SEABED MINING AND COASTAL AND MARINE ENVIRONMENTS

OF THE NORTHERN TERRITORY

NORTHERN TERRITORY GOVERNMENT

This document was prepared by the Department of Environment and Natural Resources

ISBN: 9781743501689
Cite report as: Smit, N., Groom, R., and Griffiths, A.D. (2018). Seabed mining and coastal and marine environments of the Northern Territory. Department of Environment and Natural Resources, Palmerston.

Executive Summary

There is a growing interest in exploitation of mineral resources from marine environments. However, mining the seabed carries significant risks that have a direct and indirect impact on environmental values. Furthermore, management of these risks is poorly understood due to the lack of knowledge of the marine environment and understanding of how to mitigate these risks.

On 6 March 2012, the Northern Territory Government established a three year moratorium on exploration and mining in coastal waters of the NT until 2015. The moratorium was extended by the NT Government and currently expires in 2021. The moratorium was extended to ensure appropriate review of seabed mining in the NT is completed. The moratorium applies to the coastal waters of the Northern Territory under the *Mineral Titles Act* and the *Mining Management Act*.

This report aims to describe environmental values of the Northern Territory's coast and seas, the potential impacts of seabed mining on the environmental values and the information gaps to manage these impacts.

The Northern Territory coastal and marine environments contain values that are of national and international significance. These values include a rich marine fauna, extensive coastal and benthic habitats and complex processes that drive these systems. Our knowledge of these values in the Northern Territory is limited. In general, we have a relatively good understanding of the distribution of marine vertebrate fauna but not the long term trends or environmental processes that drive these populations. Less is known of our invertebrate marine fauna and lesser still on the distribution of benthic habitats.

There are a wide range of direct, indirect and cumulative impacts to the marine environment that can occur through the extraction of mineral resources from the seafloor. Impacts from seabed mining include entrainment and collision, removal and alteration of habitat, underwater noise, reduction in water quality, marine pests, organic enrichment, light and air emissions, chemical discharges and hydrocarbon spills.

Limited information is currently available on many of the coastal and marine values of the Northern Territory. This is a major constraint on management and mitigation of risks from seabed mining. Baseline information on the distribution and abundance of many marine species and their habitats is lacking, as is an understanding of the processes that drive these populations and how disturbance from extraction, processing and transportation would impact them. Significant investment in scientific research and information gathering would be required prior to authorising activities to extract mineral resources from the NT coastal waters.

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1.1.1 Background

There is a growing interest in exploitation of mineral resources from marine environments. Seabed mining operations all rely on a similar approach of using a seabed collector system, a lifting system and support vessels involved in offshore processing and transporting ore. Mining the seabed carries significant risks that have a direct and indirect impact on environmental values (Miller *et al.* 2018). Furthermore, management of these risks is poorly understood due to a lack of knowledge of the marine environment and experience in mitigating these risks.

On 6 March 2012, the Northern Territory Government established a three year moratorium on exploration and mining in coastal waters of the NT until 2015. The moratorium was extended by the NT Government and currently expires in 2021. The moratorium was extended to ensure appropriate review of seabed mining in the NT is completed. The moratorium applies to the coastal waters of the Northern Territory under the *Mineral Titles Act* and the *Mining Management Act*.

1.1.2 Scope

This report focusses on the coastal and marine environment of the Northern Territory coastal waters (i.e., waters within three nautical miles from the coastline). Due to the inter-related and broad scale nature of the marine environment, many of the values covered in this report also extend or apply to adjacent Commonwealth waters. This report is complementary to other reports prepared as part of the review of the seabed mining moratorium, including the review paper on seabed mining in the Northern Territory (Advisian 2017), underwater cultural heritage (Cosmos Archaeology 2017), and the social and cultural impacts (True North Strategic Communication 2017).

1.2 Objectives

This report has three objectives:

1. Describe environmental values of the Northern Territory's coast and seas.
2. Describe the potential impacts of seabed mining on the environmental values of the Northern Territory's coast and seas.
3. Describe the information gaps to manage the potential impacts of seabed mining on the environmental values of the Northern Territory's coast and seas.

2 Coastal and marine environments of the Northern Territory

The Northern Territory coastline extends for 10,953 km and the coastal waters covers an area of approximately 72,000 km^2 or 17.5% of Australia's coastal waters (Figure 1). There are 887 islands, three of which are some of Australia's largest: Melville Island (3rd largest), Groote Eylandt (4th largest) and Bathurst Island (6th largest).

The coastal waters encompass several seas and major estuaries. The Gulf of Carpentaria covers the east coast and is characterised by shallow waters with fringing reefs and seagrass meadows. The Arafura Sea covers the north coast and lies over the Sahul Shelf that connected Australia and New Guinea in the last glacial period. The Timor Sea covers the west coast and is adjacent to three substantial inlets on the Northern Territory coast; the Joseph Bonaparte Gulf, Beagle Gulf and the Van Diemen Gulf. Collectively, they represent one of the world's most intact marine and coastal environments.

The NT marine and estuarine environments are largely characterised by shallow, flat (50-200 m) shelves with scattered troughs, shoals and banks across the Timor and Arafura seas and the remains of two large basins: Gulf of Carpentaria and Joseph Bonaparte Gulf (Rochester *et al.* 2007). The largest rivers in the NT are the Victoria, Daly, McArthur River and Roper rivers (Ferns 1999), and are important for freshwater and nutrient input, driving the productivity and life histories for many species (Burford *et al.* 2009).

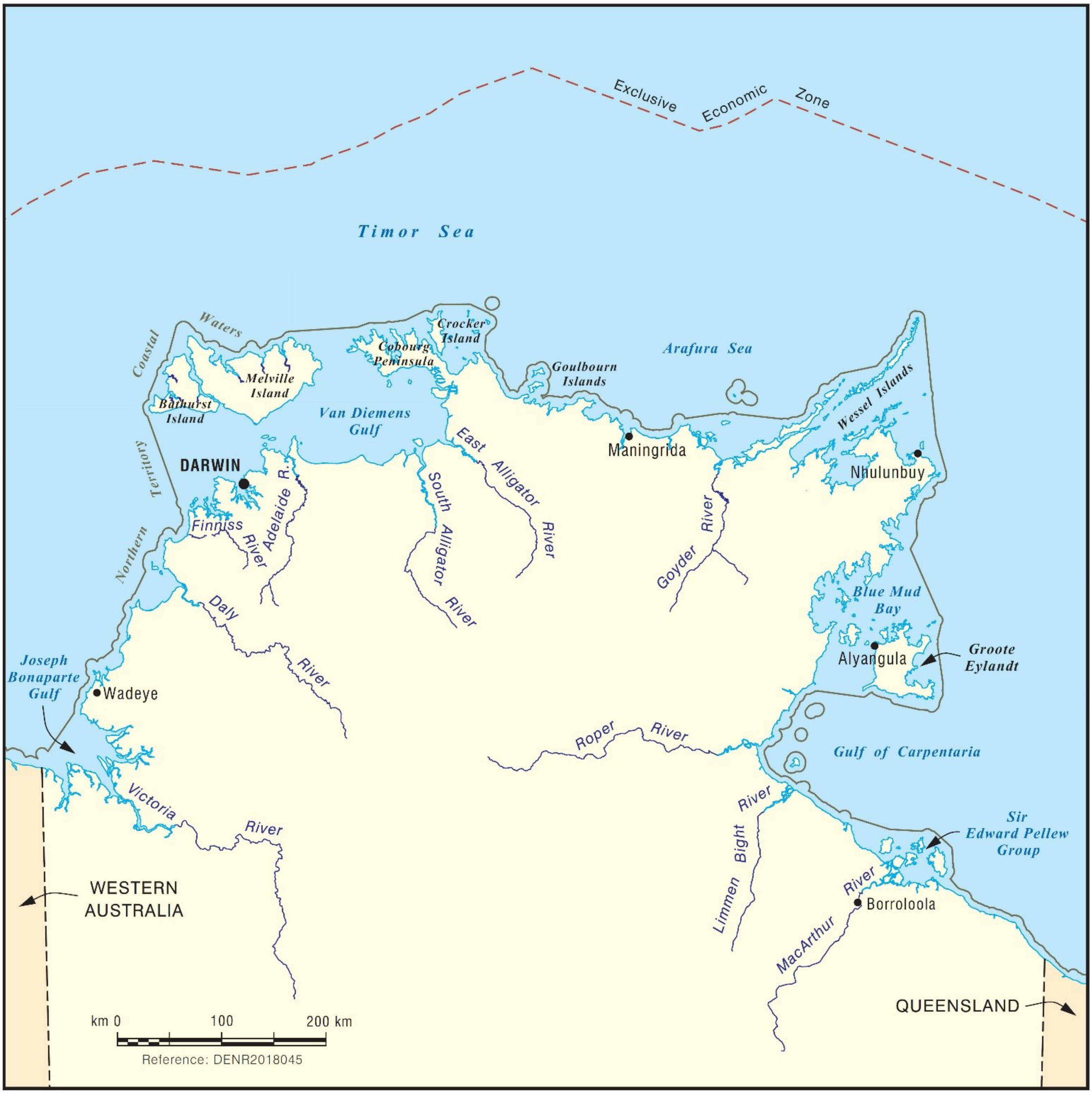
These topographic regions have distinct differences in physical drivers which influence species dispersal, population dynamic and community structure. Many of these physical drivers are the result from sea level rise over the last 18,000 years and has been relatively stable since 6-7,000 years. Nonetheless, the physical environment and the habitats it supports are still adapting to this change in environmental settings (Northern Marine Planning Section 2007). This characteristic should be considered when determining the importance of present day species biodiversity (Russell *et al.* 2008).

Offshore habitats include the wide and shallow continental shelf, soft sediment basins, narrow canyons, rocky shoals and coral reefs. Island chains, particularly in the eastern part of the Top End, provide a wide range of reef habitats and conditions (e.g. swift turbid water channelling between islands of the Wessel Islands). More sheltered bays and reefs support rich coral growth.

The coastline itself is a mixture of rocky cliffs, sandy beaches, broad mangrove forests and salt flats, becoming more complex where large rivers enter the sea. With a tidal range of nearly 8 m in the Joseph Bonaparte Gulf to 2-4 m along the Arnhem coastline and 2-0 m in the Gulf of Carpentaria. Low tides expose extensive mudflats and rocky reef flats. Mangroves are a significant habitat in the NT, in particular in sheltered bays and Gulf of Carpentaria, with 42% of Australia's mangrove communities being found in the NT (Duke 2006).

The following section describes the specific values of the NT coastal and marine environment, including the fauna, key habitats and the ecosystem processes that maintain them.

Figure 1 Marine and coastal environment of the Northern Territory.



2.1 Fauna

2.1.1 Marine mammals

Cetaceans

The current state of knowledge of cetaceans (dolphins and whales) in the Northern Territory has increased substantially over the previous 10 years compared to many other marine fauna. Recent large scale aerial surveys and intensive boat-based surveys has resulted in improved understanding of the distribution, abundance and movement of the most common coastal dolphin species. However, understanding the less common species and non-resident species that occur in Territory waters remains limited.

A total of 17 species of cetaceans occur in the Northern Territory (Appendix I). Of these, seven species are considered to be resident or occasional visitors. These species include the Australian snubfin dolphin (*Orcaella heinsohnii*), Australian humpback dolphin (*Sousa sahulensis*), dwarf spinner (*Stenella longirostris roseiventris*), false killer whale (*Pseudorca crassidens*), killer whale (*Orcinus orca*), humpback whale (*Megaptera novaegliae*) and Indo-Pacific bottlenose dolphin (*Tursiops aduncus*).

Coastal dolphins (Australian humpback dolphin, Australian snubfin dolphin and the Indo-Pacific bottlenose) rely on the waters of the NT and adjacent coastal areas for breeding and foraging (Brown *et al.* 2014; Brooks *et al.* 2017). A recent broad-scale helicopter survey found coastal dolphins were present along the extent of the NT coast (Palmer *et al.* 2017b). Bottlenose dolphins were significantly more abundant in coastal areas than in estuaries and the Australian snubfin and Australian humpback dolphins were broadly distributed around the coast (Palmer *et al.* 2017b). False killer whales also use NT coastal waters, with a recent study demonstrating individuals travelling up to 7,577 km in 104 days, with almost a third of their habitat use recorded within 10 km from the coast (Palmer *et al.* 2017a).

Humpback whales are the most common whale species recorded in the NT. They visit the NT coast annually in low numbers (<20 individuals) during calving migrations (July-October). The genetic stock remains undetermined due to limited sampling but it is likely that the humpback whales represent the upper range limit of the Western Australian stock. The calving period is a time when adult and calf humpback whales are vulnerable given their use of coastal waters for resting. Other whale species occur infrequently in NT waters and some are only known through stranding records (Chatto and Warneke 2000).

All of these cetacean species are listed as migratory and marine under the *Environment Protection and Biodiversity Conservation Act* (EPBC Act) and either Data Deficient or Least Concern under the *Territory Parks and Wildlife Conservation Act* (TPWC Act). The humpback whale is listed as Vulnerable under the EPBC Act.

Dolphin species feed on a wide variety of fish associated with inshore habitats (Parra and Jedensjö 2013). Preliminary information suggests that humpback dolphins in Australian waters exist as a meta-population of small and genetically isolated population fragments (Brown *et al.* 2014). They are known to occur in small numbers ranging from 15 to about 200 individuals per study area (Brown *et al.* 2016; Parra and Cagnazzi 2016; Brooks *et al.* 2017). Similar attributes have been observed for the snubfin and bottlenose dolphins. Combined with the slow life history patterns of dolphins, these features make these species potentially vulnerable to habitat degradation and fragmentation.

Threats to these cetacean species in NT coastal waters are not well-documented however, interactions with fishing gear (Allen *et al.* 2014), chemical discharge (Cagnazzi *et al.* 2013), underwater noise (Weilgart 2007; Paiva *et al.* 2015), prey depletion, habitat loss, and coastal development are some of the threatening processes that may impact cetaceans though these are poorly quantified in Australia, particularly the NT (Commonwealth of Australia 2012b; Brown *et al.* 2014; Mann and Karniski 2017).

Dugongs

Knowledge of the dugong populations in the Northern Territory is relatively robust compared to other marine animals. Large scale aerial surveys over the last 30 years, mostly in the Gulf of Carpentaria, have provided important information on the size and distribution of the population. In addition, extensive research into the demography and ecology of the species in Queensland and Western Australia is applicable to the Territory population.

The waters of the NT support significant populations of dugongs (Bayliss and Freeland 1989; Groom *et al.* 2017a). The most recent broad-scale dugong aerial survey for the NT estimated a population of 8,176 (± 958) (Groom *et al.* 2017a). The population is distributed across the entire coastal waters of the NT but the majority (almost 60%) occurs in the Gulf of Carpentaria. Other high density regions include the Tiwi Islands and Cobourg Peninsula. The dugong is listed Near Threatened under the TPWC Act and migratory species under the EPBC Act.

Dugongs are strictly marine herbivores, feeding on seagrass habitats in the coastal zone usually in waters <10 m deep (Grech *et al.* 2011). They have been observed to undertake movements at local scales as well as long distance (100s of km in a few days) (Sheppard *et al.* 2006).

The population biology of dugongs makes them particularly vulnerable to mortality as adults (Marsh *et al.* 2011). Dugong demography is characterised by long lifespans (greater than 70 years), long gestation (12–14 months), single offspring, long intervals between births (more than 2.5 years), prolonged periods until sexual maturity (6–17 years) and high and temporally stable adult survival (Marsh *et al.* 1984). Adult survival is the most important determinant of population growth. The maximum rate of population increase under optimum conditions when natural mortality is low is approximately 5 per cent per year. The maximum sustainable mortality rate of adult females killed by human activities is approximately 1 or 2 per cent (Marsh *et al.* 1997; Heinsohn *et al.* 2004; Marsh *et al.* 2004), and lower when food supplies are low. Given their reliance on seagrass beds, dugong populations may be at risk from changes in the extent of seagrass meadows caused by anthropogenic sources (Grech *et al.* 2011) or natural disturbances such as cyclones (Meager and Limpus 2014).

2.1.2 Birds

The current state of knowledge is based on extensive aerial and ground surveys conducted in the 1990s. While the majority of this information on shorebird and seabird distribution is still relevant, it is likely that there have been significant changes in abundance due to changes in the population status for many species due to impacts in countries that they migrate to (Garnett *et al.* 2010).

The Northern Territory is home to significant populations of marine and migratory bird species. The coast and seas provide important breeding and foraging habitat for a diverse range of breeding and non-breeding bird species. There have been 33 species of shorebird bird species recorded in the Northern Territory (Chatto 2003). Of these, 26 species are likely to represent >1% of total Australian population, which classifies them as significant under the EPBC Act. The largest populations of shorebirds in the NT include Anson and Fog Bays on the west coast, Van Diemen Gulf east of Darwin, Castlereagh and Buckingham Bays and the Cadell Straits on the north coast, and the Limmen Bight River and Port McArthur on the east coast (Chatto 2003).

The Northern Territory coast and offshore islands contain significant breeding colonies of seabirds (Chatto 2001). The group is dominated by Terns but also includes species such as Gulls and Noddys. The main species include Silver Gull, Caspian Tern, Lesser Crested Tern, Crested Tern, Roseate Tern, Black-naped Tern, Little Tern, Bridled Tern and Common Noddy. Almost 150 individual breeding colonies have been recorded, the largest being >60,000 individuals (Chatto 2001). The breeding colonies occur predominantly on northern and eastern coasts of the Northern Territory, in particular the area from north east Arnhem Land to Groote Eylandt and the Sir Edward Pellew Islands (Chatto 2001). Importantly, all species use the seas for foraging.

Waterbird populations occur throughout the coast and offshore islands of the Northern Territory (Chatto 2006). Colonial waterbirds include species of egrets, herons, cormorants, ibises, and the Australian Pelican, Darter and Royal Spoonbill. This includes nationally and globally significant numbers of colonial nesting waterbirds, particularly Intermediate, Great, Little and Cattle Egrets. Mangrove forests are used by 14 of the 15 waterbird species for breeding sites (Chatto 2006). The most important areas for colonial waterbird breeding were the floodplains between the Moyle and Finniss Rivers and between the Adelaide River and Murgenella Creek.

There are numerous threats to migratory shorebirds and seabirds. The loss or degradation of breeding and foraging habitat is the most significant factor responsible for observed declines; however, regional climate change and possibly micro-plastics are possible future threats (Sutherland *et al.* 2012).

2.1.3 Marine reptiles

Marine turtles

The current state of knowledge of the Northern Territory's marine turtles is mainly confined to the distribution of nesting beaches. This is based on extensive aerial and ground surveys conducted in the 1990s (Chatto and Baker 2008), and while the majority of this information is still relevant, it is likely that there have been significant changes over time. Much less is known on the ecology and demography of marine turtles in the Northern Territory, although research from Australia and overseas is relevant to the populations occurring here.

Six of the seven species of marine turtles inhabit the coastal waters of the Northern Territory. The region supports globally significant populations of green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*) and flatback (*Natator depressus*) turtles. There is also a nationally significant population of Olive Ridley (*Lepidochelys olivacea*) turtles. All species nest in the NT apart from the loggerhead turtle (*Caretta caretta*), including the only remaining recorded nesting for the leatherback turtle (*Dermochelys coriacea*) in Australia.

All six species are listed as threatened and migratory under the EPBC Act. Under the TPWC Act, one is Critically Endangered, three are Vulnerable, one Near Threatened and one Data Deficient (Appendix I).

The coastal waters of the Territory provide foraging habitat for marine turtles from multiple populations from other national and international jurisdictions including Queensland, Western Australia, Timor Leste and Indonesia. Some turtles that nest on the Territory coast spend most of their time foraging in other jurisdictions whilst others forage exclusively within NT waters (Commonwealth of Australia 2017). The Gulf of Carpentaria, in particular the south-west region is a significant foraging habitat for marine turtles (Commonwealth of Australia 2017). Based on aerial survey, the highest turtle density in NT waters was recorded in the Limmen Bight region with a density of 18.7 turtles per km2 (Unpublished data, Groom *et al.* 2017).

There is limited understanding of the long-term trends in abundance and nesting of marine turtles in the Northern Territory. The flatback turtle is the only species that has been monitored. The analysis of long-term nesting population abundance and trend was investigated on Field Island (Kakadu National Park) the population was found to be relatively small with a few hundred nesting turtles and generally stable (Groom *et al.* 2017b). This may be indicative of other NT flatback turtle nesting sites but further study is required. Other nesting studies on flatback turtles in the NT have not been analysed to date and no other population abundance estimates on NT nesting stocks are available.

There are multiple pressures affecting marine turtles in the Northern Territory. These include but are not limited to: marine debris (Wilcox *et al.* 2012); interactions with commercial fisheries (Riskas *et al.* 2016); habitat (seagrass, reef, open water, nesting beaches) degradation and loss; unsustainable use; lighting near nesting beaches (Kamrowski *et al.* 2012; Kamrowski *et al.* 2014); underwater noise; predation and climate change affecting sea-level rise; nesting temperatures (Jensen *et al.* 2018) and habitat quality (Butt *et al.* 2016; Commonwealth of Australia 2017). These pressures affect different turtle species at different stages of their life-cycle and vary depending upon their location. Accounting for existing threatening processes in a region is important when assessing potential project impacts to a population as there is likely to be a cumulative effect (Groom *et al.* 2018).

Saltwater crocodiles

The Northern Territory represents saltwater crocodile (*Crocodylus porosus*) populations have recovered strongly across northern Australia since their protection more than 30 years ago (Webb *et al.* 2010). Monitoring studies show large geographical variations in abundance across northern Australia with the NT having considerably higher densities than adjacent jurisdictions (Fukuda *et al.* 2007). Standardised monitoring that began in 1975 provides longitudinal relative density indices (1975–2009) as a record of their post-protection recovery. The current estimate of crocodiles (not including hatchlings) is estimated to be in the order of 80,000–100,000 individuals (Y. Fukuda, NT Department of Environment and Natural Resources, unpublished data). The high reproductive capacity of *C. porosus* has contributed to its successful recovery.

The saltwater crocodile is referred to as an opportunistic feeder and uses either an 'active hunting' or an 'ambush' strategy (Cooper-Preston and Jenkins 1993). Its primary food sources are crustaceans, insects, fish, amphibians and small mammals with larger crocodiles consuming larger mammals. Studies indicate that in areas of higher salinity (mangroves), crocodiles eat larger volumes of crab and a smaller volume of shrimp, fish and insects. In freshwater swamps and upper mangroves, individuals consumed more insects (Taylor 1979). The saltwater crocodile is highly adapted to saline environments, predominantly select freshwater habitats for nesting (Fukuda and Cuff 2013). Nest site selection seems to be influenced by multiple factors, including freshwater habitats being more available than saline habitats, physiological advantages of freshwater to nesting females and/or hatchlings, and the suitability of the ground layer vegetation for constructing mound-like nests. Vegetation communities may be used to assess the suitability of nesting habitat for management and conservation purposes (Fukuda and Cuff 2013).

Threats to the saltwater crocodile include mortality due to fishing nets and the effects of habitat destruction (Taplin 1987). In Arnhem Land, Northern Territory, feral animals such as the buffalo (*Bubalus bubalis*) destroy wetland habitat by increasing drainage and reducing vegetation (Webb *et al.* 1987).

Sea snakes

The NT coast and seas are an important area for sea snakes and is one of the richest areas for sea snakes along the Australian coastline. It has all the widely distributed Australian species of true sea snakes and two regional endemics: the mud snake species and marine file snake.

More than 20 species are known to occur in the region and are all listed as Marine species under the EPBC Act (National Oceans Office 2004; Commonwealth of Australia 2012a). Under Northern Territory legislation, some species of sea snake such as *Aipysurus laevis* and *Hydrophis elegans* are listed as Least Concern because they are believed to be wide spread and abundant. Others such as *Enhydrina schistosa* and *Hydrophis czeblukovi*, are considered Data Deficient (National Oceans Office 2004).

Sea snake life histories are characterised by relatively long-lived individuals, growing slowly after birth and taking at least several years to reach sexual maturity. Females produce smaller broods in their early breeding years and have long gestation periods with only one brood per year or every second year as resources allow (National Oceans Office 2004).

The distribution of sea snakes is influenced by seasonal factors associated with either mating or breeding aggregations of gravid females. Such aggregations for *Aipysurus eydouxii* presumably occur in estuaries across northern Australia (Limpus 1975). Sightings of large aggregations of sea snakes were recorded around and to the south of the Wellesley Islands, to the north and west of Groote Eylandt (COMALCO 1993).

Sea snakes utilise a variety of habitat types including shallow waters near land, around islands, coral reefs, somewhat sheltered waters, as well as near estuaries and mangrove swamps (Stidworthy 1974; Rasmussen 2001). They have also been reported swimming up rivers, 160 km from the sea (Rasmussen 2001). Pelagic species such as *Pelamis platurus*, are found in drift lines or slicks of floating debris brought together by surface currents (Dunson and Ehlert 1971).

Sea snakes feed selectively on small fish, their eggs and eels (National Oceans Office 2004). As specialist feeders, any increase in turbidity that impacts on either their prey or their ability to detect their prey would impact negatively on sea snake populations. Sea snakes are vulnerable to human-induced pressures because of their slow growth rates and low fecundity (Heatwole 1997). Impacts such as dredging or increased boat traffic have the potential to disrupt normal feeding activities. Additionally, the noise generated by increased boat traffic and associated machinery is a source of potential disruptive noise pollution capable of displacing sea snakes out from important habitat (Commonwealth, 2012). Boat strikes are a common cause of sea snake mortality in areas where sea snakes and small boats share the same waterways (National Oceans Office 2004). The greatest source of mortality to sea snake populations in NT waters is commercial fishing. The annual trawler bycatch of sea snakes during 1984 to 1986 in the Gulf of Carpentaria was estimated at almost 120,000 sea snakes, of which, almost half of the individuals died (Wassenberg *et al.* 1994). Similar catch rates were recorded in the Gulf of Carpentaria in 1989 and 1990 (Ward 2000).

2.1.4 Fish

Our current state of knowledge is largely around taxonomic knowledge through numerous species inventories and a broad understanding of fish fauna distribution from a regional perspective. We have a poor understanding of the environmental drivers that determine fish fauna distribution, their life histories and habitat use, and connectivity of fish populations within and between subregions, such as Gulf of Carpentaria, Arafura and Timor Seas and Joseph Bonaparte Gulf.

The Northern Territory has a diverse fish fauna. Some 1474 fish species (195 families) have been found to occupy a diverse range of Northern Territory (NT) marine and freshwater habitats (Larson *et al.* 2013). The most speciose family is the Gobiidae (gobies) with 150 species and inhabit coral reefs and mangroves (Larson *et al.* 2013). The Northern Territory's fish fauna is grouped within the Central Indo-Pacific region (Kulbicki *et al.* 2013) and most closely resembles that of north-western Western Australia (Larson *et al.* 2013). Most of these species are not unique to northern Australia, with only about 14% of fish species are endemic to tropical Australia, and only 2.1% of fish species are endemic only to the NT (Hoese *et al.* 2006). Nevertheless, within northern Australia there are three sub regions with distinct boundaries at the Torres Strait and NW Western Australia (Russell *et al.* 2008) provides a comparison between fish communities of Melville Bay and adjacent seas.

Among the Northern Territory's fish fauna there are 56 species considered to be threatened under various listings (TPWC Act, EPBC Act). For some species, NT waters may be one of the few remaining geographical regions where viable populations remain in Australia (Pogonoski *et al.* 2002), however, the poor state of knowledge of the NT's fish populations and their true distributions hinders assessment (Larson *et al.* 2013).

Besides being of economic importance, fishes are the major predator within the marine ecosystem. As such, they have a far reaching role in balancing the trophic structure within the ecosystem and structuring habitats (Blaber 2000). The reverse is also true, in that, large changes in habitat characteristics or loss of habitat, can lead to changes in fish community structure, which is often irreversible.

Biological surveys can be traced back as far as 1803, when Mathew Finders and Robert Brown visited northern Australia (Specht 1964). The majority of the scientific information collected in the early 1800s are centred on Port Essington. More recently, fish assemblages have been described for assessing the biological values within the economic development, fisheries or conservation context (e.g. Darwin Harbour, Nhulunbuy, Groote Eylandt, Bing Bong, Kakadu National Park, Arnhem Land and Gulf of Carpentaria). At least 460 bony fish and 56 cartilaginous species (e.g. sharks and rays) have been recorded as bycatch from trawl fishery in coastal areas of the NT.

Although, sampling seems to be extensive, many information gaps remain. Specifically, sampling in tandem with environmental and habitat characteristics to allow for a better understanding of environmental drivers for fish distribution and abundance (e.g. determining physiological tolerances) and habitat use by fishes in terms of their breeding, feeding and migration traits (Blaber 2000). Much of the life history of fishes is unknown (Larson *et al.* 2013), except for a few commercial species, such as barramundi (Griffin 2007). In particular, there is a lack of understanding which habitats are important for spawning and which are important as juvenile refuge/feeding areas. It is important to note that juveniles and adults are often partitioned across different environmental niches and therefore assessments of impacts requires assessments across multiple habitats that are important for the different life histories of fishes (Galaiduk *et al.* 2017). Further, there is insufficient information about the connectivity between regions and the movement of fish between regions and local scales (e.g. habitats). Understanding fish population connectivity plays a fundamental role in local and metapopulation dynamics, community dynamics and structure, genetic diversity, and the resiliency of populations to human exploitation (Cowen *et al.* 2007; Berkström *et al.* 2013).

It is difficult to identify specific threats to many fish species because there is very little known about their ecology and biology. Natural variability (seasonal and long-term climate variability) and large weather events (cyclones and storms) all play a role in structuring marine and coastal

environments (Booth *et al.* 2011). However, habitat degradation and loss as well as activities that change ecosystem processes that underpin the entire life cycle of fishes are likely threats that have the potential to change whole ecosystem functions. For example, activities that lead to a reduction in oxygen content in the water (e.g. dredging, habitat destruction) can change the escape behaviour of prey and swimming and feeding behaviour of predators. This has the potential to cause major changes in the relative pathways of different energy pathways in estuarine food webs.

2.1.5 Invertebrates

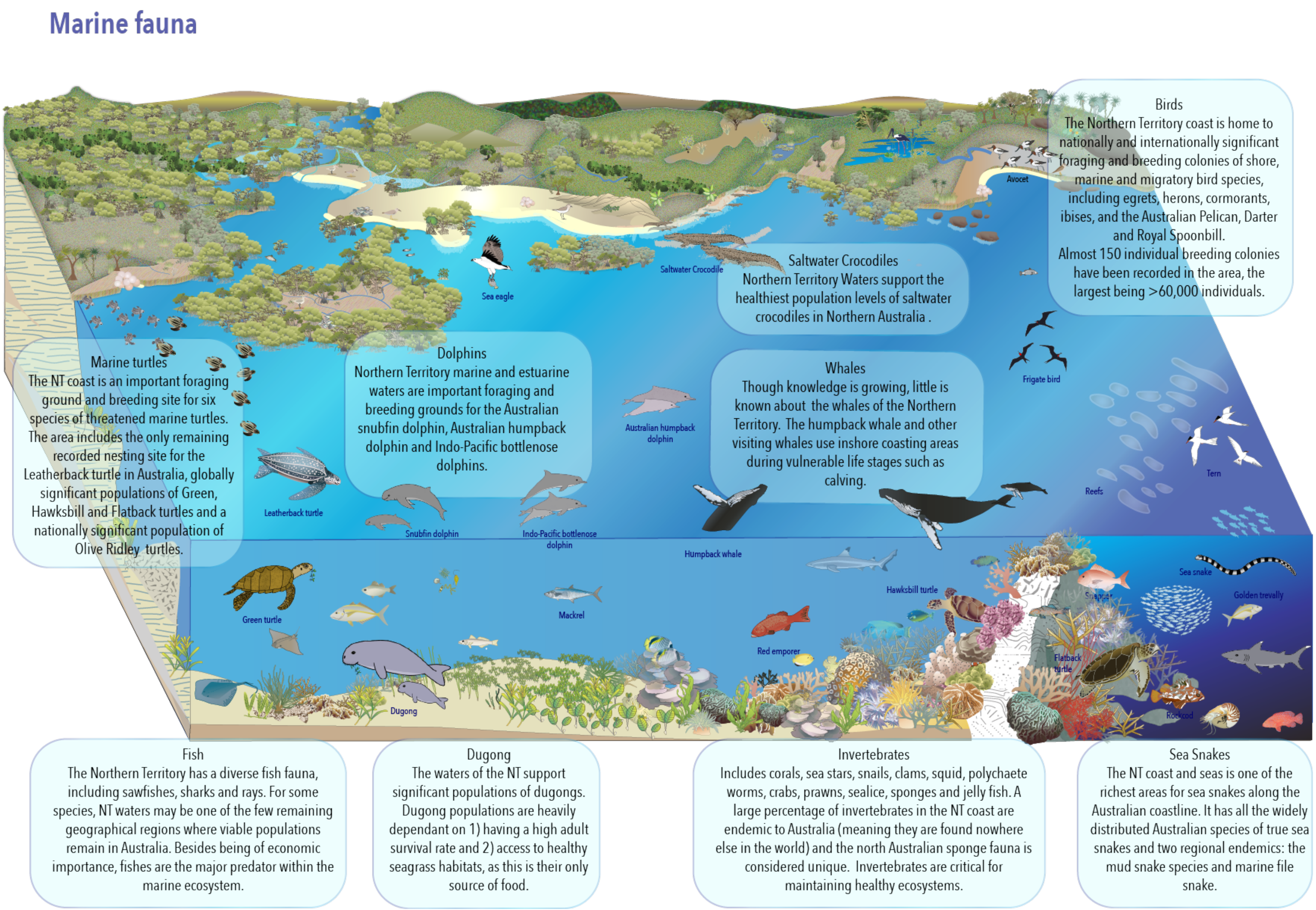
The state of knowledge of taxonomy, biological and ecological knowledge of marine invertebrates in the Northern Territory is generally poor. From a taxonomic perspective, intertidal and shallow waters of the Darwin region are relatively best understood, while remaining coastal areas and deeper offshore invertebrate fauna are virtually unknown. A large percentage of identified species are endemic to Australia and the north Australian sponge fauna is considered unique. There is an acknowledgement that invertebrates are critical for maintaining healthy ecosystems, however, we have a poor understanding of the key drivers for invertebrate distribution, the habitats they depend on, and their specific roles within the coastal and marine ecosystems.

Most of the existing data (taxonomic and distribution) resides with museums and has been collected through a number of surveys across a number of regions. The purpose of many of the surveys are around describing the biological values (e.g. Commonwealth Marine Parks, (Heap *et al.* 2010), (Przeslawski *et al.* 2011), Beagle Gulf (Smit *et al.* 2000), NW Arnhem Land (Russell and Smit 2007), Gulf of Carpentaria (Harris *et al.* 2006; Post 2006). The number of species present in NT waters is largely unknown, however, a collation of existing taxonomic databases estimates that there are approximately 12,500 marine taxonomic units and there are about 3000 species in Darwin Harbour alone. Among the Northern Territory's invertebrate fauna there are no species considered to be threatened / endangered under various listings (TPWC Act, EPBC Act).

Marine invertebrates include all members of the animal kingdom, except vertebrates and include, for example, snails, clams, squid, polychaete worms, crabs, prawns, sealice, sponges, jelly fish, corals and sea stars. They range from microscopic to several metres in size. They can be found in all environments and live in a wide range of habitats, including the open water (pelagic), on the seafloor (epifauna - reefal habitats, mangroves, intertidal and subtidal mud/sand flats and shelfs) and within the sediments (infauna). Their importance cannot be underestimated. All exploited marine fauna depend on invertebrates either directly or indirectly and marine ecosystems would collapse without their services. Their ecological and biological importance can only be broadly described, with even the best studied species; their environmental envelope is poorly understood. In broad terms, they form the basis many ecosystem processes, including:

- recycling of nutrients, where they breakdown of organic matter and detritus (e.g. mangrove crabs consume 30-80% of mangrove litter);
- oxygenating and irrigation of sediments which allows the majority of bacteria to

Figure 2 Summary of marine fauna of the Northern Territory's coastal and marine environment.



breakdown organic matter and nutrients (Gray and Elliot 2009);

- stabilising ecosystems and carbon sink and allowing energy and nutrient transfer between trophic groups;
- regulating water quality (invertebrate filter feeders filtering water) and sediment quality (infauna processing organic matter to improve sediment quality);
- provide habitat and structure for other flora and fauna (e.g. a sponge can have over 100 invertebrate species living on/in it); and
- play a key role in reproductive cycle of other marine fauna and flora (refuge, predation, herbivory and parasitism).

Some invertebrates (e.g. all corals, some sponges and soft corals) form symbiotic relationships with photosynthetic organisms, such as blue-green algae, micro and macro algae. These invertebrates are entirely or somewhat dependent on light for survival.

As there is a lack of understanding about the key drivers for invertebrate distribution, the habitats they depend on, and their specific roles within the coastal and marine ecosystems it is difficult to identify specific threats from seabed mining activities to invertebrates. There is a considerable risk that without this knowledge, it will not be possible to make an informed decision about the impacts that seabed mining may have on invertebrate fauna and the ecosystem processes that they control. However, degradation and loss of habitat and activities that change ecosystem processes are likely to impact on the ability of invertebrates to effectively contribute towards maintaining the ecosystems in its original state.

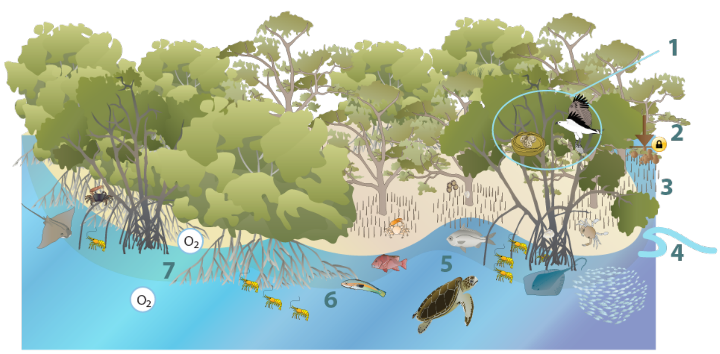
2.2 Habitats

2.2.1 Mangroves

Our current knowledge of mangroves in the Northern Territory is based on distribution of mangrove vegetation communities which have been mapped at a scale of 1:100,000 along the Territory's coastline (Brocklehurst and Edmeades 1996) and in Darwin Harbour and Bynoe Harbour at finer resolution of 1:25,000 (Brocklehurst and Edmeades 2003). In addition, the geomorphological dynamics and evolution of mangroves forests have also been studied in detail (Woodroffe *et al.* 1989).

The mangrove communities of the Northern Territory are floristically diverse containing 51 species, they cover over 4000 km of the coastline and river systems and comprise over one third of Australia's mangrove resource (Wightmann 2006). The most floristically diverse regions of the Top End occur in north-west and north-east corners where over 40 species have been

Figure 3 Summary of values of mangrove habitat in the Northern Territory.



Values of mangrove habitats

The mangrove communities of the Northern Territory are floristically diverse containing 51 species. They occur over 4,00km of the coastline and river systems and comprise over one third of Australia's mangrove resource. They are the most pristine mangroves in Australia, and probably the world.

Mangroves provide:

1 Nesting sites for 14 of the 15 sea bird species
2 Carbon capture and storage
3 Shoreline stabelisation
4 Storm surge protection
5 Habitat for terrestrial and aquatic fauna (e.g. fish, crustaceans, turtles and dolphins)
6 Nursery grounds and habitat for economically important fish and shellfish species
7 Improve water quality (reducing nutrient load and suspended sediments) and releases oxygen into the water column during the day, as well as oxygenate the sediment

recorded in one degree latitude grid cells (Wightmann 2006). They are the most pristine mangroves in Australia, and probably the world.

Mangroves play an important role in coastal and marine environments, including habitat for terrestrial and aquatic fauna (e.g. fish, crustaceans, turtles and dolphins), storage of carbon and mitigation of coastal erosion (Figure 3). Australia's coastline is lined by approximately 11,000 km of mangrove vegetation (~18%) and this represents the third largest area of mangroves in the world. Importantly, they contain many species that are used by Aboriginal people.

There are no listed threatened mangrove species under Commonwealth or Northern Territory legislation. However, there are a number of very rare species and single endemic species, *Avicennia integra* to the Northern Territory with small and isolated populations. Collectively, mangroves are classified as "Sensitive Vegetation" under the Planning Scheme in the *Northern Territory Planning Act*.

Between late 2015 and early 2016 extensive areas of mangrove vegetation died along 700 km of the coastline of Australia's remote Gulf of Carpentaria (Duke *et al.* 2017). The dieback was severe and widespread, affecting around 7000 ha of mangrove vegetation from the Roper River estuary in the Northern Territory to near Karumba in Queensland. Based on preliminary investigations, this dieback event was co-incident with periods of notably high temperatures and coral bleaching along the north-eastern coastline of Australia. This unusually severe dieback of mangroves is the first recorded instance of its kind attributed to drying conditions and high temperatures, likely associated with climate change. Recovery of mangrove vegetation is likely to be dependent on a return to normal wet season conditions.

2.2.2 Submerged aquatic vegetation

Submerged aquatic vegetation represent plant communities that live in marine and estuarine environments, and seagrass and seaweed are the most common (Figure 4). It does not include corals and other invertebrates that are symbiotic with blue-green, macro or micro algae. The Northern Territory marine environment contains important areas of these habitats.

Seagrass

Our current knowledge of seagrasses in the Northern Territory is mainly around the distribution of seagrass species and meadows in intertidal areas. Much of our knowledge comes from helicopter surveys along the north and west coasts (e.g. Van Diemen Gulf, northern Arnhem Land and Gulf of Carpentaria) (Roelofs *et al.* 2005a), surveys in the Gulf of Carpentaria related to their importance to the northern prawn fishery (Poiner *et al.* 1987;

Poiner *et al.* 1989), and activities around seagrass monitoring in the Darwin Harbour region. Subtidal seagrass communities are much less understood, in particular their extent, the environmental characteristics that influence their distribution and change in extent; and the role that they play within the ecosystem.

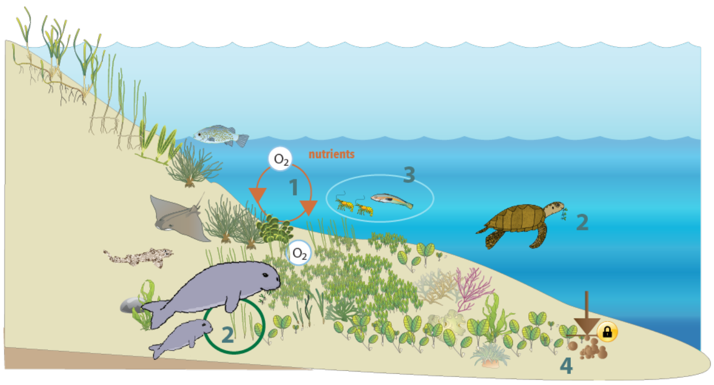
There are about 34 species in Australia, of which about 15 occur in northern Australia and 11 in the Northern Territory (Short and Coles 2001; Coles *et al.* 2004; Roelofs *et al.* 2005b). Species diversity increases from two to three species in the western NT to 11 to 13 species the Gulf of Carpentaria (Russell and Smit 2007), (Poiner *et al.* 1987; Poiner *et al.* 1989). Melville Bay in north east Arnhem Land has a unique *Enhalus* meadow that is extensive and is more comparable to those occurring in Papua New Guinea and south east Asia.

Seagrass communities in the NT are considered to be restricted to the littoral zone, ephemeral and consist generally of pioneer species. In general, seagrass cover is low for genera such as *Halodule, Halophila* and *Syringodium*. Poiner (1989) reports that seagrass is not solely restricted to muddy sand substrates, and can also occur on reefs (10%). There seems to be some zonation in the distribution of seagrass with depth, with *Halodule* preferring high intertidal, *Halophila* low intertidal/shallow subtidal, *Syringodium* and *Cymodocea* shallow subtidal. This is likely to be caused by light availability, turbidity and tidal exposure. However, *Halodule ovalis* has been found to grow at depths of 20 m in SE Gulf of Carpentaria (Coles *et al.* 2004) and may indicate that seagrass could occur in areas that have not yet been surveyed or even considered as a suitable seagrass habitat. Similarly, the distribution of dugong also seem to point towards extensive subtidal seagrass meadows that have not yet been characterised (e.g. Hays *et al.* 2018).

Seagrasses are important for nutrient cycling, stabilising sediments and provide food for dugong and green turtle, and refuge for juvenile fish, shellfish and invertebrates (Hemminga and Duarte 2000). In particular, seagrasses in the Gulf of Carpentaria are considered important as juvenile habitat for four species of prawns that are commercially important to the Northern Prawn Fishery (Poiner *et al.* 1987).

Our understanding of the environmental characteristics that influence seagrass distribution, biomass and composition in the Northern Territory is poor. This makes it is difficult to fully assess the role that seagrass plays within the broader marine ecosystem. Threats to seagrass include changes in environmental conditions such as hydrological currents, sediment characteristics, suspended sediment, light availability, water quality, nutrient availability as well as climate change (Orth *et al.* 2006; Unsworth *et al.* 2012, Hanington *et al.* 2014).

Figure 4 Summary of submerged aquatic vegetation (seagrass and algae) in the Northern Territory.



Values of submerged aquatic vegetation (seagrass and algae) habitats

1 Submerged aquatic vegetation improve water quality (reducing nutrient load and suspended sediments) and release oxygen into the water column during the day, as well as oxygenating the sediment
2 Generate primary production and provide food for a variety of animals, including dugong and sea turtles
3 Are a refuge for juvenile fish and invertebrates
4 Sequester carbon and stabilise sediments

Algae

There is very little information on the distribution, extent and importance of seaweeds in the Northern Territory. This is a major gap in our knowledge.

Seaweeds, or macro algae, are grouped into three broad groups: Red, Green and Brown. Red algae have over 1300 species in Australia, they never form extensive beds and are small to medium size. Green algae have over 2000 species in Australia and have the widest distribution from marine to freshwater. Brown algae having about 350 species in Australia are the most conspicuous group, restricted to marine environment, generally medium to large size). Besides macro algae, phytoplankton and blue-green algae (not a true algae but photosynthetic bacteria and can take on a filamentous/bulbous appearance) are present in northern Australia waters.

Macro algae and benthic phytoplankton are an important component of shallow water estuarine and marine environments. They are the primary producers and form the basis of trophic pathways. Besides playing an important role in the food chain, they are important by providing refuge for juvenile and adult fish and shellfish, reducing sediment mobility, buffer the environment from wave actions and currents, improving water quality by reducing nutrient load and suspended sediments.

The environments are generally shallow, as they are dependent on light penetration. A key environmental driver of algae is light availability at the seafloor and suitable substrate type. Light availability is dependent on water quality parameters (turbidity, suspended solids, chlorophyll a content, nutrient levels (dissolved inorganic and phosphorous concentrations).

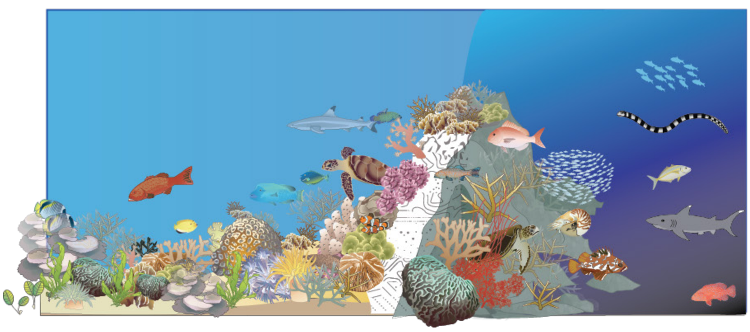
2.2.3 Reefs

The coastal and marine environment of the NT is surrounded by extensive reef habitat. However, our knowledge of the distribution and composition of reefs is limited. Reef ecosystems are among the most biologically diverse and economically important. They provide ecosystem services that are vital to human societies and industries through fisheries, coastal protection, building materials, new biochemical compounds, and tourism (Moberg and Folke 1999) (Figure 5).

Most NT reefs are shallow and have only been recently established (since the last ice age 7-9000 years ago). However, a number of 'deeper' water reefs have been located in the Gulf of Carpentaria within a very narrow depth range (26-31 m depth) and are considered to have existed for several glacial cycles, extending over at least the past 120,000 years. These reefs are slow growing and need protection, because of their limited capacity to recover from natural and human-induced disturbances (Harris *et al.* 2004; Harris *et al.* 2006).

The coral communities around Northern Territory coastal waters have developed on a

Figure 5 Summary of reef habitat values in the Northern Territory.



Reef habitat values

The extensive coastal and marine reefs of the Northern Territory are biologically diverse and economically important. Reefs provide ecosystem services that are vital to human societies and industries through fisheries, coastal protection, building materials, new biochemical compounds and tourism.

terrigenous substrate (Veron 2004). The composition and condition of these reef habitats is not well documented with only some detailed studies available from Darwin Harbour, Cobourg Marine Park, Arnhem Land and some parts of the Gulf of Carpentaria (Wolstenholme *et al.* 1997; Veron 2004).

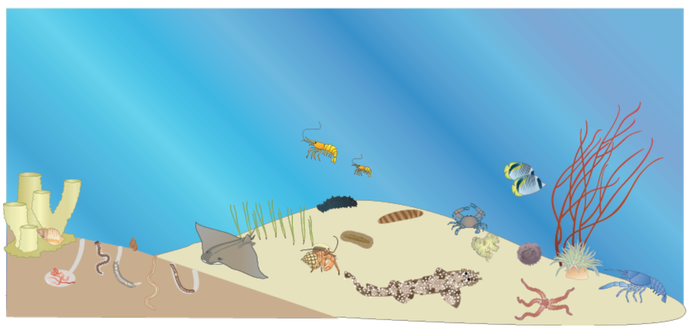
Although limited, the sites that have been surveyed in the NT are recognised as having diverse assemblages of hard corals (Wolstenholme *et al.* 1997; INPEX 2013). Wolstenholme *et al.* (1997) suggest that strong tidal currents in Darwin Harbour are one of the factors explaining the diversity of species surviving in such a turbid environment as they reduce the effects of sedimentation by physically removing the sediment from the surface of colonies periodically. Hard coral communities are found from the lower subtidal to 5-10 m below lowest astronomical tide (LAT) in areas where there are strong currents. These coral species are tolerant to the variable salinity, high turbidity and sedimentation that exclude most coral species. A total of 123 species of corals has been recorded in Darwin Harbour (Wolstenholme *et al.* 1997).

Arnhem Land is known to have the eastern-most limit of a number of Western Australian coral species and the western-most limit for some species found in eastern Australia with apparently little immigration from Indonesia (Veron 2004). Coastal Arnhem Land also has several coral species which appear common but are rare elsewhere in Australia. Whilst on survey in Arnhem Land in 2004, Veron (2004) noted a relative lack of bleaching which was unexpected given bleaching had been recorded on eastern and Western Australian coasts, he referred to the sites surveyed as 'in pristine condition'.

Most corals obtain the majority of their nutrition autotrophically, so prolonged and elevated levels of turbidity and light attenuation may eventually result in mortality. Fluctuations in light and variable rates of sedimentation occur naturally in the NT due to regular resuspension of particulate matter during large tidal change, as well as during storms and cyclones. Sedimentation is a stress to corals because they may need to invest energy into the removal of sediment from their surface to prevent partial mortality and colony death (Cortés and Risk 1985). Turbidity refers to the amount of particulate matter suspended in the water column; this increases light attenuation and therefore the amount of photosynthetic active radiation available to symbiotic algae in corals (zooxanthellae). When the photosynthetic output of a coral's zooxanthellae is reduced, the coral may become stressed as there will be a reduction in the amount of autotrophic nutrition obtained by the coral (Philipp and Fabricius 2003).

Coral reefs are in decline worldwide due to a combination of increasing local and global anthropogenic pressures (Le Nohaic *et al.* 2017). Rising atmospheric CO_2 concentrations are causing ocean warming, which leads to more intense and frequent mass coral bleaching events. The most devastating coral bleaching has occurred during El Nino events, with bleaching reported to be a direct result of increased sea surface temperatures (SST). However, El Nino itself does not cause SST to rise in all regions that experience bleaching (McGowan and Theobald 2017). Bleaching most commonly occurs during periods of thermal stress when

Figure 6 Summary of soft sediment habitat values in the Northern Territory.



Soft substrate habitat values

Soft sediment substrate forms a vital habitat for many invertebrate organisms including polychaetes, amphipods, bivalves, sponges, gorgonians, echinoderms and decapods (e.g., crabs and prawns) and some species of fish.

The fauna and flora that live on and in the sediments are the basis for many fish and bird feeding activities, nutrient cycling and locking up pollutants and contaminants. They are critical in maintaining a healthy marine ecosystem.

corals lose their algal dinoflagellate symbionts (*Symbiodinium* spp.), resulting in a pale or white appearance of the coral colony. A reduction in water quality is also a major contributor to the degradation of coral reefs (De'ath and Fabricius 2010).

2.2.4 Soft substrate habitats

Our current knowledge of soft substrate habitats is tied to our knowledge about the distribution and taxonomy of marine invertebrates. Systematic mapping and/or characterisation has only occurred in a few areas, including Darwin and Bynoe harbours, Beagle Gulf and Gulf of Carpentaria. Soft substrate marine habitats are the dominant habitat in NT waters.

Soft substrate habitats are the results of suspended matter being deposited under favourable environmental conditions onto the seafloor, and thus creating sediments. Many of the physical and biological processes associated with sediments work on different spatial scales and different sediment depths. As a result, sediments are three dimensional, highly variable spatially and temporally.

Sediments form a habitat for many invertebrate organisms and some species of fish. Benthic organisms can be characterised by their mobility (or lack of) and their position on and in the sediment (epifauna, infauna respectively) (Figure 6). Only a small percentage of seafloor fauna/flora can be on the surface, with most buried in the sediments. They range from microscopic (bacterial) to several metres in size. In general terms, the number of individuals decrease from micro to macro invertebrate; the reverse is true for species diversity. The most common macro-fauna (animals > 0.5 mm) are polychaetes (marine worms), amphipods, bivalves, sponges, gorgonians (e.g. sea fans, sea whips), echinoderms (e.g. sea stars, sea cucumbers) and decapods (e.g. crabs and prawns).

The distribution of benthic communities in NT waters is largely unknown. The general consensus is that they are patchy by nature, reflecting the highly spatially and temporal variability of the distribution of sediments. In some cases, epifauna can form dense communities of sponge gardens that can rival the species richness of rocky reefs. These epibenthic communities are important refuge, breeding and feeding habitats for a wide range of marine fauna (including juvenile and adult fishes and invertebrates). Other areas form monospecific stands of, for example, marine worms.

The fauna and flora that live on and in the sediments are the basis for many fish and bird feeding activities, nutrient cycling and locking up pollutants and contaminants. They are critical in maintaining a healthy marine ecosystem.

Many anthropogenic activities have an influence on the ecological drivers that characterise a soft substrate habitat. These can be of physical (changes in sediment load and sediment type, turbidity, built structures and changes in hydrodynamics, removal of habitat); chemical (pollutants/contaminants) and biological (introduced species, pathogens) nature.

2.3 Coastal and marine processes

The NT marine and estuarine environments are largely characterised by shallow (50-200 m), flat shelf with scattered troughs, shoals and banks and the remains of two large basins Gulf of Carpentaria and Joseph Bonaparte Gulf. The NT is broadly divided into three geomorphic provinces: Gulf of Carpentaria, Arafura Shelf and Sahul Shelf. The Sahul Shelf contains the Joseph Bonaparte Gulf.

Important characteristics that have shaped the NT coastal and marine environment include: ocean levels became recently stable (6-7000 years ago) so relative new environment with many species still colonising it; a shallow shelf environment; a strong influence of seasons and the semi-enclosed nature of Gulf of Carpentaria waters and season changes in vertical mixing.

The tropical marine environments that are unique within the Australian margin, with large-scale processes and drivers that are important in determining and maintaining the ecological character of the region are discussed and illustrated (Figure 7).

2.3.1 Primary productivity and nutrient cycling

The northern Australian shelf is considered shallow, relatively warm sea that supports high productivity. Freshwater runoff during the wet bring nutrients into the deeper waters and warmer waters support high primary production from phytoplankton communities (Burford *et al.* 2008; Burford *et al.* 2012). Dry season conditions restrict primary production to the coastal zone.

With changes in environmental conditions (cooling of water, nutrient load being absorbed by phytoplankton, little nutrient input from coastal rivers during the dry), phytoplankton die off and slowly sink through the water column providing a food source for primary consumers (zooplankton). Zooplankton in turn feed filter feeders (juvenile and adult invertebrates) which in turn are a food source for high order carnivores (e.g. crustaceans, fishes).

Decomposition can either happen in the water column or on/in sediments. First broken down by detritus feeders, after which bacteria play their role in breaking down organic matter into nutrients that are then used by primary producers (phytoplankton and macro algae, seagrasses, invertebrates (e.g. corals, sponges) which live in symbiosis with micro and macro algae).

Rainfall is a major driver of primary productivity in the Territory's marine environment. For example, river flow carries nutrients and sediment into the Gulf of Carpentaria (25% of Australia's rainfall ends up in the Gulf of Carpentaria), and remains trapped in the coastal zone, supporting high primary productivity. Rainfall and freshwater runoff is considered an important ecological driver for many marine and estuarine species (e.g. barramundi, prawns, crabs, box jellyfish).

2.3.2 Hydrology and oceanic currents

There are three major ocean currents occurring in NT waters: the Indonesian Throughflow, Gulf of Carpentaria Gyre and water exchange through the Torres Strait. Overall, a net westward flow occurs in the dry season and an eastward flow during the wet, primarily driven by the seasonal trade winds.

The Gulf of Carpentaria has unique and important oceanic currents. Circulation is considered to be a single clock-wise gyre (giant circular oceanic surface current), resulting in a more nutrient rich coastal waters and nutrient poor central waters. This circulation supports two distinct ecological zones that are hydrological and biological independent. Generally, the Gulf of Carpentaria coastal waters are well mixed and are largely influenced by climate variables.

The Joseph Bonaparte Gulf coastal waters are primarily driven by large tidal range with strong currents, monsoonal winds, cyclones and wind generated waves; waters are generally turbid; little transfer of nutrients form coastal to offshore waters.

NT waters are primarily influenced by tidal flows and less by ocean currents. Tidal range decreases from west to East, with Darwin tidal range being 8 m, Arnhem Land 2-4 m and Gulf of Carpentaria less than a metre. Tides are semidiurnal, however, in the Gulf of Carpentaria this gets severely modified in the southern part, where there is one tidal cycle per day.

2.3.3 Connectivity

Marine ecosystems are maintained by the flow of energy from primary producers at the base of food webs through to intermediate consumers, top predators (including humans), and pathogens, and then back again through decomposition and detrital pathways (Doney *et al.* 2012). Thus, marine communities are biological networks in which the success of species is linked directly or indirectly through various biological interactions (e.g. predator-prey relationships, competition, facilitation, mutualism) to the performance of other species in the community. The aggregate effect of these interactions constitutes ecosystem function (e.g. nutrient cycling, primary and secondary productivity), through which ocean and coastal ecosystems provide the wealth of free natural benefits that society depends upon, such as fisheries and aquaculture production, water purification, coastal protection, and recreation. Physical and chemical changes have strong direct and indirect effects on the physiology and behaviour of marine organisms, which can translate to population- and community-level changes. Consequently, changes in ocean conditions and key biological interactions can alter the underlying dynamics that govern ecosystem structure and function.

2.3.4 Climate regulation

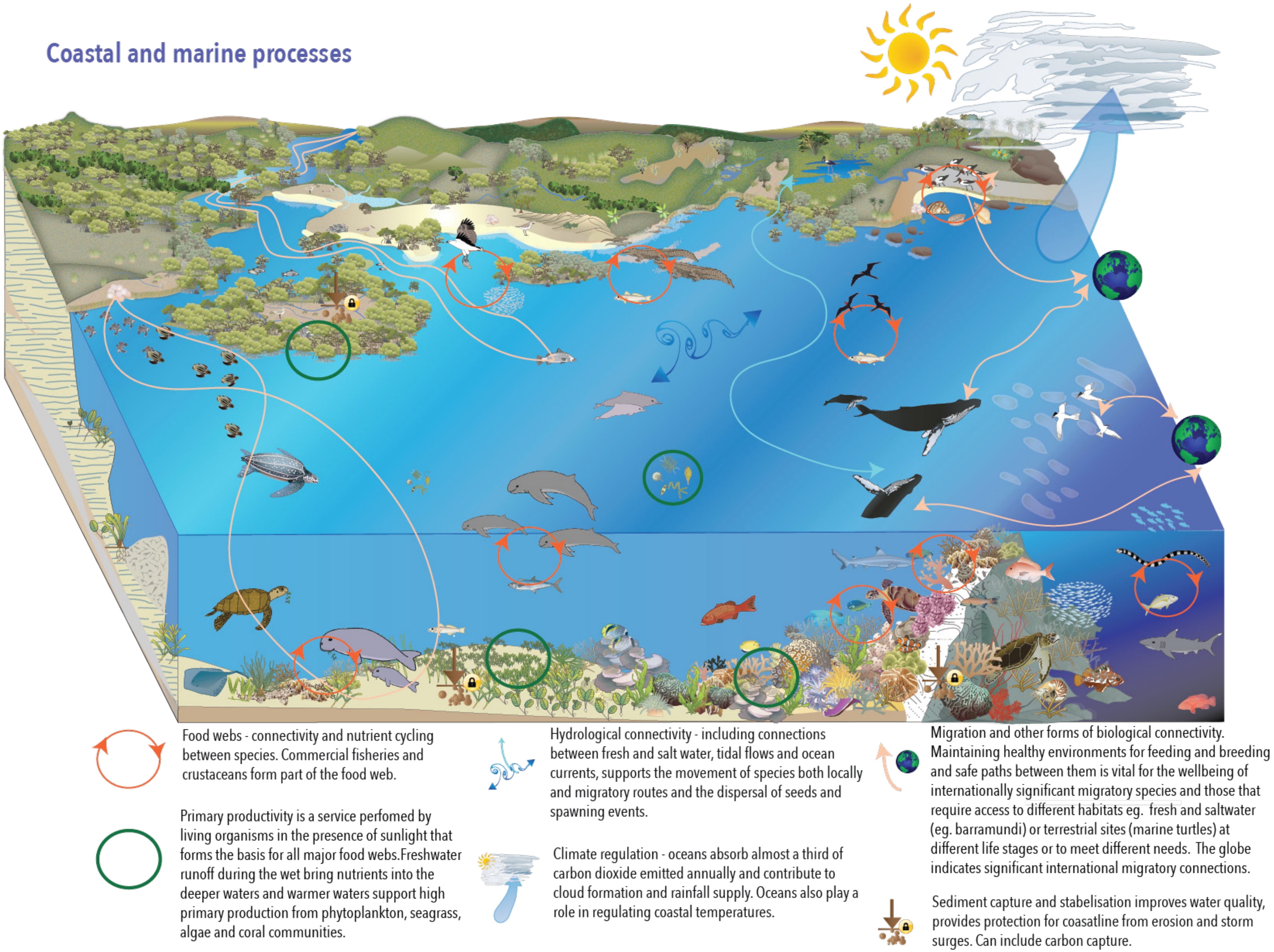
Climate change is likely to have a large impact on the shallow shelf and coastal waters. Acidification, sea level change and water temperature and increase in severity and frequency of large weather events (cyclones and storms) present a realistic risk to marine and coastal flora and fauna.

Marine ecosystems regulate global and regional climates by (i) providing sinks of greenhouse gases (affecting global warming) and sources of aerosols (affecting temperature and cloud formation); (ii) by enhancing evapotranspiration and thereby cloud formation and rainfall (Kleidon *et al.* 2000); and (iii) by affecting surface reflection and illumination thereby affecting radiative forcing and temperature (Betts 2000; Smith *et al.* 2013). Ecosystems can therefore affect local microclimates through the provision of shade and shelter and the regulation of humidity and temperature. In marine ecosystems, rising atmospheric CO_2 and climate change are associated with concurrent shifts in temperature, circulation, stratification, nutrient input, oxygen content, and ocean acidification, with potentially wide-ranging biological effects.

Climate change also exacerbates local stresses from declining water quality and overexploitation of key species, driving benthic habitats increasingly toward a tipping point of functional collapse (Hoegh-Guldberg *et al.* 2007).

Population-level shifts may occur because of physiological intolerance to new environments, altered dispersal patterns, and changes in species interactions. Together with local climate-driven invasion and extinction, these processes result in altered community structure and diversity, including possible emergence of novel ecosystems. Impacts are particularly striking for the tropics, because of the sensitivity of coral-algal symbiosis to minor increases in temperature. Cumulative effects may modify energy and material flows as well as biogeochemical cycles, eventually impacting the overall ecosystem functioning and services upon which people and societies depend (Doney *et al.* 2012).

Figure 7 Summary of ecosystem processes that influence the coastal and marine environment in the Northern Territory



3 Potential impacts from seabed mining in Northern Territory coastal waters

There are a wide range of direct and indirect impacts to the marine environment that can occur through the extraction of mineral resources from the seafloor. Direct impacts occur through direct interaction of an activity associated with seabed mining (i.e. exploration, extraction, processing and transport) with an environmental value. Indirect impacts on the environment are those which are not a direct result of an activity (as defined above), and are often produced away from the activity or as a result of a complex impact pathway. The indirect impacts are also known as secondary or even third level impacts.

In addition to both direct and indirect impacts, cumulative impacts can occur. Cumulative impacts are created as a result of the combination of a seabed mining project together with other activities causing related impacts. They may be related to compounding activities in a single seabed mining operation, multiple mining operations or interactions with other activities. These impacts occur when the incremental impact of a project is combined with the cumulative effects of other past, present and reasonably foreseeable future projects.

Based on the review by Advisian (2017), impacts from seabed mining include entrainment and collision, removal and alteration of habitat, underwater noise, a reduction in water quality, marine pests, organic enrichment, light and air emissions, chemical discharges and hydrocarbon spills. The following sections provide a brief overview of direct, indirect and cumulative impacts to the values of the Northern Territory's coastal and marine environment. More detail on specific impact pathways are provided in the report by Advisian (2017).

3.1 Marine fauna

Seabed mining has the potential to directly impact marine fauna in the Northern Territory (Table 1, Figure 8). The most prevalent direct impacts are entrainment and collisions from vessels and dredging as well as chemical discharges and hydrocarbon spills. Underwater noise, in particular blasting, is also considered to be a direct impact by causing mortality to animals from pressure waves.

There are numerous indirect impacts of seabed mining to marine fauna (Table 2). The most significant indirect impact is likely to be the removal or degradation of habitat. A loss of habitat reduces the food resources which will reduce the survival and reproduction within a population. Cumulative impacts from other activities are also likely to occur. In the Northern Territory these include interactions with commercial fishing, chemical discharges and oil spills, other dredging campaigns and pollution.

The Australian Government has developed a set of guidelines to assist in defining a significant impact on matters of national environmental significance. Criteria are provided to assess if an action is likely to have a significant impact on a threatened species and criteria for species listed as Critically Endangered are defined below. If there is a real chance or possibility that the action will:

- lead to a long-term decrease in the size of a population
- reduce the area of occupancy of the species
- fragment an existing population into two or more populations
- adversely affect habitat critical to the survival of a species
- disrupt the breeding cycle of a population
- modify, destroy, remove, isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline
- result in invasive species that are harmful to a critically endangered or endangered species becoming established in the endangered or critically endangered species' habitat
- introduce disease that may cause the species to decline, or interfere with the recovery of the species.

Figure 8 Impacts of seabed mining on marine fauna of the Northern Territory.

Impacts of seabed mining on fauna

1 Boat strikes and entanglement of wildlife impacting marine reptiles, marine mammals, fish, birds and invertebrates

2 Underwater noise, blasting and vibration potentially causing mortalities or stress, disruption of natural behaviours and reducing access to feeding grounds, nesting sites or other essential areas impacting marine reptiles, marine mammals, fish and invertebrates

3 Chemical discharges and hydrocarbon spills can poison wildlife impacting marine reptiles, marine mammals, fish, birds and invertebrates

4 Turbidity (sediment stirred up into the water, blocking light) and smothering with sediment impacting invertebrates and fish

5 Marine pests (inluding foreign algae, shellfish and other invertebrate species) can outcompete and prey on native species of invertebrates

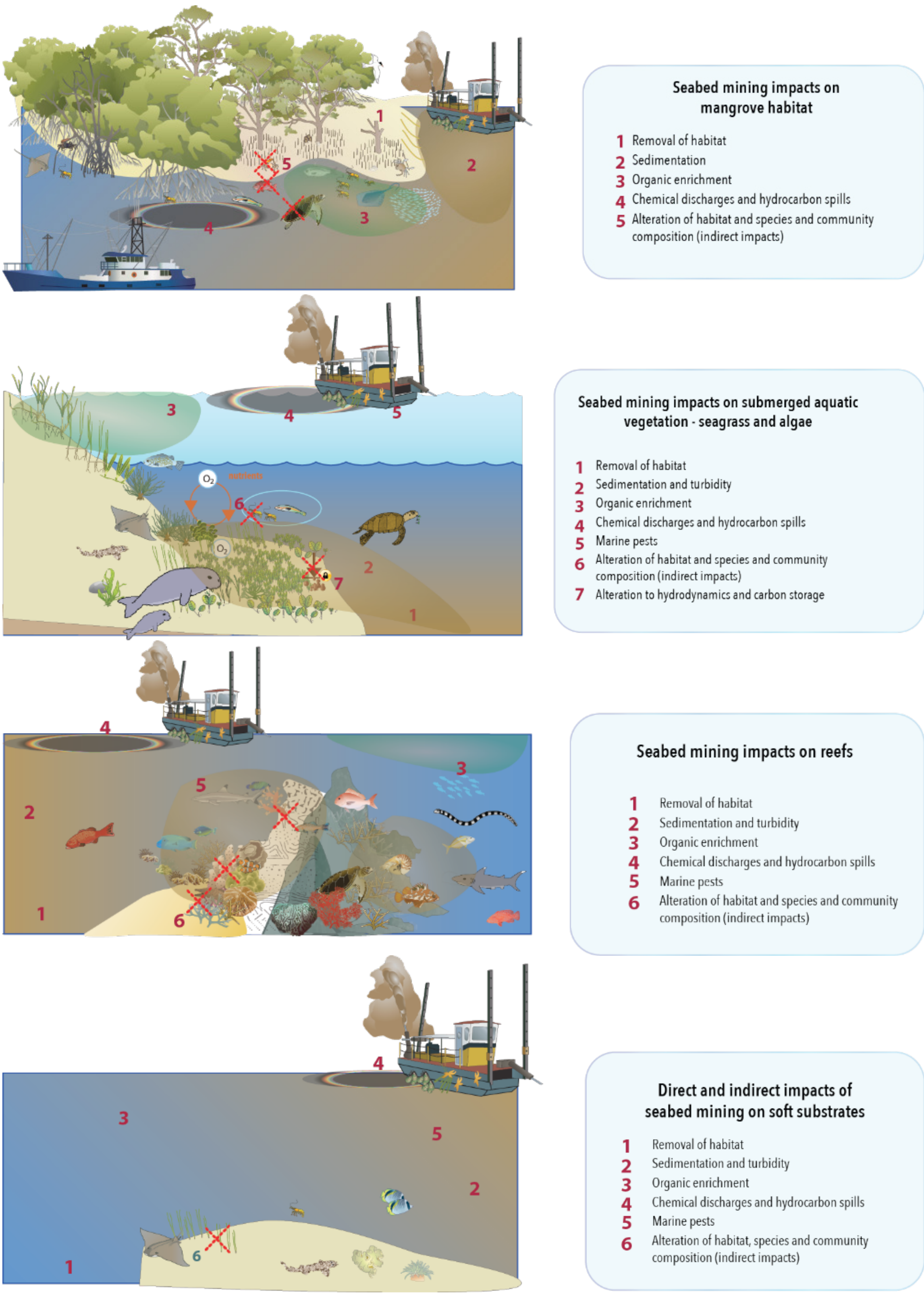
6 Removal and alteration of habitat (indirect impact)

3.2 Marine habitats

Seabed mining has the potential to directly impact marine habitats in the Northern Territory (Table 1, Figure 9). The removal of habitat is clearly the most likely direct impact. However, it is difficult to understand how the loss of habitat affects the adjacent/remaining habitats and the fauna supported by these habitats. The Australian Government has developed a set of guidelines to assist in defining a significant impact on the environment in a Commonwealth marine area if there is a real chance or possibility that the action will:

- result in a known or potential pest species becoming established in the Commonwealth marine area
- modify, destroy, fragment, isolate or disturb an important or substantial area of habitat such that an adverse impact on marine ecosystem functioning or integrity in a Commonwealth marine area results
- have a substantial adverse effect on a population of a marine species or cetacean including its life cycle (for example, breeding, feeding, migration behaviour, life expectancy) and spatial distribution
- result in a substantial change in air quality or water quality (including temperature) which may adversely impact on biodiversity, ecological integrity; social amenity or human health
- result in persistent organic chemicals, heavy metals, or other potentially harmful chemicals accumulating in the marine environment such that biodiversity, ecological integrity, social amenity or human health may be adversely affected.

Figure 9 impacts of seabed mining on coastal and marine habitats of the Northern Territory – A – mangroves, B – submerged aquatic vegetation, C – reefs, and D – soft substrates.



3.3 Coastal and marine ecosystem processes

The impact of seabed mining on coastal and marine ecosystem processes is complex and difficult to quantify. Depending on the scale of the activity, seabed mining can influence all important processes such as primary productivity, hydrology and connectivity (Figure 10). The most pervasive impact expected relates to increases in turbidity and sedimentation as a result of extraction. This has the potential to alter primary productivity and nutrient cycling which in turn will effect foraging habitats for many different marine animals. Similarly, removal of habitat will impact on food webs, primary productivity, hydrology and connectivity. Furthermore, cumulative impacts are likely to be amplified when multiple activities occur in the same area.

Figure 10 Impacts of seabed mining on coastal and marine environmental processes of the Northern Territory

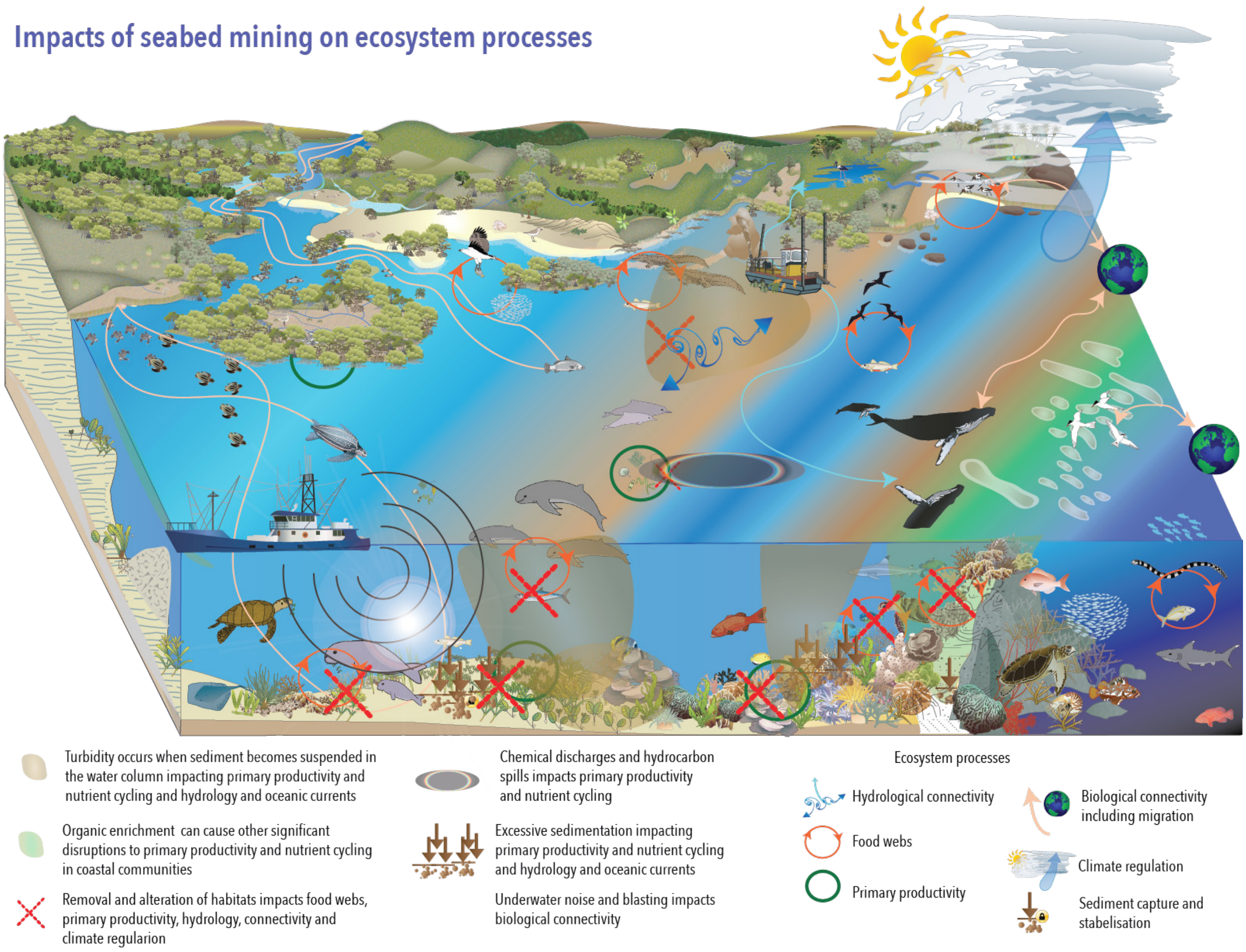


Table 1 Summary of direct impacts of seabed mining on coastal and marine values of the Northern Territory.

Potential impact	Birds	Marine reptiles	Marine Mammals	Fish	Invertebrates	Mangroves	Submerged aquatic vegetation	Reefs	Soft substrates	Primary productivity and nutrient cycling	Hydrology and oceanic currents	Connectivity	Climate regulation
Entrainment and collisions	✓	✓	✓	✓	✓								
Removal of habitat						✓	✓	✓	✓				
Alteration of habitat and species and community composition													
Underwater noise, blasting and vibration		✓	✓	✓	✓								
Turbidity				✓	✓		✓	✓					
Sedimentation				✓	✓	✓	✓	✓	✓	✓	✓		
Organic enrichment						✓	✓	✓	✓	✓			
Release of contaminants				✓	✓						✓		
Light emissions													
Air emissions													
Chemical discharges and hydrocarbon spills	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Marine pests					✓		✓	✓					

Table 2 Summary of indirect impacts from seabed mining in coastal and marine environmental values of the Northern Territory.

Potential impact	Birds	Marine reptiles	Marine Mammals	Fish	Invertebrates	Mangroves	Submerged aquatic vegetation	Reefs	Soft substrates	Primary productivity and nutrient cycling	Hydrology and oceanic currents	Connectivity	Climate regulation
Entrainment and collisions													
Removal of habitat	✓	✓	✓	✓	✓					✓	✓	✓	✓
Alteration of habitat and species and community composition	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Underwater noise, blasting and vibration	✓	✓	✓	✓	✓							✓	
Turbidity	✓	✓	✓	✓	✓		✓	✓	✓	✓			
Sedimentation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Organic enrichment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Release of contaminants	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Light emissions		✓	✓										
Air emissions													✓
Chemical discharges and hydrocarbon spills	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
Marine pests	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	

4 Information needs specific to managing impacts of seabed mining in coastal waters of the Northern Territory

The Northern Territory marine and coastal environment remains poorly studied or described. This lack of information introduces the largest and most significant uncertainty for assessing and managing risks of seabed mining. Without these data it will be challenging to conduct evidence-based risk assessment of impact from seabed mining on marine and coastal values.

There are a wide range of data required to manage seabed mining. Table 3 provides a summary of likely data needs for the physical environment to make informed impact assessment associated with seabed mining activities. Table 4 provides a summary of likely data needs for the biological environment. The data needs listed are by no means comprehensive and specific activities will need to be assessed on a case by case basis.

It is important to understand that the data needs are many and that a single project will not be able to collect all required data sets to fulfil evidence based assessment criteria. Therefore, some consideration should be given to establishing a “communal” database for baseline and monitoring data that can be accessed by proponents, research and regulatory institutions. Furthermore, ensuring that data are compatible for combined use (i.e. universal adopted data standards), the increase of data over time is likely to; provide for a more robust impact assessment and identify critical data gaps to inform data needs.

Table 3. Summary of physical environment data needs for assessing and managing risks from seabed mining on coastal and marine environments of the Northern Territory.

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Physical Environment				
Bathymetry: Depth	Detailed bathymetry for the zone of influence (before and after impact) and broad scale regional bathymetry The bathymetric survey/sampling should be full coverage at 1 m grid size with a horizontal resolution of 0.25 m and vertical resolution of 0.15 m (Hydrographic standards) Grid outputs will depend on modelling needs (e.g. hydrodynamics, benthic communities, sediment transport, plume modelling) Water column data should be collected together with depth data (see below)	Bathymetry is core data set and allows for • Critical for predictive mapping of benthic communities / species • Hydrodynamic modelling (modelling of currents, sediment transport, waves, tides, plume modelling) • Seascape analyses (environmental envelopes for impact site and sensitive species, major communities) • Determining Geomorphological characteristics (informs sediment transport, benthic community structure) • Assessing conditions for potential recovery of benthic and environmental conditions • Characterising and assessing changes in physical dynamics and local conditions • Assessment of noise propagation • Assessment of changes in sediment transport, including near-shore environments, beaches and dune systems • Assessment of wave conditions and impacts on beach and dune systems • Characterising the environment for an energy perspective (influences sediment characteristics, sedimentation rates and benthic community structure)	Depth of seabed impacts: • currents • waves • tides • sediment transport • benthic community structure • geomorphology • sediment grainsize • sediment physical characteristics • water quality • beach and dune morphology • noise propagation • light availability at the seafloor • predictive mapping	Broad scale available, inaccurate in shallow waters Only for Darwin Harbour and Bynoe Harbour and parts of Melville Bay at appropriate scale
Bathymetry: Backscatter	Backscatter grid Derived from Multibeam Echo Sounder (MBES) data	Backscatter is used to • model grainsize distribution using acoustic backscatter signature and ground-truthed with collected sediment samples • predict the presence of hard substrates	Backscatter enables: • Characterise sediment and grainsize distribution • identify potential reefal areas or areas with thin veneer overlaying rocky substrate	Darwin Harbour and Bynoe Harbour

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Bathymetry: Water column	Acoustic signature of water column Collected using the same equipment as for MBES Bin size needs to small enough to identify epibenthic communities / structure	Acoustic signature of water column allows for • identifying epibenthic communities (e.g. sponge gardens, but unlikely seagrass meadows) • snap shot of bottom and pelagic species of fishes (non-shark species)	Acoustic signature of water column allows for • improved efficiency for mapping habitats • identifying high density habitat use • increases information collected on benthic habitats and fish	Not available
Hydrodynamic model	3D hydrodynamic modelling to determine current, wave and sediment transport characteristics; sediment plume characteristics and dispersal; sedimentation characteristics including flocculation characteristics; Model resolution should have broad regional aspect and fine-scale local aspect; and characterise Baseline and calibration information should take into account seasonal information, including wind, currents, wave characteristics for at least 2 years , and flocculation characteristics with varying salinity regimes; Calibration and validation is undertaken by comparing the modelled results against actual field based measurements Modelling outputs need to take into account short and long-term impacts.	Hydrodynamic model outputs are core data sets and allow for: • Modelling of currents, current stress (surrogate for benthic biodiversity), waves, sediment and suspended sediment modelling • Assessment changes in current, wave, sediment transport conditions due to changes bathymetry / topography from mining activities • Assessment of how the excavation may impact on the sheltering of the coastline • Modelling sediment deposition from overflow/disposal • Assessment of recovery conditions (water column and seafloor) after mining activities • Assessment of connectivity at local and regional scale for larvae, fish and megafauna) • Sediment – water column coupling of water qulaity • characterising the energy regime (from currents and waves) within the marine system	Hydrodynamic modelling outputs are critical for determining before and after conditions for: • currents • wave • energy • sediment transport • suspended sediment dispersal (plume modelling) • sediment deposition and erosion (changing sediment composition and infauna composition, recovery conditions) • current strength at the seafloor (structures benthic communities) • mangrove, beach and dune erosion/accretion • larval connectivity • source/sink areas for sediment	Only for Darwin Harbour and Bynoe Harbour and parts of Melville Bay at appropriate scale Large scale models available across northern Australian waters (e.g. MET Bureau model, CSIRO model, JCU).

1 If there is uncertainty about the methodology used in modelling, then the methodology and the model outputs should be independently peer reviewed at the cost of the proponent.

2 Baseline data should reflect normal environmental conditions. If seasonal conditions lie outside the norm, then additional data needs to be collected, so that there is at least data for 2 years of normal conditions.

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Hydrodynamic model: Sediment transport	Sits within Hydrodynamic model Data layer(s) that describe pre-existing conditions and natural fluctuations, including seasonality, duration, frequency aspects at local and regional scales Ability to model to sediment transport within the natural settings and after sediment is deposited from dredge spoil or sediment plumes Calibration and validation • validated with by comparing the modelled results against actual field based measurements e.g. acoustic Doppler current profiler (ADCP) current measurements and sediment flux measurements; • robust assessment of uncertainties ion the model • take into account the presence / absence of benthic fauna	Sediment transport model is a core data set that allows for • Quantifying and modelling the transport and fate of sediments • Assessing littoral transport systems, long-shore sediment transport and seasonal variability • Assessing the fate of sediments in excavated areas and implications to benthic communities and recovery rates • Assessing sedimentation rates and implications for turbidity bathymetry, currents, benthic composition within in local and regional context • Determine seabed erosion / deposition rates • Assessing max excavation depth before inducing changes in local hydrodynamics, benthos integrity and shoreline changes • Assessing recovery rates and if the impacted area has a potential for recovery • Determine the susceptibility of spawning habitat, corals, mangroves, benthic flora and fauna to smothering due to sedimentation and setting tolerance levels • Benthic – water column coupling water quality • Determining sediment grainsize distribution and implications for benthos life histories • Establishing turbidity – light – sedimentation relationships	Sediment transport model is critical for determining before and after conditions of: • sediments • benthic fauna and flora (feeding, spawning and settlement) • currents • erosion/accretion of sediments on beaches/ dunes (turtle nesting) • water and sediment quality	Darwin Harbour and Bynoe Harbour, uncalibrated

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Hydrodynamic model: Sediment Plume	Sits within hydrodynamic model Data layer(s) that describes the natural variability of suspended sediments (frequency, duration, seasonality) at local and regional scales Ability to model the extent, duration, size and depth characteristics of suspended sediment plumes and consequences to benthic and pelagic environment Calibration and validation • validated with by comparing the modelled results against actual field based measurements e.g. ADCP current measurements and sediment flux measurements; • robust assessment of uncertainties ion the model	Sediment plume modelling is a core data set that allows for: • Determining the extent, duration, size and depth characteristics of suspended sediment plumes • Assist with defining the Zone of Influence • Determining the fate of suspended sediments • Determining the grain size of suspended particles that will settle on the seafloor, the amount of sedimentation from plumes • Assessing the implications of suspended sediment sedimentation / flocculation on plankton, fishes and benthic communities and how this may change benthic community structure/composition	Sediment plume model is critical for determining before and after conditions of: • suspended sediments • predator-prey interactions (invertebrate, fish, dolphins) • benthic fauna and flora life histories (feeding, spawning and settlement) • water and sediment quality • light quality water column • phytoplankton, seagrass and macro-algal health	Developed on a case by case basis
Environmental conditions Waves	Wave model Data layer(s) that describes the natural variability of wave characteristics (frequency, height, duration, seasonality) at local and regional scales	Wave characteristics is a core data set that allows for: • Determine the natural variability of wave conditions at impact site • Determining the influence of waves on sediment resuspension and redistribution • Asses if changes in bathymetry due to extraction has consequences for wave characteristics • Assess if changes in wave characteristics have follow on consequences to benthic communities and beach and dune systems	Waves: • shape shallow water coastal systems • redistribute sediments according wave energy characteristics, • shape beaches and dune systems • are important to nesting turtles, • shape benthic assemblages, in particular their life forms	Model is not available

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Sediments	Continuous interpolated data using predictive modelling techniques to derive the spatial distribution of grainsize characteristics, % muds, sands (fine medium and coarse) and gravel	• Fundamental niche for micro-organisms and invertebrate species that drive nutrient cycles, trophic and reproductive pathways, and sediment health	Impacts relating to sediments affect: • benthic habitats • sediment chemistry • nutrient cycles • foraging habits (e.g. turtles, wader birds, migratory) • turbidity • light regimes	Offshore predictive maps available, nearshore predictive maps have high uncertainty Darwin Harbour, Bynoe Harbour fine scale
Depth of redox layer within sediments	Modelled across zone of influence Depth of start of anoxic layer in sediments Calibration and validation • validated with by comparing the modelled results against actual field based measurements and sediment flux measurements; • robust assessment of uncertainties in the model	• Proxy for biodiversity within sediments • Assists with designing sediment and infauna sampling / monitoring programs	Impacts that change the depth of redox layer within sediments affects: • biodiversity and sediment health indices • sediment chemistry • microbial productivity	Not available
Seawater temperature	Sea temperature at the surface and sea floor	• Benthic and pelagic environmental envelopes • How excavation may change water temperatures, by changes in currents, and water depth	Impacts relating to temperature affect: • productivity • nutrient growth • reproductive and feeding characteristics • habitat type	Sea surface temperatures available at broad scale; Sea floor water temperatures unavailable
Salinity	Modelled, Predicted grid, and point data Min, max medium, 2SD, seasonal variability, temporal and spatial variability (local and regional)	• Flocculation characteristics • environmental envelopes	Impacts relating to salinity affect: • water quality	Time series for Darwin Harbour

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Turbidity	Natural variability (means and peaks) Predicted grid Mean, variability measure, time duration, intensity, light – turbidity relationships Modelled	• To determine the typical ambient conditions (temporal and spatial) and natural variability within the system (time duration and short term variability) • Characterise turbidity conditions in context to seagrass, macro-algae, phytoplankton, mangroves and corals and other light dependent/sediment sensitive keystone invertebrate species • Assessment of how turbidity from excavation and waste may impact on food webs • Assess turbidity conditions in context to species specific sensitivity and tolerance, thresholds in terms of life history requirements • Establishing turbidity – light - sedimentation relationships	Impacts relating to turbidity affect: • light dependent habitats • filter feeders • sedimentation • organic matter • water quality	Sea surface turbidity available broad scale (satellite imagery); With water column not available, project specific Darwin Harbour
Nutrients	Modelled speciation of nutrients within fine scale and seasonal context, Organic matter, Nutrient pathways with water column and sediments	• Establish natural variability (spatial and temporally) nutrient path ways within the water column and sediments • Establish thresholds and trigger values for maintaining WQ objectives • Establishing primary production parameters and conditions • Establish the likelihood of nutrients from sediments being dissolved into the water column and potential impacts to WQ • Establish nutrient pathways in key sediments types to assess how extraction and side casting of material may change nutrient pathways and nutrient remineralisation rates	Impacts relating to nutrients affect: • productivity • nutrient cycles • benthic habitats • foraging • epiphytic growth	Darwin Harbour
Light water column	Natural variability of light conditions in the water column and at the seafloor Predicted grid Time duration estimates of low light conditions, seasonal variability, light – turbidity relationships	• Light availability submerge vegetation (seagrass, macro-algae, phytoplankton and corals and other light dependent keystone invertebrate species) • Determining minimum light requirements (duration, amount, seasonality, natural variability), and thresholds for keystone species • Determining primary production parameters and conditions • Establishing turbidity – light - sedimentation relationships	Impacts relating to light in the water column affect: • photo zone • seagrass and macro algae • corals • primary productivity and phytoplankton • nutrient cycles	Some data for Darwin Harbour

3 A keystone species is a species that has a disproportionate effect on its environment relative to its abundance. Such species affect many other organisms in an ecosystem and help to determine the types and numbers of various others species in a community.

4 Thresholds / triggers: based on existing time-series data and known stressor–response relationship, with corresponding target levels or thresholds that signal the onset of conditions that may result in significant ecosystem degradation

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Light Artificial	Light glow intensity and direction	• Assessing impact of artificial light on marine flora and fauna (nesting turtles, migratory birds, fish and marine mammals)	Impacts relating to artificial light affect: • marine turtles nesting and hatchling dispersal • migratory birds • behaviour nocturnal species • fish aggregation • predation-prey dynamics	Project specific
Chlorophyll	Monthly variability of chlorophyll Broad scale, satellite imagery analysis Local scale, part of WQ measurements/ monitoring	• Establishing primary productivity parameters and conditions • Establishing fate of nutrients from primary productivity, flocculation of organic material and uptake into sediments	Impacts relating to changes in chlorophyll affect: • productivity • organic matter • nutrient pathways	Broad scale available, Chl and primary productivity (satellite imagery)
Contaminants	Modelled, Determine measurable endpoints of sediment and nutrient biological effects	• Assessment of contaminant loads and sources in sediments • Establish thresholds and trigger values for maintaining WQ objectives • Assessment of impact pathways to biological and physical pathways	Impacts relating to release of contaminants affect: • benthic and foraging habitats • toxicity • bio-accumulation	Darwin Harbour

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Noise underwater	Modelled; Parameters to be established: PK per minute, SPL / fast time weighted SPL per impulse; SEL per impulse and accumulated over operation length / 24 hr period; SPL / fast time weighted SPL (over specified time period; SEL accumulated over operation length / 24 hr period Establishing cumulative exposures and integration time windows; maximum over depth and seafloor levels; Modelling accounts for geoacoustic properties (sediment type and sediment thickness, depth, bathymetry, sound speed profiles (seasonal and spatial) and other relevant oceanic / environmental variables Assumptions clearly stipulated and justified	• Establish background underwater noise characteristics within a local context and environmental conditions (depth, substrate types, water temperature, salinity,) • Setting tolerance limits for underwater noise by taking into account factors including the source of the noise and the sensitivity of the receptors in the marine environment • Establishing decay characteristics of underwater noise from seabed mining activities • Assessing the impact of underwater noise from mining activities on keystone species at various life stages (benthos, fishes, turtles and mammals)	Impacts relating to underwater noise affect: • displacement from important habitat • direct physical injury / mortality (marine mammals, turtles, fishes, invertebrates) • change in behaviour and communication	Site and project specific
Seascapes and geo-morphology	Modelled, using seascape and physical environmental parameters Grid, at the same scale as habitat maps	• Characterise physical environment and identifying areas that have similar environmental conditions and attributes within a local and regional context • Core component for identifying ecological windows for species, assemblages and keystone species • Establishing biotic indices / surrogates • Identifying primary, secondary and derived variables for biotic indices • Assessing the before and after conditions for benthic fauna and flora • Contribute towards habitat maps • Identify areas with similar environmental conditions within the impact, zone of influence for selecting of monitoring sites	Impacts relating to changes in seascape geomorphology affect: • benthic habitats • environmental characteristics • environmental windows	Darwin Harbour and Bynoe Harbour

Table 4. Summary of the biological environment data needs for assessing and managing risks from seabed mining on coastal and marine environments of the Northern Territory.

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Biological Environment				
Habitats	Predictive model, best estimate at the time Characterise habitats based on environmental characteristics and biological assemblages within water column and seafloor (on the seafloor and within sediments) Establish spatial and temporal variability; Calibration and validation is undertaken by comparing the modelled results against actual field based measurements Fine scale mapping for Zone of Influence, broad scale for regional context	Habitat characterisation is a core data set to allow for: • Describing existing physical and biological habitats within local and regional context • Understanding of the importance and ecosystem pathways for affected habitats; understanding of importance in a regional context; recolonisation • Understanding of size of the impact, including after dredging has been completed (neighbouring habitats maybe indirectly affected by removal) • Assess representativeness of habitats present • Assessing to what degree physical disturbance will have on densities of ecosystem engineers and subsequent changes in benthic ecosystem processes • Characterising mechanisms for connectivity local and regional perspective • Identify keystone species and sensitive habitats for feeding, spawning, nesting, refuge, connectivity and asses those species sensitive to seabed mining activities • Assess guild and functional analysis • Identify areas with similar assemblages and environmental conditions within the impact, zone of influence and non-impacted areas to allow for selecting of monitoring sites • Assessment of cumulative impacts on flora and fauna assemblages • Assessment of changes in habitat characteristics and species composition, abundance and distribution due to excavation and deposition of sediments • Assessment of habitat fragmentation, connectivity and implications on integrity of sensitive habitat and the flora and fauna they support • Understanding of the importance and ecosystem pathways for affected habitats within local and regional context • Assessment of potential change/shift the state of the ecosystem; within the short, medium and long-term • Understanding of size of the impact, including after dredging has been completed (neighbouring habitats maybe indirectly affected by removal) • Assessment of ecological recovery and recolonisation potentials	Impacts relating to changes in habitat affect: • species diversity • loss of / shift in ecosystem function • interruption of life cycle pathways • recruitment • loss of feeding areas • connectivity	Darwin Harbour and Bynoe Harbour

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Habitats Reef communities	Characterise habitats based on environmental characteristics and biological assemblages in reefal habitats Establish environmental envelopes and spatial and temporal variability; Species composition, abundance, life-form characteristics, extent, exposure (seasonal, temporal, and time duration variability), primary productivity,	• Reef communities are ecosystem engineer and provide coastal protection • Reef communities are important for trophic, reproductive, nutrient pathways • Reef communities are important nursery habitat, in particular for commercial and recreational fisheries and cultural practices. • Identify keystone species and sensitive habitats for feeding, spawning, nesting, refuge, connectivity and asses those species sensitive to seabed mining activities • conduct guild and functional analysis • Assessment of impacts from hydrological alteration, habitat loss and burial / smoothing on benthos and trophic pathways • Establish environmental envelopes to determine trigger values of declining health (including light, currents, suspended sediments, nutrients) for keystone species	Impacts relating to changes in reef communities affect: • loss biodiversity • loss of / shift in ecosystem function • interruption of life cycle pathways • recruitment • loss of feeding areas • beach dynamics	Darwin Harbour and Cobourg Peninsula
Habitats Seagrass / macro-algae	Presence / absence; species composition, abundance, extent, temporal and spatial variability; reproductive periods and mechanisms	Important feeding habitat dugong and turtle • Important nursery habitat • Assess the potential for declining health of a seagrass / macro-algae habitats, potential loss from changes in sedimentation, currents and wave regimes • Assess indirect impacts to trophic pathways, and, reproductive and nursery niches • Identify keystone species and assess the impact from seabed mining activities may have on feeding, spawning, nesting, refuge, connectivity and assess those species sensitive to seabed mining activities	Impacts relating to changes in seagrass and macro-algae communities affect: • Dugong foraging habitat • sediment erosion/ deposition • nursery habitat • commercial fisheries • primary productivity and food web	Incomplete, selected Intertidal areas between Darwin – Nhulunbuy and Gulf of Carpentaria

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Habitats Mangroves	Community composition, biomass, structure,	• Mangroves are ecosystem engineer • Mangroves are import for trophic, reproductive, nutrient pathways • Mangroves are important nursery habitat, in particular for commercial and recreational fisheries and cultural practices. • Identify keystone species and sensitive habitats for feeding, spawning, nesting, refuge, connectivity and asses those species sensitive to seabed mining activities • Assess impacts from seabed mining activities mangrove health • Assess indirect impacts to trophic pathways, and, reproductive and nursery niches	Impacts relating to changes in mangrove communities affect: • commercial and recreational fisheries • life cycles birds • fishes and invertebrates • nursery habitat • roosting areas • nutrient pathways • food chain pathways • sedimentation process • coastal protection • water quality • carbon storage	Fine scale Darwin Harbour and Bynoe Harbour Broad scale NT wide
Habitats Intertidal and subtidal flats	Sediment characteristics, infauna, epifauna composition, primary productivity, exposure (seasonal, temporal, and time duration variability),	• Important feeding habitat for fish, and migratory birds • Important habitat for nutrient mineralisation, nutrient cycles, primary productivity, • Identify keystone species and sensitive habitats for feeding, spawning, nesting, refuge, connectivity and asses those species sensitive to seabed mining activities • Assessment of impacts from hydrological alteration, habitat loss and burial / smoothing on benthos and trophic pathways • Establish environmental envelopes to determine trigger values of declining health • Establish sediment / water column connectivity in regards to nutrient pathways	Impacts relating to changes in intertidal and subtidal habitats affect: • food webs • nutrient cycling • sedimentation • water quality • sediment health • productivity • commercial fisheries • foraging habitat for migratory birds • sediment characteristics (grainsize, slope, stability and available oxygen), hydrological characteristics (waves and currents) • sediment chemistry • primary productivity	Darwin Harbour

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Fauna Flora Keystone species (non EPBC listed species)	Keystone species Presence / absence; abundance, extent, habitat use / requirements, temporal and spatial variability; Field-based (multi generation perspective); modelling short time scale hypothesis testing)	• Characterise keystone species role and representativeness • Identify critical habitats for life history of keystone species (larval origin, spawning grounds, dispersal / connectivity, nursery grounds, feeding ecology) • Establish ecological windows for keystone species • Identify keystone species or species groups within identified assemblages (pelagic, epibenthic or infauna) for food webs, nutrient cycling, primary production, bio-structure • Feeding ecology of top predators, major herbivores and ecosystem engineers • Identify ecological windows important to keystone species	Impacts relating to changes in keystone species affect: • food webs • predator-prey dynamics • productivity	Not available
Fauna - Keystone species (non EPBC listed species – Dugong)	Presence / absence; abundance, extent, habitat use / requirements, temporal and spatial variability; Survey and monitoring design needs to be designed with sufficient statistical power to detect changes before and after impacts with local and regional ecological context Baseline data to establish pre-impact reference point for seasonal presence, abundance, habitat use for feeding, reproduction and migration. Establish trigger points for behavioural changes, noise levels for dugong, habitat use, decline in abundance/presence, and health.	• Identify critical habitats for dugong (calving, juvenile and feeding areas) within temporal and spatial context • Assess potential impacts from habitat loss, noise, turbidity on dugong • Identify ecological windows important to dugong • Identify migration paths	Impacts relating to changes in dugongs affect: • seagrass dynamics • subsistence value for Aboriginal Traditional Owners	Regional distribution available Local use not available

A keystone species is a species that has a disproportionate effect on its environment relative to its abundance. Such species affect many other organisms in an ecosystem and help to determine the types and numbers of various others species in a community.

Topic	Data description / conditions	Justification (e.g.)	Impacts	Data availability?
Fauna Flora EPBC and TPWC listed species	Baseline data to establish the abundance (time duration and frequency), distribution, seasonality, habitat use for feeding, reproduction, nursery, roosting and dispersal / migration characteristics for listed species Establish trigger points for behavioural changes, noise levels for listed species, habitat use, decline in abundance/presence, and health. Establish habitat requirements (physical and biological) in context of e.g. foraging, breeding, nesting, roosting, migration / dispersal (adults, juveniles and larvae). Survey and monitoring design needs to be designed with sufficient statistical power to detect changes before and after impacts within local and regional ecological context Assessment includes field-based (multi generation perspective) and modelling short time scale hypothesis testing	• Determine abundance, population size, distribution, source and sink dynamics, population cycles within local and regional context • Establish habitat requirements in context of e.g. foraging, breeding, nesting, roosting, or dispersal. • Determine the extent and spatial and temporal variability of sensitive habitats within a locally and regional context • Establish reproductive and dispersal behaviour / cycles • Determine environmental and biological drivers that influence reproductive, growth, population structure and distribution of listed species • Determine ecological windows for listed species • Assessment of risk to fragmenting population by seabed mining activities • Identify potential pathways (indirect / direct) for activities impacting feeding, reproductive and migration traits	Impacts relating to changes in listed species affect: • Listed threatened species • migratory species • ecological communities, benthic habitats • larval distribution	Species distribution and their nesting and roosting sites identified across the NT but incomplete at a regional or local scale.
Fauna Fishes	Field-based (multi generation perspective); modelling short time scale hypothesis testing) Larval origin and connectivity; variation in dispersal, Nursery grounds (net importer vs net exporters) Feeding ecology of top predators	• Determine abundance, population size, distribution, source and sink dynamics • Establish habitat requirements in context of e.g. foraging, recruitment, or dispersal • Establish reproductive and dispersal behaviour / cycles • Determine environmental and biological drivers that influence reproductive, growth, population structure and distribution • Assessment of risk to fragmenting population by seabed mining activities • Identify potential pathways (indirect / direct) for activities impacting feeding, reproductive and migration traits	Impacts relating to changes in fishes communities affect: • commercial and recreational fisheries • nutrient pathways • food chain pathways	Available for some commercial species

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Appendix I Conservation status of marine turtle and mammal species known to occur in Northern Territory waters.

Species	TPWC Act	EPBC Act status (2012)	Use of NT coast/ waters
Marine Turtles			
Leatherback Turtle *Dermochelys coriacea*	Critically Endangered	Endangered	Migration, Foraging, Nesting
Loggerhead Turtle *Caretta caretta*	Vulnerable	Endangered	Foraging, Migration
Hawksbill Turtle *Eretmochelys imbricata*	Vulnerable	Vulnerable	Resident, Foraging, Migration, Nesting
Olive Ridley Turtle *Lepidochelys olivacea*	Vulnerable	Endangered	Resident, Foraging, Migration, Nesting
GreenTurtle *Chelonia mydas*	Near Threatened	Vulnerable	Resident, Foraging, Migration, Nesting
Flatback Turtle *Natator depressus*	Data Deficient	Vulnerable	Resident, Foraging, Migration, Nesting
Marine Mammals			
Dugong *Dugong dugon*	Appendix I	Listed Marine and Migratory	Resident
Blue Whale *Balaenoptera musculus*	Data Deficient	Endangered	Stranding only
Bryde's Whale *Balaenoptera brydei*	Data Deficient	Listed as marine and migratory species	Stranding only
Humpback Whale *Megaptera novaeangliae*	Least Concern	Vulnerable	Seasonal migratory
Sperm Whale *Physeter macrocephalus*	Data Deficient	Listed as cetacean species and as a listed migratory species	Stranding only
Dwarf Sperm Whale *Kogia sima*	Data Deficient	Listed as cetacean species	Stranding only
Cuvier's Beaked Whale *Ziphius cavirostris*	Data Deficient	Listed as cetacean species	Stranding only
Short-Finned Pilot Whale *Globicephala macrohynchus*	Data Deficient	Listed as cetacean species	Stranding only
Risso's Dolphin *Grampus griseous*	Data Deficient	Listed as cetacean species	Stranding only
Australian Snubfin Dolphin *Orcaella heinsohni*	Data Deficient	Listed as cetacean species and as a listed migratory species	Resident

Species	TPWC Act	EPBC Act status (2012)	Use of NT coast/ waters
Killer Whale *Orcinus orca*	Data Deficient	Listed as cetacean species	Occasional visitor
Melon-Headed Whale *Peponocephala electra*	Data Deficient	Listed as cetacean species	Stranding only
False Killer Whale *Pseudorca crassidens*	Least Concern	Listed as cetacean species	Resident/regular visitor
Australian Humpback Dolphin *Sousa sahulensis*	Data Deficient (as *S. chinensis*)	Listed as cetacean species and as a listed migratory species – Bonn (as *S. chinensis*)	Resident
Pantropical Spotted Dolphin *Stenella attenuate*	Data Deficient	Listed as cetacean species and as a listed migratory species – Bonn	Stranding only
Spinner Dolphin *Stenella longirostris*	Data Deficient	Listed as cetacean species and as a listed migratory species – Bonn	Bycatch (1980-85) offshore
Dwarf spinner dolphin *Stenella longirostris roseiventris*	Data Deficient	Listed migratory species	Resident
Bottlenose Dolphin * *Tursiops aduncus* # *Tursiops truncatus*	* # Least Concern	* # Listed as cetacean species	Resident Bycatch (1980-85) offshore

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