity (degree of infection among infected individuals) of these parasitic and other infections provides a means by which to monitor spatial and temporal changes in fish health that could be associated with factors such as changes in environmental conditions, immune suppression and stress (Ellis 1981; Khan and Thulin 1991; Diamant et al. 1999).

A diverse suite of internal and external parasites and infections were recorded by the research team on and in the fish (Figure 68) and crabs (Figure 69) examined as part of the monitoring program. This included a range of heteroxenous parasites (i.e. parasites with complex life cycles, including an intermediate host/s and/or ecological pathways such as nematode worms, metacestode tapeworm larvae and didymozoid digenean flatworms); monoxeneous parasites (i.e. parasites with a direct life cycle infecting only one host, such as copepods, isopods, ciliate protozoans, monogenean flatworms and Octolasmis barnacles); and other diseases (e.g. bacterial infections and neoplasms). The prevalence and intensity of these infections recorded throughout the monitoring program have generally remained stable, indicating that the health of fish and crabs sampled in and around Darwin Harbour, Bynoe Harbour and around the mouth of the Adelaide River is generally good.

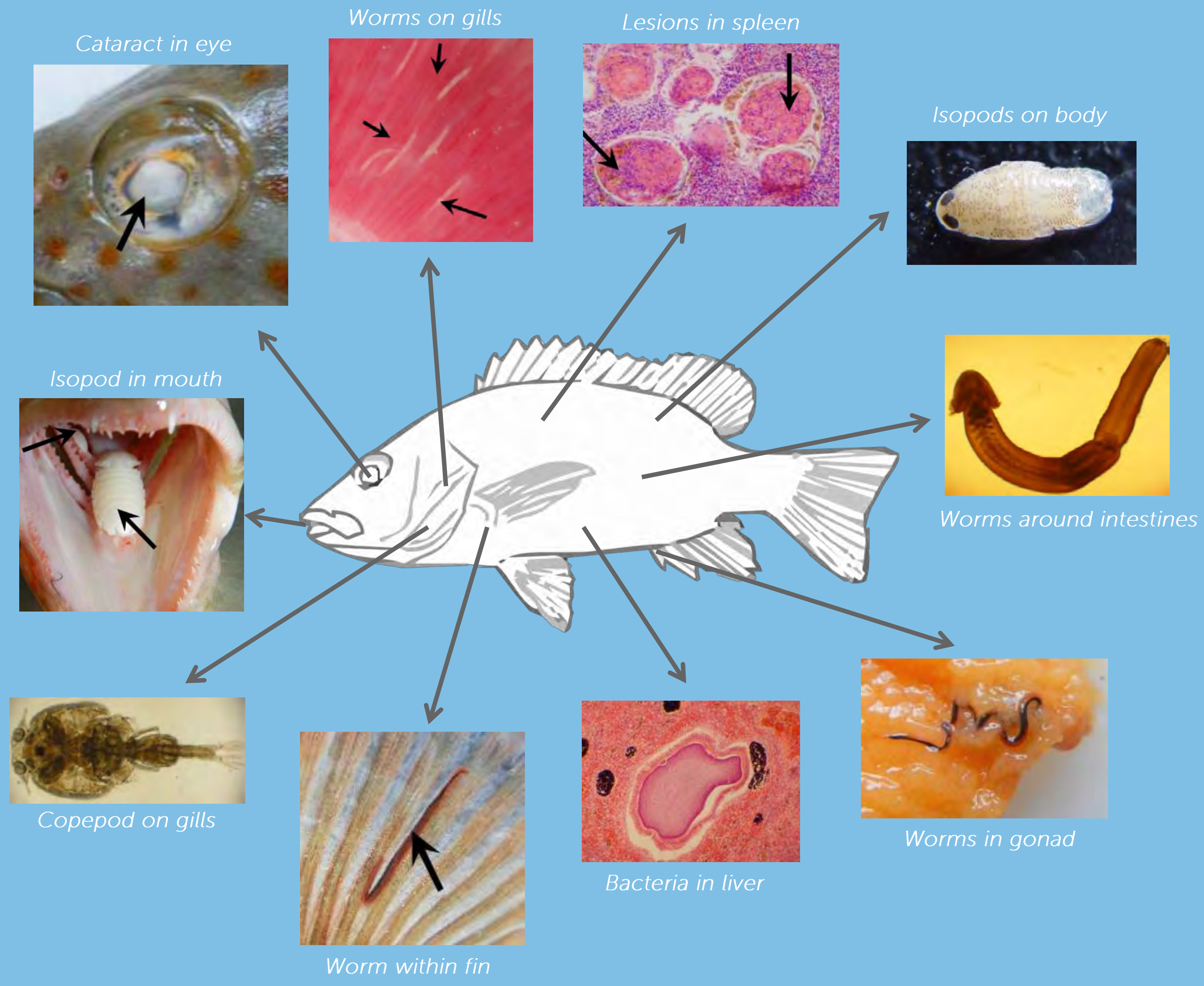
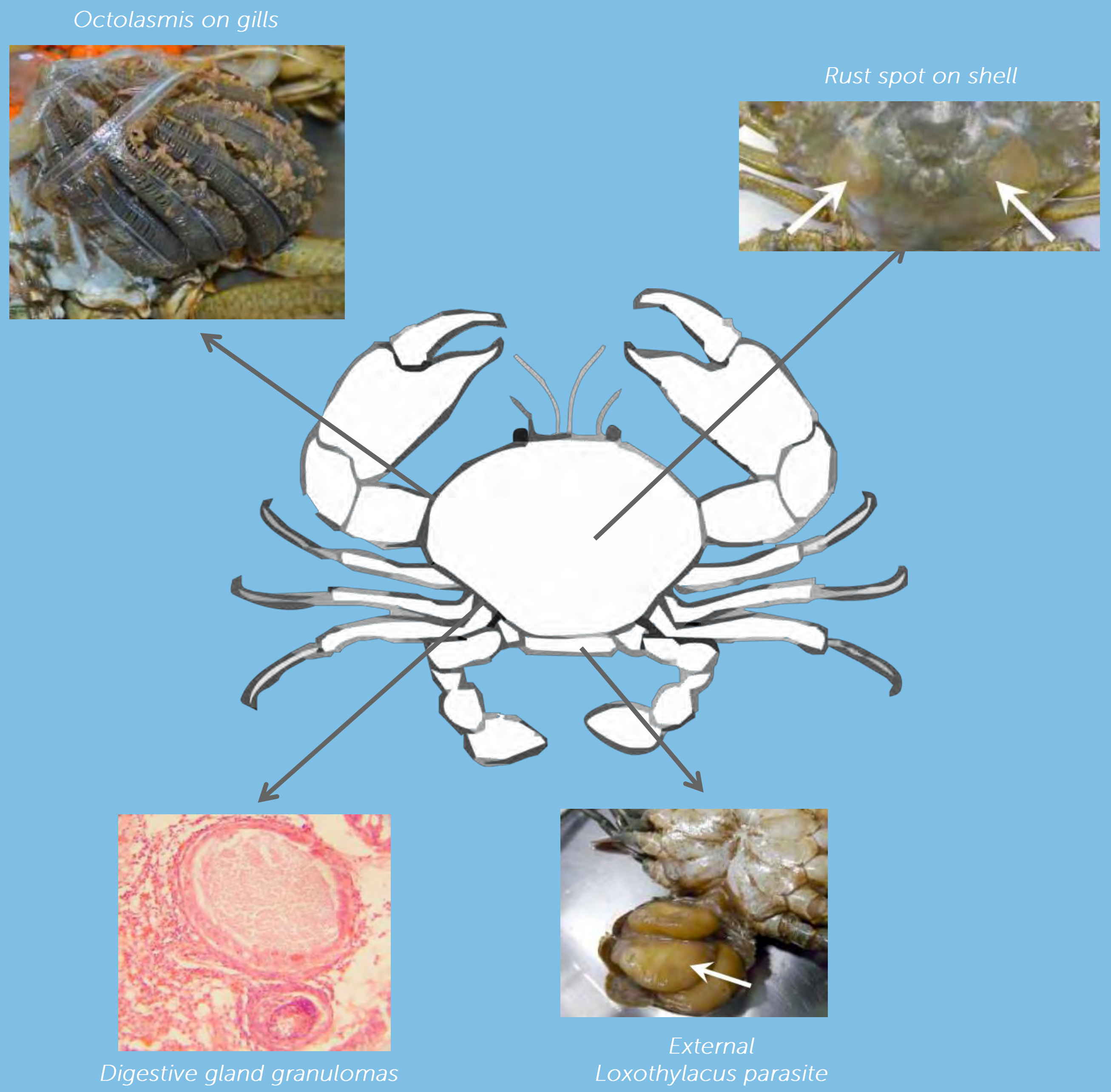


Figure 68 Examples of the parasites, lesions and deformations recorded on finfish from Darwin Harbour and surrounding waters



The detailed health assessments completed as part of the monitoring program have provided a thorough inventory of the types of parasites naturally associated with the recreationally popular fish and crab species of the Darwin region, including barramundi, golden snapper, goldspotted rockcod, mud crab, sand crab and a range of other species. More than 66 different finfish parasite species and 29 crab parasite species have been identified to date. The most common parasites associated with finfish have been dactylogyrid monogeneans in the gills (Figure 68), while in crabs, the most common parasites have been Octolasmis barnacles attached to the shell and gills (Figure 69). Five parasite species new to science were identified from the monitoring program. These are the philometrid nematodes (Philometra australiensis, P. macrochiri and P. zabidii) (Moravec and Diggles 2014) and the dactylogyrid monogeneans (Euryhaliotrema longibaculoides and E. lisae) (Kritsky and Diggles 2014). The descriptions were published in international scientific journals.

Figure 69 Examples of the parasites, lesions and deformations recorded on crabs in Darwin Harbour and surrounding waters

Boat Ramp Interviews

From 2012 to 2014, around 2,600 boat-based recreational fishing parties were approached for interview at boat ramps in Darwin Harbour, Bynoe Harbour and around the mouth of the Adelaide River to collect information about recreational fishing and catches (APS; Figure 70). Participation rates among those parties approached were very high (approximately 95%), demonstrating the willingness of recreational fishers to assist in the surveys. The APS found that boat ramps in Darwin Harbour with upgraded facilities such as Dinah Beach, East Arm and Palmerston are generally more popular for launching recreational fishing trailer boats than are other ramps in and around Darwin Harbour, in Bynoe Harbour, and around the mouth of the Adelaide River. In addition, and perhaps not unexpectedly, boat-based recreational fishing has been found to be far greater on weekend days than weekdays at most ramps.

Of all the fishing parties interviewed, 63% were classified as avid, in that they undertake more than 12 fishing trips a year, while 27% were classified as regular, in that they undertake between six and 12 fishing trips a year. The clear majority (83%) of all people in fishing parties interviewed were classified as 'locals', living within 300 km of Darwin. While the parties interviewed included many fishers younger than ten and older than 80 years of age, the majority ranged between 20 and 60 years old. Fishing parties were found to generally spend between five and eight hours on the water during a fishing trip and most vessels had between two to three people on-board actively fishing.

Figure 70 Access point surveys are conducted at boat ramps within Darwin Harbour, Bynoe Harbour and around the mouth of the Adelaide River to collect information about recreational fishing and catches

The APS monitoring has confirmed that, in general, the fish species most commonly targeted and caught by recreational anglers in Darwin Harbour and surrounds have been barramundi, golden snapper, black jewfish, threadfin salmon, bream and mackerel. Other types of fish commonly caught include stripey snapper (also known as Spanish flag), javelin (also known as grunter or ock-ock), grass emperor (also known as tricky snapper), saddletail or red snapper, goldspotted rockcod, trevally and queenfish.

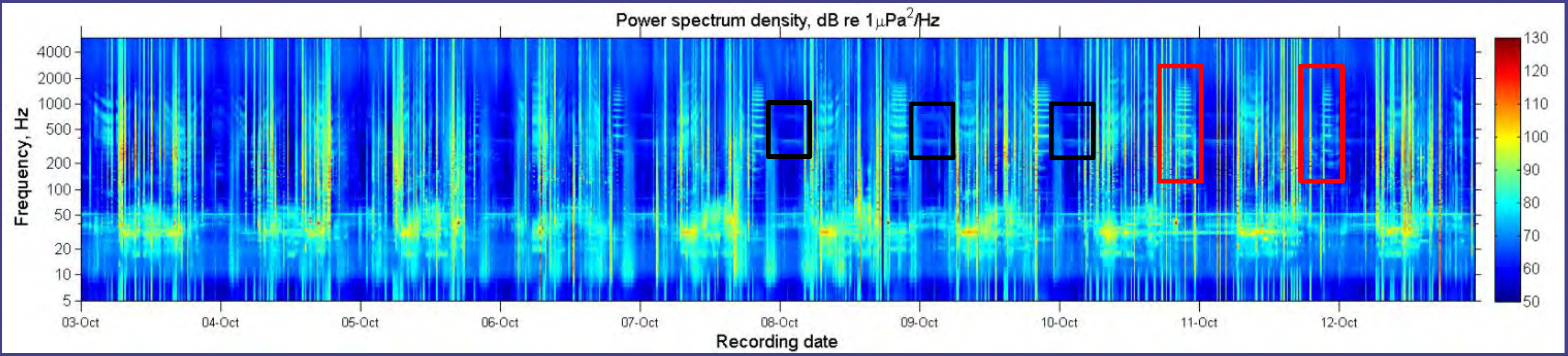
Targeting of reef fish (particularly golden snapper), barramundi, pelagic species (e.g. mackerel and tuna) and mud crab are all popular, although there are differences in the relative popularities of these target groups depending on the climatic season. Targeting of barramundi is relatively more popular during wet season months, while reef fish, pelagic species and mud crab are relatively more popular during the dry season. This pattern has been generally consistent irrespective of location and is consistent with patterns in targeting documented by previous studies of recreational fishing in the NT.

Case Study: Underwater Noise of Fish in Darwin Harbour

A plethora of fish calls and choruses have been recorded in Darwin Harbour over the last two years of underwater noise logger deployments. Six choruses have been detected, all of which exhibited acoustic characteristics similar to those recorded in tropical Australian waters.

Fish choruses were recorded at all three hydrophone locations throughout the year, though most consistently in Middle Arm. The most predominant chorus would appear for several days before disappearing for nearly as many. Over the wet season the chorus lasted for more days than during the dry season.

Acoustic characteristics of calls are very similar to those of calls produced by "grunters", a family of fish named after their distinctive sounds. A second chorus, recorded less frequently has been attributed to black jewfish (Protonibea diacanthus), also most common at the Middle Arm site, while a third chorus comprised calls similar to those recorded in the presence of batfish species. Three other choruses have yet to be attributed to particular fish, though comparisons between the recordings and sounds reportedly from species (or close relatives) known to inhabit the area is being conducted. Snapping shrimp noises were evident at all three sites.



Spectrogram of sea noise recorded over a ten-day period of passive acoustic recording in October 2013. The black and red boxes highlight two distinct fish choruses

Marine Pests

Marine pests are plants or animals that are not native to a region, usually introduced from overseas, that have a significant impact on our marine industries and environment (DAFF 2009). Marine pests can grow or reproduce quickly and out-compete other native species by preying directly on them or competing for food. Some pests can reduce biodiversity and cause problems by fouling pipes, wharf piles, pontoons, boat hulls and other marine structures. The most common way marine pests are introduced is via boats and other large vessels, either attached to the submerged surfaces of ships ('biofouling') or in the ballast water carried by modern vessels to maintain stability.

Given the number and type of vessels entering Darwin Harbour as part of the Project, a marine pest monitoring program was established to detect potential marine pests, which has resulted in the most intense survey of marine pests ever undertaken in Darwin Harbour.

The monitoring program was designed to align with Australia's National System to ensure the most up-to-date survey methods were used, the most recent information on distribution of pest species around Australia was considered, and to provide a clear line of reporting to a national body should a targeted marine pest be identified in Darwin Harbour (DAFF 2010). The monitoring program in Darwin Harbour focused on pest species that had been recorded previously and those whose biology would allow them to flourish in tropical harbour conditions. Marine pest species on the target list ranged in size from microscopic dinoflagellates to larger animals, such as fish and crabs. They included common groups such as algae, sea squirts, barnacles, oysters, snails, worms and fish. The targeted pest species live on or in soft sediments, in the open water and on a variety of natural and man-made hard surfaces, where they have greater potential to be observed and damage or disable marine infrastructure.

Figure 71 Native barnacle species such as Amphibalanus cirratus closely resemble pest species and must be dissected to verify their identification

The survey methods used varied depending on the habitat being sampled. Soft sediment environments make up the dominant habitat in Darwin Harbour. These were sampled by divers using hand-held cores to collect samples, grabs deployed from a boat, and trawl nets collecting sediment surface samples. In addition, hundreds of photographs of the sediment surface were taken by divers and examined by experts. Plankton nets were towed through open water to look for pest comb jellies. Artificial sampling units (ASUs) were deployed on wharves and on channel markers to trap larvae of potential pest species. These are made from gutter-guard mesh, aquarium filter wool and even mop heads and kitchen scouring pads. Divers swam along transects to look for potential fish pests, and scrapings were taken from marker buoys, wharves and jetties.

Further pest detection was undertaken by examining high-quality photographs taken during the seagrass, fish, coral, and subtidal and intertidal benthos monitoring programs. Experts pored over thousands of photographs looking for marine pests; locations of 'suspect' specimens were then noted and divers collected specimens for verification.

The program was a collaborative effort between government agencies, academic institutions, Cardno, Golder Associates and INPEX. Specimens collected from all habitats were sorted at laboratories provided by NT Fisheries and examined to determine if any were likely to be pest species. Any 'suspects' were examined by expert taxonomists from the Museum and Art Gallery of the Northern Territory (MAGNT), the Royal Botanical Gardens, the University of Tasmania, the Marine Invasive Taxonomic Services units (MITS) of New Zealand's National Institute of Water and Atmospheric Research (NIWA), Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Cardno marine specialists.

One pest species from the target list, Perna viridis (Asian green mussel), was identified by non-Project divers on the hull of a cargo vessel unloading bulk goods (both Project and non-Project goods) at East Arm wharf during routine maintenance; however environmental monitoring found no specimens and no evidence of establishment of the species onto Darwin Harbour marine infrastructure or habitats surveyed. Two pest species were detected as part of the targeted monitoring program (ascidian species Didemnum perlucidum and Botrylloides leachi); however they did not display invasive characteristics and were unrelated to Project activities (see Observed Effects – Marine Pests*).*

This detailed look at Darwin Harbour's marine life has provided valuable new information on the distribution of native marine invertebrates not previously recorded from Darwin Harbour. These 'range extension' records are valuable additions to our understanding of the Harbour's biodiversity and biogeography of marine flora and fauna. For example, taxonomists from NIWA are preparing to publish a paper describing three species of small crabs caught in epibenthic trawls nets and in pier scrapings collected from the monitoring program that have not previously been recorded from Darwin Harbour.

Figure 72 The native green algae growing amongst corals closely resembles the marine pest species Caulerpa racemosa

Turtles and Dugongs

Marine turtles and dugongs are iconic species that are found in the warmer waters of northern Australia. However, very little is known about their population density or distribution around the Darwin region and until recently there had been no dedicated or long-term monitoring program on the distribution and abundance of turtle or dugong populations in the Darwin region.

Aerial surveys have been used to estimate the populations of marine megafauna species around Australia since the 1970s. Undertaken from a small aircraft at a constant height and speed, population estimates can be calculated and compared over time. Trained observers within the aircraft count the number of marine megafauna sighted along predefined paths or transects. These counts are then used to estimate population sizes of turtles and dugongs (using Marsh and Sinclair (1989) and Pollock et al. (2006) estimation methods) in specific areas, taking into account various factors that may influence the number of animals seen by the observers, such as the turbidity of water or sea state.

During the monitoring program, observations of turtles and dugongs from aerial surveys were undertaken three times a year during the dry season when conditions were most favourable, with approximately 3,500 linear kilometres flown over a 40 hour period during each survey.

Dugongs

The dugong is the only remaining member of the taxonomic family Dugongidae. The species is listed as 'threatened with extinction' under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and is listed as 'vulnerable' in the International Union for Conservation of Nature (IUCN) and Natural Resources Red list of threatened species. In Australian waters, dugongs are listed as 'migratory' and afforded protection as a 'matter of national environmental significance' under the Environment Protection and Biodiversity Conservation Act 1999 (Cwlth) (EPBC Act).

Dugongs are herbivorous marine mammals and spend their entire life in tropical and subtropical shallow coastal waters. They have low fecundity, due to a highly inconsistent reproductive rate. In northern Queensland, calving occurs in late August through to November, predominantly in protected shallow waters such as around tidal sandbanks and in estuaries. In the Darwin region, although the calving period is not known, calves were sighted during each survey during the course of the monitoring program.

Dugongs have been opportunistically sighted in both the Darwin Harbour Inner and Darwin Outer regions since the late 1970s. During aerial surveys undertaken for the monitoring program, very few dugongs were sighted in Darwin Harbour Inner, however they were regularly observed in Darwin Outer coastal region (Figure 74), presumably foraging on seagrass habitats, their preferred diet, as well as possibly feeding opportunistically on algae-covered rocky reefs.

Dugong population estimates calculated from sightings observed during the monitoring surveys have been spatially and temporally variable. Generally, dugong sightings increased throughout the dry season, from May to October, which was evident during both the Baseline and Dredging surveys (Figure 74). Estimates have remained low and consistent over time, suggesting a relatively small population of dugongs that inhabit the Darwin region of approximately 180 to 300 individuals. Variability is a result of a number of factors; most likely the inherent behaviour of dugongs being highly mobile and constantly submerging in search of optimal foraging grounds, as well as changes in the distribution of seagrass which they feed on almost exclusively.

There was a higher frequency of sightings in shallow regions (5 m to 10 m water depth), and with an increased variability with depth and distance from shore, i.e. the further offshore, the lower number of dugongs sighted (Figure 74). Dugongs prefer shallow, coastal waters and are dependent on seagrass for food. Therefore, with variability of seagrass, there was often variability with dugong distribution, which was evident during the monitoring program. Dugong distribution and seagrass mapping provided insight into spatial variability of dugong numbers over time. Distribution mapping of dugongs and seagrass data provided evidence that seagrasses, particularly H. decipiens, the preferred diet of dugongs, had an important influence on dugong density. Movement patterns of dugongs were generally correlated with variation in seagrass distribution (see Figure 74).

Given the observed relationship between dugong distribution and H. decipiens during the monitoring program, it can be concluded that the presence, distribution, density and species composition of seagrass habitats is likely to be important for dugongs in the Darwin coastal region and that movement patterns of seagrass is correlated with movements of dugongs.

Figure 73 Dugong sighted from Channel Island Bridge during the monitoring program

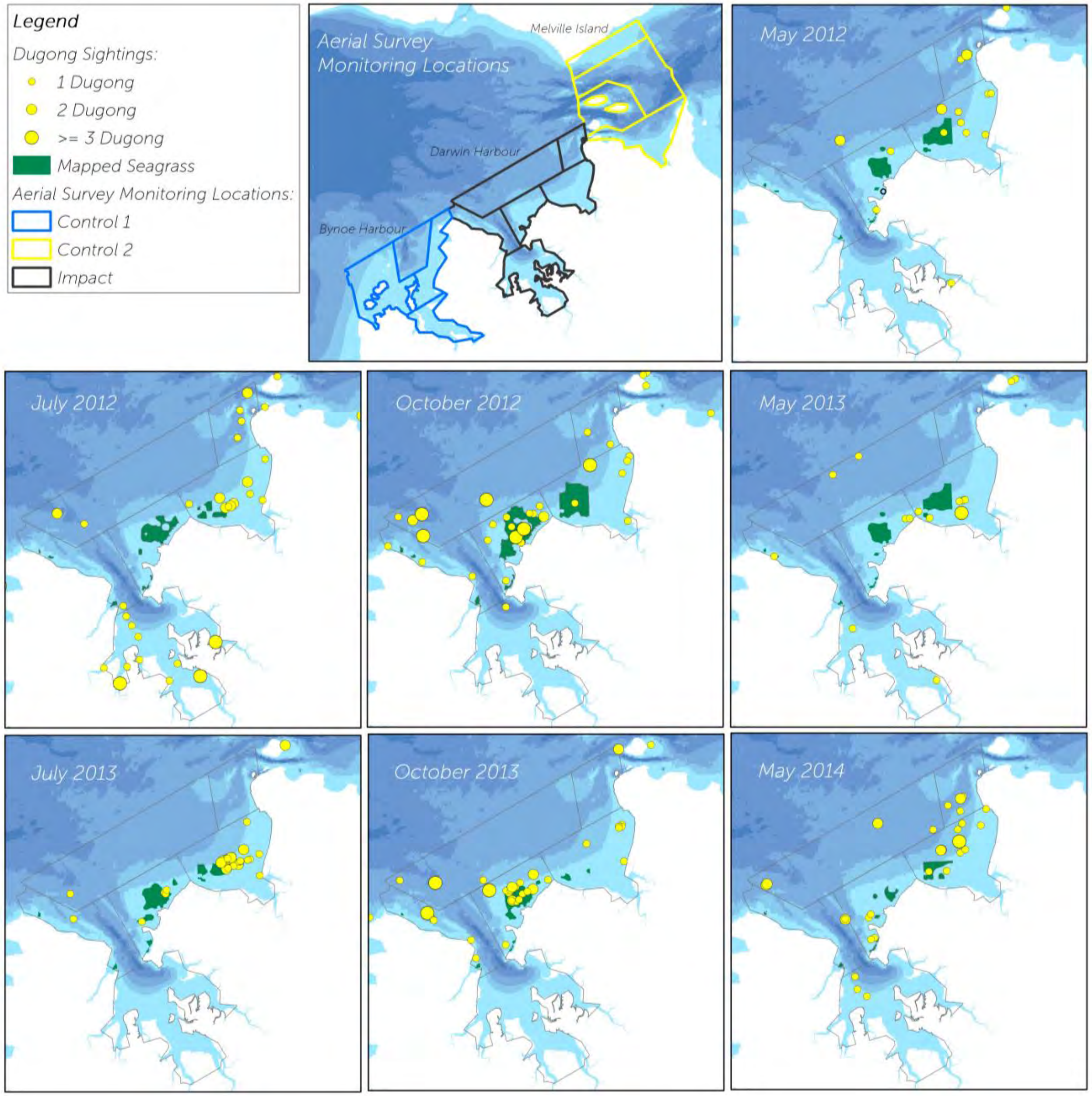


Figure 74 Dugong sightings around the Darwin region during each aerial survey of the monitoring program

Turtles

Similar to dugongs, limited information was available on distribution and abundance of marine turtles in the Darwin region prior to the monitoring program. Of the six species of marine turtles known to be present in Australian waters, four are thought to occur opportunistically around the Darwin region, including green, hawksbill, olive ridley and flatback turtles. Surrounding habitats are known to provide important foraging grounds for hawksbill and green turtles, as well as significant nesting areas for greens and flatbacks, and to a lesser extent hawksbill and olive ridley turtles (Chatto and Baker 2008; Whiting 2001). These species are listed as 'threatened with extinction' under CITES and are protected under the EPBC Act and NT legislation. Olive ridley turtles are listed as 'endangered', while the green, hawksbill and flatback turtles are listed as 'vulnerable' under the EPBC Act.

All marine turtles have the same general life cycle. They grow slowly and take decades to reach sexual maturity. Between 20 and 50 years, males and females leave their feeding grounds and migrate up to 3,000 km to a nesting area located in the region of their birth.

Around Darwin Harbour, green turtles are the most common turtle species sighted. Once green turtles grow to between 30 and 40 cm (curved carapace length), which takes about five to seven years, they begin foraging around habitats including coral and rocky reefs and seagrass beds close to the coast. In the Darwin Harbour region, juvenile and adult green turtles have been regularly observed around both reef and non-reef habitats (Figure 75). In Darwin Harbour Inner, close to Channel Island, green turtles have been sighted in relatively high abundance during the monitoring program, displaying behaviour consistent with foraging, where they are known to feed predominantly on seaweed (algae), seagrass, jellyfish and sponges, but may also feed on mangrove fruit (Garnett et al. 1985).

Australia has the largest breeding population of hawksbill turtles in the world. This species has been shown to migrate up to 2,400 km between their nesting and foraging locations. Within Darwin Harbour, juvenile hawksbill turtles are occasionally sighted near Channel Island.

Figure 75 Juvenile green turtles are sighted regularly at Channel Island

Flatback turtles live only in the tropical seas around northern Australia, Papua New Guinea and West Papua. In the Darwin Harbour region, flatback turtles are the most commonly encountered nesting species during the dry season. Nesting sites are critical to the conservation of turtles because individual females return to nest on the same beach where they hatched. Casuarina Beach, a popular Darwin beach, has been monitored for nesting turtles since the mid-1990s, with only a few nests located in more recent years. During the program, Casuarina Beach was monitored during the nesting period in late 2012 where observations were made of one nesting flatback turtle during this period.

Olive ridley turtles are the smallest marine turtle in Australia, and although the most abundant species in the tropical and subtropical ocean waters throughout the world, they are the least common species of marine turtles in Australian waters. They are known to occur in Darwin Harbour; however, little is known as they are rarely seen in shallow waters and none were observed during the monitoring program.

Throughout the monitoring program, there have been a large number of turtles observed throughout the survey area, which has remained relatively consistent over time (Figure 76). Population sizes are estimated to be between 500 and 1,000 turtles.

Turtle sightings were widely distributed and varied with depth across the three monitoring locations (Figure 76). There has been a continuously high density of turtles sighted around Fannie Bay and Shoal Bay suggesting preferred environments for foraging and associated activities. Overall, the distribution and abundance of turtles remained fairly stable and consistent during the monitoring program.

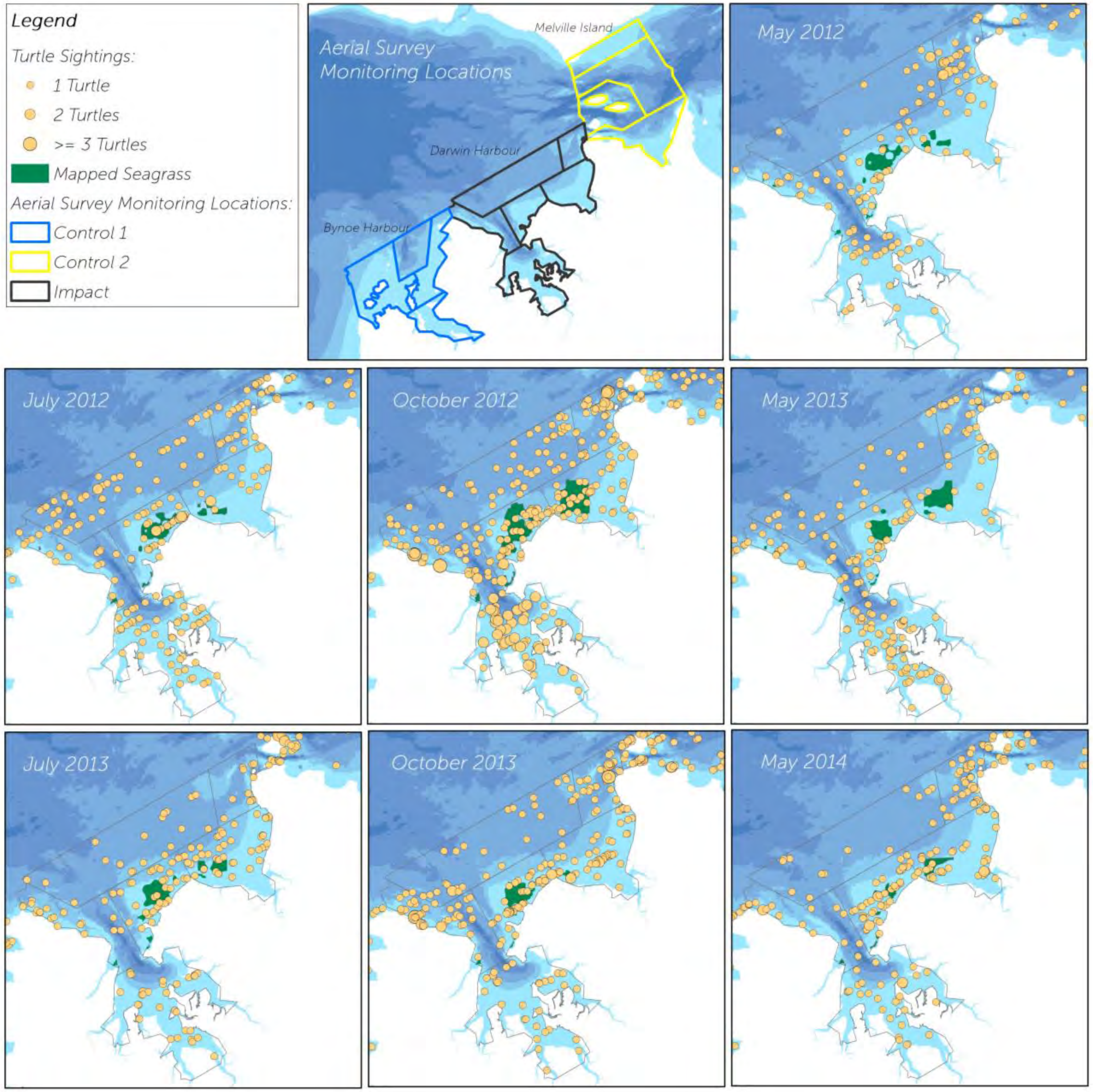


Figure 76 Turtle sightings around the Darwin region during each aerial survey of the monitoring program

Turtle Tagging

Another component of turtle monitoring was turtle tagging with satellite transmitters and flipper tags, undertaken in order to monitor patterns of movement and behaviour of individual animals over longer distances and time periods; this has not been previously attempted in Darwin Harbour. Capturing turtles for satellite tracking and flipper tagging was undertaken approximately 500 m north of the Channel Island Bridge during extreme spring tides, the preferred time for catching turtles, when water and weather conditions are most suitable. Due to high turbidity and poor visibility, and the risk of encountering crocodiles and box jellyfish, a unique capture method was used whereby a net was deployed from a small boat to snag turtles swimming past. Capturing turtles in this area was only possible during the lowest spring tides, which only occur twice a year, when the reef around Channel Island is exposed and acts as a natural barrier that can concentrate turtles into an area small enough to allow netting.

Once captured, each turtle was measured and weighed to estimate its age and assess whether it was suitable for tagging. A tracking device was then attached to the shell (carapace) of each turtle (Figure 77), which is naturally shed over time as the turtle grows. Tags are able to plot a turtle's location and record depth and dive times beneath the water, transmitting this information via satellites each time a turtle comes to the surface to breathe (Figure 78).

Figure 77 Carapace of a juvenile green turtle being cleaned and prepared for satellite transmitter attachment, and flipper tagging and attachment prior to release

In November 2012 a juvenile green turtle was successfully captured. This turtle, named Malakai, was tagged with a satellite transmitter and tracked for 12 days, during which period it remained in close proximity to the capture site near Channel Island.

Tagging was also undertaken in November and December 2013 and one small hawksbill turtle and three juvenile green turtles were captured and assessed for tagging. The hawksbill turtle was considered too small for tagging and was released. The three green turtles caught were deemed suitable and were satellite and flipper tagged. Satellite transmissions recorded 92, 97 and 168 days of data for these turtles, named Chloe, Hendrix and Pepin respectively (Figure 79). Location data and mapping of turtle movements captured from the satellite tags showed that the turtles remained relatively close to where they were captured and released near Channel Island. The general spatial area travelled by Chloe and Hendrix was 1.2 km^2 and Pepin travelled within an area of 1.9 km^2. All three turtles travelled primarily within a 2.5 km range from their capture and release site. This is a unique aspect of juvenile green turtle biology that has not yet been determined in studies elsewhere. On one occasion, Chloe and Pepin travelled briefly up to 10 km outside their home range; however both returned to their home ranges within a week. Pepin was tracked until May 2014 and remained close to mangrove habitats on the western side of the southern end of the channel, indicating a preferred habitat for this juvenile green turtle (Figure 79).

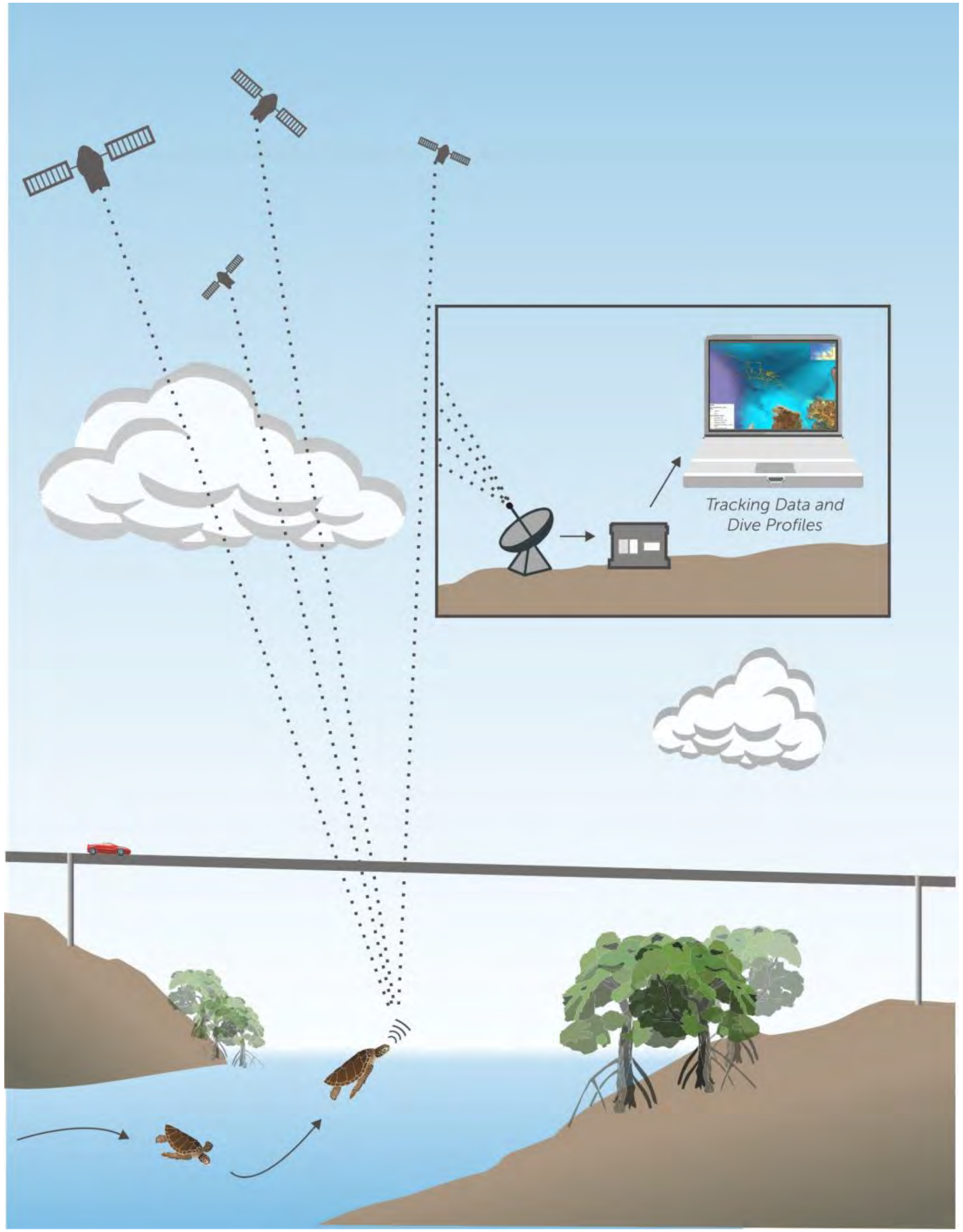


Figure 78 Diagram illustrating how data are transmitted via satellites when a tagged turtle comes to the surface to breathe

In addition to tracking turtle movements, the satellite tags also yielded interesting information on the diving behaviour of juvenile green turtles. The dive depth sensors logged approximately 6,300 dives by the three turtles and, of these, 93% of dives were within the top 5 m of water. Observations of turtles during aerial surveys also showed a preference for turtles in the water depths to 5 m. Furthermore, dive duration data indicated that 70% of dives were between 5 and 15 minutes duration. Although the green turtle has the ability to hold its breath for substantial periods of time, the relatively shallow waters surrounding Channel Island means turtles cannot take a deep breath for a long dive as they become too buoyant. Instead, turtles appear to take frequent and relatively shallow breaths. In this way turtles do not need to swim as hard to remain underwater, subsequently expending less energy to feed. Nonetheless, dives of 60 minutes or greater were still recorded, which may reflect underwater resting periods.

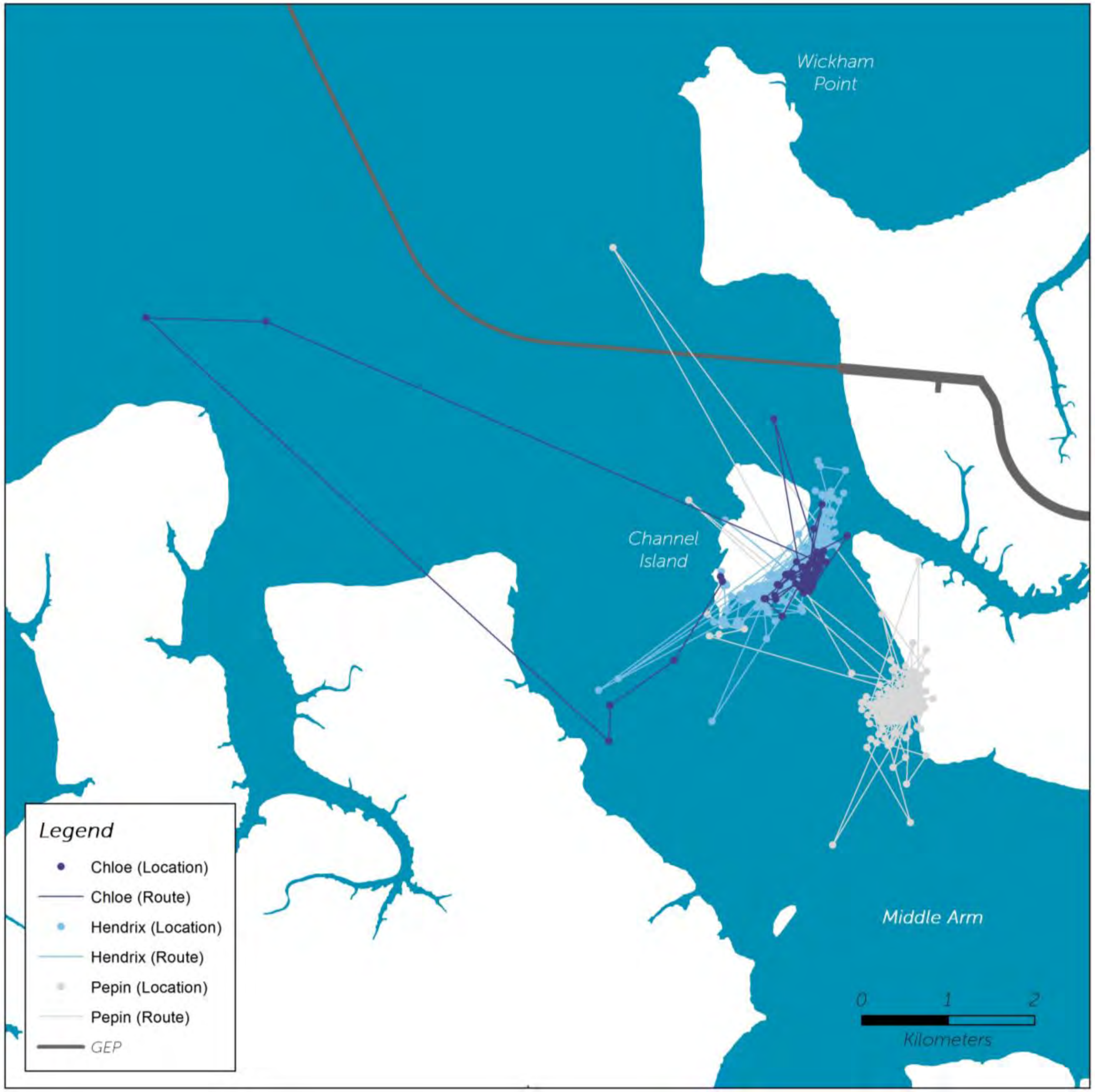


Figure 79 Patterns of movement of three juvenile green turtles around Channel Island, from November 2013 until April 2014

Benthic Assemblages

Soft sediment habitats represent a large proportion of the total habitat area (approximately 80%) of Darwin Harbour (McKinnon et al. 2006) and the offshore environment beyond, but are often mistakenly perceived as lacking in structure and marine life. This environment, however, is home to a diverse group of invertebrates including amphipod crustaceans, bivalve and gastropod molluscs, polychaete (or bristle) worms, and other worm-like phyla such as nemerteans and nematodes. These animals are an important part of the ecosystem as they are a source of food for wading birds and fish that live in the Harbour, help in nutrient-cycling and creating habitat variability through reworking of the sediments. This group of animals, collectively termed 'infauna' (living within the sediments) or 'epifauna' (living on the sediment surface), are generally greater than 0.5 mm in diameter and collectively contribute to a significant amount of biomass of soft sediment habitats in tropical marine environments (Schwinghamer 1981).

Darwin Harbour Infauna and Epifauna

The work carried out as part of the monitoring program has been unique in that no previous research has surveyed soft sediment assemblages extending all the way from the mangroves through to the offshore subtidal environment, nor has previous work been replicated in both space and time. The intertidal and subtidal surveys alone have involved the collection of over 1,000 samples, with specimens having been identified mostly to family level. In addition, 2,880 images have been taken of the seabed to record the diversity of animals living on the sediment surface and over 400 samples analysed to describe the composition and physico-chemical properties of the sediment (including particle size distribution, ORP and pH).

The information gained from these surveys has built upon previous studies and provides a detailed understanding of the complex seabed ecosystem of Darwin Harbour and the offshore environment. The seemingly barren surficial soft sediments, while not exceptionally unique in terms of the animals that live there, do provide habitat for a rich and taxonomically diverse assemblage of *invertebrates which fulfil a multitude of ecological roles. These include polychaete worms, crustaceans (including tanaids, isopods, amphipods, cumaceans, crabs, prawns and ostracods), molluscs (gastropods, bivalves and opisthobranchs), echinoderms (sea stars, sea urchins, sea cucumbers) and other worm-like taxa such as nematodes, nemerteans, oligochaetes, phoronids, flatworms and sipunculids (peanut worms). Other groups recorded included sea anemones, ascidians (sea squirts), hydroids, sponges, lancelets, brachiopods (lamp shells) and pycnogonids (sea spiders). Examples of some of these taxa are shown in Figure 80.*

Consistent with previous investigations of Darwin Harbour mangrove assemblages (Metcalfe 2004, 2005, 2007, Smit et al. 2000), crustaceans were the most taxonomically diverse group of invertebrates recorded across all of the habitat zones (intertidal, subtidal inner (Darwin Harbour Inner) and subtidal outer (Darwin Outer)) accounting for 38% of all taxa recorded, followed by polychaete worms and molluscs, which accounted for 25% and 24% of taxon richness respectively. The most numerically abundant group, however, was the polychaete worms. These groups are commonly recorded in estuarine soft sediment environments (Hutchings 1998, 1999; Snelgrove 1999).

Taxon richness was generally greatest for the subtidal inner and outer habitats, and lowest in the Seaward mangrove assemblage. Taxon richness also decreased from the Seaward mangrove assemblage towards the Hinterland Margin. These findings were similar to earlier studies (e.g. Metcalfe and Glasby 2008; Connell and Gillanders 2007; Smit 2003). Sampling effort and methods were not, however, directly comparable and are therefore are only indicative.

Habitat zones were also characterised by distinct assemblages at the family level (Figure 81). The polychaete worms family Magelonidae, for example, was the most numerically abundant family occurring within the intertidal zone, whereas tanaidacean crustaceans of the family Apseudidae and amphipod crustaceans of the families Aoridae, Photidae and Isaeidae were representative of the subtidal inner and subtidal outer habitat zones.

Figure 80 Left to right, top to bottom: family Sabellariidae (polychaete); family Phyllodocidae (polychaete); family Carditidae (bivalve mollusc); family Muricidae (gastropod mollusc); family Sepiolidae (cephalopod mollusc); family Ampeliscidae (crustacean), phylum Echinodermata (echinoid); phylum Cnidaria (hydroid)

Crabs from the families Grapsidae and Ocypodidae (which include shore crabs, ghost crabs and fiddler crabs), were the most abundant families recorded within the Seaward mangrove assemblage. Both of these crab families are considered important in the mangrove

ecosystem and their members are recognised as 'keystone' species as they recycle mangrove leaf litter and make it available as food for invertebrates at lower levels of the food chain. Polychaete worms of the families Spionidae, Maldanidae and Capitellidae were notably abundant across all of the habitat zones sampled and are some of the most ubiquitous polychaete species found in soft sediments of tropical and temperate estuaries in Australia and overseas.

Overall, results have shown that of the families contributing most to the total abundance, there is a prevalence of deposit-feeding animals across the intertidal, subtidal inner and subtidal outer habitat zones, although the grapsid and ocypodid crabs inhabiting the Seaward mangrove assemblage are predominantly herbivorous 'shredders'. Deposit feeders obtain their food by ingesting nutrients from particles suspended in the sediment. This is consistent with the findings of tropical tidal flats of other parts of Australia and overseas (Dittmann and Vargas 2001) and it is suggested that this type of feeding mode is sustained via the microscopic algae and detritus from nearby mangroves. The highest proportion of deposit feeders were also found within the intertidal zone and decreased towards the subtidal inner and subtidal outer zones (Figure 81).

The distribution of infaunal assemblages within the intertidal zone was variable at the small scale (i.e. hundreds of metres) but did not vary at the broader scale (i.e. several kilometres), whereas assemblages associated with the subtidal inner and subtidal outer habitat zones were variable at both small and broad spatial scales.

Taxon richness and abundance in the intertidal zone has remained very stable through time and did not appear to be influenced by the monsoonal wet season conditions. Taxon richness across the subtidal inner and subtidal outer zones also appeared to remain stable through time although abundance was more variable, particularly within the main channel of the East Arm of Darwin Harbour.

Epifauna associated with the seabed across the subtidal inner and outer habitat zones was generally sparse and limited to the rare occurrence of bryozoans, hydroids, sea whips, ascidians, sponges, anemones, bryozoans, macroalgae and occasional hard corals. The distribution of assemblages was highly variable at small and broad spatial scales.

Sediment composition varied across the habitat zones with finer silts, clays and organic material characteristic of the intertidal habitat zone and more sandy sediment types associated with the subtidal inner and subtidal outer habitat zones. Sediment associated with the subtidal inner zone was the coarsest.

Some of the key patterns described above are broadly summarised in Figure 81.

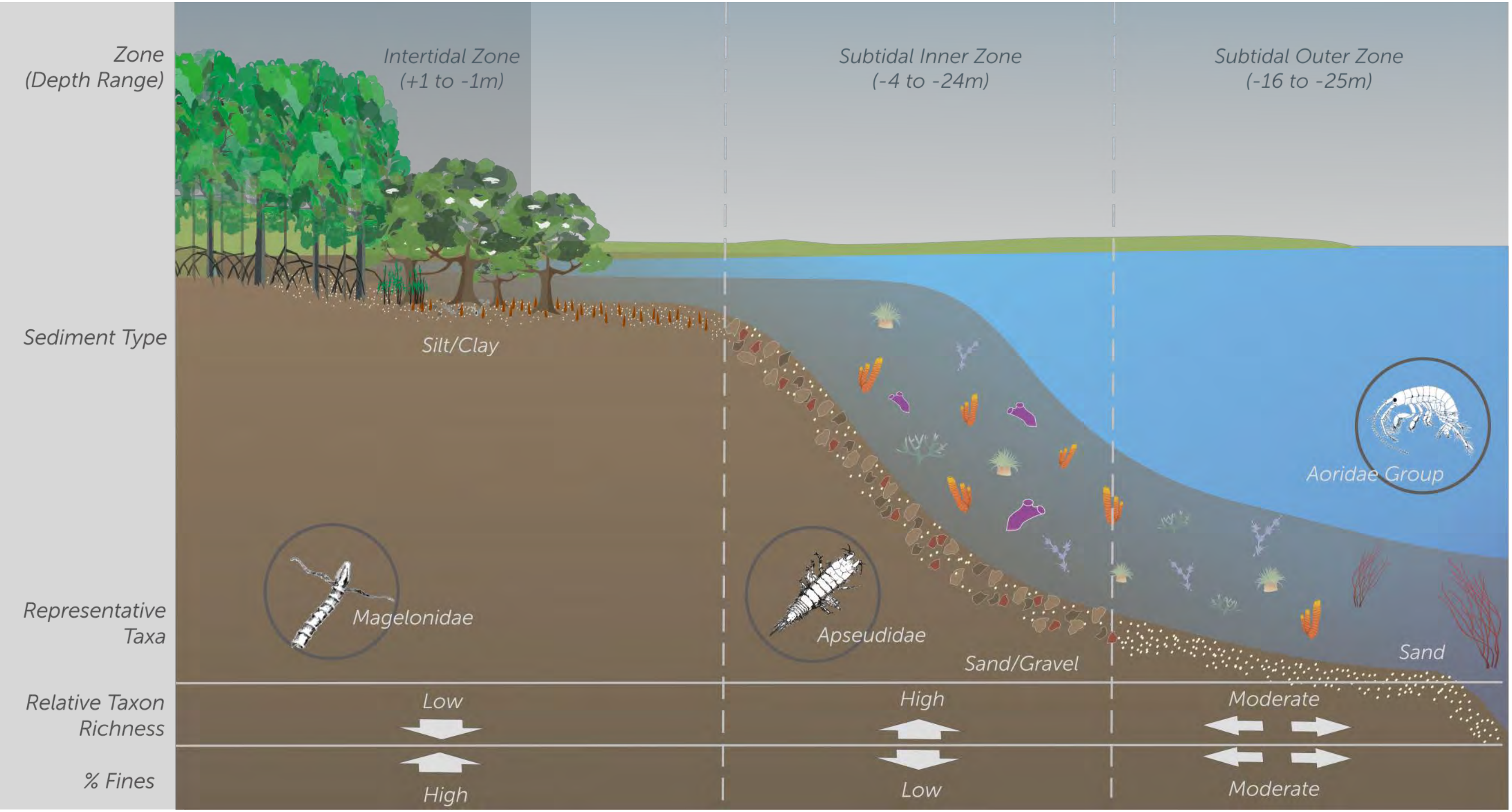


Figure 81 Key patterns in benthic assemblages in Darwin

Patterns in Distribution and Diversity

A range of biophysical factors potentially drive the patterns in distribution and diversity of infauna assemblages in soft sediments.

Sediment composition, in particular, may be a factor in structuring taxonomic richness, with the highest number of taxa recorded in association with the coarsest sediment type (found within the subtidal inner zone) and the least number of taxa recorded within the intertidal zone (containing the highest proportion of fines). Deposit-feeders were also prevalent in the intertidal zone which is consistent with findings from similar studies (Dittmann and Vargas 2001). Sediment properties and benthic distribution patterns are not, however, easily correlated and other hydrographic and physico-chemical processes may influence these patterns.

Despite the dynamic macrotidal and seasonal conditions experienced within Darwin Harbour, the infaunal assemblages associated with the intertidal habitat zone have remained stable. It is therefore likely that these taxa have adapted to fluctuations in environmental conditions, or have life histories that allow rapid recolonisation following disturbance.

Overall, the findings of these and previous investigations show that the composition and distribution of infaunal assemblages associated with the soft sediment habitats of Darwin Harbour and the surrounding offshore environment are rich and diverse, but comparable with those of other Australian tropical and temperate estuaries. Furthermore, while this and previous investigations highlight some consistent patterns in relation to the distribution, diversity and abundance of benthic marine fauna, the mechanisms driving these patterns are highly complex and often prove difficult to predict.

Glossary

Term/ Acronym	Definition
APS	Access Point Survey
ASU	Artificial Sampling Unit
BACI	Before After Control Impact
Benthic assemblages	Biota (living) and abiota (non-living) components of the sea bed
BHD	Backhoe Dredger
Bleached (coral)	Corals that have lost their symbiotic algae due to stress and the live tissue of which appears pale or white
BOM	Bureau of Meteorology
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
Chl-a	Chlorophyll-a
CPCe	Coral Point Count with Excel extensions
CSD	Cutter Suction Dredger
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DI	Darwin Harbour Inner
DLRM	Department of Land Resource Management
DNA	Deoxyribonucleic acid
DO	Darwin Outer
DoE	Department of Environment
DSDMP	Dredging and Spoil Disposal Management Plan
DSEWPaC	Department of Sustainability. Environment, Water, Populations and Communities
EIS	Environmental Impact Statement
EPBC Act	The Environment Protection and Biodiversity Conservation Act 1999
Epifauna	Animals living on top of sediments
GBR	Great Barrier Reef
GEP	Gas Export Pipeline
HAT	Highest Astronomical Tide
Infauna	Animals living within sediments
Informative Monitoring	Monitoring programs designed to measure environmental responses to dredging and spoil disposal activities and to provide textual information on effects of sedimentation and turbidity on sensitive receptors
IPDEP	Ichthys Project Dredging Expert Panel
IUCN	International Union for Conservation of Nature
LAT	Lowest Astronomical Tide
LCL	Lower Confidence Limit
Mangrove Assemblage/ Zone	Major mangrove community assemblages in Darwin Harbour: Hinterland Margin, Salt Flat, Tidal Flat, Tidal Creek and Seaward
MAGNT	Museum and Art Gallery of the Northern Territory
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs

Term/ Acronym	*Definition*
MITS	*Marine Invasive Taxonomic Services*
MLWN	*Mean Low Water Neaps*
MLWS	*Mean Low Water Springs*
MMM	*Maximum of the Monthly Mean*
MODIS	*Moderate Resolution Imaging Spectroradiometer*
MOF	*Module Offloading Facility*
MPB	*Microphytobenthos*
MSL	*Mean Sea Level*
National System	*National System for the Prevention and Management of Marine Pest Incursions*
NDVI	*Normalised Difference Vegetation Index*
Neap tide	*Tides for which the difference between high and low tide is least (occurs approximately twice per month)*
NEMP	*Nearshore Environmental Monitoring Plan*
NIWA	*New Zealand's National Institute of Water and Atmospheric Research*
NRETAS	*Department of Natural Resources, Environment, the Arts and Sport*
NT	*Northern Territory*
NT EPA	*Northern Territory Environment Protection Authority*
NTHR	*Northern Territory Heritage Register*
NTU	*Nephelometric Turbidity Units*
ORP	*Oxidation Reduction Potential*
PAR	*Photosynthetically Active Radiation*
pH	*A measure of the acidity/alkalinity (e.g. of soil or water)*
PSU	*Practical Salinity Units*
Reactive monitoring	*Monitoring programs that include triggers that initiate targeted monitoring and adaptive and contingency management responses to manage impacts within the limits of acceptable loss*
RNE	*Commonwealth Register of the National Estate*
SE	*Standard Error*
Sedimentation	*Assumed accretion or erosion measured as change in sediment bed level over time relative to a benchmark*
SEIS	*Supplement to the Draft Environmental Impact Statement / Environmental Impact Statement*
SEM	*Scanning Electron Microscopy*
SHB	*Split Hopper Barge*
SP	*Separable Portion*
Spring tide	*Tides for which the difference between high and low tide is greatest (occurs approximately twice per month)*
SSC	*Suspended Sediment Concentration*
TC	*Tropical Cyclone*
TL	*Tropical Low*
TS	*Tropical System*
TSHD	*Trailing Suction Hopper Dredger*
TSS	*Total Suspended Solids*
UCL	*Upper Confidence Limit*
Zooxanthellae	*Symbiotic algae that live in coral tissue and provide nutrition to coral hosts*

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This report is available in an electronic format and may be accessed on the Ichthys LNG Project website

This report should be cited as:

Cardno (NSW/ACT) Pty Ltd (2014) Darwin Harbour – A Summary of the Ichthys LNG Project Nearshore Environmental Monitoring Program. Report prepared on behalf of INPEX Operations Australia Pty Ltd.

The following project documents are also available on the Ichthys Project website:

Cardno (2014). Ichthys Project: Nearshore Environmental Monitoring Plan, Rev 5. Report for INPEX. Prepared by Cardno (NSW/ACT) Pty Ltd, Sydney.

INPEX (2013). Dredging and Spoil Disposal Management Plan – East Arm Rev 4. INPEX Operations Australia Pty Ltd.

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Scope	Report Title	Field Survey Dates	Document Number
Baseline Reports			
Intertidal Sedimentation and Mangrove Community Health	Intertidal Sedimentation Monitoring Program Baseline Report	18 to 28 May 2012; 18 to 27 June 2012; 18 to 27 July 2012	L384-AW-REP-10000
	Mangrove Community Health Monitoring Program Baseline Phase Report	2 to 27 June 2012; 18 July 2012 to 11 August 2012	L384-AW-REP-10001
	Mangrove Community Health Remote Sensing Baseline Report	14 to 28 July 2012	L384-AW-REP-10015
Coral Monitoring	Coral Monitoring Baseline Report	16 June 2012 to 18 August 2012	L384-AW-REP-10003
Seagrass	Seagrass Monitoring Program Baseline Report	29 May 2012 to 28 August 2012	L384-AW-REP-10002
Water Quality and Subtidal Sedimentation	Water Quality and Subtidal Sedimentation Monitoring Program Baseline Report	1 May 2012 to 26 August 2012	L384-AW-REP-10004
Subtidal Benthos	Subtidal Benthos Monitoring Baseline Report	30 May 2012 to 02 June 2012; 13 to 16 June 2012; 27 June 2012 to 01 July 2012; 12 to 17 July 2012	L384-AW-REP-10005
Intertidal Benthos	Intertidal Benthos Monitoring Baseline Report	12 to 16 June 2012; 28 July 2012 to 01 August 2012	L384-AW-REP-10011
Research Fishing and Fish Health	Recreational Fishing Monitoring Program Baseline Report Season 1	28 June 2012 to 19 August 2012	L384-AW-REP-10008

Scope	*Report Title*	*Field Survey Dates*	*Document Number*
	Recreational Fishing Monitoring Program Baseline Report Season 2	*11 October 2012 to 25 November 2012*	*L384-AW-REP-10510*
	Research Fishing and Fish Health Monitoring Program Baseline Report Season 1	*3 August 2012 to 15 September 2012*	*L384-AW-REP-10009*
	Research Fishing and Fish Health Monitoring Program Baseline Report Season 2	*7 to 26 October 2012*	*L384-AW-REP-10511*
Primary Productivity	*Primary Productivity Monitoring Baseline Report*	*June 2012 to August 2012*	*L384-AW-REP-10010*
Turtles and Dugongs	*Turtle and Dugong Monitoring Program Baseline Report*	*June 2012 to August 2012*	*L384-AW-REP-10013*
Marine Pests	*Marine Pest Monitoring Program Baseline Survey 1 Report*	*August 2012*	*L384-AW-REP-10007*
Routine Reports			
Intertidal Sedimentation and Mangrove Community Health	*Quarterly Intertidal Sedimentation – Dredging Report 1*	*15 to 21 October 2012*	*L384-AH-REP-10006*
	Quarterly Intertidal Sedimentation – Dredging Report 2	*10 to 16 January 2013*	*L384-AW-REP-10016*
	Quarterly Intertidal Sedimentation – Dredging Report 3	*8 to 14 April 2013*	*L384-AW-REP-10017*
	Quarterly Intertidal Sedimentation – Dredging Report 4	*9 to 16 July 2013*	*L384-AW-REP-10018*
	Quarterly Intertidal Sedimentation – Dredging Report 5	*4 to 10 October 2013*	*L384-AW-REP-10019*
	Quarterly Intertidal Sedimentation – Dredging Report 6	*14 to 20 January 2014*	*L384-AW-REP-10020*
	Quarterly Intertidal Sedimentation – Dredging Report 7	*12 to 21 April 2014*	*L384-AW-REP-10021*
	Quarterly Mangrove Community Health Monitoring Report – Dredging Report 1	*27 October and 22 November 2012*	*L384-AH-REP-10007*
	Quarterly Mangrove Community Health Monitoring Report – Dredging Report 2	*24 January 2013 to 18 February 2013*	*L384-AW-REP-10031*
	Quarterly Mangrove Community Health Monitoring Report – Dredging Report 3	*23 April 2013 to 17 May 2013*	*L384-AW-REP-10032*
	Quarterly Mangrove Community Health Monitoring Report – Dredging Report 4	*22 to 31 July 2013*	*L384-AW-REP-10033*

Scope	Report Title	Field Survey Dates	Document Number
	Quarterly Mangrove Community Health Monitoring Report – Dredging Report 5	*17 October 2013 to 11 November 2013*	*L384-AW-REP-10034*
	Quarterly Mangrove Community Health Monitoring Report – Dredging Report 6	*14 to 23 January 2014*	*L384-AW-REP-10035*
	Quarterly Mangrove Community Health Monitoring Report – Dredging Report 7	*12 to 21 April 2014*	*L384-AW-REP-10036*
	Quarterly Remote Sensing - Dredging Report 1	*2 to 27 November 2012*	*L384-AW-REP-11525*
	Quarterly Remote Sensing - Dredging Report 3	*25 April 2013*	*L384-AW-REP-11527*
	Quarterly Remote Sensing - Dredging Report 4	*15 July 2013*	*L384-AW-REP-11528*
	Quarterly Remote Sensing - Dredging Report 5	*13 October 2013 and 1 November 2013*	*L384-AW-REP-11529*
	Quarterly Remote Sensing - Dredging Report 6	*8 January 2014*	*L384-AW-REP-11530*
Coral Monitoring	*Bimonthly Coral Monitoring Report – Dredging Report 1*	*22 to 26 October 2012*	*L384-AW-REP-10003*
	Bimonthly Coral Monitoring Report – Dredging Report 2	*5 to 9 December 2012*	*L384-AH-REP-10008*
	Bimonthly Coral Monitoring Report – Dredging Report 3	*17 to 22 February 2013*	*L384-AW-REP-10082*
	Bimonthly Coral Monitoring Report – Dredging Report 4	*17 to 21 April 2013*	*L384-AW-REP-10083*
	Bimonthly Coral Monitoring Report – Dredging Report 5	*16 to 20 June 2013*	*L384-AW-REP-10084*
	Bimonthly Coral Monitoring Report – Dredging Report 6	*14 to 19 August 2013*	*L384-AW-REP-10085*
	Bimonthly Coral Monitoring Report – Dredging Report 7	*26 to 30 October 2013*	*L384-AW-REP-10086*
	Bimonthly Coral Monitoring Report – Dredging Report 8	*9 to 14 December 2013*	*L384-AW-REP-10087*
	Bimonthly Coral Monitoring Report – Dredging Report 9	*23 to 28 February 2014*	*L384-AW-REP-10088*
	Bimonthly Coral Monitoring Report – Dredging Report 10	*8 to 14 March 2014*	*L384-AW-REP-10089*
	Bimonthly Coral Monitoring Report – Dredging Report 11	*7 to 10 April 2014*	*L384-AW-REP-10090*
	Bimonthly Coral Monitoring Report – Dredging Report 12	*8 to 10 May 2014*	*L384-AW-REP-10091*
Seagrass	*Bimonthly Seagrass Monitoring Report – Dredging Report 1*	*6 to 9 November 2012*	*L384-AH-REP-10003*

Scope	Report Title	Field Survey Dates	Document Number
	Bimonthly Seagrass Monitoring Report – Dredging Report 2	*6 to 9 December 2012*	*L384-AW-REP-10048*
	Seagrass Habitat Monitoring February 2013	*18 to 22 February 2013*	*L384-AW-REP-10076*
	Seagrass Habitat Monitoring May 2013	*16 to 20 May 2013*	*L384-AW-REP-10077*
	Seagrass Habitat Monitoring August 2013	*29 August 2013 to 4 September 2013*	*L384-AW-REP-10078*
	Quarterly Seagrass Monitoring Report – Dredging Report August 2013	*29 August 2013 to 4 September 2013*	*L384-AW-REP-10050*
	Quarterly Seagrass Monitoring - Dredging Report 5	*11 to 15 November 2013*	*L384-AW-REP-10051*
	Seagrass Habitat Monitoring November 2013	*9 to 16 November 2013*	*L384-AW-REP-10079*
	Quarterly Seagrass Monitoring Dredging Report 6	*22 to 26 February 2014*	*L384-AW-REP-10052*
	Seagrass Habitat Monitoring February 2014	*22 to 26 February 2014*	*L384-AW-REP-12967*
	Seagrass Dark Recovery Experiment	*24 September to 24 November 2012* *25 November 2012 to 24 February 2013*	*L384-AW-REP-10047*
Water Quality	*Weekly Water Quality Report Week 1 & 2*	*27 August to 09 September 2012*	*L384-AW-REP-10104*
	Weekly Water Quality Report Week 3	*10 to 16 September 2012*	*L384-AW-REP-10105*
	Weekly Water Quality Report Week 4	*17 to 23 September 2012*	*L384-AW-REP-10106*
	Weekly Water Quality Report Week 5	*24 to 30 September 2012*	*L384-AW-REP-10107*
	Weekly Water Quality Report Week 6	*1 to 7 October 2012*	*L384-AW-REP-10108*
	Weekly Water Quality Report Week 7	*8 to 14 October 2012*	*L384-AW-REP-10109*
	Weekly Water Quality Report Week 8	*15 to 21 October 2012*	*L384-AW-REP-10110*
	Weekly Water Quality Report Week 9	*22 to 28 October 2012*	*L384-AW-REP-10111*
	Weekly Water Quality Report Week 10	*29 October to 4 November 2012*	*L384-AW-REP-10112*
	Weekly Water Quality Report Week 11	*5 November to 11 November 2012*	*L384-AW-REP-10113*
	Weekly Water Quality Report Week 12	*12 November to 18 November 2012*	*L384-AW-REP-10114*
	Weekly Water Quality Report Week 13	*19 November to 25 November 2012*	*L384-AW-REP-10115*

Scope	Report Title	Field Survey Dates	Document Number
	Weekly Water Quality Report Week 14	*26 November to 2 December 2012*	*L384-AW-REP-10116*
	Weekly Water Quality Report Week 15	*3 to 9 December 2012*	*L384-AW-REP-10117*
	Weekly Water Quality Report Week 16	*10 to 16 December 2012*	*L384-AW-REP-10118*
	Weekly Water Quality Report Week 17	*17 to 23 December 2012*	*L384-AW-REP-10119*
	Fortnightly Water Quality Report Weeks 18/19	*24 December 2012 to 6 January 2013*	*L384-AW-REP-10120*
	Fortnightly Water Quality Report Weeks 20/21	*7 to 20 January 2013*	*L384-AW-REP-10122*
	Fortnightly Water Quality Report Weeks 22/23	*21 January to 3 February 2013*	*L384-AW-REP-10124*
	Fortnightly Water Quality Report Weeks 24/25	*4 to 17 February 2013*	*L384-AW-REP-10126*
	Fortnightly Water Quality Report Weeks 25/26	*11 to 24 February 2013*	*L384-AW-REP-10128*
	Fortnightly Water Quality Report Weeks 27/28	*25 February to 10 March 2013*	*L384-AW-REP-10130*
	Fortnightly Water Quality Report Weeks 29/30	*11 to 24 March 2013*	*L384-AW-REP-10132*
	Fortnightly Water Quality Report Weeks 31/32	*25 March to 7 April 2013*	*L384-AW-REP-10134*
	Fortnightly Water Quality Report Weeks 33/34	*8 to 21 April 2013*	*L384-AW-REP-10136*
	Fortnightly Water Quality Report Weeks 35/36	*22 April to 5 May 2013*	*L384-AW-REP-10138*
	Fortnightly Water Quality Report Weeks 37/38	*6 to 19 May 2013*	*L384-AW-REP-10140*
	Fortnightly Water Quality Report Weeks 39/40	*20 May to 2 June 2013*	*L384-AW-REP-10142*
	Fortnightly Water Quality Report Weeks 41/42	*3 to 16 June 2013*	*L384-AW-REP-10144*
	Fortnightly Water Quality Report Weeks 43/44	*17 to 30 June 2013*	*L384-AW-REP-10146*
	Fortnightly Water Quality Report Weeks 45/46	*1 to 14 July 2013*	*L384-AW-REP-10148*
	Fortnightly Water Quality Report Weeks 46/47	*8 to 21 July 2013*	*L384-AW-REP-10149*
	Fortnightly Water Quality Report Weeks 48/49	*22 July to 4 August 2013*	*L384-AW-REP-10151*
	Fortnightly Water Quality Report Weeks 50/51	*5 to 18 August 2013*	*L384-AW-REP-10153*
	Fortnightly Water Quality Report Weeks 52/53	*19 August to 1 September 2013*	*L384-AW-REP-10155*

Scope	Report Title	Field Survey Dates	Document Number
	Fortnightly Water Quality Report Weeks 54/55	*2 to 15 September 2013*	*L384-AW-REP-10157*
	Fortnightly Water Quality Report Weeks 56/57	*16 to 29 September 2013*	*L384-AW-REP-10159*
	Fortnightly Water Quality Report Weeks 58/59	*30 September to 13 October 2013*	*L384-AW-REP-10161*
	Fortnightly Water Quality Report Weeks 60/61	*14 to 27 October 2013*	*L384-AW-REP-10163*
	Fortnightly Water Quality Report Weeks 62/63	*28 October to 11 November 2013*	*L384-AW-REP-10165*
	Fortnightly Water Quality Report Weeks 64/65	*11 to 24 November 2013*	*L384-AW-REP-10167*
	Fortnightly Water Quality Report Weeks 66/67	*25 November to 8 December 2013*	*L384-AW-REP-10169*
	Fortnightly Water Quality Report Weeks 67/68	*2 to 15 December 2013*	*L384-AW-REP-10170*
	Fortnightly Water Quality Report Weeks 69/70	*16 to 29 December 2013*	*L384-AW-REP-10172*
	Fortnightly Water Quality Report Weeks 71/72	*20 December 2013 to 12 January 2014*	*L384-AW-REP-10174*
	Fortnightly Water Quality Report Weeks 73/74	*13 to 26 January 2014*	*L384-AW-REP-10176*
	Fortnightly Water Quality Report Weeks 75/76	*21 January to 9 February 2014*	*L384-AW-REP-10177*
	Fortnightly Water Quality Report Weeks 77/78	*10 to 23 February 2014*	*L384-AW-REP-10178*
	Fortnightly Water Quality Report Weeks 79/80	*24 February to 9 March 2014*	*L384-AW-REP-10179*
	Fortnightly Water Quality Report Weeks 81/82	*10 to 23 March 2014*	*L384-AW-REP-10180*
	Fortnightly Water Quality Report Weeks 83/84	*24 March 2014 to 6 April 2014*	*L384-AW-REP-10181*
	Fortnightly Water Quality Report Weeks 85/86	*7 April 2014 to 20 April 2014*	*L384-AW-REP-10182*
	Fortnightly Water Quality Report Weeks 86/87	*13 to 27 April 2014*	*L384-AW-REP-10183*
	Fortnightly Water Quality Report Weeks 88/89	*28 April to 11 May 2014*	*L384-AW-REP-10184*
	Fortnightly Water Quality Report Weeks 90/94	*12 to 25 May 2014*	*L384-AW-REP-10185*
	Fortnightly Water Quality Report Weeks 92/93	*26 May to 8 June 2014*	*L384-AW-REP-10186*
	Bimonthly Water Quality & Subtidal Sedimentation Report – Dredging Report 1	*27 August 2012 to 04 November 2012*	*L384-AH-REP-10001*

Scope	Report Title	Field Survey Dates	Document Number
	Bimonthly Water Quality & Subtidal Sedimentation Report – Dredging Report 2	01 November 2012 to 31 December 2012	L384-AW-REP-10191
	Bimonthly Water Quality & Subtidal Sedimentation Report – Dredging Report 3	1 January 2013 to 28 February 2013	L384-AW-REP-10192
	Bimonthly Water Quality and Subtidal Sedimentation Report 4	1 March 2013 and 9 May 2013	L384-AW-REP-10193
	Bimonthly Water Quality and Subtidal Sedimentation Report 5	1 May 2013 and 30 June 2013	L384-AW-REP-10194
	Bimonthly Water Quality and Subtidal Sedimentation Report 6	1 July 2013 and 31 August 2013	L384-AW-REP-10195
	Bimonthly Water Quality and Subtidal Sedimentation Report 7	1 September 2013 and 31 October 2013	L384-AW-REP-10196
	Bimonthly Water Quality and Subtidal Sedimentation Report 8	1 November 2013 and 31 December 2013	L384-AW-REP-10197
	Bimonthly Water Quality and Subtidal Sedimentation Report 9	1 January 2014 and 28 February 2014	L384-AW-REP-10198
	Bimonthly Water Quality and Subtidal Sedimentation Report 10	1 March 2014 and 30 April 2014	L384-AW-REP-10199
Subtidal Benthos	Subtidal Benthos Monitoring Dredging Report 1	19 to 21 May 2013; 03 to 05 June 2013; 03 to 07 July 2013; 15 September 2013	L384-AW-REP-10205
Intertidal Benthos	Intertidal Benthos Monitoring Dredging Report 1	17 June 2013 to 20 June 2013	L384-AW-REP-10230
Research Fishing and Fish Health	Recreational Fishing Monitoring Program Dredging Report Season 1	21 February 2013 to 7 April 2013	L384-AW-REP-10214
	Recreational Fishing Monitoring Program Dredging Report Season 2	20 June 2013 to 4 August 2013	L384-AW-REP-10215
	Research Fishing and Fish Health Monitoring Program Dredging Report Season 1	20 November to 10 December 2012	L384-AW-REP-10217
	Research Fishing and Fish Health Monitoring Program Dredging Report Season 2	4 to 13 March 2013	L384-AW-REP-10512
	Research Fishing and Fish Health Monitoring Program Dredging Report Season 3	9 to 17 October 2013	L384-AW-REP-10218
	Research Fishing and Fish Health Monitoring Program End of Dredging Report	3 to 10 March 2014	L384-AW-REP-10221

Scope	Report Title	Field Survey Dates	Document Number
Primary Productivity	Primary Productivity Dredging Report 1	September 2012 to April 2013	L384-AW-REP-10224
	Primary Productivity Dredging Report 2	March 2013 and August 2013	L384-AW-REP-10225
	Primary Productivity Dredging Report 3	September 2013 and December 2013	L384-AW-REP-10226
Turtles and Dugongs	Routine Turtle and Dugong Monitoring Program Report – Dredging Report 1	September 2012 to October 2012	L384-AW-REP-10245
	Routine Turtle and Dugong Monitoring Program Report – Dredging Report 2	9 May 2013 to 27 May 2013	L384-AW-REP-10246
	Routine Turtle and Dugong Monitoring Program Report – Dredging Report 3	27 July 2013 to 11 August 2013	L384-AW-REP-10247
	Routine Turtle and Dugong Monitoring Program Report – Dredging Report 4	11 October 2013 and 27 October 2013	L384-AW-REP-10248
Marine Pests	Routine Marine Pests Monitoring Report – Dredging Report 1	March 2013	L384-AW-REP-10208
	Biannual Marine Pests Monitoring Report – Dredging Report 2	27 August 2013 to 6 September 2013	L384-AW-REP-10209
	Biannual Marine Pests Monitoring Report – Dredging Report 3	9 March 2014 to 16 March 2014	L384-AW-REP-10210

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