Marine Biodiversity Hub

National Environmental Science Programme

FINAL REPORT

Scoping a Seascape Approach to Managing and Recovering Northern Australian Threatened and Migratory Marine Species

Project A12 - Australia's Northern Seascape: assessing status of threatened and migratory marine species (Phase 1)

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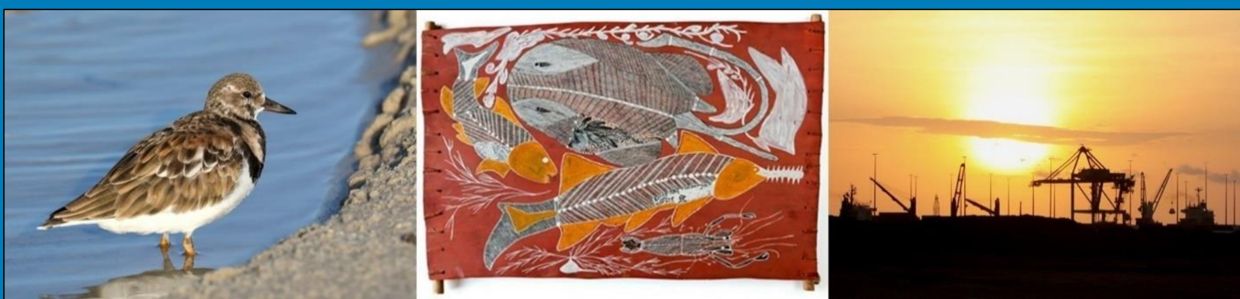
July 2018

Research Plan v3 (2017)



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Important Disclaimer

Contents

1. INTRODUCTION

Northern Australia is currently the focus of substantial economic development, which also has the potential to impact biodiversity and cultural values. The Northern Seascape scoping project (NESP Marine Biodiversity Hub Project A12 Phase 1) assessed the state of knowledge of Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC*)-listed Threatened and Migratory marine species, and pressures, Indigenous priorities, coastal habitats, and fisheries bycatch in relation to them across the North Marine Bioregion. The focus was at a multiple taxa level, including elasmobranchs (sharks and rays), shorebirds, marine turtles, Dugong, and cetaceans. The project scoped the research needs and directions for a broad Northern Seascapes project for the years 2018–2020.

1.1 Project Scope

The current 'Developing the North' agenda includes plans and potential for large-scale development activities such as agriculture, aquaculture, port development, mineral industry infrastructure, and water extraction which have the potential to impact biodiversity and cultural values. The need to balance future development with existing industries (for example, commercial fisheries), Matters of National Environmental Significance (MNES), and Indigenous priorities drives the need for a broad landscape (here termed 'seascape') approach to managing and recovering Threatened and Migratory marine species in the North Marine Bioregion. The key aspects of the project scope were:

- ***Project Scope:*** Northern Seascapes Phase 1 was a scoping project to understand research needs for potential 2018–2020 NESP Marine Biodiversity Hub research on Threatened and Migratory marine species in Northern Australia;
- ***Species Scope:*** The species scope was limited to *EPBC*-listed Threatened and Migratory marine species. The project will identify knowledge and knowledge gaps for the species, which may direct future Hub species-specific or species-group research.
- ***Geographical Scope:*** The geographical scope was limited to the North Marine Bioregion (Figure 1), from Torres Strait, Queensland, through the Gulf of Carpentaria and the Top End to the Northern Territory/Western Australia border, encompassing coastal and estuarine habitats to the edge of the Australian Exclusive Economic Zone (EEZ). This region includes Kakadu National Park, and areas included as part of the North Marine Parks Network (formerly, 'Commonwealth Marine Reserves').
- ***Indigenous Engagement Scope:*** The project was a NESP Category 1 project for Indigenous engagement and participation, with an assessment of Indigenous research and management priorities. Indigenous land and sea managers have been identified as primary research end users and are expected to play a central role in the on-ground research in Phase 2.

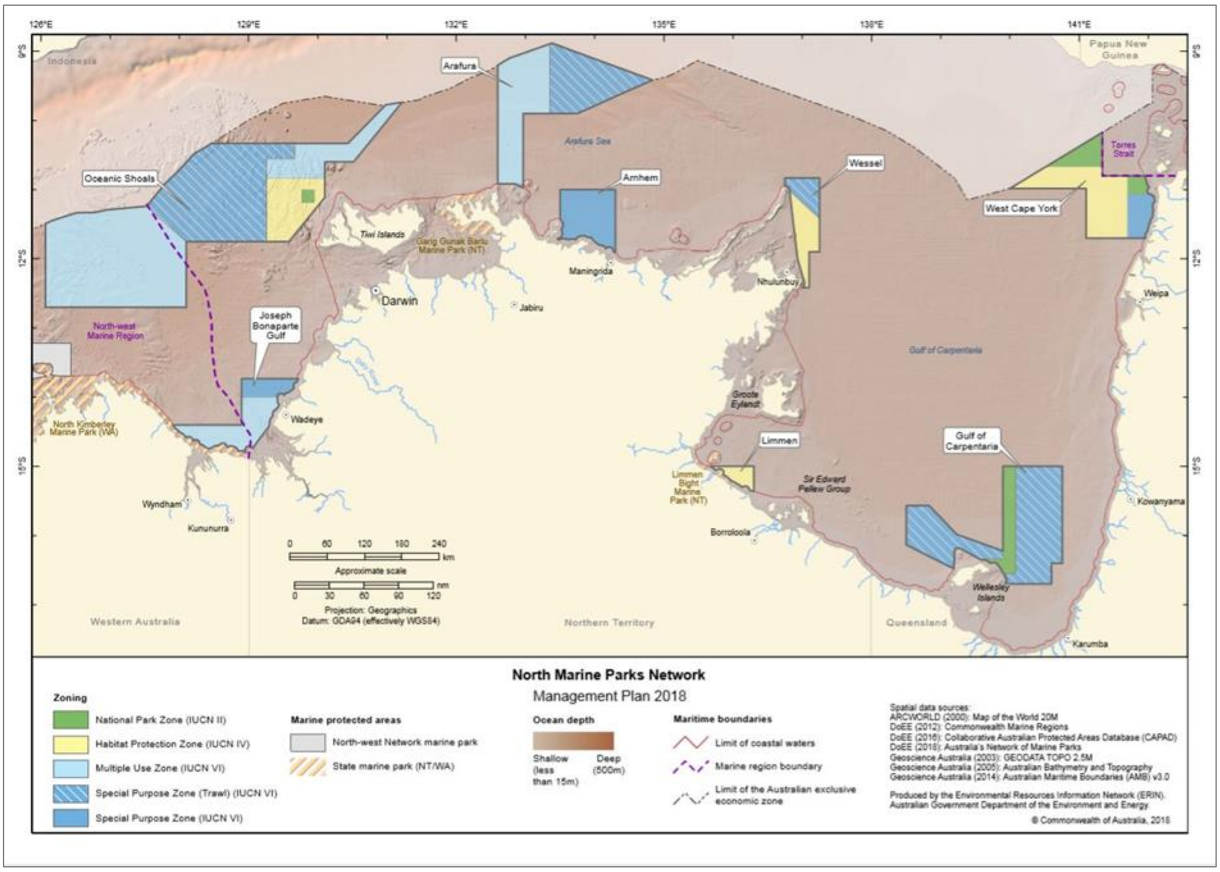

Figure 1. Map of the North Marine Parks Network, including outline of the North Marine Bioregion. Source https://parksaustralia.gov.au/marine/parks/north/maps/

1.2 Objectives

The Northern Seascapes Scoping Project aimed to:

- Improve our knowledge of key marine species and ecosystems to underpin their management and protection;
- Identify key opportunities to collaborate and build Indigenous participation and knowledge into the management and protection of marine species;
- Determine the causes of, and relationships between, pressures on the marine and coastal environment, to inform government investment;
- Identify past and current changes in and pressures on the marine and coastal environment, and understand their impact to better target policy and management actions; and,
- Better understand issues that are common to the fishing industry and the environment including identifying solutions of mutual benefit.

1.3 Report Structure and Research Component Objectives

The Northern Seascape scoping project consisted of five research components with their broad objectives given below. Each component is presented as a chapter of this report, with each opening with a selection of ‘Key Points’ as a summary. These chapters are followed by a synthesis section, which concludes by ranking North Marine Bioregion sub-regions as a prioritisation exercise to direct future research (see Section 7.7).

Species

Objective: Review existing knowledge on Threatened and Migratory marine species, including Biologically Important Areas, movements and corridors, habitat and ecology, and critical areas through a gap analysis approach.

Pressures

Objective: Review pressures (a summary of the human activities and environmental change) on Threatened and Migratory marine species through a pressure mapping approach.

Indigenous Priorities

Objective: Review Indigenous priorities for Threatened and Migratory marine species research and management through a desktop review and consultation with Traditional Owner groups.

Coastal Habitats

Objective: Depict the extent and timing of change in key coastal habitats over the last three decades at selected locations in Northern Australia through a proof-of-concept exercise to determine the feasibility of developing a reprocessed and restructured Australian Landsat archive (Data Cube) habitat-change analysis tool that could be applied across the coast of Northern Australia.

Fisheries Bycatch

Objective: Examine Threatened and Migratory marine species bycatch issues in the commercial fishing industry in Northern Australia through stake-holder engagement (a bycatch workshop) and fishing effort and interaction analysis.

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2. SPECIES

KEY POINTS

- Of the ~80 *EPBC*-listed Threatened and Migratory marine species known to occur in the North Marine Bioregion, 16 were identified as priority species through consultation with research end-users and experts. This priority group consisted of three sawfishes, two river sharks, two inshore dolphins, six shorebirds, two marine turtles and Dugong.
- A gap analysis was undertaken for these priority species by comparing information and distribution maps present in the Species Profile and Threats Database (SPRAT) with new data found in the peer-reviewed and grey literature, unpublished data and open access databases.
- The approach used by DoEE for species distribution mapping is largely based on simple associations of the habitat underlying species observations and extrapolation and not based on quantitative relationships between species occurrence and habitat, such as is obtained from species distribution modelling and recommended here.
- Dwarf and Green Sawfish had the most data gaps, followed by the other elasmobranchs, inshore dolphins, Hawksbill Turtle, Dugong, Olive Ridley Turtle, and shorebirds.
- Many new datasets were identified that have not yet been incorporated into SPRAT profiles and distribution maps. This new data can fill data gaps for all 16 species, and analysis of these datasets can improve the distributions and potentially the designation of critical areas and BIAs.
- Even when considering these new datasets, additional data collection is still required for all elasmobranchs, Hawksbill Turtles and inshore dolphins to improve data coverage for distribution modelling and mapping.
- Research identifying and assessing the relevance and impact of threats to each individual species was an identified gap.

2.1 Introduction

Northern Australia is the current focus of substantial economic development. It is also an area that sustains rich marine biodiversity, encompassing critical habitats (nesting, breeding and foraging grounds, migration corridors) for many *EPBC*-listed Threatened and Migratory marine species, including dugongs (*Dugong dugon*), pelagic and coastal cetaceans, marine turtles, sea snakes, birds, fishes and elasmobranchs. Key to assessing *EPBC* referrals for these species in relation to development is an understanding of the distribution, abundance and movement patterns of these species over a range of spatial and temporal scales. However the spatial products currently available to assess referrals are typically data poor, with maps of distribution and Biologically Important Areas (BIAs) largely built on presence only data from unstructured surveys and the use of qualitative approaches (e.g. spatial buffering around observations and extrapolation based on habitat known or thought to be preferred). Although there may be more robust datasets in existence (e.g. in the published and grey literature), these are largely not publicly available and thus quantitative approaches such as species distribution modelling are often not possible. In some cases, access to these datasets may improve species distribution maps but in others, data of sufficient quantity and quality may simply not exist. In a region where there are numerous threatened species and resources are limited, understanding the differences between these two conditions across species can assist in deciding whether research funds should be directed to data compilation and analysis or whether further data collection is necessary, or neither. To meet this need we undertook a gap analysis of both knowledge and spatial data for Threatened and Migratory marine species in the North Marine Bioregion.

2.2 Objectives

The aim of this component of the project was to identify the gaps in the knowledge, distribution maps and data currently available to Department of the Environment and Energy (DoEE) as a means of identifying future research needs for managing Threatened and Migratory marine species in the North Marine Bioregion. We reviewed information available in the Species Profile and Threats Database (SPRAT, http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl) and distribution maps and compared it to what was available in the peer-reviewed and grey literature and unpublished data.

2.3 Methods

The objective proposed for the species component was a review of existing knowledge on Threatened and Migratory marine species in the North Marine Bioregion (~80 species), including Biologically Important Areas, movements and corridors, habitat and ecology, and hotspots/critical areas to identify knowledge and data gaps, and to identify research needs and direction. It became apparent that time constraints associated with the scoping phase of the A12 project (< 12 months) would prevent the completion of a gap analysis for the full list of Threatened and Migratory marine species. After consultation with research end-users and project partners, the list of species was reduced to those considered as priority due to their Threatened *EPBC* Status, while retaining a diversity of taxa to guide future needs. The priority list consisted of three sawfishes, two river sharks, Dugong, two inshore dolphins, six shorebirds, and two marine turtles (Table 1).

Table 1. List of priority species and their *Environment Protection and Biodiversity Conservation Act 1999 (EPBC)* listings.

Species	Common name	Threatened *EPBC* Status	Migratory
Glyphis garricki	Northern River Shark	Endangered	No
Glyphis glyphis	Speartooth Shark	Critically Endangered	No
Pristis clavata	Dwarf Sawfish	Vulnerable	Yes
Pristis pristis	Largetooth Sawfish	Vulnerable	Yes
Pristis zijsron	Green Sawfish	Vulnerable	Yes
Eretmochelys imbricata	Hawksbill Turtle	Vulnerable	Yes
Lepidochelys olivacea	Olive Ridley Turtle	Endangered	Yes
Calidris canutus	Red Knot	Endangered	Yes
Calidris ferruginea	Curlew Sandpiper	Critically Endangered	Yes
Calidris tenuirostris	Great Knot	Critically Endangered	Yes
Charadrius leschenaultii	Greater Sand-Plover	Vulnerable	Yes
Charadrius mongolus	Lesser Sand-Plover	Endangered	Yes
Numenius madagascariensis	Eastern Curlew	Critically Endangered	Yes
Dugong dugon	Dugong		Yes
Orcaella heinsohni	Australian Snubfin Dolphin		Yes
Sousa sahulensis	Australian Humpback Dolphin		Yes

The main resources used by the DoEE to assess referrals under the *EPBC Act* are Species Recovery Plans and the Species Profile and Threats Database (SPRAT). The latter provides distribution maps as well as a species profile containing information on population, habitat, movements, feeding, reproduction and taxonomy of listed species, whereas the former sets out the research and management actions necessary to support the conservation of these species. The Conservation Atlas might also be referred to, and this provides spatial information on BIAs for some of these species. Not all Threatened and Migratory marine species have recovery plans or BIAs identified (or complete), but all have a SPRAT distribution map and profile. We thus used the SPRAT profile and distribution maps as the main basis for the gap analysis. However, this approach was complicated by the reference list as provided on the SPRAT profile not being linked to the distribution maps. Thus, it is unclear which references (if any) relate to the distribution map. Clearly identifying the data used in the distribution maps in the SPRAT profile would facilitate a more routine updating of the maps.

The species distribution maps are considered indicative only and in general combine the specific habitat type or geographic feature that contains observed locations of the species (known to occur), the suitable or preferred habitat occurring in close proximity to these locations (likely to occur); and the broad environmental envelope or geographic region that encompasses all areas that could provide habitat for the species (may occur) (DoEE). The observed species locations come from a database of species observation records (SPRAT database), and the habitat data for extrapolating from the locations comes from national and regional-scale environmental data (DoEE). Knowledge from scientific research is also used to understand habitat requirements, e.g. if experts/research outputs identify reef as important for a species then all reef areas in the broad vicinity (large spatial buffers are often specified) of species observation records might be designated as 'may occur'. As this information and habitat data is often incomplete, this approach to distribution mapping may lead to both under and over prediction of habitat use. In some cases, modelling is used to quantify the relationship between habitat variables and species occurrence and then species distributions can be predicted based on these modelled relationships (e.g. Maxent), however for all 16 priority species this was not the case (Marcus Baseler pers. comm). The source of the data in the SPRAT database was largely State and Territory wildlife atlases, the Atlas of Living Australia (ALA), Birdlife Australia's Birdata and museums (Marcus Baseler pers. comm). As the SPRAT database is not open access we requested access to the data in order to undertake the gap analysis for the 16 priority species but it was not able to be provided due to licensing restrictions. However, the internal DoEE high resolution distribution maps were provided as was as a spreadsheet with the names of the specific government departments, atlases, museums and conservation organizations that had contributed the data. Although this would theoretically have enabled us to identify where or if, there was new data not included in the SPRAT database, this information did not identify the original data sources (published/unpublished study or simple observations) and thus details of the nature and quality of the data were unknown.

The first part our gap analysis process was to review the information in the SPRAT profile (using the SPRAT profile reference list) and the distribution maps for the North Marine Bioregion. As we could not access the data in the SPRAT database and had no information regarding its original source (as mentioned above), our assessment of the data behind the distribution maps was based on our understanding of the data using the information provided to us by DoEE (Appendix B) and our understanding of the data generally available for these species (from the SPRAT profile reference list). A score was assigned against a range of categories (listed below) according to the resolution (spatial, temporal and quality) of the data (high: 3; medium: 2; low: 1). We then summed the score in order to understand in relative terms how good the knowledge and data were for each species and then averaged and rounded the score for each species to provide an overall score of high (3), medium (2) or low (1). The following categories were used to score each species:

- Records and distribution: indicates the amount of information used in the SPRAT profile and data in the distribution map. We assessed the data behind the map using the methods described above and the relative proportion of the distribution classified as 'known to occur' in the SPRAT high resolution distribution maps. They were classed as data restricted (low: 1), data somewhat limited (medium: 2), data-rich (high: 3);

- Population sampled: indicates the representativeness of the information in the SPRAT profile and used to create distribution maps, in terms of sex, maturity class (juveniles, sub-adults, adults), season (breeding/non-breeding), and behavioural mode (foraging/migratory behaviour/nesting). If all sexes, maturity classes and behavioural modes that occur within the North Marine Bioregion were represented they received a high score (3), if it was somewhat limited it received a medium score (2) and if it was severely limited it received a low score (1);

- Identification of critical habitats: indicates whether the data and information allowed for the identification of habitats/areas associated with nesting, nurseries, breeding, and foraging in the North Marine Bioregion. If SPRAT profile indicated that critical habitats were identified across the distribution it received a high score (3), if it was spatially limited it received a medium score (2) and if there was no information or it was severely spatially restricted it received a low score (1);

- Type of data: indicates our assessment of the type of data used (telemetry, conventional tagging/marking (e.g. flipper tags, bird rings), counts, abundance, presence/absence, catch records), and the extent (temporal and spatial) to create current species distribution maps. The classification takes into consideration the resolution and scale of datasets in relation to each species expected distribution. Structured surveys or targeted studies, long term in nature got the highest score, the score was considered medium if the data was limited in some way by spatial and temporal coverage or the result of more un-structured surveys (i.e. occasional presence records on ALA), lowest score was given to data that was more incidental in nature such as arising from museum specimens and fisheries bycatch;

- Threats: identifies threats and the amount of information currently in SPRAT or Recovery Plans on the understanding and impact of threats to species distributions and populations. The highest score was given to those where threats had been identified and are being monitored and the impacts well understood, a medium score was assigned if they were identified but not monitored or well understood and the lowest score was assigned if threat are mostly unknown or not well understood;

- Biologically Important Areas or Important Bird Areas (as defined by BirdLife International and Birds Australia): those species that had BIA's or IBAs described throughout the North Marine Bioregion received the highest score, a medium score was assigned if the defined

BIAs were spatially restricted across the region and the lowest score was assigned if there were no BIAs defined in the region; and,

- Recovery Plan: indicates whether Recovery Plans have been developed by DoEE for the species. The highest score was given if they have one or have been deemed by DoEE as not required, a medium score was given if they don't have one but are included in bioregional plans and the lowest score was given if there was no recovery plan and there was no other management plan associated with the species. However, the potential effectiveness of recovery plans for species was not evaluated or taken into account during the scoring.

The second part of the gap analysis set out to uncover what new data and information exists for the priority species to update SPRAT profiles and distributions and fill the data gaps identified by the above process. This consisted of a review of the peer-reviewed and grey literature using Google Scholar, enquiries to species experts, government departments, conservation organisations (e.g. Queensland Wader Study Group (QWSG), BirdLife Australia), industry contacts (e.g. INPEX, ConocoPhillips) and searching free, online data repositories (e.g. Zoatrack, eBird, ALA, Global Biodiversity Information Facility, Australian Ocean Data Network). The classification score for each of the categories in the table was then updated for each species by taking into account the new information and datasets identified.

The final step of the gap analysis was more quantitative. We contacted owners/custodians of the new georeferenced datasets identified and ask them to contribute to the project by sharing their data. New data obtained in this way, and from open access databases, was then plotted over the SPRAT high resolution distribution maps. Where the new data was not provided, either due to time or licensing constraints or a nil or negative reply, we attempted to simply place a point on the map where the study took place (obtained from the literature). Further work with data owners may be required to liberate some of these datasets.

As we could not access the data in the SPRAT database nor comprehensive metadata for it, quantitatively assessing spatial gaps was not simply a comparison of the data used versus data available. In addition, the dataset that we compiled would contain data used in the SPRAT distribution map (i.e. not new data). Thus our approach consisted of gridding the area that contained the 'new data' (that compiled here) and the SPRAT high resolution distribution (0.1 degree grid cells). For each species we then calculated the proportion of grid cells in each occurrence category (known, likely and may) and in previously un-categorised grid cells (i.e. areas within the NMB that were not included as part of the species distribution in the SPRAT distribution maps) that contained at least one new data point. As only the 'known' category contains actual data points in the SPRAT distribution, any overlap of data in the 'likely' and 'may' categories was thus considered new data not yet included in the SPRAT distribution. To summarise where the new data came from, we defined five sub-regions within the North Marine Bioregion (Top End, Arnhem, Western Gulf, Southern Gulf, and Cape York; see Section 7.7) and for each species we calculated the proportion of grid cells in only the 'likely' and 'may occur' categories and in previously un-categorised grid cells that contained at least one new data point within each of those sub-regions. These results cannot be compared among species (only within) as the proportions are relative to the size of each species total distribution. When comparing within species among sub-regions it is also important to note that although a sub-region may not have new data it may contain existing data ('know occurrence') thus both the distribution map and sub-region map must be referred to when interpreting these results. The combination of the knowledge and spatial gap analyses allowed the identification of true gaps (no or limited data) for the priority species and assisted with recommendations to guide future research effort.

2.4 Results

The gap analysis of the information in the SPRAT profile (accessed June 2017) for 16 priority species is shown in Table 2 and the updated classification in light of new information and data (Table 5) is shown in Table 3. In addition, the before and after overall score is provided in Table 4. A table containing the summary information for the classification of each category for each species is available in Appendix B.

We identified 47 datasets and data owners for the 16 priority species (Table 5), and another 12 datasets for other Threatened and Migratory marine species not included in the priority list (Green Turtle, Flatback Turtle, Loggerhead Turtle, Estuarine Crocodile, Narrow Sawfish, False Killer Whale). The datasets for non-priority species are likely not complete and were found while searching for priority species. At least 23% of these were found and downloaded from online open access data repositories, 34% belonged to researchers/academic organisations, 8% to conservation groups, 13% to Indigenous ranger groups, 11% to State and federal government and 5% belonged to industry. Email requests were sent to all the researchers and state and federal government agencies, letters have been prepared to send to Indigenous ranger groups and enquiries have been made regarding the industry data. The datasets constituted mostly telemetry (acoustic and satellite tracking) (40%) and survey datasets (catch records; boat, aerial and ground surveys) (38%), with the remainder likely a combination of surveys and presence only observations (information unavailable to assess). Around half (23) of the identified datasets were obtained for use in the spatial gap analysis and presented in Figures 3–6. A process to make these data (or metadata if licence agreements are restrictive) available to ERIN needs to be negotiated with DoEE so that SPRAT distribution maps can be updated with this new data.

2.4.1 Sawfishes and River Sharks

The gap analysis indicated that the three species of sawfish and two river sharks had the lowest overall scores of the information currently used (Table 2), due to poor spatial coverage and overall paucity of the existing data behind the SPRAT species profiles and distributions (Figures 2–4). The gap analysis indicated that data in SPRAT consisted only of juveniles and sub-adults for both the Largetooth Sawfish and Speartooth Shark, and of adult and juveniles for the Dwarf and Green Sawfishes. In addition, the data was mostly restricted to a single study or incidental catch records limited to a small number of embayments in the Northern Territory. Threats identified in the profile are also largely related to potential or expected issues related to interaction with human activities (e.g. fishing and habitat disturbance) and little information is available for assessment of impacts. Consequently, distribution maps for most of these species are classified as precautionary with a large extrapolation of the area of use by the species. Due to this, all species received a low overall classification, except for

Largetooth Sawfish as this species had sampling occurring at a higher number of sites (Table 2, Figures 2–4).

The literature review revealed that new information is available regarding the distribution of Speartooth Shark (Lyon *et al.* 2017) and the genetic structure of river sharks (Wynen *et al.* 2009, Feutry *et al.* 2014, Li *et al.* 2015) and Largetooth Sawfish (Feutry *et al.* 2015a, 2015b) within rivers of the North Marine Bioregion. Published data also identified nurseries and critical habitats for Speartooth Shark in the Adelaide and Wenlock Rivers, and the South Alligator River for the Northern River Shark (Pillans *et al.* 2009, Kyne 2013). Additionally, new and/or unpublished datasets (catch records, and acoustic and satellite tracking) have been identified for the three sawfish and two river sharks, though new data is still limited for Green and Dwarf Sawfish (Table 5). The published information and new datasets resulted in an upgrade to a medium score for both river sharks, and Green Sawfish, however the score for the Dwarf Sawfish remained as low (Table 3). The gap analysis also identified that these elasmobranchs are found in areas of high human activity, such as mangroves and estuaries, which, combined with the lack of information on the impact of threats (Table 2, Table 3), suggests that more data are needed for elasmobranch species. An unresolved issue is that sawfishes are reported as bycatch in commercial fisheries but often not identified to species level and there are no studies on the impact of fishing on populations (see Fisheries Bycatch Chapter).

Most of the sampling is still focused on juveniles and young-of-year with a large amount of acoustic tracking, molecular work, and consideration of traditional ecological knowledge that enabled the identification of nurseries and pupping grounds. However, for some species there in an absence of data for adults and feeding grounds and large-scale movements are unknown (including continental shelf areas for some species).

For Northern River Sharks and Speartooth Sharks we found new data in grid cells previously uncategorised by the SPRAT distribution (1% for both species, Table 6). Although this seems low, it is in relation to the very large and conservative area that makes up the distribution (mostly designated as 'may occur') and thus analysis of the combined existing and new data would allow for some resolution of this area (at least in the rivers) and a refinement of the 'known to occur' distribution. However, for both species there is very little or no data in most of Arnhem, Southern and Western Gulf and Cape York. This indicates there is a need to collect more data from these sub-regions to improve the distribution in regards to the very large area designated as 'may occur' (Figure 2).

For Dwarf, Largetooth and Green Sawfish most of the North Marine Bioregion, including vast sections of the shelf is classified as 'known to occur', however we found very little data in these areas (Figures 3–4). This suggests that the data in SPRAT used to define this area may be from limited fisheries bycatch records. We know that a conservative buffer was applied to the known, likely and may extents in the SPRAT distribution, but not what spatial extent was used for the buffer (Appendix C). More data over the shelf are clearly needed to define the area of known use with more certainty. Distribution modelling with the fisheries bycatch data might improve this, however it appears the data are limited and the bycatch is not always identified to species. We found a small amount of new data in the likely category and previously un-categorised grid cells for most of these species (Table 6) As above this is partly biased by the very large, conservative area that makes up the distribution (mostly designated as 'likely') for

Largetooth and Green Sawfish. For Dwarf Sawfish, we found 20% of grid cells with new data (Table 6) and 67% of these grids were in the Top End (Figure 3). Analysis of the new data for all three species may improve the distribution in this region but not over the entire North Marine Bioregion. There is a lack of data in all other regions except Top End for the Dwarf and Largetooth Sawfish. Although the Green Sawfish has a few data points in all sub regions on the shelf, there is a paucity of data there and no data in coastal regions, as evidenced by the fact that most of it is classified as 'likely' (Figure 3). The likely habitat was simply defined by ERIN by mapping hydrological, bathymetric and marine geomorphic features. As for the river sharks, more sampling is needed. There might also be a need to update the habitat data (e.g. using Seamap Australia), however this was not assessed here.

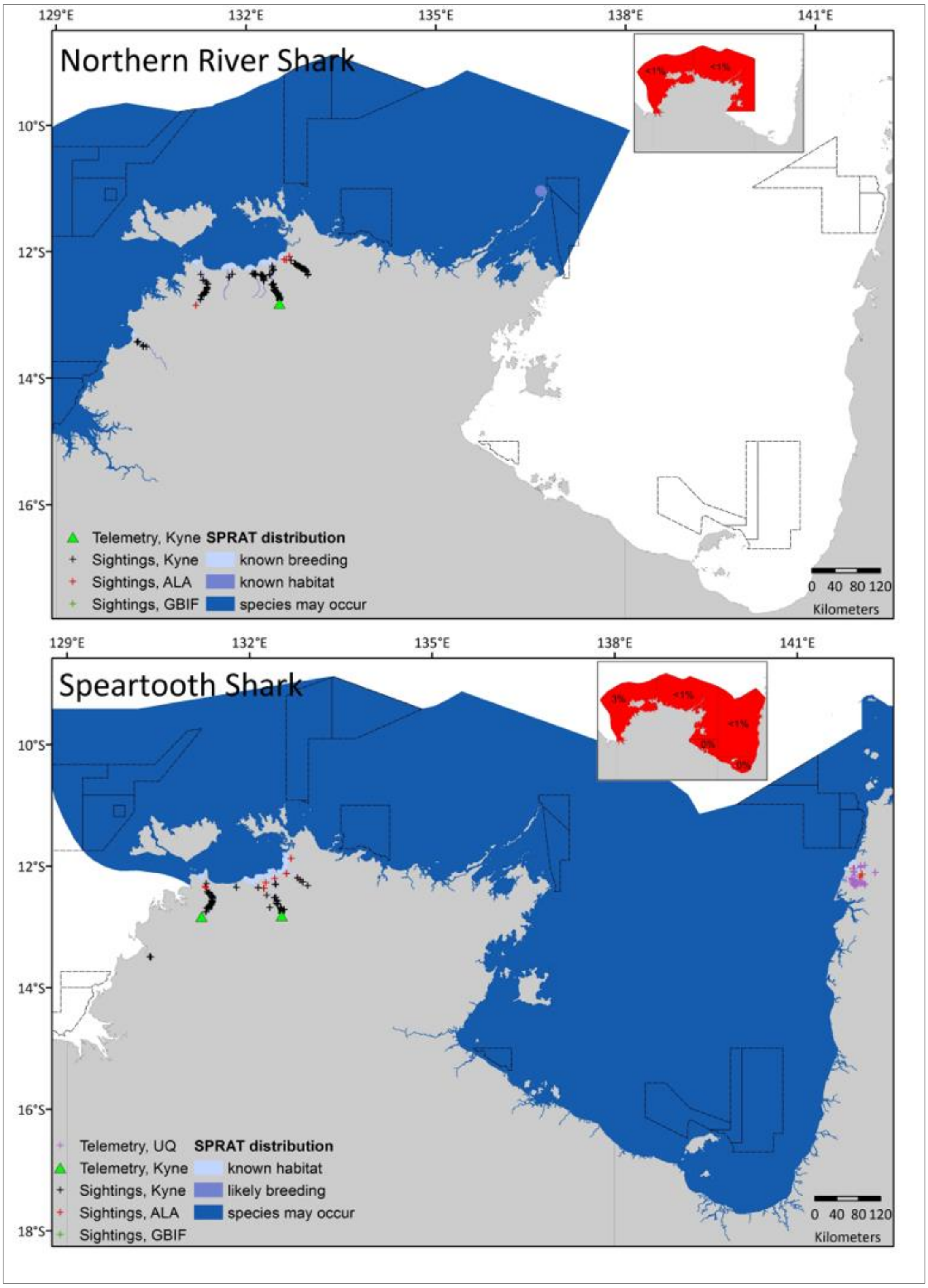

Figure 2. SPRAT distributions for sharks overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within "likely", "may", and "unrecorded" distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

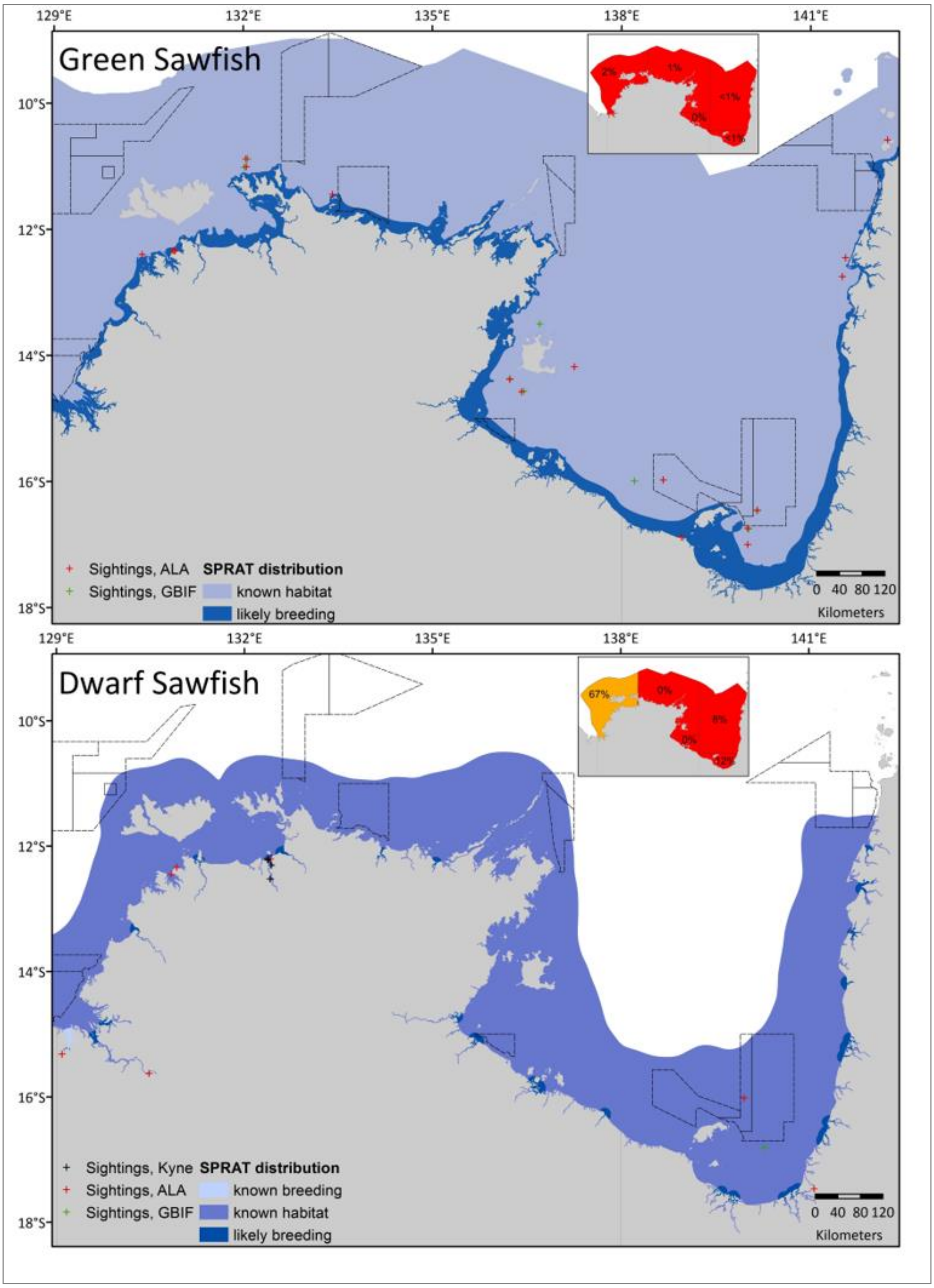

Figure 3. SPRAT distributions for Green and Dwarf Sawfish overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within “likely”, “may”, and “unrecorded” distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

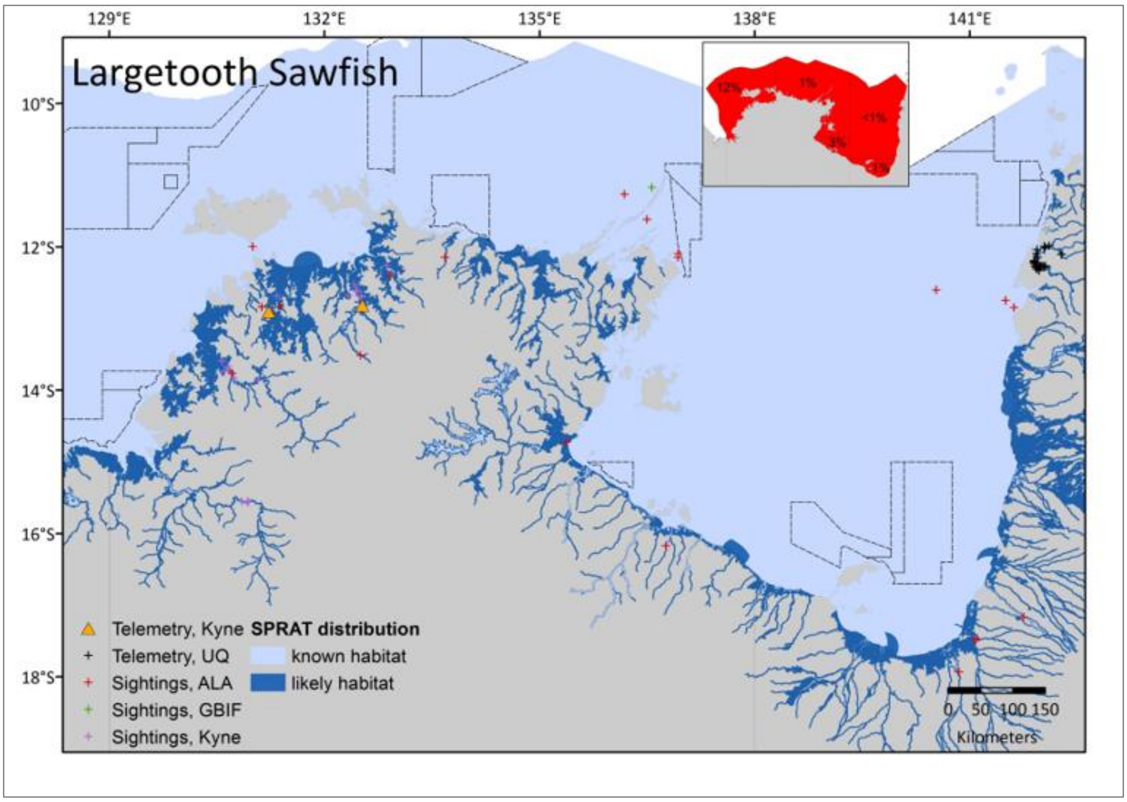

Figure 4. SPRAT distributions for Largetooth Sawfish overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within "likely", "may", and "unrecorded" distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

2.4.2 Marine Turtles

The gap analysis classified the information in SPRAT for the Olive Ridley Turtle and Hawksbill Turtle with a medium overall score (Table 2). The classification reflected the lack of information on population structure (most studies target adult females on the nesting grounds, and that critical habitats and BIAs relating to foraging and migratory pathways have not been identified for either species in the North Marine Bioregion. In addition the distribution had large areas assigned as 'likely' and 'may' (Figure 5). Although there were some structured survey data (by Ray Chatto, Table 5 and others), this only included the NT; datasets that included the whole North Marine Bioregion largely came from flipper tag returns thus the type of datasets available for SPRAT was classified as medium. The majority of the nesting areas appear to have been identified for both species (we determined this by comparing maps of nesting beaches in the Recovery Plan for Marine Turtles (DoEE, 2017) with 'known nesting' in the SPRAT distribution map). Inter-nesting areas have been identified in the SPRAT distribution by buffering the nesting grounds by 30 km (Appendix C), but there is little data outside the nesting grounds. The SPRAT distribution outside the breeding distribution was made using a combination of observations and simple habitat associations, for example, the known foraging extents for both turtle species were created by selecting reef and seagrass area features within 20 km of all known breeding areas, BIAs and observation records (Appendix C).

The literature search revealed new satellite tracking datasets available for the Olive Ridley Turtles in the Tiwi Islands (McMahon *et al*. 2007, Hamel *et al*. 2008) which were open access and downloaded (Table 4, Figure 5). New datasets were also identified from several other locations in the North Marine Bioregion, but for the telemetry data there was only a low number of transmitters deployed at each site (Table 4, Figure 5). We were not able to obtain these datasets in time and thus Figure 6 simply plots the deployment locations for these transmitters (triangles on Figure 5). Although the tracking datasets were all obtained from adult females only (transmitters attached while nesting) they provide important and largely absent in-water data points and can be used to indicate foraging areas on the continental shelf. Similarly, adult female Hawksbill Turtle tracking data from Groote Eylandt were obtained (Hoenner *et al*. 2016) and show their movement and potential foraging grounds on the shelf in the Gulf of Carpentaria and offshore coral reefs (Figure 5). Survey data (sightings) was also identified for both species (Table 6, Figure 5) and although they might assist with validating some of the 'likely' and 'may' breeding categories we were not able to obtain the data to properly assess this. The new datasets identified increased the overall score for both species but only marginally for Hawksbill Turtles, and despite an increase in scores the classification for both species remained as medium. The score was improved from the potential ability of the new datasets to help identify critical habitats and BIAs for foraging. The medium overall classification reflects the relatively low number of individuals satellite tracked from each site (Table 4), the data not being representative of the population (only nesting females usually targeted) and the limited spatial and temporal coverage of the data (mostly collected during the nesting season).

The Recovery Plan for marine turtles in Australia was updated in 2017 (DEE 2017). However, the limited knowledge on critical habitats, particularly foraging grounds and inter-nesting habitats of Olive Ridley and Hawksbill prevents an informed understanding of the risk of threats to their populations in the North Marine Bioregion especially the impact of the, potentially large numbers caught in ghost nets (Jensen *et al*. 2013, Wilcox *et al*. 2013), and high rates of turtle-fisheries interactions in the Gulf of Carpentaria (DEE 2017).

For Hawksbill Turtles, we found very little new data (Table 6), although Table 5 shows many more datasets than we obtained. Thus, this situation may improve if the data is obtained. For Olive Ridley Turtles, we found around 13% of grids with new data (Table 6, Figure 5) and 2.4% of these were not previously recorded as part of the distribution. And as for Hawksbill turtles, there were many new datasets identified, but we were not able to obtain them in time (Table 5) to include in the analysis. Thus, if the data can be obtained for Olive Ridley Turtles, modelling of these data could assist with improving the distribution maps, especially for the foraging and inter-nesting areas. Even though these are classified as 'known' in the distribution of both species, they are the result of simple habitat associations and buffering and not from modelling of actual data points (Appendix C).

We uncovered some Dugong aerial survey data for the entire coast of NT in which turtles were also recorded but not identified to species (Groom *et al*. 2015, Table 5). Distribution modelling could be applied to this data to identify general turtle important areas over the shelf, but keeping in mind that the survey was for dugongs so the spatial extent is somewhat limited to coastal areas. This would therefore only resolve a small proportion of the very large 'may' and 'likely' to occur areas over the shelf. Additional satellite tracking data is needed for this but given the many nesting beaches, the cost of representative sampling would likely be prohibitive. Perhaps targeting sub-regions associated with high threat levels might make such an approach more feasible.

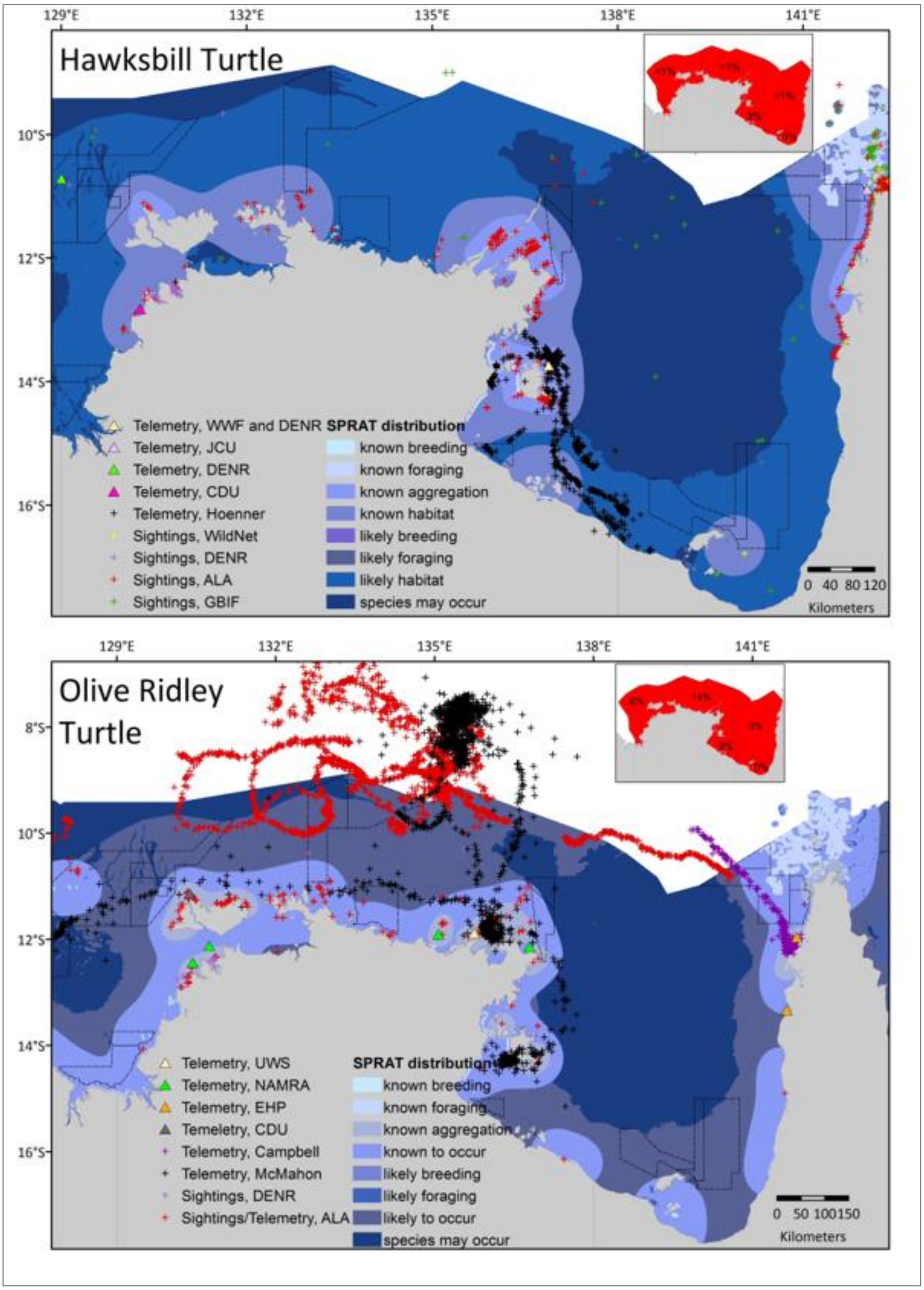

Figure 5. SPRAT distributions for marine turtles overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within “likely”, “may”, and “unrecorded” distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

2.4.3 Shorebirds

For the six species of shorebirds assessed (Red Knot, Curlew Sandpiper, Great Knot, Greater Sand-Plover, Lesser Sand-Plover, Eastern Curlew), data used in the SPRAT and distribution maps have medium to high overall scores (Table 2). Long-term datasets of shorebirds during the non-breeding season are available from surveys (counts), banding and tracking studies, and many of the foraging grounds and roosting habitats for shorebirds in general have been identified so that almost all species were scored as medium or high for most categories (Table 2). However, gaps were identified due to the fact that the SPRAT distribution shows large areas of the North Marine Bioregion as either no occurrence or in the likely and may categories for many species (Figure 6–8). Parts of Arnhem Land and the Gulf of Carpentaria represented a geographical data gap for most species except Red Knot (Figure 7). These gaps are critical as agricultural development and dredging of river mouths for development have the potential to severally impact critical habitats for shorebirds in the region. Another knowledge gap was the lack of information on the effects of potential threats to species populations and distributions (Table 2). For most shorebirds, habitat loss was identified as a key threat, however, little is known on the rate of habitat alteration of critical habitats in the North Marine Bioregion (see Chapter 5) and little is known of the impact of human disturbances on these populations (Lilleyman *et al*. 2016). The Greater and Lesser Sand-Plover were the only shorebirds with a medium overall score, mostly due to the lack of data with which to develop the distribution across a large part of their range (Figure 8) and consequently, a gap in the knowledge of critical habitats for these species. Although there are no BIAs identified by DoEE at the species level, BirdLife Australia provide spatial information on bird important areas for shorebirds in general, and these are incorporated into the SPRAT distribution, thus all the birds received a medium score for BIAs.

The overall score was improved (Table 3) when assessing new datasets with some additional information on distribution and population trends in the region (Clemens *et al*. 2010, Minton et al. 2013, Clemens *et al*. 2016, Dhanjal-Adams *et al*. 2016, Runge *et al*. 2017) when compared to information available in SPRAT. New and updated datasets have been identified by long term monitoring programs by Birdife Australia, Indigenous ranger groups, open access databases and some limited satellite tracking (Table 5, Figure 6–8). These datasets resulted in the increase to a high overall classification score for all species (Table 3). Overall the shorebird group represent the best data available in SPRAT for the 16 priority species (Table 2) and updated/additional datasets (Table 3, Figure 6–8) will assist in improving the distribution and potentially in identification of species-specific BIAs and critical habitats (Table 3). The main gap was for threats and given the high threat status of all these species, more effort needs to be directed to monitoring and understanding the impact of threats.

Red Knot and Eastern Curlew have the entire North Marine Bioregion classified as ‘may occur’ to allow for migratory routes and overfly areas (Appendix C). Although we did find new data in the may occur area, the proportions look very low due to the fact that the total area designated as ‘may’ is so large (Table 6, Figure 6–7). At the time of writing we do not yet have all the new data in hand and are awaiting the provision of important datasets from Birdlife Australia and the QWSG (Table 5). We found a lot of new data in the ‘likely’ category (33% and 38% of grid cells) so modelling of this data could resolve the uncertainty in these categories and improve the distribution in general and the designation of critical habitats and BIAs. However it is important to keep in mind that the Eastern Curlew is already the subject of a dedicated NESP Threatened Species Recovery Hub project.

For the other four species (Curlew Sandpiper, Greater Sand Plover, Lesser Sand Plover and Great Knot), though there are still some new datasets that we do not yet have in hand we do have a lot of new data in the 'likely' category (from 20 – 39% of grid cells) (Table 6, Figure 6–8). For the Curlew Sandpiper and Greater Sand Plover 50 and 74% of grid cells have new data in areas that were previously unrecorded (not included in the SPRAT distribution) (Table 6) and for Curlew Sandpiper there was also 40% of grid cells with new data in the 'may occur' category (Table 6). Thus, distribution modelling of these new data will assist in improving the distribution and in the designation of species-specific critical habitats and potentially BIAs for all of these species.

Because these species are classified as Vulnerable and Critically Endangered and show high association to coastal habitats such as mangroves and intertidal habitats, a useful exercise would be to assess and monitor the overlap between species distribution and changes in these vulnerable habitats using remote sensing techniques including those developed by Geoscience Australia as part of this project (see Sections 5.8 and 5.9). Such approaches could also monitor changes in coastal development, particularly around Darwin Harbour. The new datasets identified (Tables 5–6) offer the unique opportunity to assess this, especially important given habitat loss is considered a key threat to shorebirds.

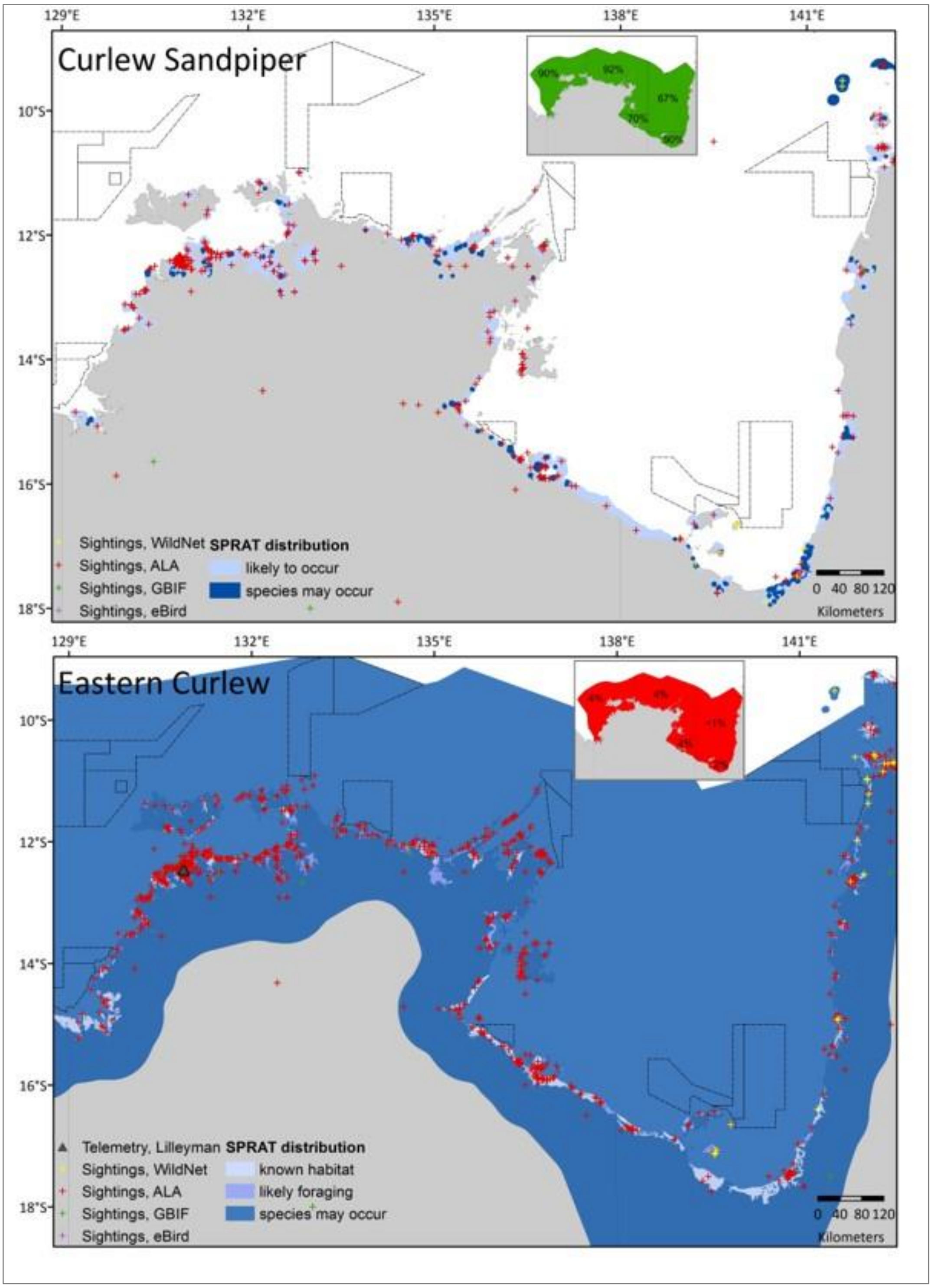

Figure 6. SPRAT distributions for the Curlew Sandpiper and Eastern Curlew overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within "likely", "may", and "unrecorded" distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

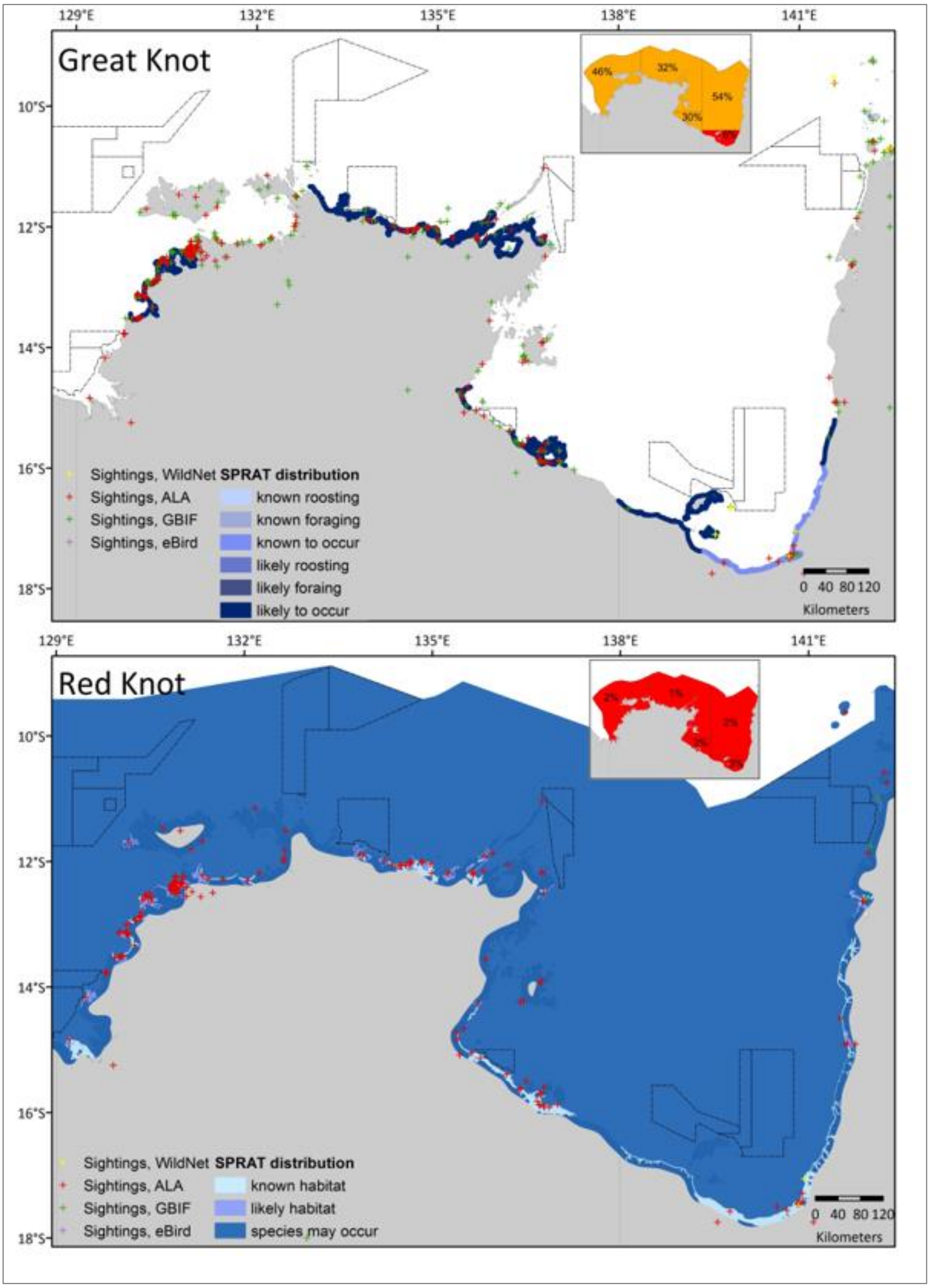

Figure 7. SPRAT distributions for Great Knot and Red Knot overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within "likely", "may", and "unrecorded" distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

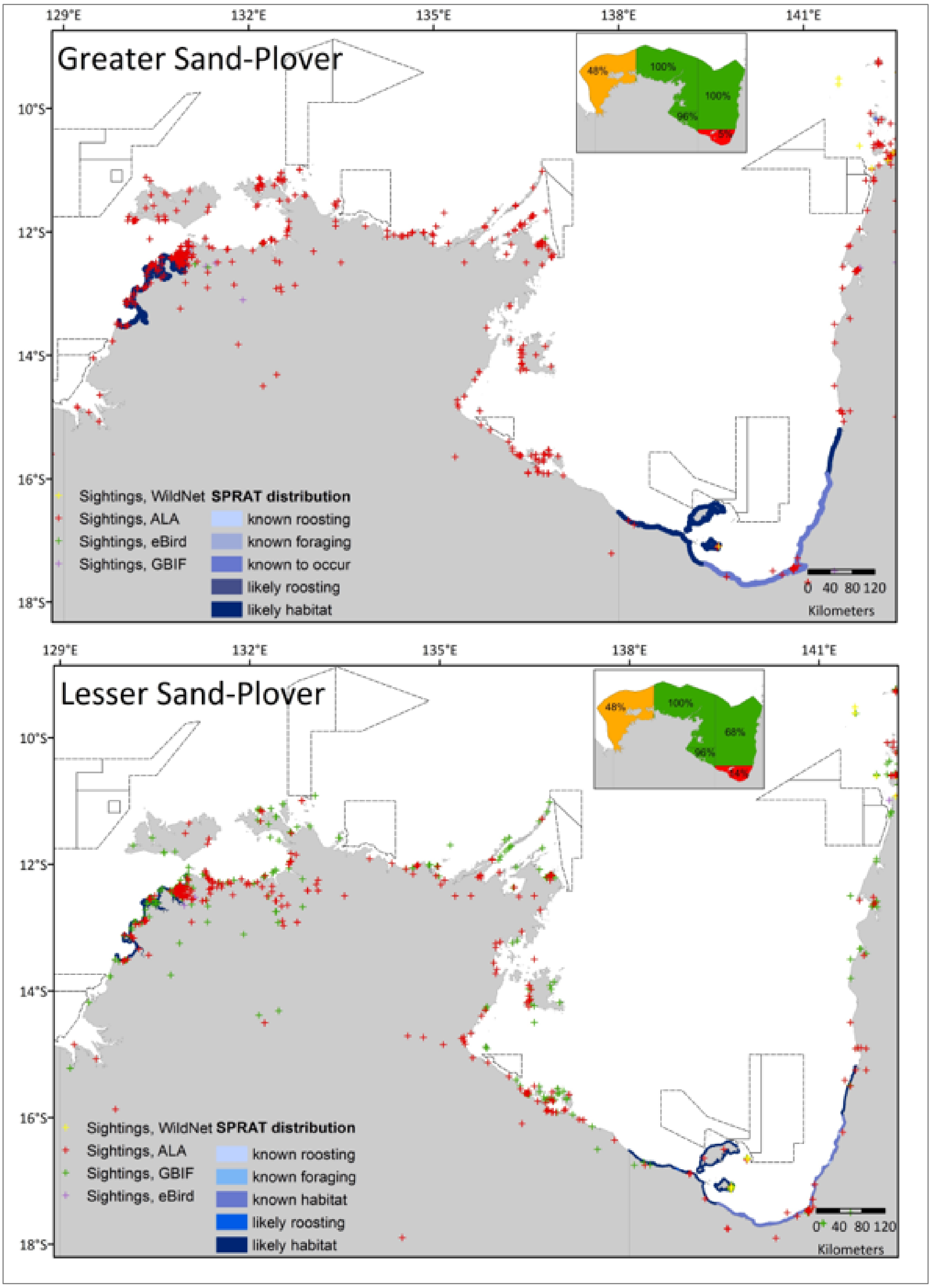

Figure 8. SPRAT distributions for Greater Sand-Plover and Lesser Sand-Plover overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within "likely", "may", and "unrecorded" distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

2.4.4 Marine Mammals

The analysis of the information currently available in SPRAT for the Dugong (*Dugong dugon*), Australian Snubfin Dolphin (*Orcaella heinsohni*), and the Australian Humpback Dolphin (*Sousa sahulensis*) indicated a medium overall score for all (Table 2, Figures 9–10). Australian Humpback Dolphins had the lowest score as most of the North Marine Bioregion appears to be unsurveyed (Figure 10). For the Australian Snubfin Dolphin and Dugong, the distribution was better, but the Southern Gulf and Cape York coast was largely classified as 'likely' and 'may' occur, suggesting that observation data were unavailable for these areas. Critical habitats have been identified in Western Australia and Queensland, but almost no information is available for the North Marine Bioregion, particularly for the inshore dolphins. For the Dugong, structured surveys in some areas identified in the SPRAT profile allowed a better understanding of the distribution and thus identification of critical habitats, when compared to inshore dolphins (Table 2). The absence of Recovery Plans (although all species have been included in Marine Bioregional Plans), and lack of detailed information on the effects of threats on populations in the region have been identified as gaps for all three species.

The literature search identified new datasets from aerial surveys of the entire coast of the Northern Territory, and more regionally focussed (e.g. Darwin Harbour) boat and aerial surveys for all the marine mammal species (Palmer *et al*. 2017, Groome *et al.* 2017) (Table 5, Figures 9–10). (Palmer 2014, Palmer *et al*. 2014a, 2014b, Brooks *et al*. 2017), though these studies did not extend across the whole North Marine Bioregion. Data from ALA filled some of the gaps for Dugong in the QLD section of the North Marine Bioregion as will other datasets that are still to come (Table 5) (e.g. Marsh *et al*. 2008). Combined, these new datasets present robust data that can be used to update the species distribution for most of the North Marine Bioregion (Figures 9–10), increasing their overall classification score, though the classification remained as medium (Table 3) due to the lack of BIAs, recovery plans and little information on the impact of threats. For inshore dolphins, to our knowledge, surveys conducted to date have not included the Gulf. This combined with the no or limited identification of BIAs in the North Marine Bioregion resulted in a medium classification for both species (Table 3). Although key areas have been identified in some sections of the NT coast (Palmer 2017), there are none identified in the QLD portion of North Marine Bioregion. Many potential anthropogenic threats were identified for marine mammal species such as incidental capture in fishing gear, habitat degradation (foraging habitat such as seagrass for Dugong, estuaries and coastal areas for dolphins), overlap with fisheries activities and vessel traffic, and underwater noise, highlighting the importance of clearly defining critical habitats in order to provide assessment of the potential impact of these threats on populations (Table 2, Table 3).

For Dugong and Australian Snubfin Dolphins, we found new data to improve the likely (~8% of grid cells) and may occur (9–12% of grid cells) categories of the SPRAT distributions (Table 6). The values calculated for Dugong will appear low given the conservative buffer applied to may occur distribution. The may occur distribution is simply based on 40 m bathymetry from Shark Bay, WA to QLD/NSW border (Appendix C). For the Australian Humpback Dolphin, we found a very large amount of data (83% of grid cells) in previously unrecorded grid cells (not included in the SPRAT distribution) (Table 6). Thus, for all marine mammals we recommend distribution modelling with this data. For Dugong, there are also new systematic aerial surveys for WA from Port Hedland to the NT border (Bayliss and Hutton 2017) such that the north and north-west distribution could be improved (there may be new data for the eastern Gulf and rest of QLD too, however we are not aware of this). There appears a data gap for the Queensland section of the North Marine Bioregion for the inshore dolphins, thus new data collection is warranted there.

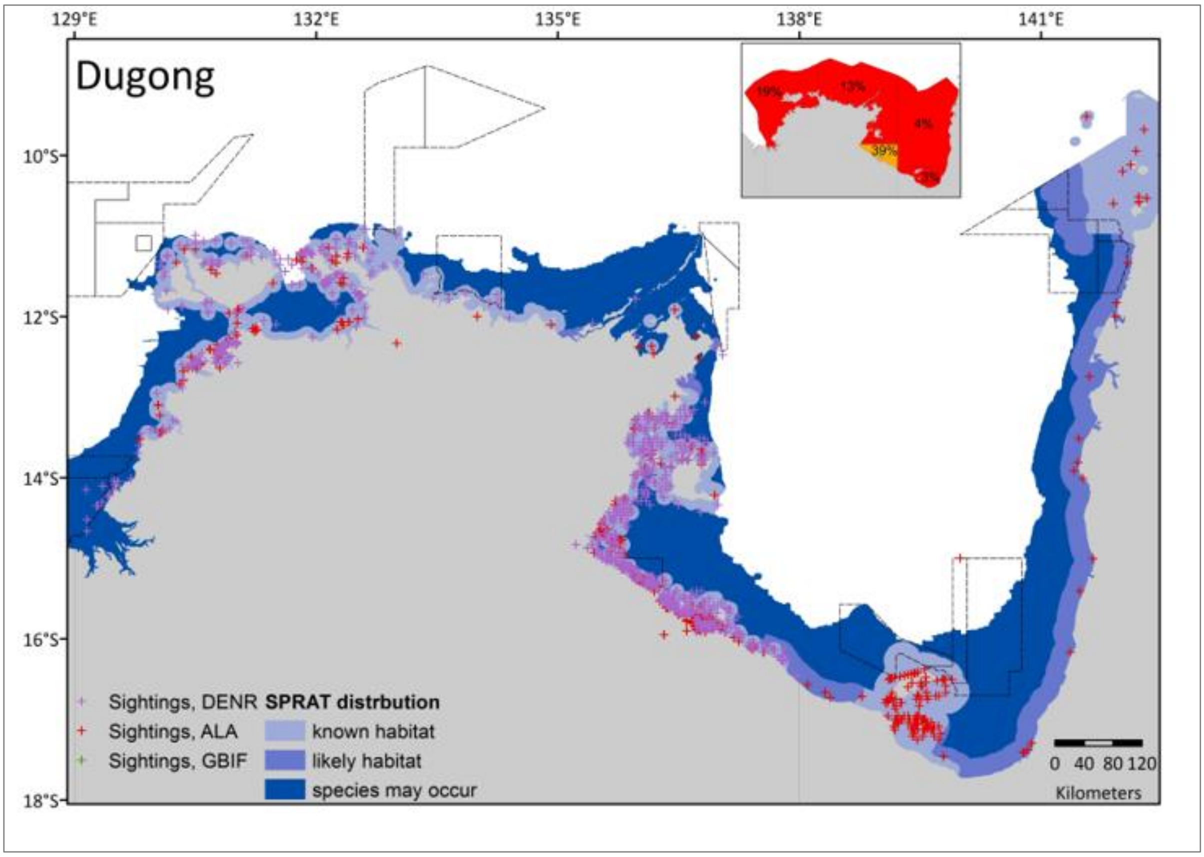

Figure 9. SPRAT distributions for Dugong overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within "likely", "may", and "unrecorded" distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

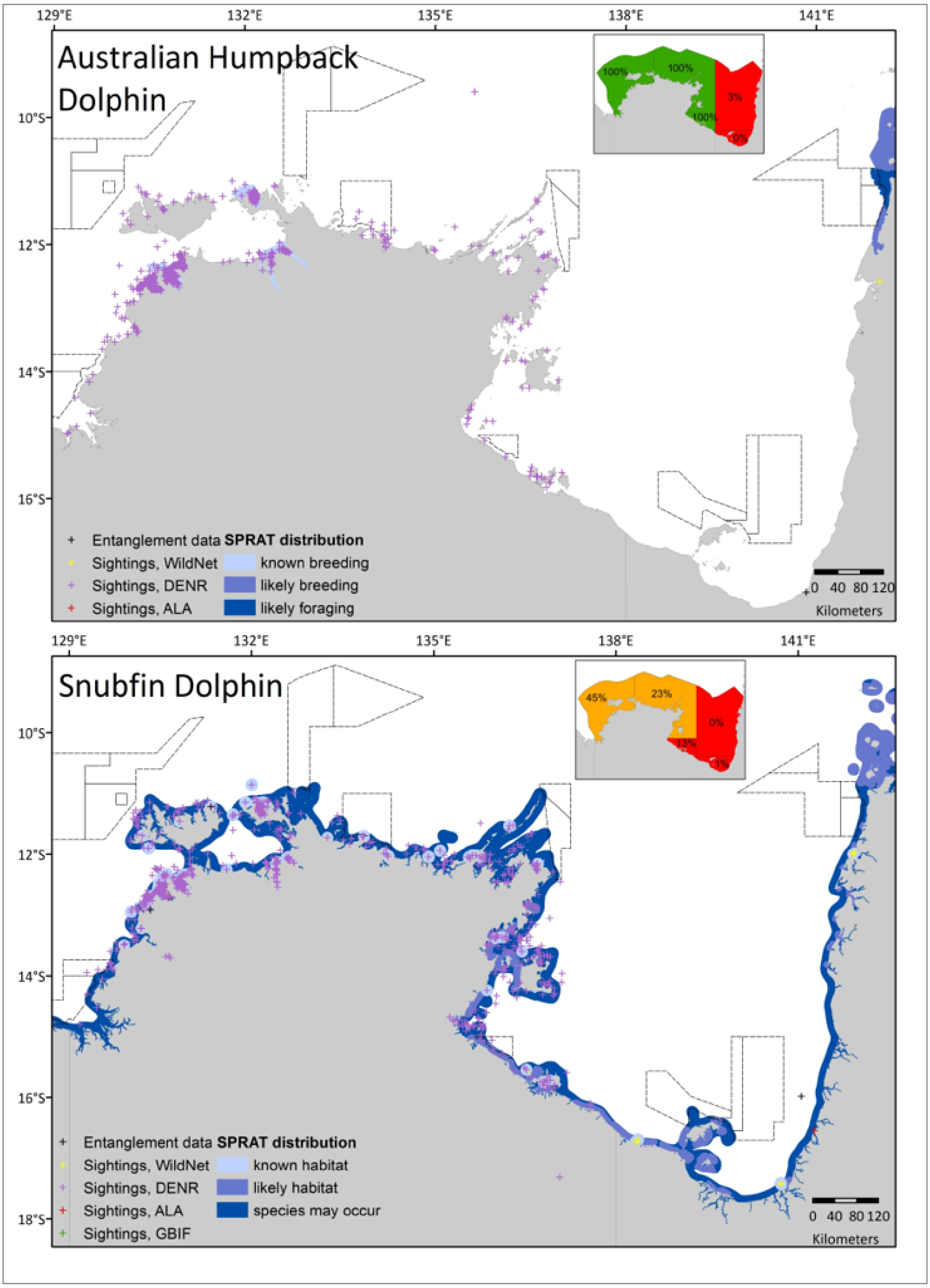

Figure 10. SPRAT distributions for Australian Humpback Dolphin and Snubfin Dolphin overlaid with new datasets obtained from those identified in Table 5. Dashed line contours represent Australian Marine Parks. Map insert represents the proportion of new data within "likely", "may", and "unrecorded" distributions in each sub-region. The calculated percentage is classified as high (>60% grids with new data = green), medium (30–60% grids with new data = orange) and low (<30% grids with new data = red); and represented as the coloured polygons in the small insert map.

2.5 Discussion and Conclusions

We identified many new data in areas that were previously un-categorised or classified as “likely” and “may” in the SPRAT distributions (Tables 5–6). The new datasets should be used to improve all 16 priority species distribution maps ideally using species distribution modelling. This process may also assist in the identification of critical habitats and potentially BIAs. To some extent the new information and maps produced here could immediately assist in informing response to referrals without any further analysis. We also highlight that the approach used by DoEE for species distribution mapping of these species is largely based on simple associations of the habitat underlying species observations which are largely not from structured surveys. Although we appreciate that a conservative approach to distribution mapping might be more appropriate where data are limited (e.g. sawfish and river shark marine areas of use, marine turtle foraging areas, shorebird overfly areas), where data are sufficient, a more quantitative approach is recommended, which would model the relationships between species occurrence and a range of habitat variables and use these modelled relationships to predict distribution across the region of interest (e.g. species distribution modelling). More informed distribution maps will also improve efforts to assess the overlap and potential impact of existing and future pressures. This information is urgently required in order to provide for informed management actions in light of proposed development in the region. We also found new datasets for threatened migratory and marine species not on the priority species list (Table 5) that may also be assessed for the development of species distribution maps in the future. Importantly, species distribution models and mapping require habitat data in relatively high resolution and at the scale of use of species. Although habitat data used to inform the SPRAT distributions were not assessed here, given they might also be incomplete, an assessment and potential update of this data in the SPRAT distribution mapping process may also be necessary.

Although all species still had data gaps (Table 4), the majority were filled when considering the potential of new data sources not currently incorporated in SPRAT profiles and distributions, except for Dwarf and Green Sawfish, where the data only marginally improved the scores (Table 6, Figures 2–10). The elasmobranchs had the most gaps, followed by Hawksbill Turtles and the inshore dolphins, then Olive Ridley Turtles and Dugong (Table 4). The shorebirds had the least data gaps relative to the other priority species, largely due to the extensive new datasets found for all five species and their potential to significantly improve the distributions and designation of critical areas and BIAs on a species-specific basis.

The reason for the sawfish and river sharks having the lowest scores was not entirely due to a lack of studies, as we found ten new datasets. It was largely due to the fact that most of the data for them are from coastal environments (and often from a limited spatial scale) with very little robust data for them in offshore areas. In addition, most of the data come from juveniles and sub-adults. Similarly, with marine turtles, with most data from the nesting beaches and from largely one component of the population (adult females during the nesting season). The reason for the birds having the most extensive data was due to the conservation organisations in Australia and around the world dedicated to bird observations (e.g. Birdlife International, Birds Australia, Australian Wader Society Group).

For all 16 priority species there was a lack of data on the impact of threats or assessments that link threats and pressures to risks for species populations (Table 4). The analysis also highlighted the need to collect more data to improve the spatial coverage for all elasmobranchs, Hawksbill Turtle, and inshore dolphins in order to provide data over the whole North Marine Bioregion with which to improve distribution maps (Table 4). The data needed for inshore dolphins (Table 4) can be obtained from aerial surveys but the offshore data needed for elasmobranchs and marine turtles may need to come from telemetry. Although data are available from fisheries bycatch records, these are generally unreliable due to poor identification to species-level, and are somewhat patchy depending on the area of operation of the fisheries. The logistical and financial constraints of telemetry, especially satellite telemetry, will need to be weighed up against the need to better resolve the very large offshore areas designated as ‘likely’ and ‘may occur’ for these two groups.

Although we did not obtain all the datasets listed in Table 5, we received positive responses from many data owners and also requests for data sharing agreements (listed as pending in Table 5) which typically take time to negotiate. Nevertheless, for the majority of the 16 priority species our quantitative analysis still showed a relatively large proportion of grid cells containing new data (falling within likely, may and un-categorised grids in the SPRAT distribution).

This gap analysis of 16 priority Threatened and Migratory marine species has identified where true gaps in knowledge and data exist within the North Marine Bioregion, allowing us to identify where further analysis of existing data can be prioritised over the more expensive and time-consuming option of additional data collection. Our analysis has also allowed for the prioritisation of species, which provides for a more informed process of directing limited research funds for field data collection. Importantly, we have amassed a dataset (and metadata for additional datasets) of georeferenced data which can be used in species distribution models to develop more robust species distribution maps. Such an approach would ideally follow an agreed procedure with the DoEE and ERIN that could eventually be applied more broadly.

Table 2. Classification scores for information available for each species in the SPRAT species profile and distribution maps in the North Marine Bioregion. Red colour indicates low score (1), orange indicates medium score (2), and green indicates high score (3). The rounded average score was used to assign the overall score or low, medium or high.

Species	Common name	Records and distribution	Population sampled	Critical habitats	Data type	Threats	Biologically Important Areas	Recovery Plans	AVERAGE SCORE	SUMMED SCORE
Glyphis garricki	Northern River Shark	1	1	1	2	1	1	3	1.4	10
Glyphis glyphis	Speartooth Shark	1	1	1	1	1	1	3	1.3	9
Pristis clavata	Dwarf Sawfish	1	1	1	1	1	1	3	1.3	9
Pristis pristis	Largetooth Sawfish	2	1	1	2	1	1	3	1.6	11
Pristis zijsron	Green Sawfish	1	2	1	1	1	1	3	1.4	10
Eretmochelys imbricata	Hawksbill Turtle	2	2	2	2	2	2	3	2.1	15
Lepidochelys olivacea	Olive Ridley Turtle	2	2	2	2	2	2	3	2.1	15
Calidris canutus	Red Knot	3	3	3	3	2	2	3	2.7	19
Calidris ferruginea	Curlew Sandpiper	1	3	3	3	2	2	3	2.4	17
Calidris tenuirostris	Great Knot	1	3	3	3	2	2	3	2.4	17
Charadrius leschenaultia	Greater Sand-Plover	1	3	2	3	2	2	3	2.3	16
Charadrius mongolus	Lesser Sand-Plover	1	3	2	3	2	2	3	2.3	16
Numenius madagascariensis	Eastern Curlew	3	3	3	3	2	2	3	2.7	19
Dugong dugon	Dugong	2	3	2	2	2	1	2	2.0	14
Orcaella heinsohni	Australian Snubfin Dolphin	2	3	1	1	2	2	2	1.9	13
Sousa sahulensis	Australian Humpback Dolphin	1	3	1	1	2	1	2	1.6	11

Table 3. Classification scores for information available for each species in the SPRAT species profile and distribution maps in the North Marine Bioregion updated with new knowledge and data identified. Red colour indicates low score (1), orange indicates medium score (2), and green indicates high score (3). The rounded average score was used to assign the overall score (1, 2, or 3).

Species	Common name	Records and Distribution	Population sampled	Critical habitats	Data type	Threats	Biologically Important Areas	Recovery Plans	OVERALL SCORE (AVERAGE)	OVERALL SCORE (SUM)
Glyphis garricki	Northern River Shark	1	2	2	3	1	1	3	1.8	13
Glyphis glyphis	Speartooth Shark	1	2	2	2	1	1	3	1.7	12
Pristis clavata	Dwarf Sawfish	1	1	1	1	2	1	3	1.4	10
Pristis pristis	Largetooth Sawfish	2	1	2	3	2	1	3	2.0	14
Pristis zijsron	Green Sawfish	1	2	1	1	2	1	3	1.6	11
Eretmochelys imbricata	Hawksbill Turtle	2	2	3	2	2	2	3	2.3	16
Lepidochelys olivacea	Olive Ridley Turtle	3	2	3	2	2	3	3	2.6	18
Calidris canutus	Red Knot	3	3	3	3	2	3	3	2.9	20
Calidris ferruginea	Curlew Sandpiper	3	3	3	3	2	3	3	2.9	20
Calidris tenuirostris	Great Knot	3	3	3	3	2	3	3	2.9	20
Charadrius leschenaultii	Greater Sand-Plover	3	3	3	3	2	3	3	2.9	20
Charadrius mongolus	Lesser Sand-Plover	3	3	3	3	2	3	3	2.9	20
Numenius madagascariensis	Eastern Curlew	3	3	3	3	2	3	3	2.9	20
Dugong dugon	Dugong	3	3	3	3	2	1	2	2.4	17
Orcaella heinsohni	Australian Snubfin Dolphin	2	3	2	3	2	2	2	2.3	16
Sousa sahulensis	Australian Humpback Dolphin	2	3	2	3	2	1	2	2.1	15

Table 4. Overall classification scores for information available for each species in the SPRAT species profile and distribution maps in the North Marine Bioregion shown in Table 2, the updated scores after considering the new knowledge and data identified as shown in Table 3, and the gaps remaining and the recommendations. Red colour indicates low score (1), orange indicates medium score (2), and green indicates high score (3).

Species	Common name	Table 2 score	Table 3 score	Gaps remaining	Recommendations
Glyphis garricki	Northern River Shark	10	13	Need data from shelf areas, broad-scale movement data, identify critical habitats, BIAs and threats.	Analyse the combined existing and new data to improve 'known' and collect new data on occurrence in areas outside the Top End in coastal environments, and in all areas in offshore marine habitats. Help fishers identify species and get better capture rate data.
Glyphis glyphis	Speartooth Shark	9	12	Need data from shelf areas, broad-scale movement data, identify critical habitats, BIAs and threats. Sample all components of the population	As above
Pristis clavata	Dwarf Sawfish	9	10	Data spatially restricted on coast and shelf, sample all components of the population, need movement data, identify BIAs and threats	As above
Pristis pristis	Largetooth Sawfish	11	14	Need data from shelf areas, identify critical habitats, BIAs and threats. Sample all components of the population	As above
Pristis zijsron	Green Sawfish	10	11	Data spatially restricted on coast and shelf, sample all components of the population, identify BIAs and threats	As above
Eretmochelys imbricata	Hawksbill Turtle	15	16	Need data beyond nesting grounds and adult females, need to identify foraging grounds and understand threats.	Analyse tracking data to identify foraging grounds and improve distribution over the shelf. Could also analyse generic turtle survey data. Need to collect more telemetry data.
Lepidochelys olivacea	Olive Ridley Turtle	15	18	As above	Analyse tracking data to identify foraging grounds and improve distribution over the shelf. Could also analyse generic turtle survey data.
Calidris canutus	Red Knot	19	20	Threats	Analyse new data to improve distribution and designation of critical habitats and species-specific BIAs (feeding and roosting). Monitor threats such as habitat loss and disturbance
Calidris ferruginea	Curlew Sandpiper	17	20	As above	As above
Calidris tenuirostris	Great Knot	17	20	As above	As above
Charadrius leschenaultia	Greater Sand-Plover	16	20	As above	As above

Species	Common name	Table 2 score	Table 3 score	Gaps remaining	Recommendations
Charadrius mongolus	Lesser Sand-Plover	16	20	As above	As above
Numenius madagascariensis	Eastern Curlew	19	20	As above	As above
Dugong dugon	Dugong	14	17	Identify and monitor threats, identify BIA's	Analyse new data to improve distribution and consider including data from all of northern Australia.
Orcaella heinsohni	Australian Snubfin Dolphin	13	16	No data for QLD. Identify and monitor threats, identify critical habitats and BIA's	Analyse new data to improve distribution. Collect new data in the Queensland section of the North Marine Bioregion
Sousa sahulensis	Australian Humpback Dolphin	11	15	As above	As above

Table 5. Additional datasets identified for species in or adjacent to the North Marine Bioregion, not yet included in the SPRAT profile.

Species	Type	Number	Data owner	Location	Publication/source	Update	Data in hand (Y/N)
Speartooth Shark	Catch records	>250	CDU	Multiple NT & WA river systems	Marine Biodiversity Hub (Peter Kyne)	Contacted	Y
Speartooth Shark	Acoustic tracking	>150	CDU	2 river systems, NT	Marine Biodiversity Hub (Peter Kyne)	Contacted	Partially
Speartooth Shark	Satellite tracking	2	CSIRO	Port Musgrave, QLD	Richard Pillans	Contacted	N
Speartooth shark	Acoustic tracking	25	UQ/CSIRO/CDU	Wenlock and Ducie Rivers, QLD	Lyon *et al.* (2017) and available on AODN	Downloaded	Y
Northern River Shark	Catch records	>500	CDU	Multiple NT & WA river systems	Marine Biodiversity Hub (Peter Kyne)	Contacted	Y
Northern River Shark	Acoustic tracking	50	CDU	South Alligator River, NT	Marine Biodiversity Hub (Peter Kyne)	Contacted	Partially
Narrow Sawfish	Acoustic tracking	6	UQ	Wenlock and Ducie Rivers, QLD	AATAMS, Hamish Campbell	Didn't find	N
Green Sawfish	Acoustic tracking	6	UQ	Wenlock and Ducie Rivers, QLD	AATAMS, Hamish Campbell	Didn't find	N
Largetooth Sawfish	Acoustic tracking	9	CDU	Multiple NT river systems	Marine Biodiversity Hub (Peter Kyne)	Contacted	Partially
Largetooth Sawfish	Catch records	70	CDU	Multiple NT & WA river systems	Marine Biodiversity Hub (Peter Kyne)	Contacted	Y
Dwarf Sawfish	Catch records	10	CDU	Multiple NT & WA river systems	Marine Biodiversity Hub (Peter Kyne)	Contacted	Y
Green Turtle	Satellite tracking	20	CDU	Djulpan Beach, Arnhem, NT	Kennett *et al.* (2004)	Contacted	N
Green Turtle	Satellite tracking	5	Mark Hamman	Raine Is., QLD but forage in Gulf	None	Contacted	Data pending
Olive Ridley (2) and Flatback (1) Turtle	Satellite tracking	3	NAMRA	Beagle Bay, WA	Kiki Dethmers	Contacted	N
Olive Ridley (3), Green (2) and Flatback (2) Turtle	Satellite tracking	7	NAMRA	Crocodile Is., NT	Kiki Dethmers	Contacted	N
Olive Ridley Turtle	Satellite tracking	4	WWF	Wessel Is., NT	Whiting *et al.* (2007)	Contacted	N
Olive Ridley Turtle	Satellite tracking	4	CDU, UWS, GMR, TLC	Tiwi Is., NT	McMahon *et al.* (2007), freely available AODN	Downloaded	Y
Olive Ridley Turtle	Satellite tracking	9	EHP	Mapoon, QLD		Letter prepared	N
Olive Ridley Turtle	Satellite tracking	1	EHP	Aurukun, QLD		Letter prepared	N

Olive Ridley (1) and Green (1) Turtle	Satellite tracking	2	NAMRA	Wanuwuy Beach, NT	Kiki Dethmers	Contacted	N
Olive Ridley Turtle	Satellite tracking	1	NAMRA	Bare Sand Is., NT	Kiki Dethmers	Contacted	N
Olive Ridley Turtle	Satellite tracking	4	CDU (Hamish Campbell)	Cape York Peninsula, QLD	Dwyer and Campbell (2016), freely available Zoatrack	Downloaded	Y
Hawksbill Turtle	Satellite tracking	1	CDU	Fog Bay, NT			N
Hawksbill Turtle	Satellite tracking	7	CDU, DBCA, JCU, Utas	Groote Eylandt, NT	Hoenner *et al.* (2016), freely available AODN	Downloaded	Y
Flatback (4) and Green (2) Turtle	Satellite tracking	4	CVA, NTG?	Coburg Peninsula, NT			N
Flatback Turtle	Satellite tracking	4	DoEE	Field Is., NT			N
Flatback Turtle	Satellite tracking	6	LSR	Sir Edward Pellew Is., NT		Letter prepared	N
Flatback Turtle	Satellite tracking	2	ALT	Jardine River, QLD		Letter prepared	N
Flatback (13) and Green (2) Turtle	Satellite tracking	15	CDU (Mick Guinea)	Bare Sand Is., NT	Sperling (2007)	Contacted	Data pending
Flatback Turtle	Satellite tracking	15		Cape Dommett, WA	Scott Whiting	Contacted	N
Flatback Turtle	Satellite tracking	10	Mark Hamman	Torres Strait, QLD	NERP funded project	Contacted	Data pending
Flatback Turtle	Mark-recapture	-	DENR Rachel Groom?	Bare Sand Is., Field Is., West Is., NT			N
Flatback, Green and Olive Ridley Turtle	Semi regular aerial survey of nesting beaches	-	Crocodile Is. Rangers	Crocodile Is., NT		Letter prepared	N
Flatbacks and Olive Ridley Turtle	Beach track counts	-	Thamarrurr rangers	Thamarrurr, NT		Letter prepared	N
Olive Ridley Turtle	Beach track counts	-	Tiwi Rangers	Tiwi Is., NT		Letter prepared	N
Flatback, Green, Olive Ridley and Hawksbill Turtle	Beach track counts	-	Cobourg Rangers	Cobourg		Letter prepared	N
Marine turtles, inshore dolphin and Dugong 2012,13 and 14	Boat, aerial (point and strip) and land survey	multiple	INPEX, Cardno Pty Ltd	Darwin Harbour, NT	Cardno (2015)		N
Marine turtles (Green (1) and Hawksbill(1)), 2012	Satellite tracking	2	INPEX	Darwin Harbour, NT	Cardno (2015)		N
Turtles (all species) **Note: some data used in SPRAT**	Flipper tag recoveries, beach monitoring, satellite tracking	-	QLD department of Environment and Science	All North Marine Bioregion	Col Limpus	Contacted	N
Estuarine Crocodile	Satellite tracking	28	CDU (Hamish Campbell)	Western Cape York, QLD	Open access on ZoaTrack.org		N

Estuarine Crocodile	Satellite tracking	11	UQ (Ross Dwyer)	Wenlock River, Cape York, QLD	Open access on ZoaTrack.org		N
Coastal dolphins	Capture-recapture from boat	-	INPEX, DENR	Darwin Harbour, NT	Brooks *et al.* (2017)	Contacted	Y
Shorebirds	Sightings	2 datasets	QWSG	Gulf Carpentaria, QLD	Peter Driscoll	Contacted	Data pending
Shorebirds	Sightings (occasional sampling)	-	CLCAC	Gulf Carpentaria, QLD	Roger Jaensch, Jory Stariwat	contacted	Data pending
Shorebirds	Sightings	multiple	eBird	Australia	Online data repository	Contacted	Y
Shorebirds	Long-term monitoring	multiple	Birds Australia	North Marine Bioregion	Connie Lee/Dan Weller	Contacted	N
Shorebirds	Satellite tracking	1 dataset	Monash University	Ashmore Is. but birds might be using North Marine Bioregion	Rohan Clarke	Contacted	N
Eastern Curlew	Satellite tracking	2	CDU (Amanda Lilleyman)	Darwin Harbour, NT	Open access on Zoatrack.org	Downloaded	Y
Shorebirds and turtles 2003, 2008 **Note: These data appear to have been incorporated into the SPRAT distribution maps**	Ground and aerial surveys	multiple	Parks and Wildlife NT, DENR	Coast, islands and major wetlands of NT	Chatto (2003) Chatto and Baker (2008), data freely available in ALA, WildWatch, and NRMaps	Downloaded	Y
Shorebirds, marine turtles and dolphins. 27 July to 3 Aug 2010	Ground surveys (turtles and dolphins opportunistic sightings)	23 sites	DoEE	Coburg Peninsula RAMSAR site, NT	AECOM (2010)	Contacted	N
Dugong and other marine megafauna 2015	Aerial survey	Multiple	DENR	Entire NT coastline	Groom *et al*. (2017)	Contacted	Y
Coastal dolphins 2014–2017	Helicopter and fixed wing aerial surveys	Multiple	DENR	39 estuarine and coastal sites across NT coast	Palmer *et al.* (2017)	Contacted	Y
Coastal dolphins	Surveys	-	JCU	Northwest Gulf of Carpentaria and Melville Bay, NT	Beasley *et al.* (2012)	Letter prepared	N
Coastal dolphins	Entanglement locations	Multiple			Tulloch *et al*. (nd)	Contacted	Y
False Killer Whale	Satellite tracking	6	DENR (Carol Palmer), CDU (Hamish Campbell)	Groote Eylandt (2) and Coburg Peninsula (4), NT	For Coburg data: Palmer *et al.* (2017), other 2 from Groote only just deployed	Contacted	Y

Dugong and other marine megafauna 1984, 1997, 2014 **Note: the 2003 data may have been incorporated into the SPRAT distribution maps**	Aerial surveys	Multiple	DENR	Gulf of Carpentaria	Bayliss and Freeland (1989), Parks and Wildlife Service (2003), Groom *et al.* (2015)	Contacted	Y
Dugong	Aerial surveys	Multiple	JCU	Gulf of Carpentaria	Marsh *et al*. (2008)	Data pending	N
Dugong, dolphins and marine turtles **Note: these data may have been incorporated into the SPRAT distribution maps**	Aerial surveys	Multiple	JCU	Gulf of Carpentaria	Marsh and Lawler (1993), Marsh *et al*. (1995), Marsh *et al.* (2000)	Data pending	N
Marine mammals and marine turtles	Sightings	Multiple	DENR	All NT	Northern Territory WildWatch (http://root.ala.org.au/bdrs-core/nt-dlrm/home.htm)	Downloaded	Y
All species	Sightings	Multiple	QLD government	All QLD	WildNet – Queensland Wildlife Data (https://collections.ala.org.au/public/show/dr1132)	Downloaded	Y
All species	Sightings, telemetry	Multiple	Multiple	All North Marine Bioregion	ALA (https://www.ala.org.au/)	Downloaded	Y
All species	Sightings	Multiple	Multiple	All North Marine Bioregion	GBIF (https://www.gbif.org/)	Downloaded	Y

*AATAMS = IMOS Animal Tracking Database, AODN = Australian Ocean Data Network, ALA = Atlas of Living Australia, ALT = Apudthama Land Trust; NAMRA=North Australia Marine Research Alliance; CDU=Charles Darwin University; CLCAC = Carpentaria Land Council Aboriginal Corporation (Indigenous rangers); CSIRO = Commonwealth Scientific and Industrial Research Organisation; CVA = Conservation Volunteers Australia; DBCA = Department of Biodiversity, Conservation and Attractions; DENR = Department of Environment and Natural Resources; EHP= Department of Environment and Heritage Protection; GBIF = Global Biodiversity Information Facility, GMR= Gumurr Marthakal Rangers; JCU=James Cook University; LSR = li Anthawirriyarra Sea Rangers; NTG=Northern Territory Government; QWSG = Queensland Wader Study Group; TLC= Tiwi Land Council; UQ = University of Queensland; UTas=University of Tasmania; UWS= University of Wales Swansea; WWF=World Wide Fund.

Table 6. New georeferenced data found for each species not included in the SPRAT distribution, calculated as the percentage of grids with new data in relation to total number of grids for each of the 'likely' and 'may occur' classification categories in the SPRAT distribution. Empty cells indicate that that category was not a category in the SPRAT distribution for that species. In most cases data were found in grids that were not part of the SPRAT distribution and the proportion of those grids containing new data are reported here as 'un-categorised'.

	Likely breeding	Likely breeding/ habitat	Likely foraging	Likely habitat	Likely roosting	Species may occur	Un-categorised
Northern River Shark						0	0.7
Speartooth Shark						0	1
Dwarf Sawfish	3.3						19.9
Largetooth Sawfish				1.9			2.8
Green Sawfish	0.7						0.3
Hawksbill Turtle		0.1	0			0.4	0.3
Olive Ridley Turtle		9.1	0			1.6	2.4
Red Knot				33.3		2.1	0.3
Curlew Sandpiper				39.2		40	74.1
Great Knot			50	19.6	0		17.5
Greater Sand-Plover				21.8	4.9		49.7
Lesser Sand-Plover				19.2	0		46
Eastern Curlew				37.6		2.8	
Dugong				7.4		8.9	4
Snubfin Dolphin				7.6		11.9	8.4
Australian Humpback Dolphin	0		0				83.2

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3. PRESSURES

KEY POINTS

- Relevant spatial datasets for mapping historic, current, ongoing and future pressures were identified and collated.
- Pressures were categorised as resource extraction and use, pollution, habitat modification, climate, and 'other'.
- Pressures included fisheries effort, aquaculture infrastructure, location of oil and gas infrastructure, historical shipping and pollution data, location of historical seismic operations, cyclone intensity, spoil dumping, sewage outfalls, location of ports
- Two additive pressure hotspots maps were derived by combining all spatial pressure data, the first including historic, current and future pressures, and the second only ongoing and future pressures.
- Areas of high cumulative pressure were identified, which would possibly benefit from additional management.
- Some additional work is required to review and update this approach, including the addition of several data sets that could not be accessed during the project.
- High pressure areas tended to be closer to the coast where point source impacts occurred, however no area was exposed to less than 3 identified pressures due to the ubiquitous nature of climate and some pollution pressures.

3.1 Introduction

Global tropical ecosystems have been transformed under the influence of direct and indirect effects of human activities (Jameson *et al.* 1995, Bruno and Selig 2007). Understanding the spatial distribution of these human pressures is crucial in managing the use of tropical ecosystems in a way that maximizes commercial and societal benefits while minimizing degradation and species loss (Burke *et al.* 2011). The North Marine Bioregion of Australia is known for its high diversity of tropical species and is of global significance for breeding and/or feeding grounds for a number of protected, rare and threatened marine animals. This region is also coming under more and more pressure from industry, from pollution and, increasingly, from climate change. With many of Earth's systems experiencing pressures beyond safe levels (Rockström *et al.* 2009), it is important to have an up-to-date assessment of historical and current pressures in the North Marine Bioregion to focus conservation action, identify sustainable development options, and prevent further species decline or ecosystem degradation.

Cumulative pressure maps, such as the "Human Footprint" for land environments (Sanderson *et al.* 2002), or the Halpern *et al.* (2008) global map of human impact on marine ecosystems, provide large-scale information on where humans are exerting pressure on natural systems, altering them from their natural states. Such maps have been used in a large number of ecological and conservation analyses (Venter *et al.* 2016). The Halpern *et al.* (2008) pressure map, developed at a $1km^2$ resolution, identified Northern Australia as one of the least impacted areas globally. The last five years have seen a proliferation of efforts to characterize and map cumulative pressures and impacts (Halpern and Fujita 2013). A national synthesis of pressures and trends in the marine environment for Australian waters is now available through the NESP Marine Biodiversity Hub (https://www.nespmarine.edu.au/theme/understanding-pressures-marine-environment).

Global or national-scale cumulative mapping results typically do not match basic understanding of regional spatial patterns of impact. For instance, these results often integrate over shallow coastal areas which as a result, often appear less impacted than deeper areas despite human activities being concentrated on the more sensitive shallow areas particularly in tropical regions and seagrass or reef habitats (Selkoe *et al.* 2009). Maps derived for national- or global-scales and objectives cannot include the local detail of higher resolution data and information on processes and threats necessary to interpret local-scale issues. Effective and comprehensive regional-scale marine conservation for the North Marine Bioregion thus requires fine-resolution data on the spatial patterns of threats, their overlap with values of interest, and ultimately a clear understanding of how they interact. We cover the first two of these activities in this report, while recognizing additional work will be needed to interpret how values and pressures interact.

A wide range of pressures has been identified as affecting the North Marine Bioregion as part of the North Marine Bioregional Plan and Report Card (www.environment.gov.au/marineplans/north) prepared under the *Environment Protection and Biodiversity Conservation Act 1999*. That pressure analysis assessed present and emerging pressures affecting conservation values in the North Marine Bioregion, and found overall pressure is low by global standards, due to relatively low levels of marine resource use and low coastal population pressure across the region (except for around Darwin). A number of human activities and drivers of pressures, however, were identified for the region, including:

- Climate change and associated large-scale effects, including shifts in major currents, rising sea levels, ocean acidification, and changes in the variability and extremes of climatic features (e.g. sea temperature, winds, and storm frequency and intensity);
- Harvesting of living resources;
- Increasing industrial development in areas adjacent to the region; and,
- Growth in marine industries, transport and infrastructure.

Over the past decade, the population of Northern Australia has grown at a faster rate than that of the Australian average, and the economy of Northern Australia has sustained significant growth beyond the rest of the nation, now contributing to 11.7% of the Australian Gross Domestic Product (GDP). With this growth, improvements in infrastructure are required to link Northern Australia to the south of the country and to further advance economic opportunities, including regionally.

Information on the implications of environmental pressures on ecosystems at different spatial, temporal and ecological scales in the North Marine Bioregion is scant. We aimed to collate, model and map all available spatial information on identified historic, current, ongoing and future pressures in the North Marine Bioregion, and identify areas of overlapping pressures, to guide further research and analysis.

3.2 Methods

3.2.1 Mapping Data on Historic and Existing Pressures

Relevant spatial datasets to mapping pressures for the North Marine Bioregion were identified and collated (Table 7). These include national spatial datasets collated by CSIRO as part of the NESP Marine Biodiversity Hub Pressures Project C1: Improving our understanding of pressures on the marine environment, as follows:

- Commonwealth trawl fisheries effort;
- Aquaculture infrastructure;
- Mining - oil and gas infrastructure;
- Shipping; and,
- Historical shipping and pollution data;
- Seismic operations;
- Sea-surface temperature change;
- Harmful substance spills.

New data were acquired from online sources and/or data holders and spatially digitized or interpolated and modelled (Table 7, see also Appendix D). New pressures included resource extraction and use, pollution and habitat degradation, and additional climate impacts (Table 7). Further spatial data on bycatch and fisheries and ship interactions with Threatened and Migratory marine species were also collated, interpolated, and spatially digitized where possible. Details of data interpolation by layer are found in the metadata (see Appendix D). Data were mapped to a resolution of 0.1 degrees and clipped to the North Marine Bioregion using ArcGIS.

Table 7. Pressure data collated and mapped for the North Marine Bioregion, including new data sets obtained for this project.

Pressure type	Data collated	New data?
Resource extraction and use	State fisheries effort and catch (QLD, NT)	☑
	Recreational fishing	☑
	Commonwealth fisheries (AFMA)	
	Oil and gas wells	
Pollution	Aquaculture	☑
	Port infrastructure and dredging	
	Spills (garbage, chemical, oil, other)	
	Recreational boating	☑
	Sewage outfalls	☑
	Urban development	☑
	Acute nutrient and sediment risk	☑
	Industrial pollution	☑
Habitat modification	Telecommunications cables	☑
	Dredging	☑
Climate	Sea surface temperature	
	Sea-level rise	☑
	Extreme weather (cyclones)	☑
Other	Seismic exploration	
	Shipping lanes	
	Population pressure	

Exclusions

The following pressures have been identified as potentially affecting the North Marine Bioregion, but were not mapped as part of the current pressures project, due to insufficient or unavailable spatial data and/or models, or time/resource constraints:

- Ocean acidification;
- Onshore mining – downstream impacts;
- Renewable energy operations;
- Sea-level variability;
- Ghost nets; and,
- Invasive species.

Although information also exists on the impacts of marine debris on marine wildlife in the north, such as through stranding records and entanglements (e.g. Ceccarelli 2009), spatial information on the sources of marine debris is lacking. Spatial information identifying marine debris impacts is important for evaluating interaction rates, but in itself may not be an accurate spatial representation of marine debris pressures in the north.

3.2.2 Mapping Data on Future Pressures

Building on the mapping of historic and current pressures we looked to key policy documents including the Northern Australia Audit (2015) and the Our North, Our Future: White Paper on Developing Northern Australia (2015).

A Northern Australia infrastructure audit was *conducted* by Infrastructure Australia (see http://infrastructureaustralia.gov.au/policy-publications/publications/files/IA_Northern_Australia_Audit.pdf for more detailed information).

The objective of the audit was to define a policy platform for realising the potential of Northern Australia, which will:

- Define policies for developing the north to 2030;
- Capitalise on the region's strengths; and,
- Remove barriers to investment and bringing Australia's broader strengths to Northern Australia.

The scope of the audit was to:

- Collect and evaluate data for critical infrastructure assets and networks in the economic infrastructure (transport, energy, water, and communications) sectors;

- Undertake demographic and economic modelling of Northern Australia against various population growth scenarios (for the years FY16 short-term, FY21 medium-term and FY31 long-term);

- Provide a critical infrastructure gap analysis against both 'baseline' projections and the various population growth scenarios; and,

- Generate a list of critical infrastructure requirements.

The audit mainly focused on infrastructure that would connect to large population centres (>3,000 people) and areas where existing or prospective economic activity was identified. Despite their recognized need for infrastructure, many smaller remote Indigenous communities were not included at this time.

Key identified growth regions (combination of economic opportunity, government support, projects that are well advanced, and a requirement for economic infrastructure) were:

- Queensland: The Galilee Basin (thermal coal), Bowen Basin (metallurgical coal expansion) and Northwest minerals province (base metals, other minerals);

- Northern Territory: The Darwin-Katherine/Wolfe Basin and Roper River/McArthur River (both base metals and other minerals), the Tennant Creek/Wonarah region (phosphate) and the Amadeus Basin (oil, shale gas); and,

- Western Australia: The Pilbara (iron ore expansion), Canning Basin (oil, shale gas), the Browse Basin (liquefied natural gas), NorthWest Shelf (oil, gas) and the East Kimberley (Ord irrigated agricultural expansion).

The resources and mining sectors were identified as the most important contributors to the Northern Australian economy. Ports are increasingly important for domestic and international distribution of shipments, as well as providing facilities for the cruise ship industry, military and paramilitary vessels, and offshore oil and gas industry. Nearly all new port development and port expansion, which includes dredging and marine infrastructure, is associated with the natural resource sector. Many ports, including Darwin, are lacking specialised infrastructure (e.g. high capacity ship handling equipment, deep water channel access) to support large shipments, which currently impedes development of natural resource deposits. Areas including Darwin, Bing Bong (near Borroloola), Karumba, and Wyndham, have been identified as having primary infrastructure gaps, and will likely be subject to substantial growth and expansion in upcoming years to accommodate these valued markets. The development of these regions will have effects on the marine environment; thus, advice on sensitive development, along with sufficient monitoring is required to help reduce and mitigate future impacts on Northern Australia's Threatened and Migratory marine species.

Furthermore, we considered *EPBC* referrals to understand development pressure. For any project, development, undertaking, activity, or series of activities, an application (a referral) is required to address if the action will, or is likely to, have a significant impact (an action with important, notable consequence) to any matter of National Environmental Significance (NES), including National Heritage values (for more information, see http://www.environment.gov.au/heritage/management/referrals). These referrals are assessed under the *Environment Protection and Biodiversity Conservation Act 1999* (the *EPBC Act*). Each referral addresses the extent of environment to be lost, degraded, or notably altered or modified, including those species most likely to be affected by the action.

We acquired, modelled, and mapped a suite of ongoing and future anthropogenic pressures, specifically:

- Population growth;
- Recreational boating and fisheries;
- Future petroleum prospectivity;
- *EPBC* referrals; and,
- Future development.

3.2.3 Mapping Multiple Pressures to Identify Hotspots

There is a range of practices currently used by practitioners for combining and measuring pressures (Salafsky *et al.* 2003). Arithmetic measures, such as adding, multiplying, or averaging pressure values, are relatively simple, transparent, and repeatable. We derived standardized relative risk metrics for relevant pressure datasets/models, by log[X+1]-transforming and re-scaling between 0–1 each pressure layer to put them on a single, unitless scale that allows direct comparison, as per Halpern *et al.* 2008. This method assumes that the maximum level of each pressure is equivalent, and that intermediate levels of pressures are linear. We first summed all the historic, current, and future pressure values to derive an additive pressure hotspots map, following the methods of previous studies (Salafsky and Margoluis 1999, Halpern *et al.* 2008, Selkoe *et al*. 2009), as follows

$$T_x = \sum_{n=1}^{p} r_{px}$$

where r is the relative risk metric for each pressure p in grid cell x, T_x is the total additive pressure in grid cell x, summed across all pressures. By adding pressure values together, the approach is conservative, or risk-averse, giving higher weight to areas with multiple pressures of high value.

Predicting Future Hotspots

Furthermore, to provide a more *future-focussed* product that estimates ongoing anthropogenic pressures acting upon the North Marine Bioregion to 2030, we then repeated the process, after removing any pressures that were part of the cumulative value calculation above, but are no longer acting upon the marine environment, or are not likely to contribute to future pressures. These were largely pulse activities that have occurred in the past, such as seismic activity, spoil dumping, and spills.

We also consulted two reports developed for the region that outline future potential development: The Northern Australian Audit Report (Infrastructure Australia 2015) and the White Paper on Developing Northern Australia (Commonwealth of Australia 2015).

The Northern Australian Audit (January 2015) assessed critical economic infrastructure gaps and requirements to meet projected Northern Australia population and economic growth through to FY31 (2031). We used the results of modelled future population growth scenarios to inform potential future population pressure in the North Marine Region. The White Paper outlines new actions the Government is taking to promote the further development of northern Australia. There are many existing policies and programmes the Commonwealth, Queensland, Northern Territory and Western Australian governments are already undertaking that are of particular benefit to northern Australia. A selection of these is outlined in the White Paper, and these were reviewed in detail to extract those developments that might impact upon the marine environment in the North Marine Region.

Additionally, to understand the location and industries most likely to affect *EPBC*-listed Threatened and Migratory marine species across the North Marine Bioregion referrals between the period 2000 and 2016 which triggered Threatened and Migratory marine species were analysed from data provided by the Environment Standards Division of the Department of the Environment and Energy.

We included the following new or modified pressures in the ongoing and future pressures calculation. There are assumptions around modelling each future pressure, and further work outside the remit of this scoping project would be required to develop a set of future scenarios (for example, a high aquaculture scenario or a low oil and gas scenario).

- **Population growth:** We estimated future high population growth pressure acting on the region by combining the aspirational (high industry) economic growth scenario in the Northern Australian Audit and the population pressure raw values as derived from the Australian Bureau of Statistics for 2011.
- **Recreational boating and fishing:** We used population growth scenarios from the Northern Australian Audit to model future recreational boating pressure.
- **Future prospectivity:** We derived a relative index of future petroleum prospectivity based on sedimentary basins that are considered to be prospective for petroleum.

- ***EPBC* referrals:** We included current and future development as identified through the *EPBC* referral process (and see Appendix E)

- **Commercial fisheries:** Predicting future spatial extent and intensity of each commercial fishery was not possible, so instead we used the average annual effort from the most recent 5 years as the future effort value.

- **Aquaculture:** We assumed potential ongoing pressures from aquaculture due to potential nutrient and waste discharge, fish escapes, disease and chemicals. We applied the historical value for this pressure for existing aquaculture structures to the future.

- **Port infrastructure and dredging:** We assume ongoing disturbance from port activities in the future equal to historical value.

- **Land-based pressures:** We included the existing land-based pressure value for coastal ecosystems.

- **Point-source pollution:** We included the previously derived values for sewage outfalls.

- **Benthic structures (e.g. communications cables, pipelines):** Although the magnitude of impact is likely greater during construction of benthic structures, we assume ongoing episodic pressures during operation include underwater noise, disturbance, electromagnetic fields (for telecommunications cables), contamination and heat dissipation (Meißner *et al.* 2006).

- **Shipping:** We assume ongoing impacts from shipping that include vessel strike, anthropogenic noise, potential sea-floor abrasion and benthic ecosystem damage, biofouling. Globally, commercial vessel activity has been increasing (Davis *et al.* 2016). Within Australian waters, commercial vessel activity has grown by approximately 4% each year since the early 2000s. We assume homogenenous increase in shipping across the region, and so used the existing shipping values (BITRE 2015) (but we also acknowledge that modelling a future high shipping scenario could be informative, but was outside this scoping project).

- **Climate change:** We included modelled annual variance in sea surface temperature and modelled change in sea surface temperature in the future pressures index.

3.3 Results

3.3.1 Historic and Current Pressures

National Datasets

Relevant data previously collected as part of the NESP Marine Biodiversity Hub National Pressures project by CSIRO were clipped to the spatial extent of the North Marine Bioregion and are shown in Figures 11 and 12.

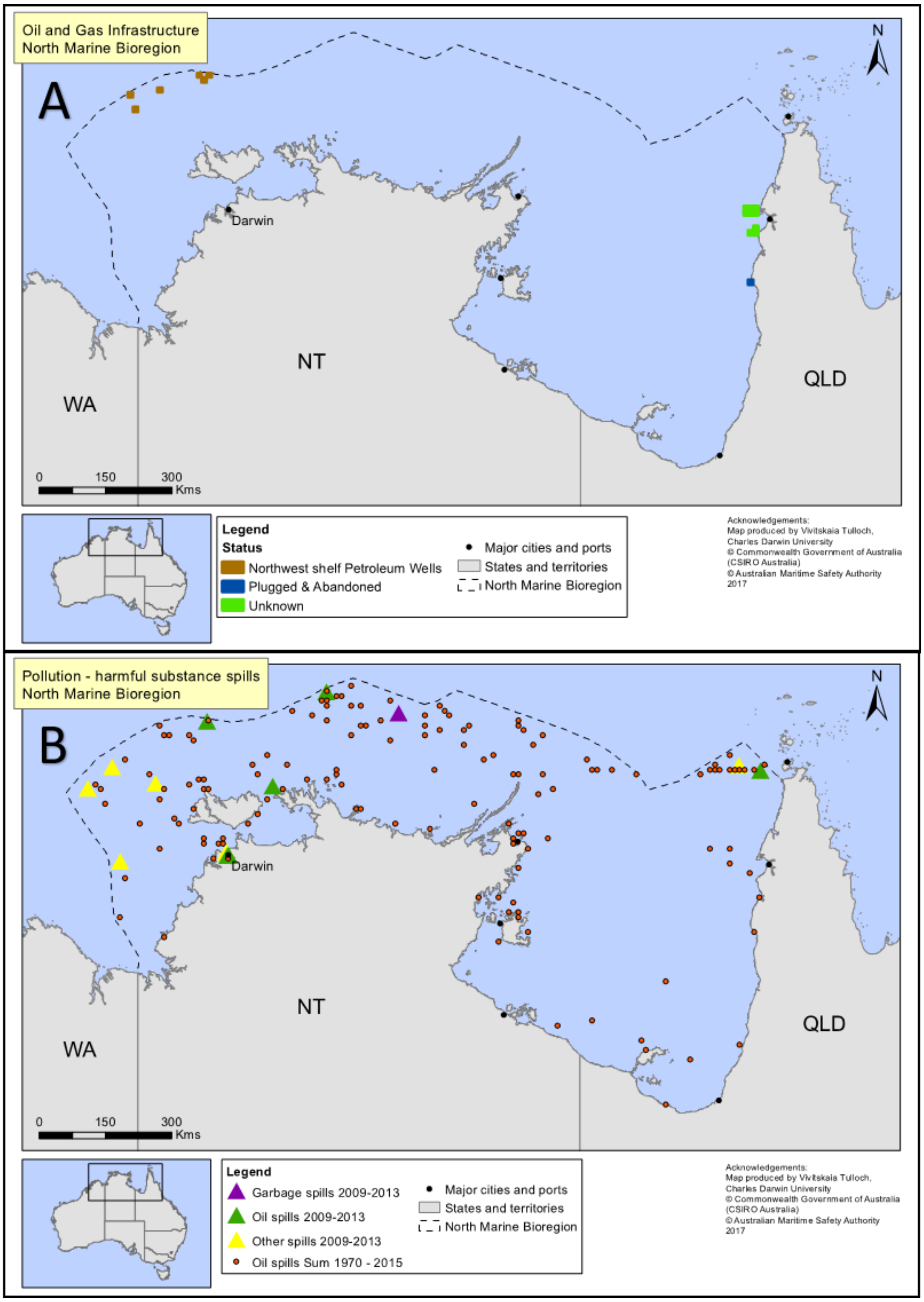

Figure 11. Human pressures within the North Marine Bioregion, (A) oil and gas infrastructure (http://www.nopta.gov.au), and (B) historical harmful substance spills (Australian Maritime Safety Authority, Australian Fisheries Management Authority).

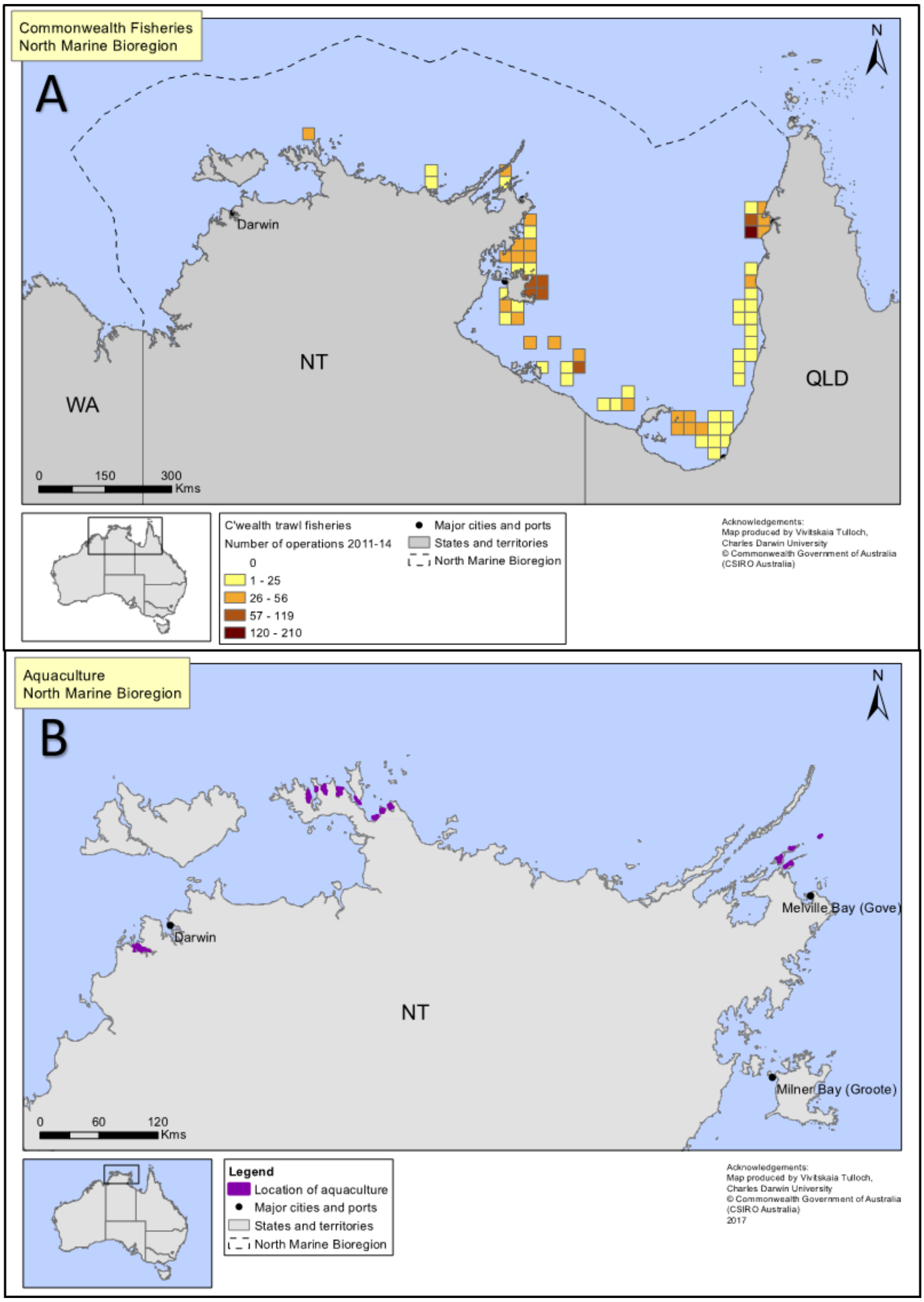

Figure 12. Human pressures within the North Marine Bioregion, (A) Northern Prawn Fishery effort (2011–2014), and (B) location of aquaculture (Department of Primary Industries and Fisheries 2016). See Appendix D for more information and metadata.

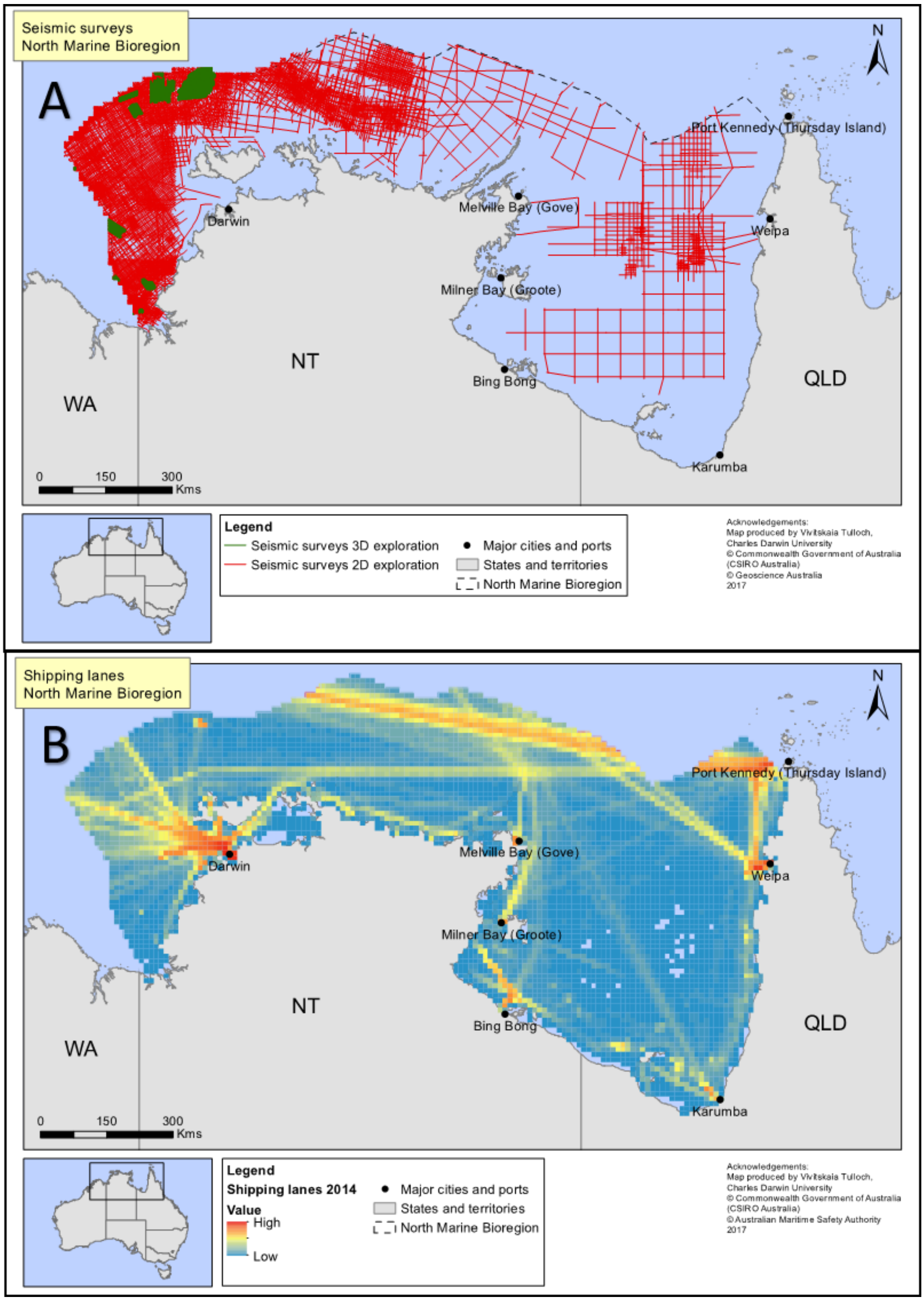

Figure 13. Human pressures within the North Marine Bioregion, (A) seismic surveys (Geoscience Australia), and (B) shipping routes (Australian Maritime Safety Authority).

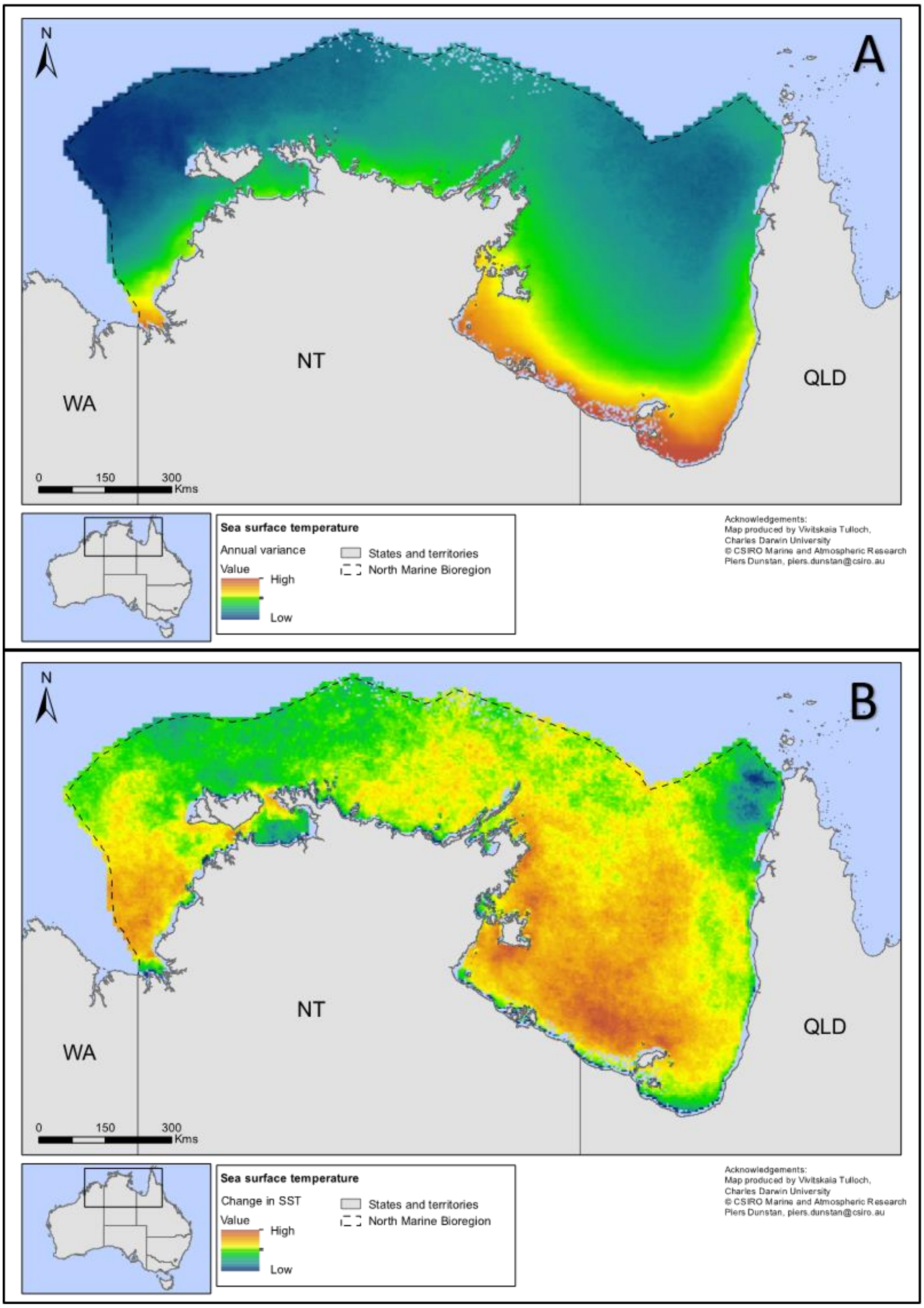

Figure 14. Human pressures within the North Marine Bioregion, (A) modelled annual variance in sea surface temperature (CSIRO, NESP), and (B) modelled change in sea surface temperature. See Appendix D for more information and metadata.

Fishery Resource Extraction

Resource extraction data acquired from the NT Fisheries consisted of catch and effort data dating back to 2006 for 14 fisheries across the North Marine Bioregion, as follows:

- Coastal line;
- Coastal net;
- Bait net;
- Spanish Mackerel;
- Offshore Net and Line;
- Demersal;
- Barramundi; and,
- Mud Crab;
- Mollusc;
- Aquarium Display;
- Trepang;
- Restricted Bait;
- Timor Reef;
- Finfish Trawl (now Demersal fishery).

Effort and catch data for each fishery in the NT were provided by the Department of Primary Industry and Resources aggregated by year, location (60 nm grid), and total net days fished (effort), with data dating from 2006 to 2018. We used data from years to 2017, as data for 2018 is still incomplete. To scale up effort and derive cumulative fishing pressure maps for the NT fisheries we calculated the average of the days fished per effort ID and grid square, summed across all fisheries (Figure 15A). Fine-scale resource extraction data for Queensland from 2011 to 2014 were also obtained but at a finer 6 nm resolution. Restrictions on effort data detail due to there being fewer than 5 vessels operating meant that fishing intensity over time could not be mapped, however we were still able to derive maps of the extent of fishing pressure (Figure 15B). Data for each gear or fishery were then standardised to 1, to be comparable with the other pressures.

The Northern Territory commercial fisheries footprint has historically covered up to 95% of the North Marine Bioregion, whilst Queensland commercial fisheries cover only 17% of the region, although the Queensland data was provided for a small number of years compared to the NT fisheries data (QLD = 4 years, NT = 12 years, respectively).

Commonwealth fisheries data from the Northern Prawn Trawl Fishery were previously collated as part of the Marine Hub Project C1 mapping national-scale pressures. These data are shown in Figure 12A.

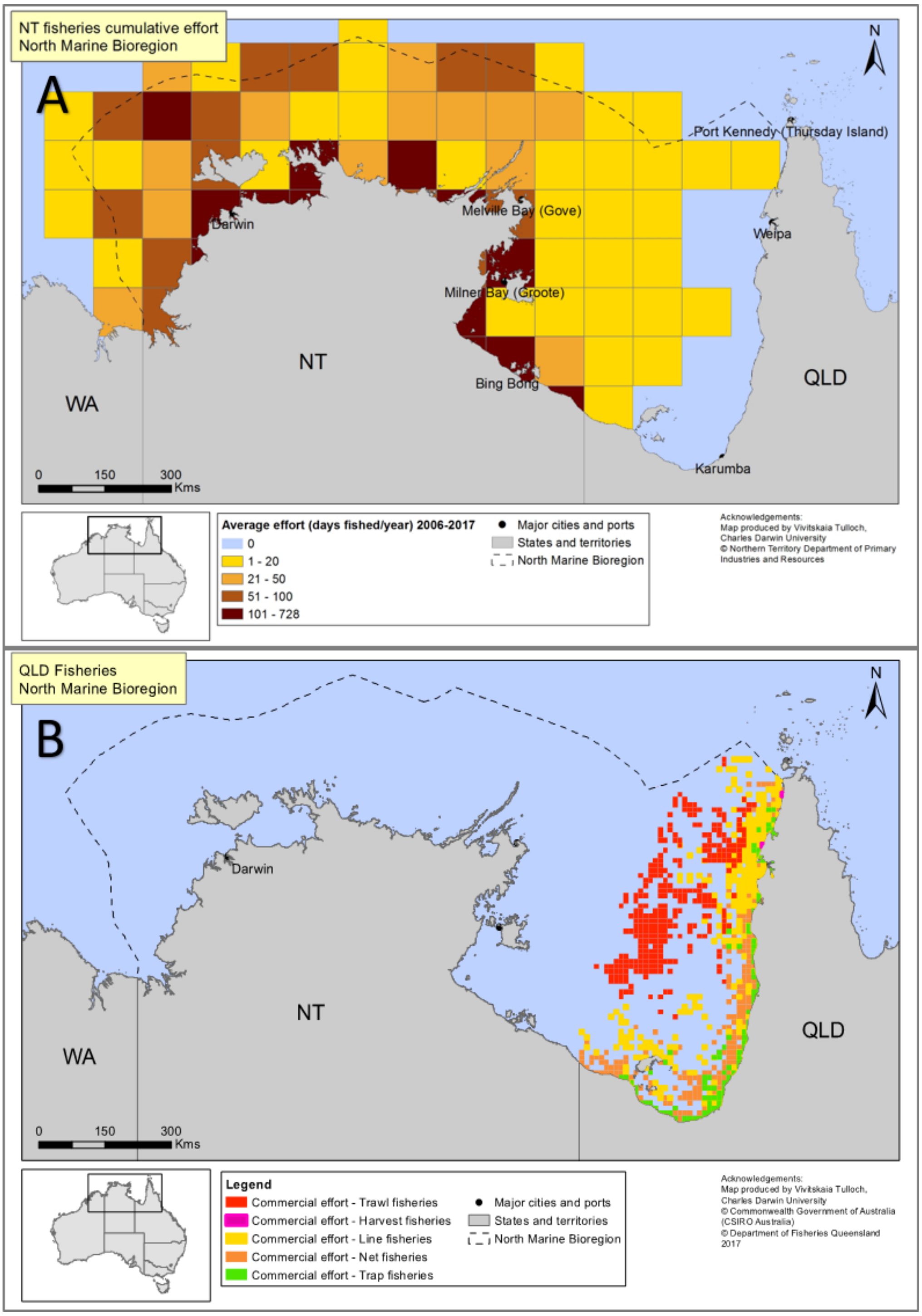

Figure 15. Cumulative fishing pressure map for (A) NT fisheries (Department of Primary Industry and Resources), calculated from the average of the days fished per effort ID and grid square, summed across all fisheries, where dark areas indicate high historical pressure, and lighter areas indicate lower pressure, and (B) QLD fisheries (Department of Agriculture and Fisheries), identifying spatial extent of fishery effort only, due to restrictions on data (low vessel numbers).

Population Pressure

Australian Population Grid 2011 and ASGC (Edition 2006) Urban Centres and Localities Digital Boundaries data were acquired from the Australian Bureau of Statistics, to derive information on current population pressure along the coast of the North Marine Bioregion.

Data were transformed by summing population numbers at sites >100 people, and creating a buffer of 20 km around each population centre to account for pollution and habitat degradation from human use. The 20 km radius was chosen arbitrarily as an average distance that people may travel to get to the coast. Buffer values were standardised by summing the population in each buffer. The resulting map (Figure 16) estimates population pressure across the North Marine Bioregion. Coastal towns and villages with <100 people were not included in the map under the assumption that these small communities exert minimal pressure on the marine environment.

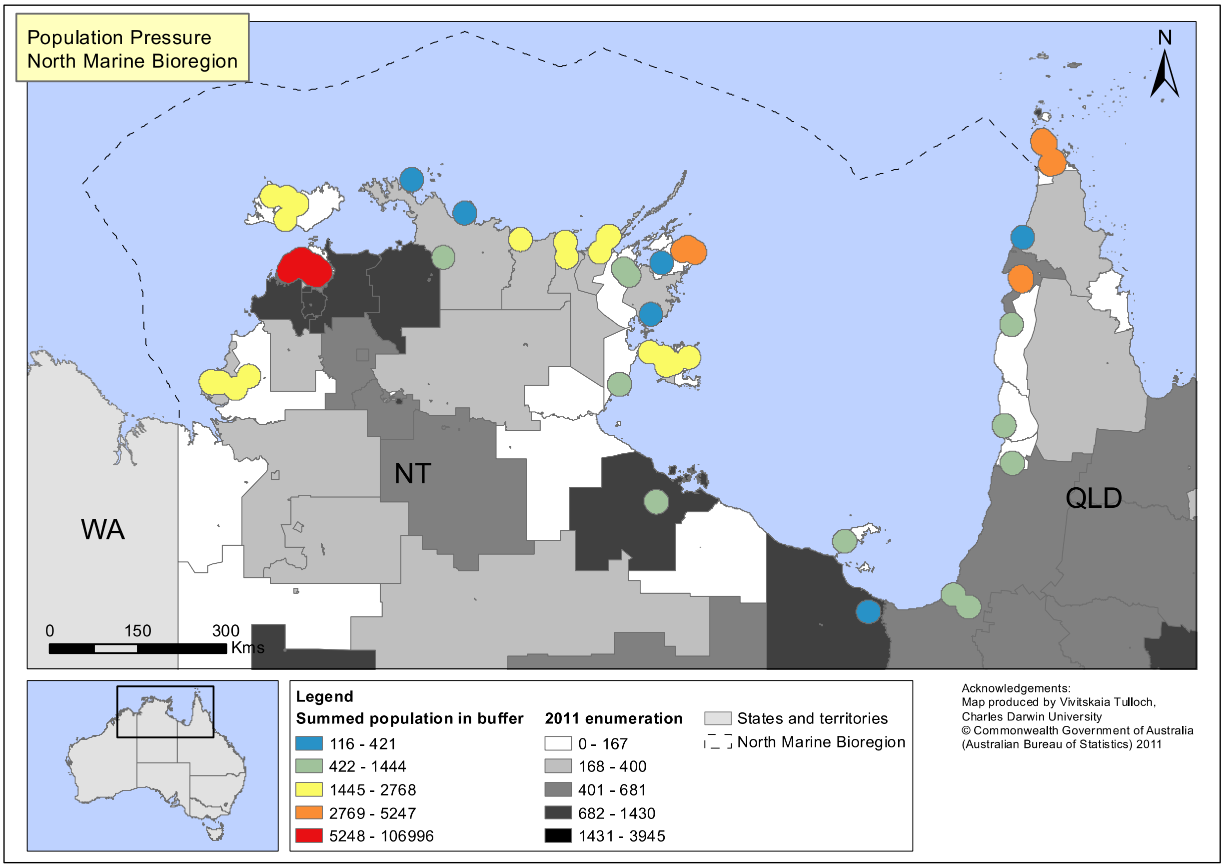

Figure 16. Existing population pressure estimated across the North Marine Bioregion for population centres with >100 people, and associated average census values for each catchment in the region (original data from the Australian Bureau of Statistics).

Recreational Boating/Fishing

Understanding the distribution and intensity of recreational boat use is a key component of the pressure on coastal marine environments. This information can be used to understand the impacts from recreational fishing and from ship strike on small marine mammals and reptiles. We have derived models of recreational boating/fishing based on previous work within the NESP Marine Biodiversity Hub (P. Dunstan, CSIRO), by combining information on the distribution of boat ramps, the distribution of boat and trailer registrations by post code, the size and power of different classes of boats, and the distances that needed to be travelled to reach boat ramps to estimate the distribution of different classes of boat using each boat ramp, and coupled this with information on population pressure to predict the distribution and intensity of recreational boat use at a resolution of 30 nm (Figure 17).

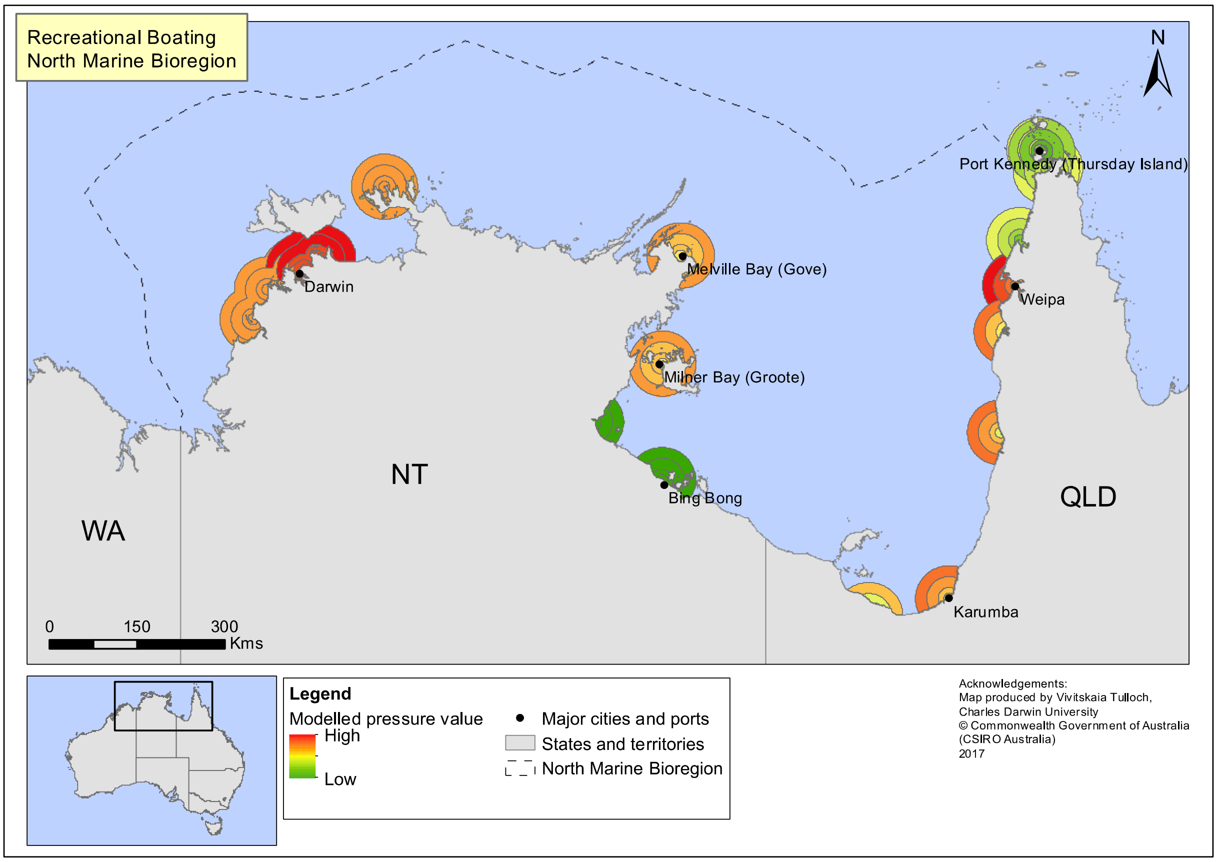

Figure 17. Modelled recreational boat use in the North Marine Bioregion (source: P. Dunstan, CSIRO).

Pollution

Data on acute and chronic pollution pressures in the North Marine Bioregion were obtained from a range of sources.

The industrial pollution layer was generated from the industrial class cover of the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) 2005–2006 land use map derived from an AVHRR satellite image (Figure 18A).

Sewage outfall data were obtained from the NESP sewage outfall project's national database (https://www.outfalls.info) and digitized (Figure 18B). We estimated dispersal distance from mixing zone of 500m, as a rough approximation, based on license information from National Outfall Database providers. If found to be important in future assessments, this assumption could be updated with oceanographic models.

Pressures on coastal marine habitats (e.g. seagrass, reef) from port infrastructure and dredging were assessed and mapped based on the locations of ports in Australia provided by the Australian Customs & Border Protection Service (http://data.gov.au/dataset/australian-ports), and Australian shipping routes (Figure 19A). We predicted that there was a high risk to seagrass habitat when there was a port located in a grid cell, a moderate risk in cells adjacent to a high cell, and a low risk in cells adjacent to a moderate cell, using shipping routes to determine the direction of risk, with a spatial threshold of three grid cells from port determining the maximum distance of impact. We considered that there was no exposure to the threat of port infrastructure and development and hence no risk in all other grid cells.

Information on the dumping at sea of hazardous substances (spoil dumping) was obtained from the Department of Defence online at http://www.hydro.gov.au/n2m/dumping/dumping.htm and digitized (Figure 19B). We re-scaled the raw point-source pollution pressure data to between 0.5 (low impact) to 1.0 (highest impact), with any grid cells not affected by these pressures allocated value of zero.

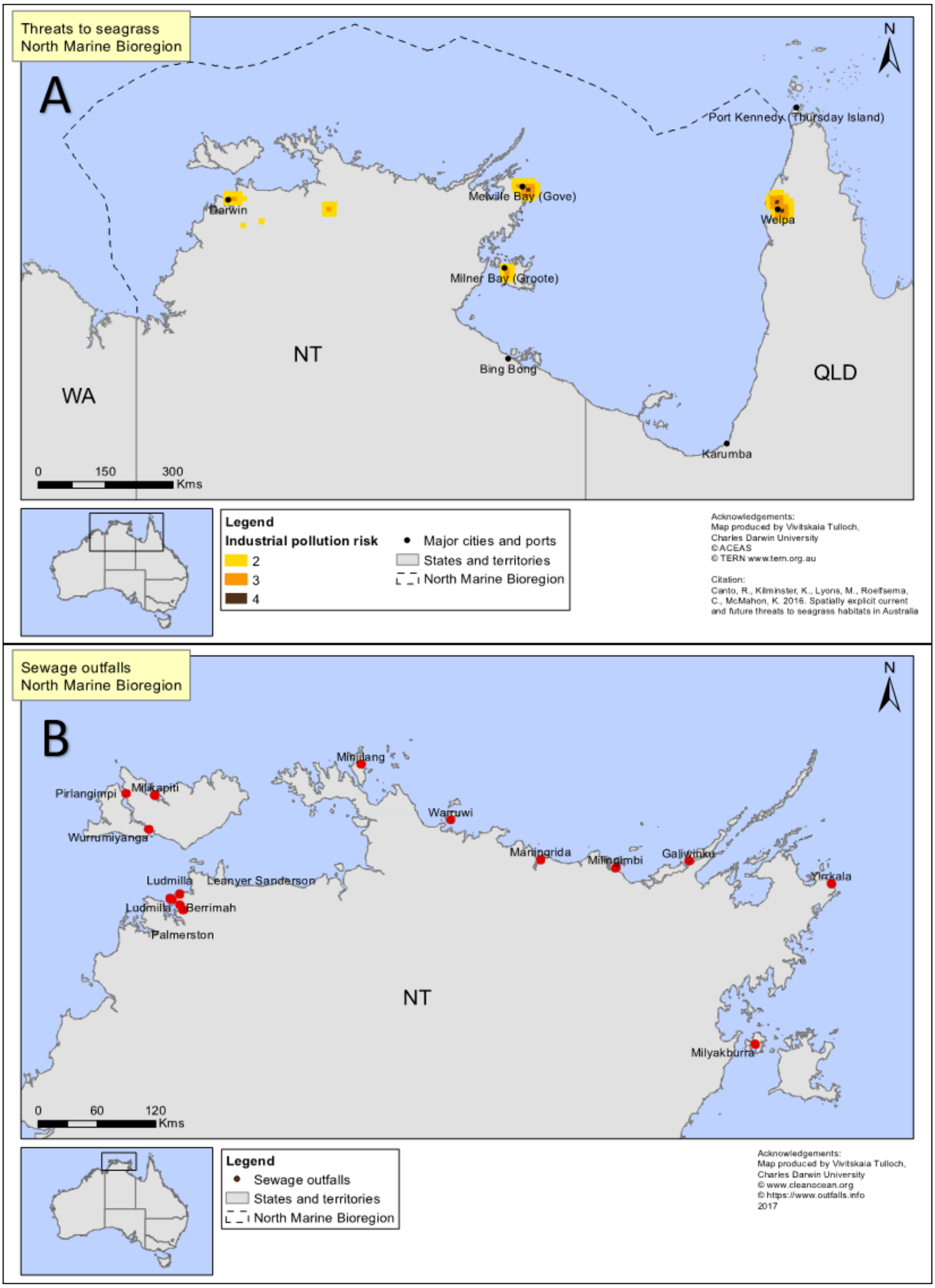

Figure 18. Human pressures within the North Marine Bioregion, (A) Industrial pollution (from ABARES), re-scaled from 0 (no pollution) to 1 (high pollution), and (B) sewage outfalls (NESP, https://www.outfalls.info).)

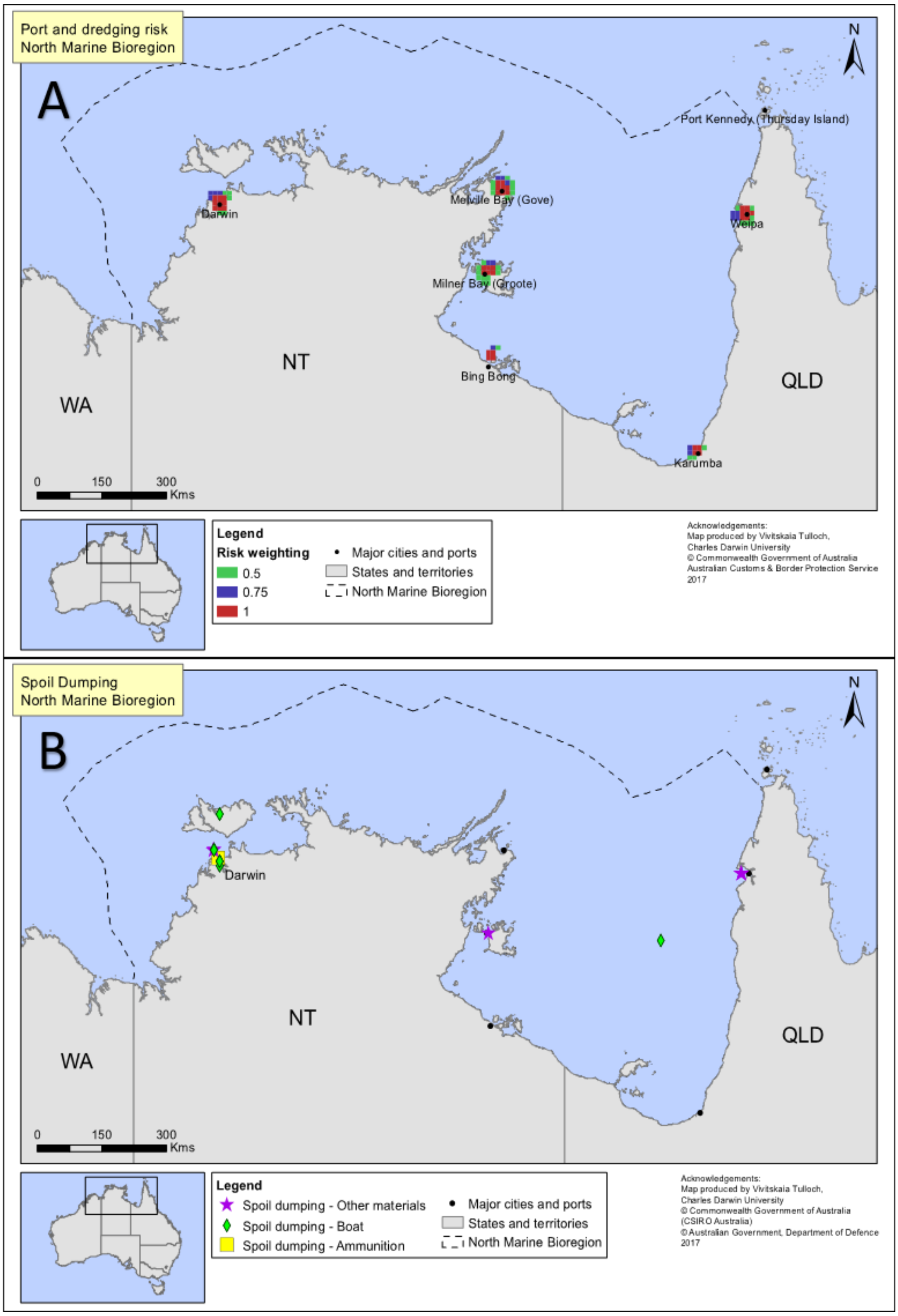

Figure 19. Human pressures within the North Marine Bioregion, (A) Port infrastructure and dredging risk (Australian Customs & Border Protection Service), and (B) Spoil dumping (ammunition, boat, other materials, Department of Defence).

Sediment and Nutrient Pollution

Spatial data describing acute and chronic sediment and nutrient risk to seagrass habitats have been derived previously by Canto *et al.* (2016). The authors derived this pressure layer by using disturbance of the catchment (as identified in the National Estuary Audit 2000, http://www.ozcoasts.gov.au/search_data/estuary_search.jsp) to describe catchment condition. As sediment and nutrient loads are strongly linked to catchment clearing and land use, Canto *et al.* (2016) assumed that catchments that were near pristine and largely unmodified would pose a low risk to seagrasses in terms of sediment and nutrient loads. Similarly, the highest risk would be from catchments which are extensively modified. Streamflow data were compiled from the Australian Bureau of Meteorology (bom.gov.au) which described the daily flows from the period 1990–1999 from 241 stream gauging stations Australia-wide. The risk of acute sediment and nutrient risk for each estuary and connected coastline was determined as a function of catchment condition moderated by the likelihood of large pulses of flow along river channels as well as the total volume of the flow.

Resuspension data was derived by Canto *et al.* (2016) from Geoscience Australia's dataset "Percentage of the time that the Shields parameter exceeded 0.25" developed during the CERF Marine Biodiversity Hub. The Shields parameter defines the bed shear stress required to initiate sediment movement. When it is >0.25, conditions on the seabed are highly mobile, hence there is more chance of resuspending sediments which can have a negative impact on seagrasses due to reductions in light. The percentage of the time that the Shields parameter exceeded 0.25 was determined from the Geological and Oceanographic Model of Australia's Continental Shelf (GEOMACS) model (Hemer 2006, Harris and Hughes 2012).

We obtained and mapped data from Canto *et al.* (2016) for urban/agricultural runoff, and sediment resuspension (Figure 20). This information was derived by considering the catchment condition moderated by the likelihood of large pulses of flow along river channels as well as the total volume of the flow.

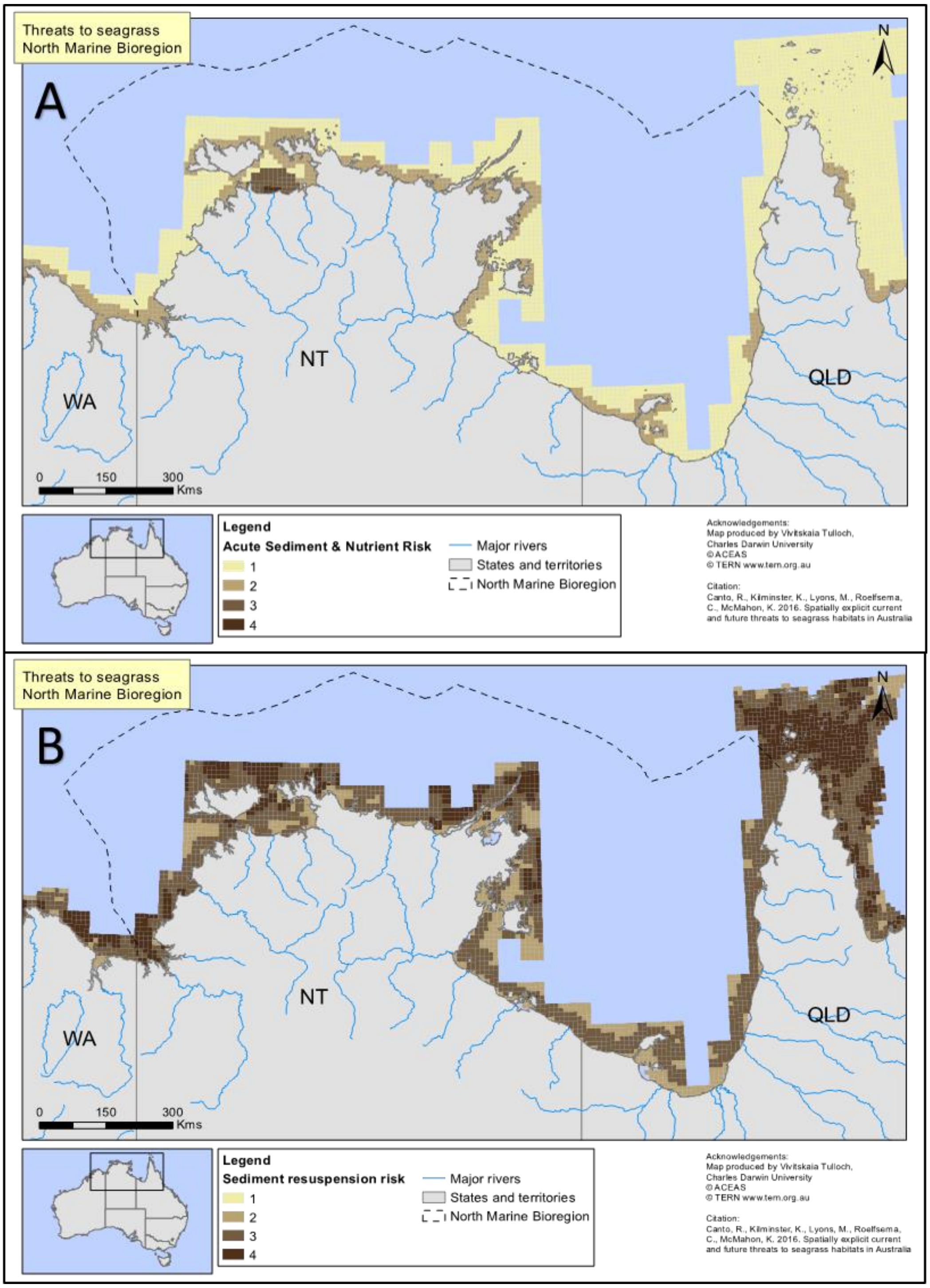

Figure 20. (A) Acute sediment and nutrient risk to coastal habitats in the North Marine Bioregion, and (B) sediment resuspension risk (from Canto *et al.* 2016).

3.3.2 Climate Drivers

Maps of extreme weather events were obtained from the Coastal and Marine Resources Information System (CAMRIS), identifying intensity, frequency and density of cyclone occurrence in the Australian region (Figure 21A). Large areas in the western Gulf, and along the coast southwest of Darwin, were identified as having high historical cyclone density and intensity. We re-scaled the values to between 0.5 and 1, to be consistent with other pressure values.

We also obtained maps of modelled increase in sea level rise for 2070 (Figure 21B) from Canto *et al.* (2016), which identified high risk of sea-level rise from Groote Eylandt extending southeast along the coast to past the Queensland border, with the rest of the coastal region identified as moderate risk from sea-level rise. We re-scaled these values to be consistent with the other pressures, so that high risk = 1 and moderate risk = 0.75.

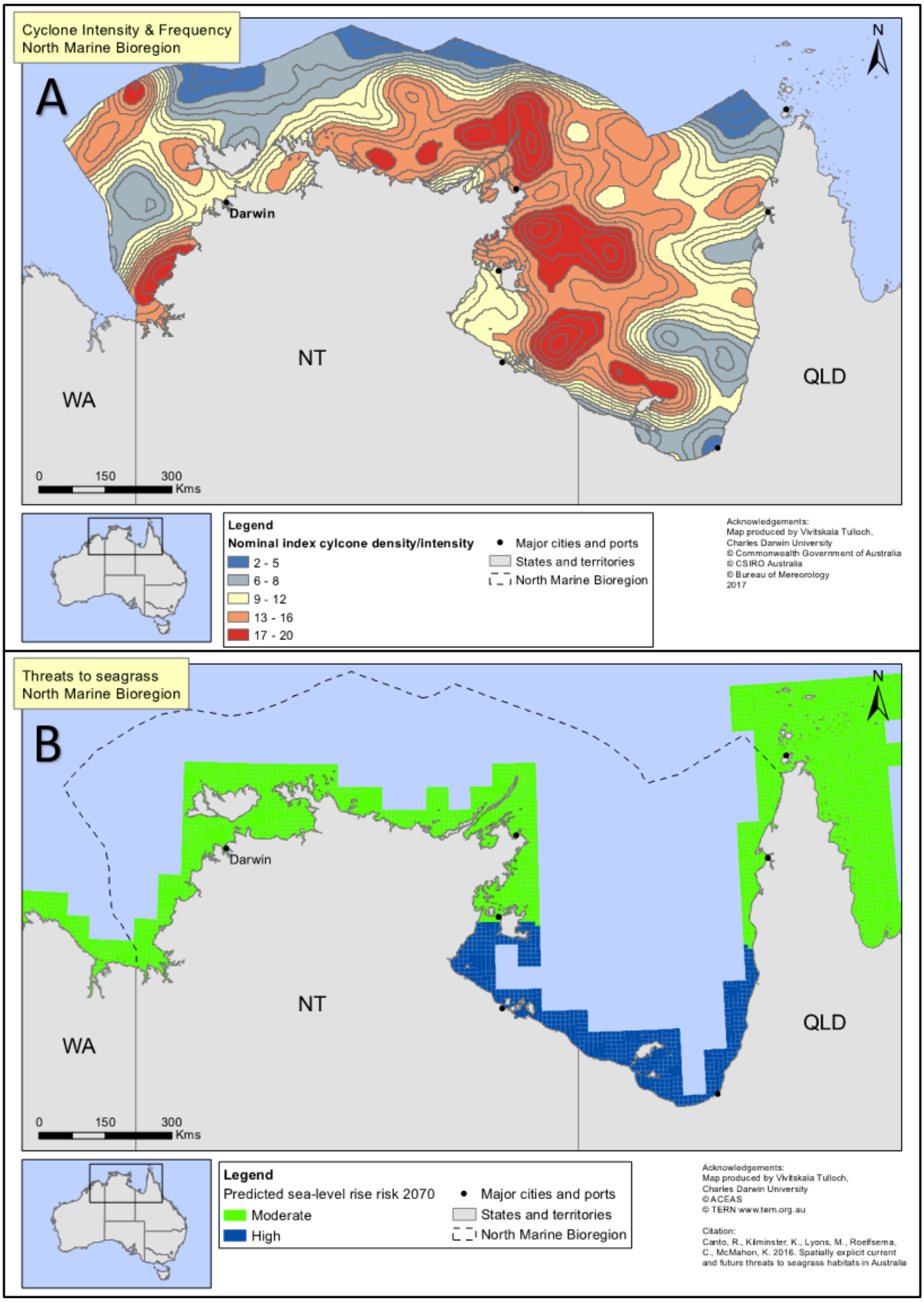

Figure 21. (A) Cyclone intensity (CAMRIS), and (B) sea-level rise risk to coastal habitats for 2070 from Canto *et al.* (2016).

3.3.3 Ongoing and Future Pressures

Population Growth

The Northern Australian Audit (January 2015) assessed critical economic infrastructure gaps and requirements to meet projected Northern Australia population and economic growth through to FY31 (2031). The report used a hybrid of Australian Bureau of Statistics and State/Territory projections to derive core population projections for five scenarios (baseline, aspirational economic growth, medium economic growth, northern population shift, and low population growth). Under the audit's core baseline population projections, Northern Australia is projected to grow at 1.8 per cent year-on-year, compared to 1.6 per cent for Australia as a whole. We used the modelled output values from the aspirational (high industry) economic growth scenario to FY31 and added these to the population pressure raw values as derived from the Australian Bureau of Statistics for 2011 to estimate future high growth pressures acting on the region (Figure 22).

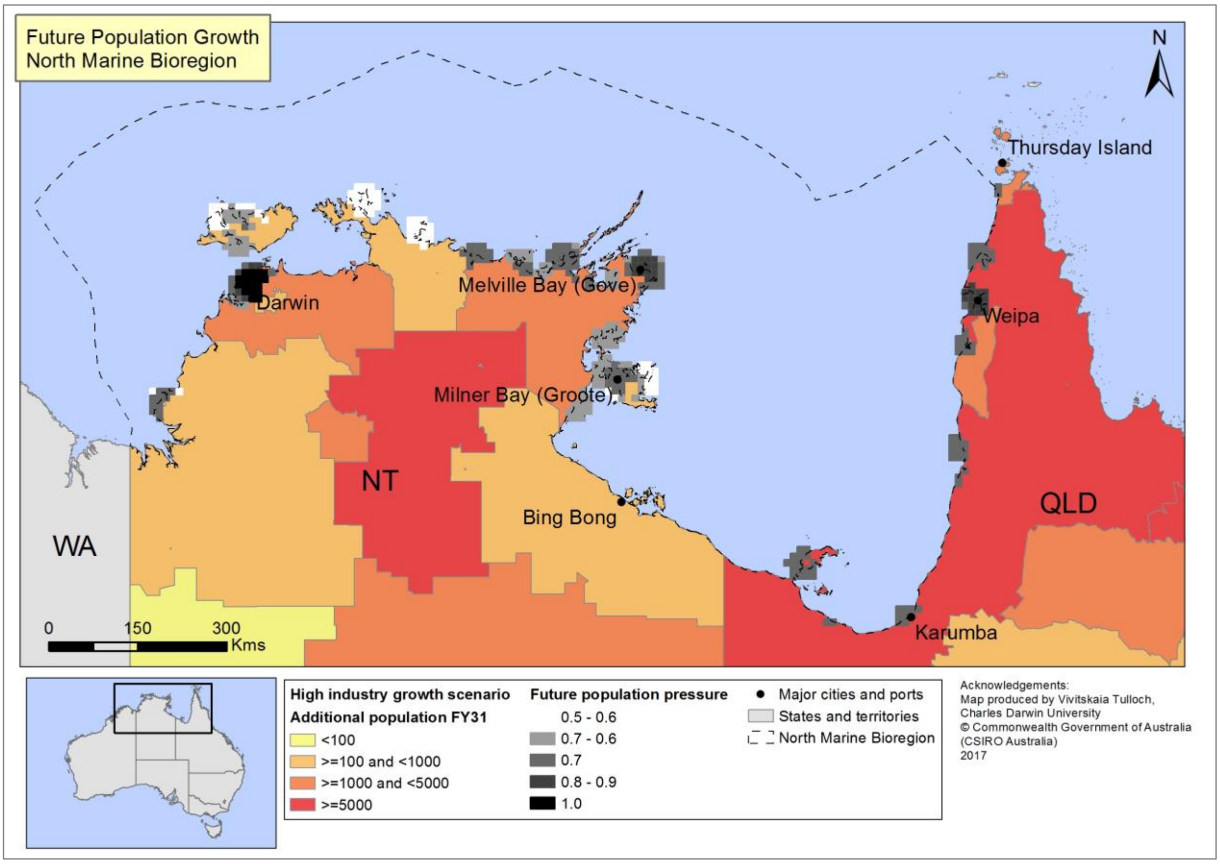

Figure 22. Future modelled population pressure increase across the North Marine Bioregion, based on modelled population and economic growth as identified in the aspirational (high industry) growth scenario of the Northern Australia Audit (2015).

Recreational Boating

We assumed recreational boating pressures will increase in intensity as per the current population growth, and used the indexes from the two population growth scenarios from the Northern Australian Audit to increase the existing recreational boating pressure index spatially.

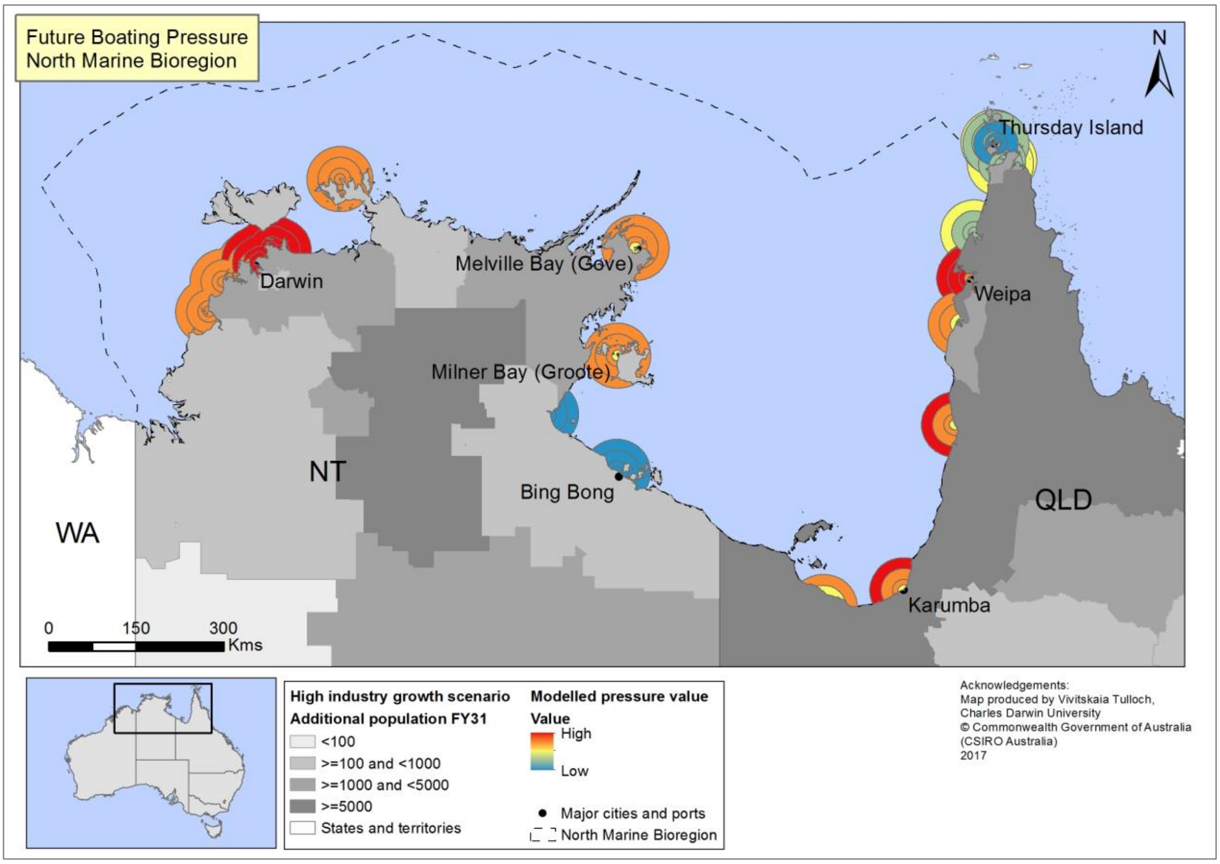

Figure 23. Future modelled boating pressure across the North Marine Bioregion, based on modelled population and economic growth as identified aspirational growth scenario of the Northern Australia Audit (2015).

Petroleum Prospectivity

This dataset is a subset of the Sedimentary Basins dataset developed by Geoscience Australia. It represents sedimentary basins that are considered to be prospective for petroleum, and it has been attributed with a rating describing the relative prospectivity of different areas. This interpretive data on relative petroleum prospectivity is derived from Geoscience Australia's internal quantitative basin evaluation work, modified in some cases after consultation with their own internal experts on particular basins. The classification terms used represent a simplified qualitative assessment of petroleum prospectivity, and are subject to future change as new data are gathered and interpreted. We applied an index between 0 and 1 based on the range of prospectivity attributes within the dataset (low, low-medium, medium, medium-high, and high), and then spatially joined the data to the north Australian grid to derive a relative index of future petroleum prospectivity to the North Marine Bioregion.

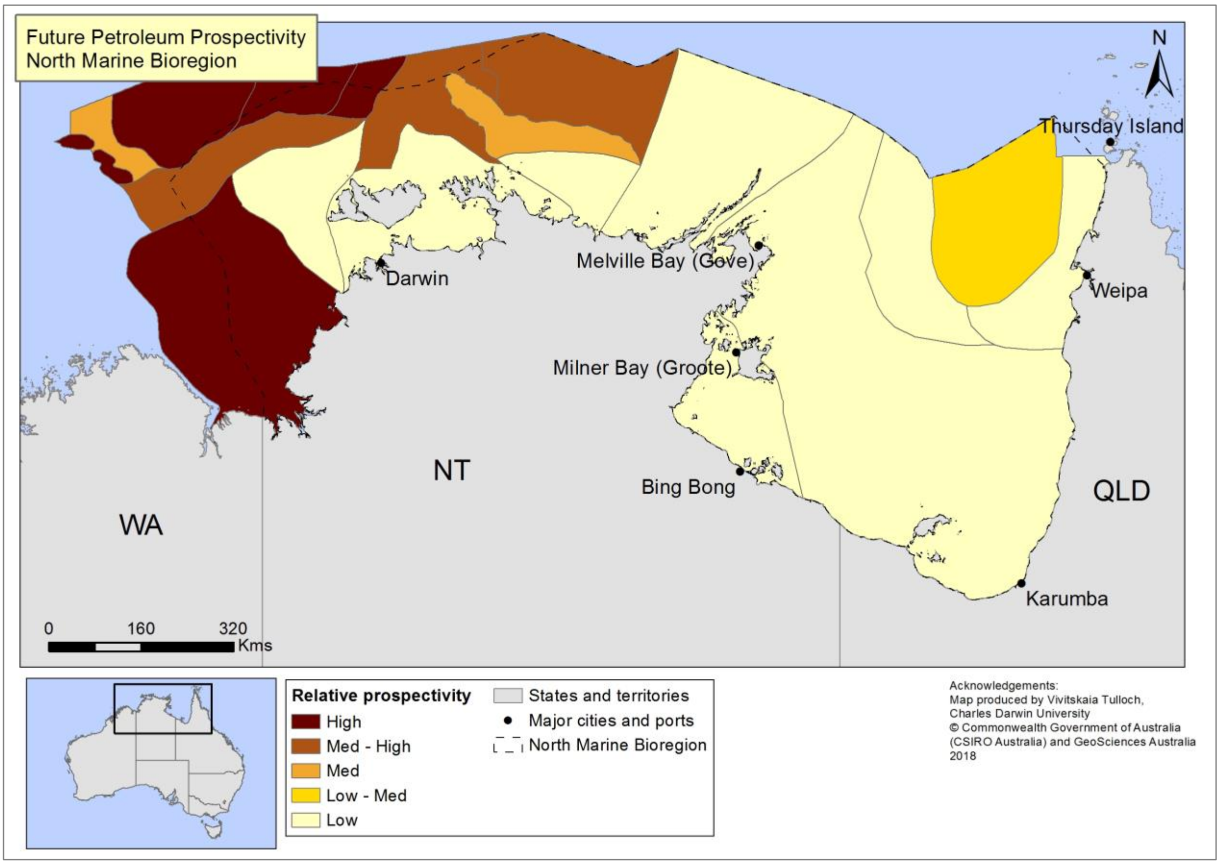

Figure 24. Petroleum prospectivity in the North Marine Bioregion as identified by Geoscience Australia.

EPBC Referrals

We included current and future development as identified through the *EPBC* referral process. First, we investigated each of the referrals identified as potentially having an impact on the marine environment, to understand if the development is current or ongoing, through web-based and literature searches. We removed those developments that were identified as completed, applications that have expired, as well as those applications that have been withdrawn. Most seismic applications had expired and were removed. We included all development application areas from the last 15 years that were identified as currently active, including coastal and marine mining operations, land development, infrastructure, aquaculture, pipelines, and renewable energy operations, and created a presence-only value layer, where the spatial extent of these ongoing applications was given a value equal to 1.

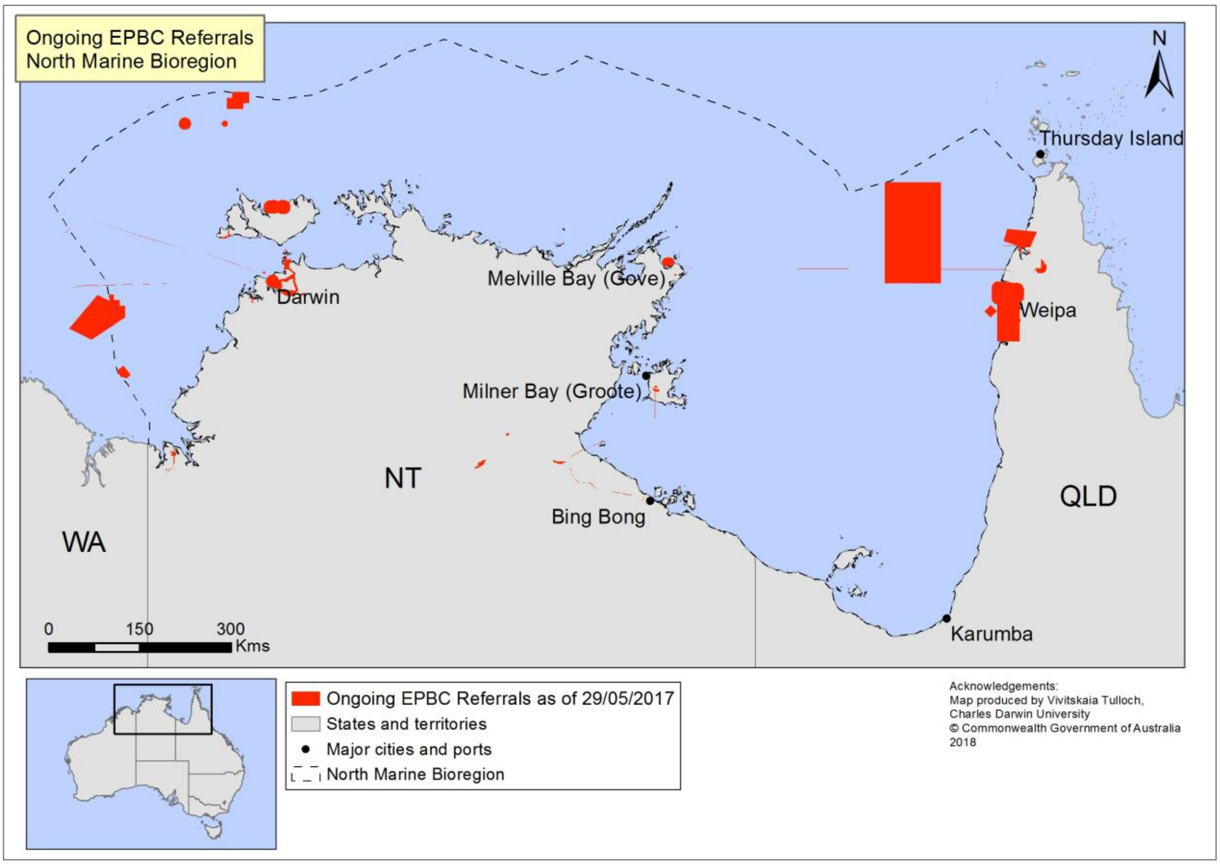

Figure 25. *EPBC* referrals (from data up to 29/5/2017) that are currently active with potentially ongoing impacts into the near future.

Proposed Development

We performed an in-depth analysis of potential developments outlined in the “White Paper on Developing Northern Australia” (Commonwealth of Australia 2015). We researched each development identified in the paper to extract those relevant to the North Marine Region that might potentially impact upon coastal or marine ecosystems and/or species, and manually digitized each selected development to provide a qualitative map of proposed or current development in northern Australia. Of the developments outlined in the paper, only 14 were identified as having potential impacts on marine environments. The remainder were located inland, or were outside the North Marine Bioregion boundary.

We list all pertinent developments in Table 8. We were able to digitize most developments, although some were set to the size of the catchment (e.g. Gulf Water Plans, Expansion of the Ord Irrigation Scheme) due to there being no easily accessible fine-scale spatial information on the scale of the development. We therefore acknowledge the coarse-scale qualitative nature of this map, and suggest it be used only to inform where future development might occur, and not to inform management unless further investigation is conducted. Only one development (Pastoral Lease diversification) could not be digitized due to there being no spatial information on the extent of the development.

Table 8. Potential developments outlined in the White Paper on Developing Northern Australia with the potential to impact on the North Marine Bioregion.

State/ Territory	Where	Name	Type	Detail
Queensland	Weipa, QLD	South of the Embley bauxite project, Weipa	Mining and Energy	Queensland is the largest bauxite producer in Australia, and Australia is the largest bauxite producer in the world with 30 per cent of the world's production in 2012. The Cape York bauxite deposits are some of the richest and largest in the world, second only to Guinea. The South of Embley bauxite project represents a new mine with up to 40 years of production at 25 to 50 million tonnes per year. The Weipa mine has been in operation since 1963. The new South of Embley mine will sustain the mining town of Weipa and provide ongoing employment for up to 1500 workers.
Queensland	Peninsula Road, Cape York	$200m+ upgrade to the Peninsula Development Road in Cape York	Infrastructure and Construction	To better connect areas of economic opportunity with local communities and support the growth of the hospitality, transport, tourism and maintenance industries.
Queensland	Flinders and Gilbert River Catchments, QLD	Gulf Water Plans	Agriculture	The Finalisation of the Gulf Water Plans will identify additional volumes of unallocated water for the Flinders and Gilbert River catchments. https://www.daf.qld.gov.au/business-priorities/business-trade/development/industry-development/flinders-gilbert-agricultural-zone/map-of-catchments
Queensland	Cape York Catchments	Cape York Water Strategy	Agriculture	The Cape York Water Strategy provides a vision for the sustainable water allocation and management across Cape York, which allows for a balanced approach to support development while being sympathetic to the cultural, recreational and environmental values of the region. https://dnrme.qld.gov.au/__data/assets/pdf_file/0009/1396116/cape-york-draft-water-plan.pdf
Northern Territory	Captured in petroleum prospectivity	Creating Opportunities for Resource Exploration	Minerals	A four year (2014–18) $23.8 million initiative aimed at stimulating minerals and petroleum exploration through new geoscience and exploration incentives.
Northern Territory	Darwin	Harbour Foreshore	Minerals	Development of an over-arching strategy to attract investment in economic infrastructure around Darwin harbour and the industrial foreshore. It will also include long term planning for industrial and residential land use.

State/ Territory	Where	Name	Type	Detail
Northern Territory	Tiwi Islands	Tiwi Islands Economic Development Partnership Agreement	Minerals	The Tiwi Land Council, Commonwealth and Northern Territory governments are negotiating an Economic Development Partnership Agreement to coordinate opportunities for business and industry development, investment and trade, and create jobs across the Tiwi Islands region.
Northern Territory	NT – no spatial information	Pastoral Lease diversification	Minerals	Working with pastoral leaseholders to diversify their business to capitalise on new Northern Territory laws allowing a portion of leases to be developed for other commercial purposes such as agriculture, horticulture, forestry, aquaculture or tourism ventures.
Northern Territory	Darwin, NT	Ichthys LNG processing plant	Private sector - under construction	Located on Blaydin Point on Middle Arm Peninsula in Darwin Harbour, the processing plant is expected to produce 8.4 million tonnes of LNG and 1.6 million tonnes of LPGs (propane and butane) each year, along with 15,000 barrels of condensate per day at peak.
Northern Territory	NT	Seafarms Sea Dragon Project	Projects where EIS process is underway	Development of 10 000 ha of Tiger Prawns on Legune Pastoral Lease, adjacent to Ord Stage 3.
Northern Territory	QLD north-west	South of the Embley	Projects where EIS has been completed	New bauxite mine, initially producing 22.5 million dry product tonnes per annum (mdpt/a) with the potential to increase to 50 mdpt/a.
Northern Territory	Darwin	Marine Industry Park	Road and Infrastructure	Northern Territory Government is seeking to develop a marine industry park in Darwin. Centrally located on Australia's northern coastline, Darwin is the gateway of choice to Asia. Located within a deep water harbour with port and rail access, immediately adjacent to major onshore and offshore gas and oil developments, a marine industry park will provide a unique opportunity to capitalise on Darwin's significantly expanding oil and gas, marine services and defence industries.
Northern Territory	Darwin	Port of Darwin Redevelopment and associated works	Road and Infrastructure	The combined Port of Darwin project is to facilitate the development of the resources rich Northern Territory and further growth in its agricultural industries, in particular the livestock market and to capitalise on the potential for Darwin to be the gateway
Northern Territory	WA	Expansion of the Ord Irrigation Scheme in Northern Territory	Road and Infrastructure	The Northern Territory Government under this project aims to offer 14,500 ha of new agricultural land with clear land title to the market as a development opportunity

We also obtained spatial data on Digital Cadastral Database (DCDB) Development Applications for the Northern Territory from the Department of Infrastructure, Planning and Logistics (http://www.ntlis.nt.gov.au), as a qualitative guide to identifying where future development on the land might impact downstream coastal systems and species (Figure 26).

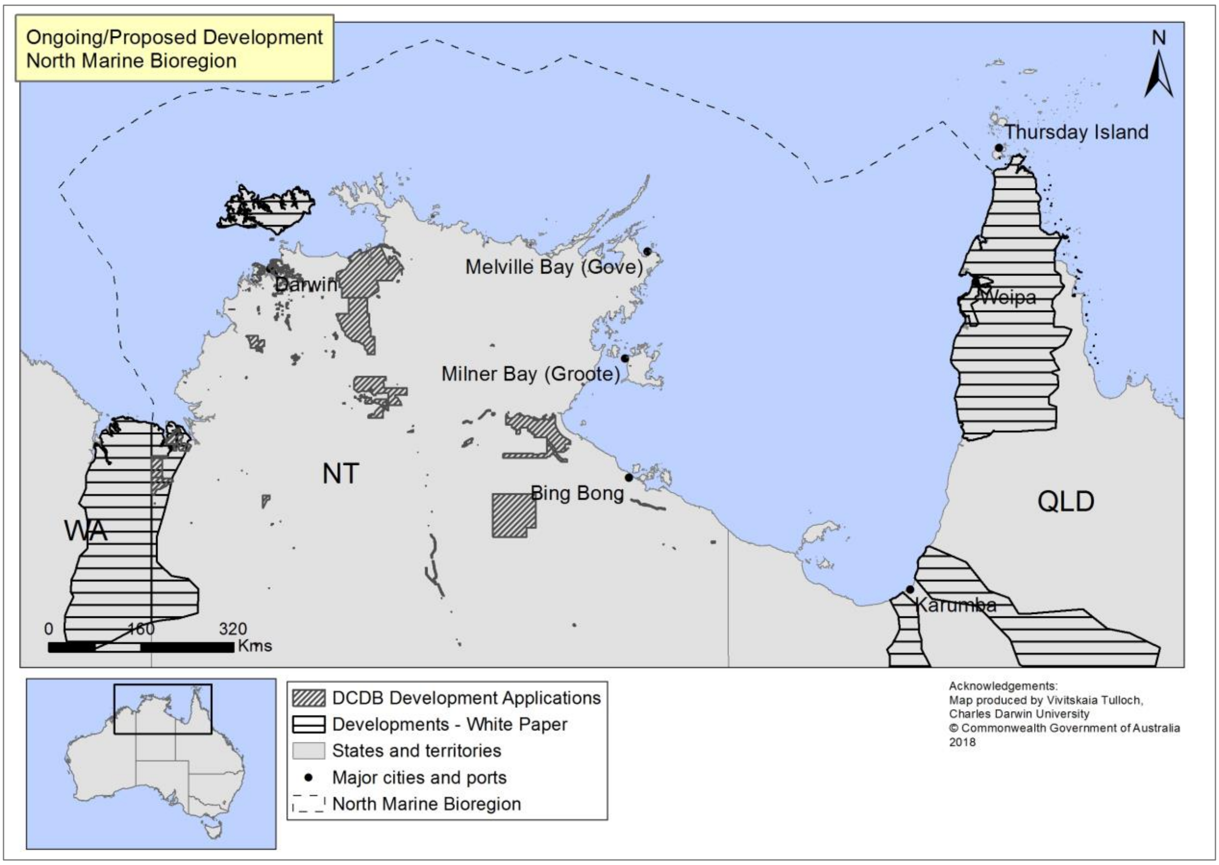

Figure 26. Proposed and potential development in northern Australia displayed as Northern Territory development applications (Digital Cadastral Database; http://www.ntlis.nt.gov.au), and potential developments extracted from the White Paper on Developing Northern Australia (Commonwealth of Australia 2015) (Table 8).

3.3.4 Hotspot Mapping

Historic and Current Pressures

Historic and current human impact on the North Marine Bioregion shows strong spatial heterogeneity (Figure 27). The total cumulative pressure mapping identified higher historical pressures overall throughout much of the Northern Territory coastal waters compared to offshore waters of the North Marine Bioregion (Figure 28), which was expected given that coastal and continental shelf areas are subjected to both land- and ocean-based pressures. The exception to this was a high pressure region in the north-west offshore waters of the North Marine Bioregion, reflecting historical offshore fishing effort and mining operations. Hotspots around Darwin, Groote Eylandt and Nhulunbuy (Gove) reflect historical fishing effort and recreational boating, combined with land-based pressures including industry, port activities, and population density. Coastal waters of east Queensland had lower cumulative pressures overall than the Northern Territory waters, with the exception being the coastal waters around Weipa, reflecting port activities including shipping and recreational boating, as well as other indirect land-based pressures. Offshore regions of the Gulf were largely identified as low to moderate cumulative pressure. Some heterogeneity in values appeared to be driven by the spatial distribution and intensity of NT and QLD State fisheries.

The data show that climate change pressures have the largest footprints, covering the entire region, roughly 625,689 km^2. The point source pollution pressures (sewage outfalls, spoil dumping, port infrastructure, etc.) had a disproportionally higher impact value compared to their footprint, which covers <2% of the region. No single grid cell showed a zero value, due to the blanket coverage of some climate change pressures (SST variance and change) and also shipping routes. This also meant that there were no areas of the North Marine Bioregion affected by fewer than two pressures per cell.

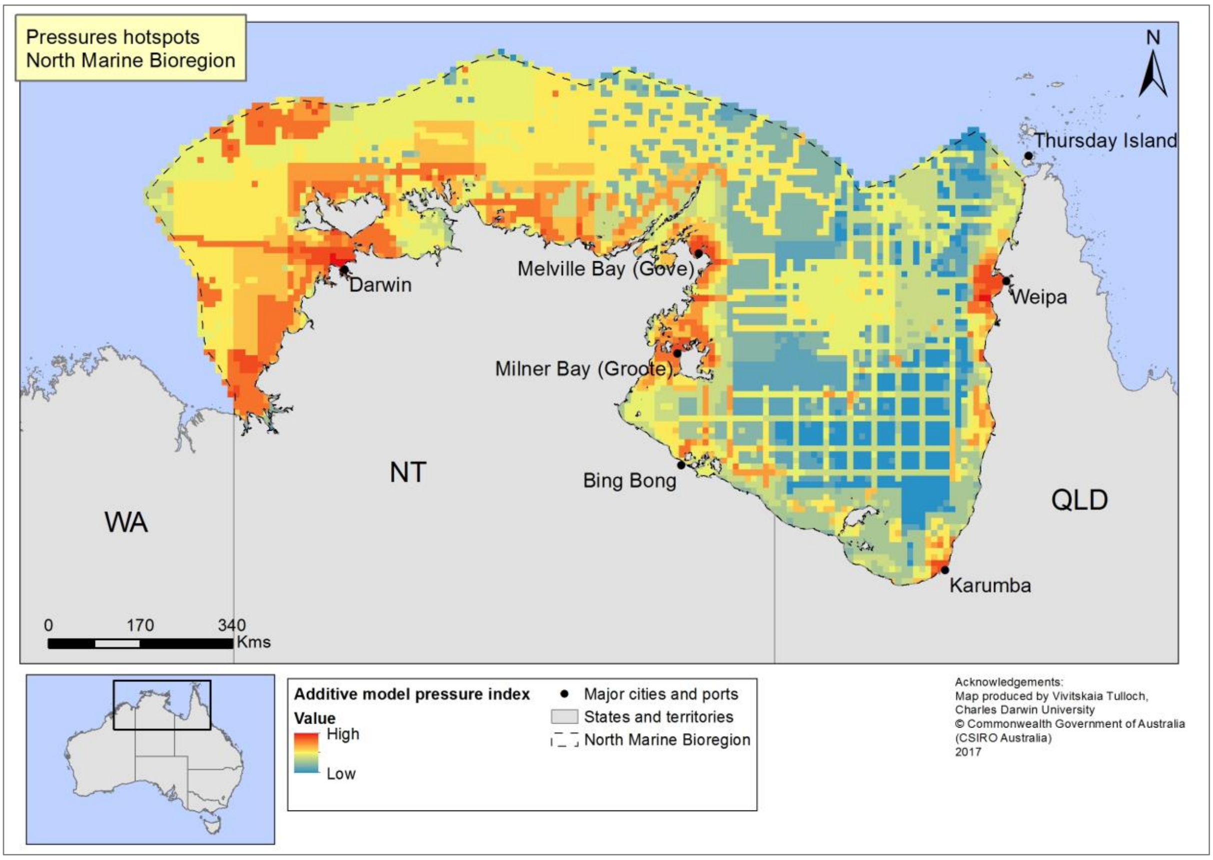

Figure 27. Total cumulative pressure hotspots map, derived by adding historic and current pressure risk metrics in each grid cell. We identify areas of high risk which might benefit from additional management (red areas), versus low risk areas that might provide options for mitigation (blue areas), for the North Marine Bioregion, given current and historical pressures.

Evaluation of the spread of historic and current cumulative pressure scores identified a right-skewed distribution of pressure scores per grid cell (Figure 28). The additive pressure scores ranged from 0.4 to 8.3, with a mean of 1.9 (Figure 24). The theoretical maximum possible score for the additive model would be 21, based on all threats occurring at their highest level. The maximum observed pressure scores (>8) occurred along the coast adjacent to Darwin, which also had the maximum number of threats. Approximately 15% of the region has been subjected to very low pressure levels (Tx <=1), though a small proportion (<1%) has very high Tx scores (>=5). A substantial proportion of the area is offshore, with fewer pressures, resulting in the great majority of grid cells in offshore areas having low cumulative pressure scores.

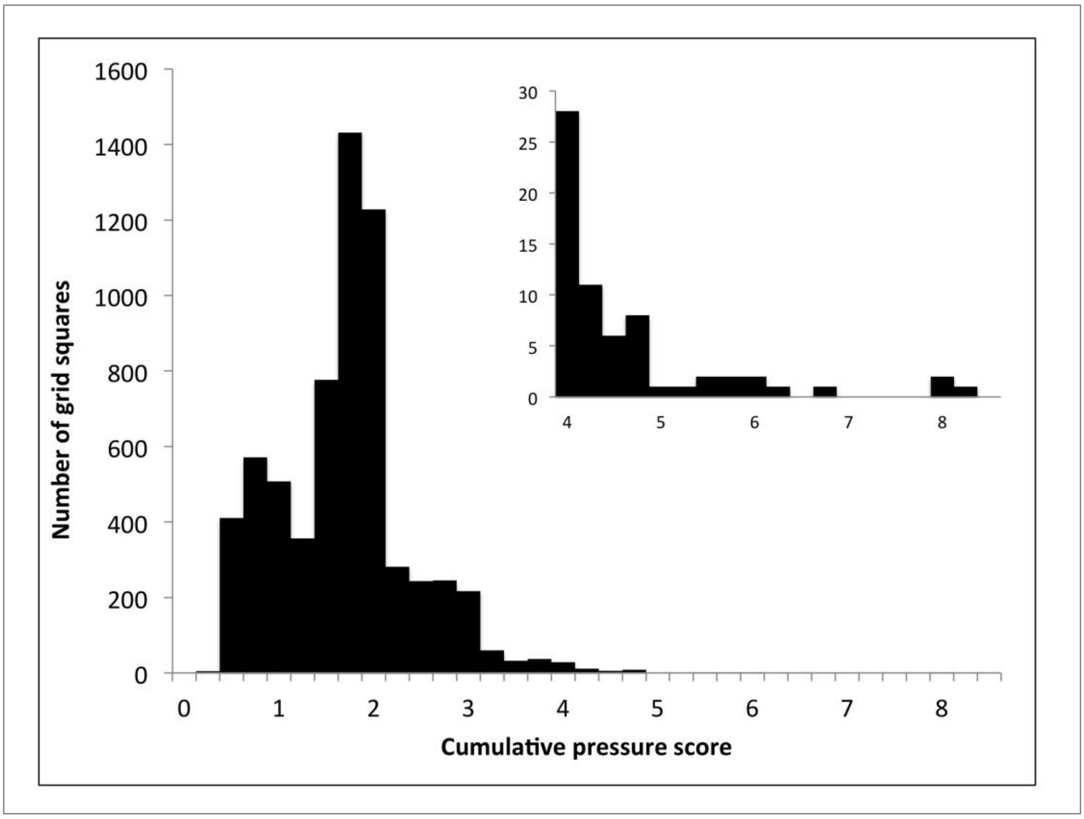

Figure 28. Histogram of cumulative impact scores depicting the fraction of North Marine Bioregion area that falls within each impact category (number of grid cells). There are no zeros; histogram bars are in bins of 0.5. (Inset: expanded views of the tail of values).

Ongoing and Future Pressures

Differences in modelled values between the total cumulative pressures (Figure 27) and ongoing and future pressures (Figure 29) were evident largely in offshore areas including the Gulf of Carpentaria region, which had lower ongoing pressures relative to those historically. Some areas of the coast had higher ongoing pressures relative to the rest of the region once historical pressures were removed, including waters extending north-west from the NT/QLD border to Groote Eylandt, which was driven by predicted population trends and associated boating as well as commercial fishing. In contrast, waters north of the Tiwi islands were predicted to have lower ongoing pressures relative to values including historical pressures.

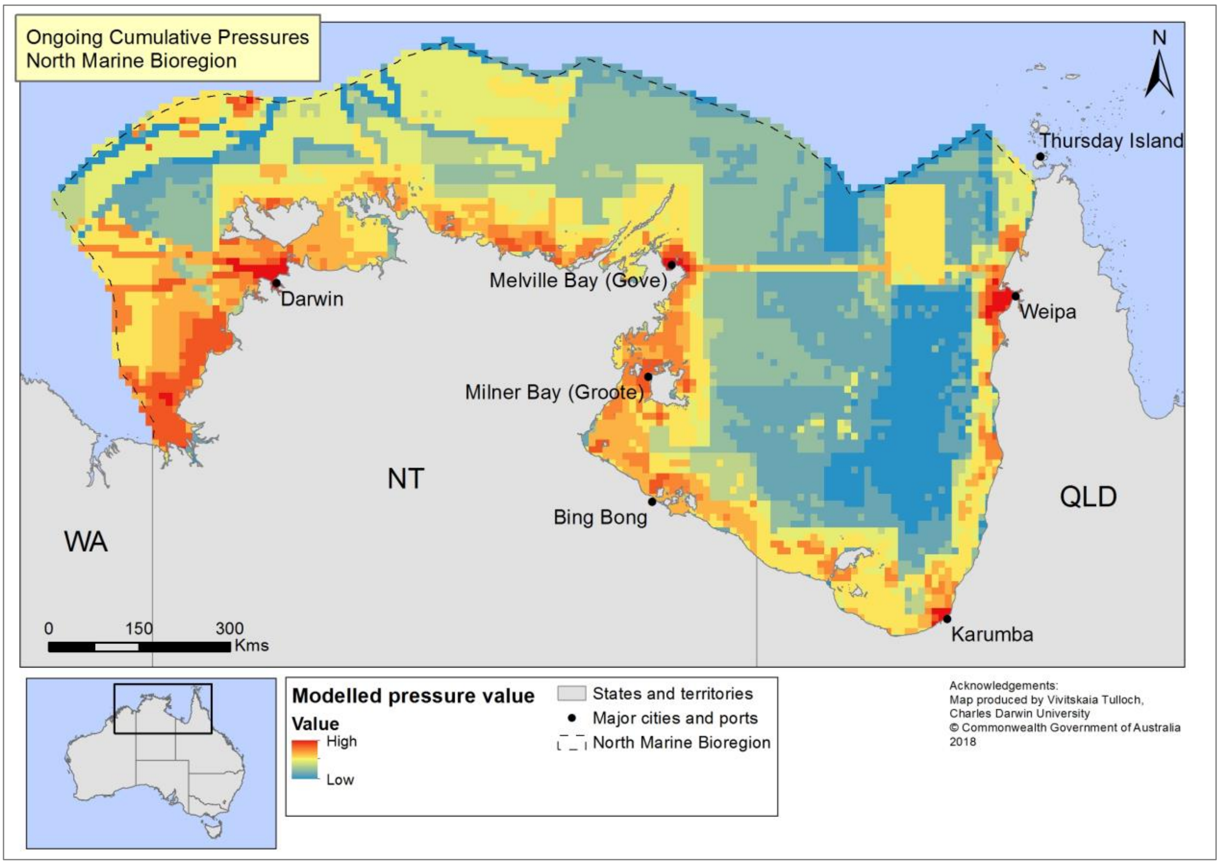

Figure 29. Cumulative ongoing and future pressure hotspots map, derived by adding current ongoing and future pressure risk metrics in each grid cell. This figure identifies hotspots of multiple current ongoing and future pressures (red) versus regions of low current ongoing and future pressures (blue).

3.4 Conclusions

We have compiled the most complete, highest resolution and regionally-consistent marine dataset on historic, current, and projected cumulative human and natural pressures on the environment for the North Marine Bioregion. It builds upon earlier NESP research on national pressure mapping by CSIRO, by not only updating previously developed maps of pressures for the North Marine Bioregion to the present day, and in some cases at a finer resolution, but also including new pressure data and models, as well as collating spatial pressure data derived by other studies as detailed in Appendix D. Furthermore, we then look to the future, examining key policy papers and interrogating *EPBC* referrals in order to (qualitatively) anticipate likely focal points for future development.

Knowledge of the current and historical distribution and intensity of pressures is an important component in decision-making to guide future research and management. The approach in this report is a first step in identifying areas of high cumulative pressures where further management of human activities may achieve a higher return-on-investment e.g. by reducing or eliminating anthropogenic drivers with high impact scores (Halpern *et al.* 2008). We also identify low pressure areas, which might not be a high priority for additional management, but may provide an opportunity for offsetting residual risks in other areas, or be prioritized for the protection of their natural values depending on which species and habitats they contain.

There are some caveats in the approach used here. Because the maps developed are static, providing a snapshot of historic or current marine use only, they do not indicate comparative trends through time. Although some data were provided as long time-series (e.g. NT fisheries effort), others were either point source snapshots of the current status or location of pressures (e.g. sewage outfall), or earlier pressures that may operate in a different spatial location now (e.g. seismic activities), or may be discontinued (e.g. inactive oil wells). It might be possible to derive some information on change over time in pressures for those data that were provided for longer time series or extrapolate information on pressure intensity over time for the point source or static data sources, but this would require further time and resources and was beyond the scope of this project. From the information we have already, it is clear that there are a number of historical pressure sources no longer affecting the North Marine Bioregion, and a number of locations where pressures have existed in the past that are not currently affected, including historical spoil dumping locations, historical seismic activity, decommissioned oil and gas wells, and decommissioned cables. However, pressures from urban development and recreational resource use has likely increased concomitant with increasing human populations particularly along the coast, and pressures and impacts from climate-driven changes in the environment will likely increase in the near future as well, potentially compounding local pressures (Brown *et al.* 2013, Poloczanska *et al.* 2013).

Because we used an additive approach, the estimates potentially inflate human impacts on coastal areas (Halpern *et al.* 2008). Some refinement to the pressure maps developed here is needed as information and resources becomes available, as some identified pressures could not be included due to data or time constraints, and the approach taken to accumulate pressures will need to be revisited for specific questions or species, building on the current Hub project for the Great Barrier Reef.

The results of the cumulative mapping represent an initial scoping exercise to show the spatial variation in anthropogenic impacts. The number of assumptions when using cumulative pressure maps to guide spatial decision-making (Halpern and Fujita 2013) preclude the use of these maps to guide management at this stage. Firstly, the additive approach assumes pressure layers are of equal importance, but underlying biases or values might place importance on some pressures, such as commercial fishing, over others, such as recreational fishing. This typically requires assumptions or expert judgment about how important particular types and groups of pressures, which has been dealt with by a range of approaches (Halpern *et al.* 2009, Allan *et al.* 2013), and is being further developed in a separate NESP Marine Biodiversity Hub project identifying approaches to consider cumulative impacts on the Great Barrier Reef, but was beyond the remit of this scoping project.

A fundamental assumption in developing cumulative pressure maps using an additive approach is that pressures are independent of one another. Synergistic effects often occur when multiple threats affect an area. For example, overfishing can make coral reefs more sensitive to disease and less resilient to coral bleaching as a result of climate change (McManus and Polsenberg 2004). Species may also respond differently to pressures (Díaz *et al.* 2013, Brown *et al.* 2014), thus the effectiveness of actions to ameliorate pressures will vary (Tulloch *et al.* 2015). Future work could address interactions between pressures by using a threshold or multiplicative approach, but this would require detailed knowledge on the synergisms between different pressures acting upon northern systems and species. We currently know very little about where, when or why non-additive responses may occur (Crain *et al.* 2008, Darling and Cote 2008). Outputs of the additive mapping approach are likely conservative compared to using a multiplicative approach that assumes interactions exist between pressures (Crain *et al.* 2008).

Although pressure maps are a way to visualise management concerns and focus future research, they tell us nothing about the impacts on species, and because of this, are very different from a cumulative impact map (e.g. Halpern *et al.* 2008, Selkoe *et al.* 2009) that include links between pressures and impacts on ecosystems and species. Information on the spatial distribution of species, especially those that are threatened, and associated impacts of pressures, is crucial for pressure impact mapping. We addressed this by developing a risk matrix of pressure interactions with threatened species to address this aspect of impact mapping, and this information is detailed in Synthesis chapter at the end of the report.

Future research should be directed towards improving the accuracy of species distribution models. Once developed, this information could be used in tandem with the pressure maps developed here through specifically developed interaction matrices, to guide effective conservation decisions that have the potential to improve the persistence of Threatened and Migratory marine species. This can be achieved by identifying the most vulnerable regions and species to guide conservation action (Tulloch *et al.* 2016), minimizing pressures to those species, while at the same time identifying where and how conservation is consistent with increased sustainable development of the existing and new sectors in the North Marine Bioregion (Tulloch *et al.* 2015, Tulloch *et al.* 2016). Building environmental forecasts around the five future population scenarios identified in the Northern Australian Audit is one approach that requires discussion amongst research end-users.

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4. INDIGENOUS PRIORITIES

KEY POINTS

- An examination of Indigenous priorities in relation of Threatened and Migratory marine species was undertaken in two stages: i) a desktop review; and, ii) a consultation phase.
- There was interest expressed by all communities engaged. Some communities did not have the resources to engage while the Mud Bay decision was proceeding.
- There are two critical factors that differ from community to community: i) capacity (including number of rangers, training and experience, availability of suitable vessels and equipment); and, ii) suitability of the proposed project timeframe.
- While priorities varied between groups, the work revealed current interest and existing capacity relating specifically to marine turtles, dugong, shorebirds and seabirds, and sawfishes, and largely within the Western Gulf of Carpentaria region (through the Numbulwar Numburindi Amalahgayag Injung, Yugul Mangi Rangers, and possibly Dhimurru), and the Daly River region of the western Top End (through the Malak Malak Rangers).
- It is important to consider not only what future research should be conducted, but how. In cross-cultural research the partnerships underlying, and processes adopted in the conduct of projects are of critical importance.
- Traditional Owners and their ranger groups are increasingly interested in driving the research agenda, including involvement in design, active participation, and ensuring beneficial local outcomes.

4.1 Introduction

Indigenous Australians have been the custodians of the seascapes of this country for millennia, continuing up to the present day. However, since European settlement, Indigenous governance and management of (land and) sea country has been significantly eroded, leaving much sea country unmanaged. New governance and management systems, interests and needs are emerging across Australia as dramatically changed circumstances, pressures, opportunities, and information needs demand critical thinking for protecting and managing healthy marine environments.

This chapter provides an overview of some of the Threatened and Migratory marine species (and extending to their populations and habitats) that Indigenous communities in the study area (North Marine Bioregion and adjacent coastal regions of the Northern Territory, including the Gulf of Carpentaria and the western Cape York region of Queensland) would like to see collaborative research effort focused on, so that they are better placed to manage sea country into the future. The information presented was derived through a combination of two processes: (1) a desktop study; and, (2) consultations with representatives from Indigenous Land Management (ILM)/Ranger groups and/or Traditional Owners (TOs) and other Indigenous community members.

The first component was a desktop study of readily available materials including Indigenous Protected Area (IPA) Management Plans (Table 9), Healthy Country Plans and other strategies framed by various ILM/Ranger groups involved in caring for sea country. Where available, IPA Management Plans and other Sea Country plans should be recognised as incorporating (to a greater or lesser extent) local and traditional knowledge, customary protocols and other enabling and empowering features of resilient communities, adapted to deliver agreed environmental management outcomes. They are generally developed over a period of several years through extensive, considered, and representative consultation with all the appropriate TOs and other relevant community members. They clearly articulate community desires with regard to sea country matters, set in the context of an ongoing commitment to continue the ancestral custodianship of their traditional estates, using both traditional and contemporary approaches to manage sea country. They are a primary resource for anyone interested in working in land and sea country. Within the study area however, IPAs cover only parts of the coast; Figure 30 shows the coverage of existing IPAs across the study area). Other material, perhaps with limited emphasis on relevant research but indicating practical interests, aspirations and concerns, were also considered.

Table 9. Indigenous Protected Areas (with a coastal boundary) within the North Marine Bioregion and relevant Management Plans.

IPA Region	Management Plan available? Year/operational period	*Ranger group/s*
Marri-Jabin (Thamurrurr)- Stage 1 Western NT	No	Thamurrurr
Djelk Central Arnhem Land, NT	Healthy Country Plan 2015–2025	Djelk
Marthakal - Stage 1 North East Arnhem Land, NT	Yes (sea country extension planned) 2015–2020	Gumurr Marthakal
Dhimurru North East Arnhem Land, NT	Yes 2015–2022	Dhimurru
Laynhapuy – Stage 1 North East Arnhem Land, NT	No, but publication imminent (sea country extension planned)	Yirralka
Anindilyakwa Gulf of Carpentaria, NT	Yes	Anindilyakwa
South East Arnhem Land (SEAL) South East Arnhem Land, NT	Yes (sea country extension mooted) 2015–2020	2 groups Yugul Mangi & Numbulwar Numburindi Amalagayag Inyung
Yanyuwa (Barni-Wardimantha Awara) Southern Gulf of Carpentaria, NT	Sea Country Plan 2007	li Anthawirriyarra
Nijinda Durlga (Gangalidda) – Stage 1 Southern Gulf of Carpentaria, QLD	Yes 2015	Gangalidda Garawa
Thuwatha/Bujimulla (Wellesley Islands) Southern Gulf of Carpentaria, QLD	Yes 2015	Wellesley Islands

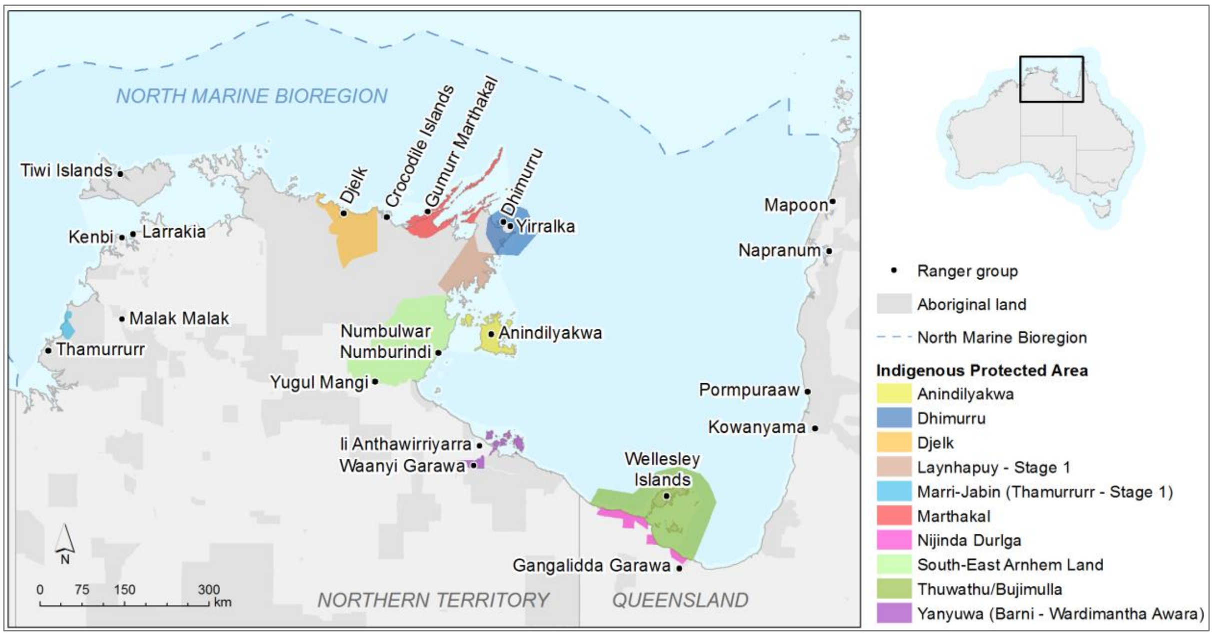

Figure 30. Coastal Indigenous Protected Areas and other coastal Aboriginal land within the North Marine Bioregion.

Aboriginal people have a clear interest in research relating to their sea country. It is important to consider not only what future research should be conducted, but how. In cross-cultural research the partnerships underlying, and processes adopted in the conduct of projects are of critical importance. Broader issues of communication, access, consent and intellectual property, scale and context, compensation, appropriate use of Indigenous knowledge and governance need to be considered in exploring what is best practice collaborative research. Some communities already have considerable experience working with western scientists, and this experience has enabled them to establish a clear process for managing engagement in research projects. In some cases, communities are driving the research agenda and actively seeking out partnerships to address identified knowledge gaps.

The Desktop Review (Appendix F) details the broader Indigenous treatment of sea country within which obligations to country and its wildlife are described and actions to meet those obligations are set out. It is through this broader contextual lens that engagement with Indigenous sea country managers over Threatened and Migratory marine species can be made meaningful and fruitful.

Following on from the desktop component we undertook targeted consultations with Indigenous community members/Ranger groups to provide a more comprehensive view of 'priority' marine fauna for future research. In addition to exploring the species of interest, the consultations were an opportunity to consider the capacity and level of interest in participating in future research endeavours.

Whilst communities have a desire to bolster their capacity to manage marine species, it is important to consider the broader context of individuals and communities sea country priorities. At this time, there is one issue in particular that exemplifies this, the Blue Mud Bay issue. When considering sea country research priorities in the Northern Territory it was important to recognise the importance of the Blue Mud Bay Native title decision and current related processes. In the past 12 months, the Northern Land Council has been in discussion with many coastal communities in relation to the Blue Mud Bay native title decision. As a consequence of the 2008 decision by the Australian High Court, negotiations are required to establish agreements for recreational and commercial fisher access to the intertidal zone on Aboriginal Land. The issue of ownership and management over the intertidal zone is of paramount importance to Indigenous sea country custodians. In some cases, we were advised that discussions about any potential sea country research were not appropriate whilst matters relating to post Blue Mud Bay management were in active negotiation.

We must also recognise some important qualifications of this work, which have been articulated in the 'Scope and qualifications' section of the Desktop Review (Appendix F).

4.2 Consultations

A brief overview of discussions during the consultation phase of the project is provided in Table 10, including comments on existing research projects communities/ranger groups are involved in, and some notes on capacity. Following on from the table is a discussion section, providing a short summary for each location/community where we engaged/attempted to engage during the project.

Table 10. Outcomes from consultations.

Location/region	Ranger group/s operating in the region	Existing research projects/partnerships of relevance	Species/groups/communities and the issues of interest	Additional species/issues discussed	Capacity and other notes
Northern Territory					
Ngukurr/ Numbulwar Western Gulf of Carpentaria	Yugul Mangi Rangers. Numbulwar Numburindi Amalahgayag Injung Rangers	Largetooth Sawfish research, NESP Marine Biodiversity Hub Project A1. Barramundi movement, Department of Environment and Natural Resources (DENR), CDU RIEL, NT Fisheries and Yugul Mangi.	Marine turtles: surveys of resident populations and nesting beaches, boat strike from rec fishers. Dugong: surveys, boat strike from rec fishers. Sharks and rays including Largetooth Sawfish. Shorebirds including Far Eastern Curlew.	Inshore dolphins Seabirds Shovelnose ray and Wedgefish	Both groups have high capacity for water-based work, vessels & qualified coxswains. Rangers have identified outstations which could act as basecamps. Year-round access to Ngukurr improving. Strong relationship established through A1.
Tiwi Islands Top End	Tiwi Land and Marine Rangers	NESP Threatened Species Recovery Hub Project 6.2 Tom Duncan PhD comparing western and local conservation values. Have previously done marine turtle research with WWF.	As part of NESP Marine Hub project A1 community members expressed an interest in Sawfish in 2016.		Current sea country focus is on renegotiating conditions of 20-year fishing access agreement. Previous attempts to schedule field sampling in 2016 unsuccessful.
Groote Eylandt Gulf of Carpentaria	Anindilyakwa Rangers	Recent collaboration with AIMS on benthic habitat mapping of IPA.			Unable to engage within the project timeframe. Demonstrated capacity for sea country work.
Maningrida West Arnhem Land	Djelk Rangers	Coastal dolphin surveys, DENR.	Seabirds including terns, concerns about overharvest of eggs, requires surveys of island rookeries. Marine turtles. General mapping of habitat & marine species distributions		Blue Mud Bay negotiations #1 priority. High capacity for ocean-based work, multiple vessels & large number of rangers.

Darwin region	Larrakia Rangers, Kenbi Rangers	DENR Darwin Harbour coastal dolphin surveys Carol Palmer. NESP Threatened Species Recovery Hub Project 5.11 Far Eastern Curlew.	Impacts of increasing in-water noise associated with seismic surveys, shipping, dredging and blasting on marine mammals. Water quality impacts on all marine life of Darwin Harbour including several Threatened and Migratory marine species.		Larrakia Rangers working hard to gain appropriate recognition. Larrakia have expressed a strong desire to be engaged in marine research generally. Kenbi & Larrakia both have vessels.
Borroloola Southern Gulf of Carpentaria	Waanyi Garawa Rangers, li Anthawirriyarra Sea Rangers	The li Anthawirriyarra rangers regularly record opportunistic sightings of Threatened and Migratory marine species, and other marine animals for their own purposes.	Dugong and marine turtles, surveys and examining potential contamination of seagrass beds from McArthur River mine, possible human health implications. Also concerns around impacts on these species from commercial fishery bycatch, ghostnets, and recreational boat strike.		Waanyi Garawa Rangers don't currently manage sea country, but they are custodians of sea country to north of IPA. li Anthawirriyarra Rangers identify as a sea ranger unit, have vessels and undertake regular marine patrols.
Nhulunbuy North East Arnhem Land	Dhimurru Rangers	Seagrass monitoring. Tern research and monitoring, Birdlife Australia.	Marine turtle and dugong incl. mortality associated with commercial fishing. Shorebirds. Marine megafauna. General marine biodiversity mapping.	Seabirds	Lost a number of staff late 2017, but eager to be involved once recruitment complete. Strong connections and positive relationships with neighbouring groups.
Laynhapuy North East Arnhem Land	Yirralka Rangers		Broad marine biodiversity mapping.		High capacity. Strong relationship with northern neighbour. Difficulty with communication at times.
Daly River Top End	Malak Malak Rangers	Largetooth Sawfish work, extension of Project A1.			Keen to continue/expand sawfish work, include acoustic tagging of relocated animals.

					Strong relationship with researchers. Small group but have vessels for river/estuary work.
Queensland					
Southern Gulf	CLCAC Gangalidda Garawa Rangers & Normanton Rangers, Wellesley Island Rangers	Shorebird research: As part of the East Asian-Australasian Flyway 2 flyway sites established, 1 within the Nijinda Durlga IPA (EAAF125) and another, near Karumba to east of IPA (EAAF120). Wellesley Island Rangers likely to be involved in surveys for NESP Marine Hub Project D3.			Difficulty engaging with groups through the CLCAC. Wellesley Islands group recently re-established so capacity may be limited.
Mapoon North West Cape York	Mapoon Land and Sea Rangers	Sawfish research, Sharks and Rays Australia. Shorebird monitoring, BirdLife Australia. Marine turtle research, QLD Dept. Environment & Heritage Protection (QLD EHP) and Western Cape Turtle Threat Abatement Alliance (WCCTTA). Aust. Snubfin Dolphin QLD EHP. Also tracking movements and monitoring nests of Estuarine Crocodiles, Sea snake population and distribution; and Dugong population and distribution.			Given the number of existing research collaborations, there is probably limited capacity to take on additional research. Furthermore, the existing portfolio of research covers many Threatened and Migratory marine species.
Napranum North West Cape York	Nanum Wungthim Land and Sea Rangers	Involved in marine turtle research with WCTTAA.	Focussed on marine turtle monitoring and research.		Unable to engage directly with group within project timeline.

Pormpuraaw South West Cape York	Pormpuraaw Land and Sea Rangers	Current focus on Olive Ridley Turtles in association with WCTTAA (turtle monitoring pre-dates WCTTAA) Rangers undertake regular Shorebird counts.	Marine turtles esp. Olive Ridley, Hawksbill & Flatback; population dynamics, possible climate change & extreme event impacts. Understanding intra & inter seasonal shorebird population fluctuations. Also sawfish & dolphins incl. Aust. Snubfin.	Shovelnose rays	
Kowanyama South West Cape York	Kowanyama Aboriginal Land & Natural Resource Management Office (KALNRMO).	Sawfish research, Dr Barbara Wueringer Sharks and Rays Australia. Climate change impacts, Dr Jeff Shellberg Griffith Uni.	Locally directed, expert assisted research on shorebirds is a priority. Interested in understanding potential climate change impacts on marine turtles.		KALNRMO ultimately aims to apply for research funding directly, then invite researchers into community.

4.3 Northern Territory

4.3.1 Borroloola Region, Western Gulf

The Waanyi Garawa Ranger group (which includes both Waanyi and Garawa people) is responsible for management of the land bound Ganalanga-Mindibirrina IPA (South East of Borroloola). Some Garawa Traditional Owners are custodians of sea country to north of the IPA and aspire to undertake marine management in future. Sampling in this region could provide a much-needed opportunity Garawa TOs to strengthen connections with their sea country. The li Anthawirriyarra Rangers operate out of Borroloola and identify as a sea ranger unit so have a good capacity for marine work. They undertake regular marine patrols throughout the waters adjacent to the Yanyuwa (Barni-Wardimantha Awara) IPA, making a concerted effort to record opportunistic sightings of marine fauna. For people around Borroloola one of the main concerns relating to sea country is the possibility that pollution from the McArthur River Mine is having an impact on marine life, particularly turtles and Dugong. Sediment (which is potentially contaminated) from upstream spreads throughout the river mouth/estuarine areas, interacting with vast meadows of seagrass, a primary food source for marine turtle and dugong. Other recognised threats, include bycatch in commercial net fisheries, mortality due to ghost nets, and physical disturbance by increasing numbers (and size) of recreational boats.

4.3.2 Darwin Region

The Larrakia Rangers (administered by Larrakia Nation Aboriginal Corporation) are located in Darwin and the Kenbi Rangers on the Cox Peninsula, on the western side of Darwin Harbour. Both groups are equipped with sea worthy vessels and have ample experience undertaking work on sea country. The Larrakia Rangers are currently supporting Darwin Harbour coastal dolphin surveys with Carol Palmer from the Department of the Environment and Natural Resources (DENR), and also the Far Eastern Curlew research by Amanda Lilleyman, NESP Threatened Species Recovery Hub Project 5.11. Unfortunately, we were unable to speak to the Kenbi Rangers within the project timeframe, however we understand they are also involved in the DENR dolphin surveys.

Broadly, Larrakia people expressed concern about water quality impacts (primarily focussed within the Darwin Harbour) on all marine life, including Threatened and Migratory marine species, such as the inshore dolphin species and marine turtles. Noise pollution was also raised as an issue (again focussed on Darwin Harbour), particularly regarding marine mammals.

Much of the discussion with the Larrakia Rangers revolved around engagement in the research process, the positive and negative aspects of previous and existing research projects. There are a number of factors that result in the Larrakia Rangers not being as easily recognisable as the ‘go to’ land managers, when compared to Indigenous ranger groups, particularly those in more remote localities. This lack of recognition means they are often overlooked when people/organisations consider research in the region.

4.3.3 Daly River

The Malak Malak Rangers are not a coastal group but manage country along a stretch of the Daly River, south west of Darwin, which has proved to be critical habitat for the Largetooth Sawfish. A strong partnership between the Rangers (and other TOs) and NESP researchers began in 2008, but was truly solidified during a Sawfish rescue mission in 2012. Since then the group has played a critical role in the 'Indigenous partnerships for management of euryhaline species' component of the NESP marine Biodiversity Hub "Project A1: Northern Australian hotspots for the recovery of threatened euryhaline species." and they are eager to continue collaborative research on the species known locally as *Tyemirerriny.*

4.3.4 Maningrida

Discussions with the Djelk Ranger Manager reiterated that any proposals for collaborative research that supported the goals of the Healthy Country Plan would be welcome, provided proposals were developed in an appropriate manner following a number of engagement principles. As detailed in the Plan, the presence of migratory species including seabirds and turtles will be used as an indicator of healthy sea and coasts, which will be measured in two ways 1) surveying community members for harvest of seabird and marine turtle eggs and 2) through population surveys of migratory species.

There has been concern expressed about possible over-harvest of seabird eggs (including, but possibly not limited to unspecified tern species) on some islands off Maningrida. The TO for the islands has expressed a strong desire for research on the local seabird population, particularly looking at harvest sustainability; which would provide vital knowledge to inform culturally and scientifically appropriate management of egg harvest in future.

At present, there is a considerable discussion around the current state of commercial (and to a lesser extent recreational) fishing in the area. Commercial fishery bycatch is a concern to many TOs. People what to know what species are caught, and in what numbers and they would like to see more effort go into utilising bycatch instead of wasting a potential food resource. However, there wasn't any discussion about bycatch as a specific threat to any particular Threatened and Migratory marine species. This was reflected by an example from Borroloola where the occasional incident of a Dugong mortality would be considered acceptable, provided the animal was not wasted, but rather provided to the community for consumption.

4.3.5 South East Arnhem Land

The Yugul Mangi Rangers are based at Ngukurr, on the banks of the Roper River; and the Numbulwar Numburindi Amalahgayag Injung Rangers are located on the coast at Numbulwar. These two groups work together to manage the recently dedicated South East Arnhem Land IPA. Although Ngukurr is inland, the Yugul Mangi Rangers readily (and regularly) access the coast via the river and so have considerable capacity for sea country work, as do their northern neighbours.

A number of other Threatened and Migratory marine species and associated subjects have been discussed with TOs in the region. There are known nesting beaches for Green and

Flatback (and possibly Olive Ridley) turtles on some islands and the mainland. TOs would like to see marine turtles and Dugong surveyed, since as far as people are aware they haven't ever been surveyed locally (unlike other populations in Northern Australia). There was a recent sighting by Police of dolphins a long way up the Roper River. Though the species was not identified they were almost certainly Australian Snubfin or Indo Pacific Humpbacks. Some of the rangers recalled that when they were much younger they used to see them up near town much more regularly, even in floodwaters. People also expressed an interest in learning more about other shark and ray species including Shovelnose Rays and wedgefish, which are seen and sometimes caught, but not well understood.

There was a discussion about shorebirds. One of the senior rangers had been involved in some shorebird work several years ago, so he explained to the others that some shorebirds travel incredible distances between breeding and feeding grounds. People agreed that the Far Eastern Curlew is seen on mudflats and other coastal habitats in the region, as are numerous other unidentified shorebirds. In addition to marine turtle nests, some of the islands are known to have extensive seabird rookeries.

A partnership with Yugul Mangi Rangers, Numbulwar Numburindi Amalahgayag Injung Rangers and NESP researchers was established during work undertaken as part of NESP marine Biodiversity Hub "Project A1: Northern Australian hotspots for the recovery of threatened euryhaline species." The level of commitment was also apparent in Yugul Mangi's willingness to spend some of their own operational funds (some $3500) on acoustic tags. Researchers, and four Malak Malak rangers travelled to the Roper River to work with the local rangers to search for Largetooth Sawfish, known by locals and visiting recreational fishers to inhabit some of the waterways in the area. This trip also served as a valuable knowledge exchange opportunity. Researchers heard historical accounts of the species, helping to increase knowledge of distribution, and gained an understanding of their cultural value. The rangers, and in turn other community members, learned about the conservation plight of the species, and began to appreciate the significance of their country as a potential stronghold for the species. Despite not catching any sawfish on that trip both ranger groups expressed a strong desire to continue the research. They requested that researchers return in 2017 to try again.

At the Sept 2017 dedication of the South East Arnhem Land IPA, rangers from both groups spoke about their desire to continue Sawfish research, showcasing the signs which were produced as part of Project A1. In October 2017 rangers and researchers made another attempt to catch and tag sawfish. An extensive sampling effort in the river resulted in one sawfish pup being caught and tagged, just upstream from the Roper Bar. Several other promising billabong sites were also suggested by community members. Within the limited time available, several of these were sampled over a short period without success, but based on their habitat characteristics are considered to be worthy of a more concerted sampling effort in future.

4.3.6 Tiwi Islands

The Tiwi Land Council's (TLC) Marine and Land Rangers operate from multiple locations on Bathurst and Melville islands (north of Darwin). The marine rangers are well equipped to undertake work on sea country and have previously collaborating with scientists on a marine turtle research project with the World Wildlife Fund.

Discussions were held with Kate Hadden, Land and Resources Manager for the TLC. We were advised that TOs are currently focussed on trying to renegotiate conditions of an existing 20-year fishing access agreement. There had been progress creating a Tiwi Islands Sea Country Management Plan, but this planning process is currently on hold until issues around the fishing agreement have been resolved. The TLC does have some good guidance around research, including research protocols and access agreements.

As part of Project A1 there was significant interest expressed about Largetooth Sawfish, however we were ultimately unsuccessful in scheduling any field work for that project. It would be worthwhile contacting the Land and Resources Manager again in 2018 to reassess the situation on the ground.

4.3.7 North East Arnhem Land including Dhimurru and Laynhapuy IPAs

Operating primarily out of Nhulunbuy, the Dhimurru Rangers manage the land and sea country of the Dhimurru IPA. They also work closely with their southern neighbours the Yirralka Rangers, who manage the Laynhapuy IPA. Both groups would be generally be considered to have a high capacity for sea country work, being equipped with necessary vessels and experience to undertake marine research activities.

Initial discussions with both groups were extremely productive, with many Threatened and Migratory marine species (and associated issues) of mutual interest identified. Dhimurru are currently working with Birdlife Australia on a project focussing on terns. Marine megafauna and shorebirds were two groups of particular interest for Dhimurru. We were not able to undertake more detailed on-ground consultations during the project timeline as the dry season is a busy time of year for both groups; and it proved particularly challenging to communicate with the Yirralka Rangers. The Dhimurru Sea Country Facilitator advised that a number of rangers and support staff left late in 2017, however they are aiming to recruit new staff early in 2018, and have stated that they are definitely interested in considering collaborative sea country research once they have returned to full capacity. A renewed effort to engage with Yirralka is also recommended.

4.4 Queensland

4.4.1 Southern Gulf including Nijinda Durlga and Thuwatha/Bujimulla IPAs

Indigenous land management in this region is primarily delivered by Carpentaria Land Council Aboriginal Corporation (CLCAC) ranger groups, Gangalidda Garawa and Normanton; and the Wellesley Island Rangers, which was also previously hosted by the CLCAC. The Wellesley Island ranger group has gone through a challenging time in recent years and was inactive for a period, before recommencing in September 2016 under the Gulf Region Aboriginal Corporation’s company Wellesley Islands Land & Sea Social and Economic Development. During the consultation period, the then CLCAC CEO would not facilitate discussions with rangers or TOs in the region. Shortly after this, the CLCAC CEO position was advertised, as was the position of IPA coordinator. These changes in key personnel at the CLCAC and the new management arrangements for the Wellesley Island ranger group may well open the opportunity to engage in discussions in 2018. It would be critical to develop a robust research agreement for any research in this region, clearly outlining data sharing arrangements; and any preliminary discussions should address these issues up front.

4.4.2 Mapoon

Mapoon Land and Sea Rangers and TOs are already involved in a number of established research projects on Threatened and Migratory marine species including sawfish with Sharks and Rays Australia, shorebirds with BirdLife Australia, marine turtles with QLD Dept. Environment and Heritage Protection (QLD EHP) and Western Cape Turtle Threat Abatement Alliance (WCTTAA), Australian Snubfin Dolphins with QLD EHP; as well as research tracking movements and monitoring nests of Estuarine Crocodiles, sea snake population and distribution; and Dugong population and distribution. The Mapoon Rangers have the infrastructure and experience to undertake marine work, however given the number of existing projects, there may be limited capacity to take on additional research. Furthermore, the existing portfolio of collaborative research project already covers many Threatened and Migratory marine species

4.4.3 Pormpuraaw

The Pormpuraaw Land and Sea Management Rangers (PLSM Rangers) are the local land and sea management group. There was a clear message that any research to be undertaken in the area should be by “invitation only”. All data is to be retained within Pormpuraaw Land & Sea Management databases, with data sharing arrangements confirmed in writing before research begins.

Threatened and Migratory marine species of particular interest to Pormpuraaw region TOs include marine turtles (particularly Olive Ridley, Hawksbill and Flatback), sawfish, dolphins (including Australian Snubfin) and shorebirds; Shovelnose rays were also discussed.

A key research interest for local TOs is getting a better understanding of local climate change impacts and their implications for Threatened and Migratory marine species and other native animals and habitats in the region, including whether locally observed changes (see below) and the occurrence of extreme weather events might inhibit or disrupt movement patterns of various Threatened and Migratory marine species, and/or have implications for marine turtle nesting rates and site selection.

Elders, PLSM Rangers and other Pormpuraaw TOs describe seeing substantive coastal changes over recent years. Locally have observed a lack of big wet seasons and substantive coastal landscape changes – in the absence of big wet season flows sediment loads aren’t getting flushed out into the Gulf’s current-driven waters as previously occurred. Sediment loads are increasing around river and creek mouths and there is increased mud-flat build up directly along beach fronts. It is suspected that the increased sediment loads are caused by cumulative upstream impacts, including grazing.

The main work being undertaken by PLSM Rangers relating to Threatened and Migratory marine species is research, monitoring and protection of Olive Ridley turtles, in partnership with WCTTAA. At the time of consultation WCTTAA funding was unclear beyond mid-2018. As described in the Desktop Review, WCTTAA work is focussed on predation control for turtle nests, and data collection on local population aggregations along the Western Cape York coastline. It is known that the largest Cape York nesting populations of Olive Ridley Turtles occur on beaches in the region, as well as smaller populations of Flatbacks and Hawksbills. The PLSM Rangers' turtle work pre-dates WCTTAA, and they have gathered a great body of local marine turtle data. A locally specific marine turtle management strategy endorsed by EHP is in place and being implemented by PLSM Rangers (subject to resources). The rangers also conduct shorebird counts and are interested in research examining intra- and inter-seasonal population fluctuations/changes.

4.4.4 Kowanyama

The Kowanyama Rangers (working through the Kowanyama Aboriginal Land & Natural Resource Management Office KALNRMO) undertake marine patrols as part of their natural and cultural resource management activities.

KALNRMO articulated clear aspirations to direct and control all future research that occurs around Kowanyama. It is considered essential to ensure a strong cultural perspective in all research work done. There is a desire to establish very strong research protocols, and agreements on use of information. KALNRMO should maintain copies of all data collected, and any information/data is shared with a research organisation should not be passed onto a third party unless permissions have been sought at the outset of any research. KALNRMO ultimately aims to apply for research funding directly, and then invite desired researchers into the community. Current practices see researchers funded to undertake projects on Kowanyama lands but KALNRMO, Rangers and TOs never seem to benefit financially from these projects or receive appropriate remuneration for the time and assistance they contribute. Shortcomings in research arrangements include not appropriately acknowledging local expertise, traditional ecological knowledge or other cultural intellectual property; and not including agreed remuneration funds for such local contributions in grant submissions.

Kowanyama's abundance of migratory shorebirds (and other birds) is seen as a strength and there is a vision to have the whole coastline declared a protected area for shorebirds, providing significant potential for high value nature and culture-based tourism. Locally directed, expert assisted research on shorebirds is a priority to support this vision. Marine turtles are also a concern, TOs have noticed changes to shorelines and turtle hatchings in recent times, with these changes often attributed to localised climate change impacts. Some recent research on potential climate change impacts around Kowanyama has been undertaken by Dr Jeff Shellberg (Griffith University). Sawfish are also a species of interest and significance, research has been done by Dr Barbara Wueringer of Sharks and Rays Australia.

4.4.5 Napranum

Land and sea management around Napranum is delivered by the Nanum Wungthim Land and Sea Rangers. We were unable to engage directly with the rangers during the project timeframe, however WCTTAA staff advised that the ranger group was heavily involved in WCTTAA led marine turtle work.

4.5 Conclusions

Findings from the consultation phase of this work reaffirmed those of the Desktop Review, that Indigenous sea country custodians and managers throughout the study area clearly have an interest in bolstering their knowledge about one or more Threatened and Migratory marine species, increasing their capacity to manage the sea country under their care. Equally important was the message that, in addition to efforts on elucidating focal and priority species (and where), the engagement process for planning and delivering collaborative research requires consideration (see 'Principles of appropriate engagement in future research' section of Desktop Review Appendix F).

As noted in the Desktop Review, whilst local knowledge systems/interests substantially overlap with formal science, for instance in identifying conservation targets, what these targets mean to traditional custodians may differ dramatically from the targets as objects of scientific research. Although the reasoning behind ascribing 'value' to a particular species may differ, both the Indigenous and western science communities share an overall goal of using informed management to ensure that these species persist in the North Australian Seascape.

Though there was interest expressed by all communities engaged, there are two critical factors that differ from community to community: 1) capacity (including number of rangers, training and experience, and availability of suitable vessels and other equipment); and, 2) suitability of the proposed project timeframe. In the Northern Territory, the question of timeframe is particularly significant as it relates to the matter of Blue Mud Bay negotiations (see Introduction and Background section of this chapter).

Of the wide diversity of Threatened and Migratory marine species in the study region, marine turtles were the most commonly discussed group. In Western Cape York, there is significant research effort already underway on turtles, primarily supported by Western Cape Turtle Threat Abatement Alliance (WCTTAA). Late in 2017, WCTTAA advised that funding for the organisation beyond mid 2018 was unclear. If funding is not forthcoming this could leave a gap in the research commitments of various groups working on turtles (assuming they are not able to continue the work without support). Any collaborative research on Threatened and Migratory marine species in the Western Cape York should (among other activities) provide an opportunity to continue, and to potentially expand, the existing scope of marine turtle work (WCTTAA's main focus is on improving hatchling survivorship), since this is clearly a priority for those communities. In the Northern Territory, research on marine turtles would also be welcomed as groups there recognised a number of pressures acting on these species.

As with marine turtles, whilst there is a vast body of traditional ecological knowledge about Dugong across Northern Australia, it is a species that almost all communities expressed some concern about. People have questions about the sustainability and health of local populations. Western science recognises that there are a variety of threatening processes impacting on the species, even in the relatively intact and undeveloped seascape of Northern Australia. With the rise of modern-day challenges, that existing body of knowledge, built over countless generations, now needs to be supplemented with information about how contemporary threats such as commercial fisheries bycatch, reduced water quality, boat strike and degradation of seagrass beds is impacting on this culturally significant species.

Sawfish were also a group of considerable interest. Traditional Owners from the Tiwi Islands were eager to see sampling for sawfish as part of NESP Project A1, unfortunately we were unable to schedule fieldwork before that project concluded. Sawfish research is already being carried out in two communities (Kowanyama and Mapoon) on Western Cape York with Sharks and Rays Australia. Continuation of the Largetooth Sawfish work with Malak Malak, Numbulwar, and Yugul Mangi Rangers is desired by communities, with a demonstrated capacity to partner on sawfish research, and produce meaningful outputs and outcomes.

A number of communities have been investing in efforts to understand and manage shorebirds and/or seabirds. In the southern Gulf of Carpentaria significant shorebird sites have been protected under the East Asian-Australasian Flyway partnership. Ranger groups there, and others in Western Cape York are undertaking regular shorebird monitoring, and TOs are interested in further research to understand species distributions and population dynamics. There are concerns about the sustainability of customary seabird harvesting, as these species are subjected to contemporary pressures such as predation by feral animals.

In the case of the two South East Arnhem Land (SEAL) IPA ranger groups, continuation of Largetooth Sawfish work could form one part of a broader multi-taxa collaborative research effort in the region. TOs of the SEAL IPA expressed an interest in a diverse range of other Threatened and Migratory marine species including shorebirds, marine mammals, turtles, and other sharks and rays. The groups have the capacity to undertake sea country work, and clearly articulated their desire to increase sea country management, aiming to extend their IPA into sea country in the future. Efforts to expand their sea country knowledge through appropriate collaborative sea country research would certainly be beneficial in supporting these aspirations.

Working in the western Gulf of Carpentaria region would also take advantage of existing positive relationships, including the relationship between the SEAL ranger groups and NESP researchers; and potentially the good working relationship between the SEAL rangers and their neighbours from adjoining IPAs to the north, the Yirrkala and Dhimurru Rangers. Even if the timing in the first stages of the field work were not suitable for Dhimurru, sampling methods and tools developed on sea country adjacent to the SEAL IPA would be largely transferable immediately to the north. Looking further ahead, provided appropriate data sharing agreements are developed, there may be opportunities for regional analysis of datasets derived from sampling during and beyond the life of this project.

Across the Top End of the Northern Territory there is currently a focus on commercial fishing licensing, as described previously for Maningrida and the Tiwi Islands. Should negotiations reach a satisfactory conclusion in the near future, there would definitely be value in renewing discussions with Djelk and Tiwi Land Council, as there is both interest in Threatened and Migratory marine species and capacity on-ground, however, it is simply not the number one priority at this time. In the greater Darwin area, where many of the pressures acting upon Threatened and Migratory marine species are most evident there is certainly keen interest in Threatened and Migratory marine species, however there are also many other pressing concerns for Traditional Owners of a highly urbanised environment. There are also a number of research projects on Threatened and Migratory marine species underway. Any new marine research in the Darwin region must involve the Larrakia Rangers, and at a minimum attempt to engage with Kenbi Rangers. Between the Western Australian border and the Darwin region there are few coastal communities, the largest being Wadeye (population ~2,300). There are two small ranger groups managing sea country along that stretch of coastline. The Thamurrurr Rangers, who deliver land management of the Marri-Jabin (Thamurrurr)- Stage 1 IPA, and the Bulgul Land and Sea Rangers. We were unable to engage with these groups during the project, but previous experience suggests limited capacity. Conversely, a strong working relationship with the Malak Malak Rangers of the Daly River region would allow continuation of sawfish research.

During this scoping project, there were a number of instances where we were either unable to engage, or were not able to progress beyond preliminary discussions with representatives from a community/Ranger group during the limited project timeframe. In several cases we recommend further attempts to engage or progress discussions in the short term, in particular Wellesley Island, Anindilyakwa, and Yirralka. More broadly, it is worth remembering that many factors may change between the consultation period for this project and the end of 2020. Staffing levels could increase, or indeed decrease. For example, assuming Dhimurru is successful in filling some key positions, their renewed capacity would allow them to engage in collaborative research. Additionally, existing projects may conclude, freeing up time in ranger work plans.

This scoping study revealed current interest and existing capacity relating specifically to marine turtles, dugong, shorebirds and seabirds, and sawfishes, and largely within the Western Gulf of Carpentaria region (through the Numbulwar Numburindi Amalahgayag Injung, Yugul Mangi Rangers, and quite likely Dhimurru), and the Daly River region of the western Top End (through the Malak Malak Rangers). The limited project timeframe, and other priorities and commitments of various communities and their ranger groups precluded understanding marine species priorities across the entire North Marine Bioregion, but the results presented here provide a sound platform to continue engagement in appropriate geographical locations in 2018, and beyond.

5. COASTAL HABITATS

KEY POINTS

- Rather than a scoping study, the Coastal Habitats components of this project was a proof of concept, with applied examples of possible focal areas for future surveys.
- Seven case study locations (Keep, Daly, Roper, McArthur, Flinders, and Gilbert River estuaries, and Darwin Harbour) were used to test the utility of the Australian Landsat data archive, a 30-year continuous record, in the Digital Earth Australia analysis platform for characterising and monitoring the condition and change in extent of coastal habitats.
- A suite of analyses was undertaken including: assessing the extent of different coastal habitats, detecting coastal change including change in mangrove communities, and the distribution of intertidal areas.
- The work was successful in: (a) generating baseline information for the case study areas, including capturing the dynamic character of several sites; and, (b) developing valuable monitoring tools for future use.
- Analysing the long and detailed Landsat time series provides unique insights into the form, timing and rate of change in estuarine landforms and habitats, and highlights the potential utility of the approach for predictive modelling of Threatened and Migratory marine species distributions and populations.
- Ground validation would be required to enable robust habitat classifications.

5.1 Introduction

This chapter provides a preliminary assessment of the utility of a satellite remote sensing approach for the identification and characterisation of coastal habitats that are critical for many Threatened and Migratory marine species in Northern Australia.

This project utilised the Australian Landsat archive in the Digital Earth Australia (DEA) analysis platform for satellite imagery and other Earth observations. The DEA incorporates advanced approaches to organising, analysing, and storing vast quantities of satellite data, enabling rapid, robust analysis across broad spatial and temporal dimensions (Lewis *et al.* 2016, 2017). The DEA Landsat archive comprises imagery for the entire continent with approximately fortnightly frequency of observation at 25 m resolution, continuously from 1987 to the present.

The potential of the DEA for mapping intertidal areas and mangrove extent has been tested, and changes over time and in extent, in seven estuaries identified: Darwin Harbour and the Keep, Daly, Roper, Macarthur, Flinders and Gilbert River estuaries. The estuaries were selected by the A12 Project team because they provide important habitat areas for key species of interest.

The focus of this scoping work, across the seven study sites, was to:

- Build understanding of the effects of tidal dynamics on the distribution of intertidal areas across this region of large and complex tides;
- Use tidal modelling and Landsat imagery to map the extent of intertidal habitat and detect coastal change; and,
- Use the Landsat archive and a normalised difference vegetation index to identify change over time in mangrove communities.

Features of importance to shorebird populations are a focus, and include the intertidal mud flats which are pertinent for feeding, and high tide areas which do not inundate with water for roosting. Such areas are variable over the lunar cycle but usually include sand spits, headlands and beaches as well as salt flats that are inundated on spring high tides.

5.2 Methods

New approaches to remotely mapping the extent of intertidal areas and important coastal habitats were tested. Intertidal areas were identified using the DEA archive based on modelled tide height (Egbert and Erofeeva 2002, 2010) that occurred at the time of image acquisition (Sagar *et al.* 2017). This analysis utilises an advanced image classification scheme that enables viewing of coastal regions at selected tide stages. In this approach, composite images of coastal regions over varying stages of the tide and varying time periods are generated as a way of showing coastal change. Furthermore, this tidally attributed archive of coastal imagery enables mapping of intertidal extents, which effectively characterises the topography of intertidal zones.

Changes in vegetation cover can also be effectively mapped using the DEA. This project looked specifically at the effectiveness of mapping changes in mangrove extent over the past 30 years in the nominated priority estuaries.

These image-based characterisations of the study sites aim to reveal both the topography and cover types of the intertidal zone, in addition to detecting both event based and more gradual change in landscapes and habitats. An important aim is to develop products that provide a baseline understanding of the extent and dynamics of critical habitats on the northern coast, and that can be used to better understand how both the habitats and key inhabiting species respond to change.

5.3 Tidal Composite Imagery

For the purposes of tidal modelling, the Australian coastline was divided into 306 tidally self-similar polygons, from which 'regional' tide dates and heights were modelled and extracted. For a given date of Landsat image acquisition within a given polygon, the corresponding modelled tide height was attributed to the image (Figure 31). This allows the image archive to be sorted by tide height. Clear composite images of the northern coastline can then be generated based on tide stage/height and date range. Such an approach is invaluable for characterising coastal habitats, particularly in Northern Australia. This is because seasonal effects contaminate many of the individually captured satellite images with cloud cover. Our synthetic compositing approach creates an average reflectance value from the nominated dataset for every cloud-free pixel. The images produced in this work are composited from these average pixel values. As a result, the image composites assume coastal stability during the nominated time-range even though this will not always be the case.

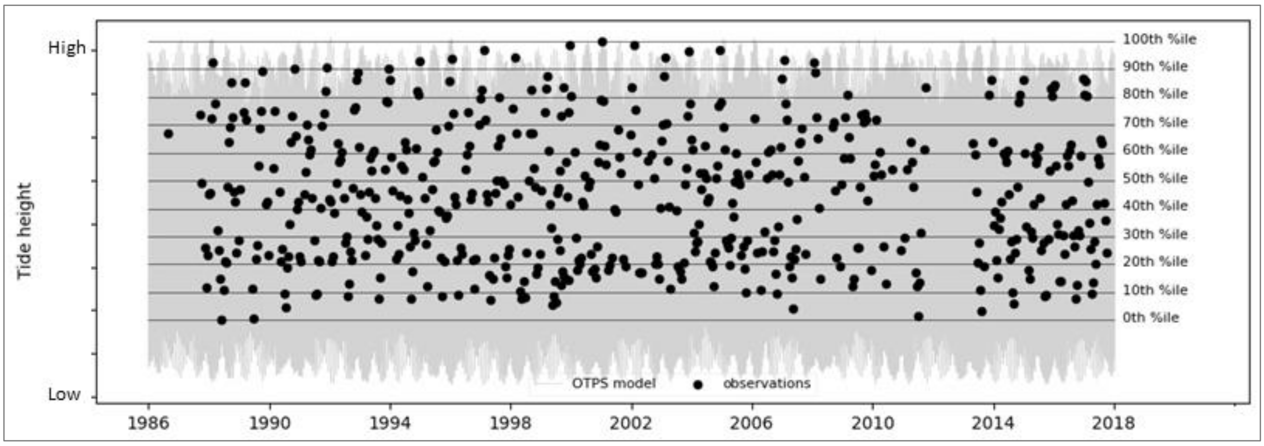

Figure 31. For any given coastal or marine region, tidal modelling (gray line – OTPS model) can be generated. All Landsat image acquisitions within that region (overlaid symbols – Observations) are attributed to the corresponding modelled tide height (meters above sea level). The dataset can then be sliced by tide range (represented as percentiles of the observed tidal range on the secondary y-axis) and/or date to generate a synthetic geomedian (Roberts *et al.* 2017) composite image of the nominated region.

5.3.1 High and Low Tide Composites

Composite images of high (HOT) and low (LOT) tide, in this work, represents the top and bottom 20% of tidal observations (from tide-tagged satellite imagery) respectively. Typically, the images are composited from Landsat observations acquired between 2000 and 2017. The only exceptions to this date range are for the low tide composites from the Daly and Keep Rivers where the data quality and resolution were sufficient to reduce the timeline to observations made between 2005 and 2017.

All high and low tide composites are shown as true colour images. That is, the red, blue and green spectral bands, measured via Landsat, are combined to produce an image that is representative of how the human eye naturally observes light.

5.3.2 Coastal Change Composites

The dynamic nature of intertidal zones makes them difficult to image or map consistently in any assessment of coastal change. In this work, the mid-tidal range (40^{th} to 60^{th} percentiles) of the tide-tagged subset of observations was used, being the most data rich part of the observed tidal range and representative of the region for the greatest part of the tidal cycle.

To assess how change affects the appearance of coastal regions, image composites were generated for short time periods of the total DEA archive. In this work, 6-year composites were produced, spanning 5 discrete epochs between 1988 and the present.

The coastal change composites are presented as false colour images. These images are generated using Landsat's short- and near-wave infrared and green bands. This band combination is very effective at distinguishing vegetation (which appears as bright green) from sediment laden water and saturated soil (both appear as bright blue). The appearance or absence of either water or vegetation is often the dominant feature of the change composite images and so false colour has been used here to highlight these changes. In the case of the Keep River, the data quality of the false colour composites was inferior to the true colour composites which were used instead.

5.4 Intertidal Extents Model

The Intertidal Extents Model (ITEM) is a national dataset of the exposed intertidal zone; the land between the observed highest and lowest tide (Sagar *et al.* 2017). ITEM provides the extent and topography of the intertidal zone of Australia's coastline (excluding off-shore Territories) and was generated using the same tidal modelling methodology that underpins the composite generation detailed above. ITEM uses a water identification algorithm to identify the tidal water extent in coastal imagery for every coastal image in the DEA archive. For every 10% increase in tide height, the average water extent is incorporated into the model. The result is an intertidal topographic model with 10 stepwise increments representing average tide height (or equivalently, average land exposure) at every 10% increase in the tidal range.

ITEM also has an associated confidence layer. This layer represents the average overall standard deviation (std) from each layer in ITEM. Regions of low confidence (high std) can represent areas where the original tidal modelling or ITEM methodology may not perform optimally. Low confidence may represent issues with the generation of a single layer of ITEM, which is propagating into the average std calculation for example. However, some areas show low confidence where the modelling and methodology is known to work well. In these places, coastal change is often reflected and is usually seen around river deltas and sandbars for example. The high std, generated from imagery collected since 1986, can be a useful indicator for areas of coastal change.

5.5 Normalised Difference Vegetation Index (NDVI) of Mangroves

5.5.1 Normalised Difference Vegetation Index

The Normalised Difference Vegetation Index (NDVI) is an algorithm that exploits the absorbance and reflectance characteristics of various parts of the light spectrum, as detected by Landsat. The returned values range between -1 and +1 and offer an interpretation of the analysed scene. Negative values usually correspond to non-vegetative targets such as water, values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow, while low, positive values usually represent shrub and grassland (~0.2 to 0.4), and high values are indicative of healthy crops or dense vegetation such as temperate and tropical rainforests (values approaching 1).

NDVI is calculated as:

(NIR – RED) / (NIR + RED)

where RED and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively.

5.5.2 Hovmoller Plots

Hovmoller plots are used in this report to exploit the full depth of the DEA archive. These plots show landscape and land cover change over time. For a given spatial transect (x-axis), every DEA observation of the pixels along that transect is shown (y-axis). In this report, the NDVI of each pixel is shown, depicting the interpreted location of water, sand and vegetation over time.

5.5.3 Mangrove Dieback Event Detection

The 2015/2016 mangrove dieback event in Northern Australia is highlighted in this work as a demonstration of the DEA's event detection capabilities.

The Global Mangrove Watch (Thomas *et al.* 2015) is a global mangrove baseline extent map, based on mangrove extents in 2010, as observed using radar and optical satellite data. For the current work, a prototype DEA mangrove extent product calculated NDVI within the Global Mangrove Watch extent mask for each of the case study sites. A well-documented mangrove dieback event occurred over 2015/2016 in Australia (Duke *et al.* 2017) so for this work, NDVI was generated within the mangrove mask for each of 2014 and 2016. The results present the NDVI difference ($NDVI_{2016}$ – $NDVI_{2014}$) within the masked mangrove area and highlights areas of dieback or increased growth within the mangrove canopy area, as detected by Landsat.

5.6 Estuary Characterisation

The seven case study estuaries are well distributed across the north marine bioregion (North MBR) and have one or more of the following features:

- Known occurrence of threatened and migratory elsmobranch, shorebird or inshore dolphin species;
- Potential or realised development pressures;
- Indigenous Sea Ranger group capacity; and,
- Links to other NESP Hubs working in Northern Australia (Threatened Species Recovery Hub, Tropical Water Quality Hub and Northern Australia Environmental Resources Hub).

Northern Australia experiences some of the largest tidal ranges in Australia and this is reflected in the morphology and functioning of the estuaries examined in this study. The Keep, Daly and Roper Rivers are all tidally dominated estuaries. Similarly, Darwin Harbour is classed as a tide dominated system. This is contrasted by estuaries on the eastern side of the Gulf of Carpentaria where the tidal range is much lower. The McArthur, Gilbert and Flinders Rivers are all river dominated systems with tide dominated deltas. All six river systems are considered to be in near-pristine condition, while until recently Darwin Harbour was largely unmodified, except primarily for the urban Darwin area. More recently, the area around the Port of Darwin has been a focus of significant development activity, including LNG processing facilities and other infrastructure projects.

Australia's north coast has a tropical monsoonal climate with marked wet and dry seasons. The discharge of coastal rivers is limited to the wet season, during which tropical cyclones regularly occur. The combination of strong tidal currents and episodic river discharge is largely responsible for the distinctive estuarine morphologies of Northern Australia, modified by local waves and cyclone-induced erosion. Australia's northern estuaries and low-gradient coast are also characterised by extensive mangrove communities that line the coast and the margin of channels, typically sitting landward of extensive mud flats and seaward of a supratidal zone (e.g. salt flats; low vegetation). Mangroves are also susceptible to damage by the passage of intense cyclones and may take several years to recover (e.g. Brooke *et al.* 2017).

A number of these sites has been identified as being critical waterbird and shorebird habitat (Olsen and Weston 2004). The McArthur, Roper and Daly river wetlands have been identified as qualifying for listing under the Ramsar Convention (designating them wetlands of international significance) and/or as sites under the East Asian-Australasian Shorebird Site Network (Olsen and Weston 2004). Darwin Harbour, as well as the McArthur, Roper and Daly Rivers have also been identified as wetlands of national importance (Environment Australia 2001). The Daly River contains a number of habitats that are unique to the Northern Territory, including habitat for most of the Territory's freshwater turtle species as well as two species of threatened elasmobranchs, the Freshwater Whipray and the Largetooth Sawfish (Murray *et al.* 2006 and references therein).

The following sections provide an overview of the potential utility of the Landsat archive and analysis tools in the DEA for mapping and monitoring key habitat and important areas for

Threatened and Migratory marine species. For each of the case-study estuaries the Landsat archive is employed to describe:

- The extent and stability of the intertidal zone;
- The dynamics of coastal landforms – the rate and extent of geomorphic change; and,
- The distribution and dynamics of mangrove extent, including evidence of recent dieback events.

5.7 Regional Context

Composite imagery of the high and low tides at the mouth of each estuary show persistent coastal features that are visible above the water line at each extreme of the tidal range. Low tide composites reveal the intertidal zone, enabling differentiation between substrate types and show the location of persistent islands and sandbars in the channel and offshore. High tide composites show the typical extent of the high tide water mark and the habitats that interact with the high tide.

Tidal modelling and satellite imagery are combined (ITEM) to show the tidal extents for these same estuary mouths, indicating the dynamism of the tide at each location. This effectively provides a bathymetric map of the intertidal zone. The confidence maps associated with ITEM can be useful for identifying locations of coastal change. Thirty years of input imagery is used in the tidal modelling and coastal change that is represented in the confidence layer will have occurred at some time during that same period.

5.7.1 Gilbert River

The low (Figure 32) and high (Figure 33) tide image composites for the southern end of the Gilbert estuary show that the coastal topography at this site is considerably different between the two tide stages due to the extensive beached areas and sandbar. Figure 32 indicates the vegetated areas (green).

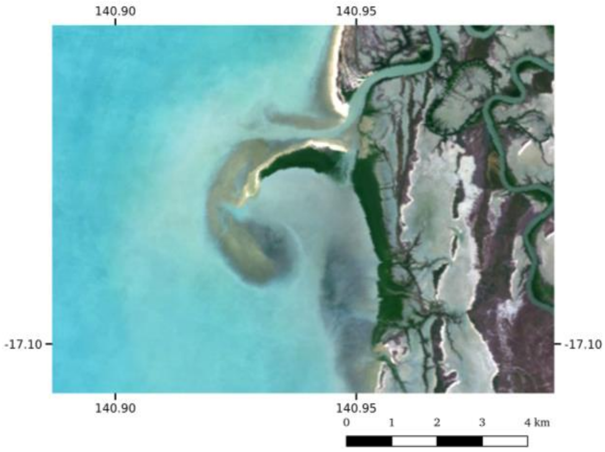

Figure 32. Lowest observed tides (LOT) composite image for the southern end of the Gilbert estuary.

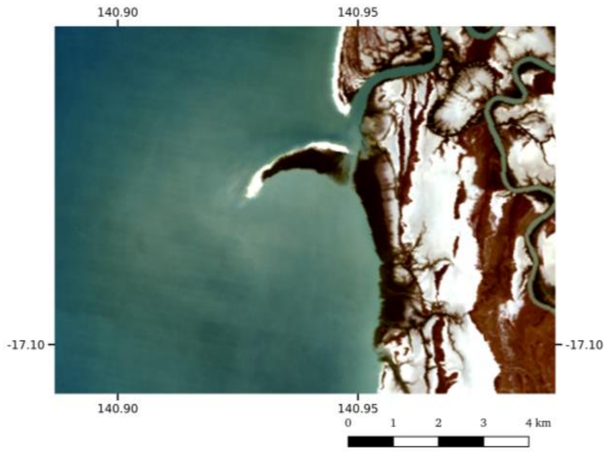

Figure 33. Highest observed tides (HOT) composite image for the southern end of the Gilbert estuary.

Intertidal extent modelling shows the broad intertidal zone that exists around the sandbar at the southern end of the Gilbert River estuary (Figure 34). The confidence layer associated with the tidal extent modelling shows that uncertainty is high around the sandbar, possibly indicating a region of change (Figure 35).

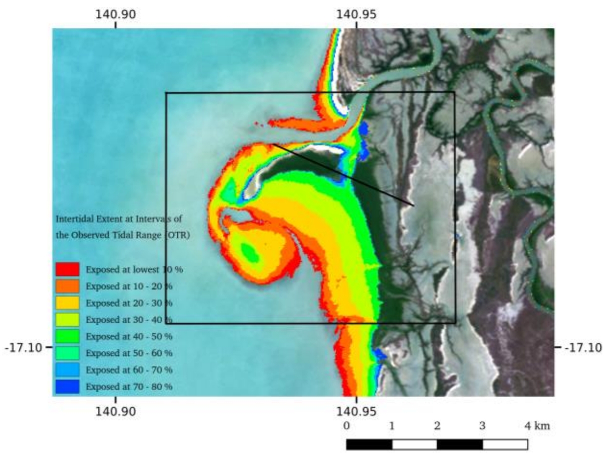

Figure 34. Tidal extent, southern mouth of the Gilbert River estuary. The colour coding represents exposed land at varying percentage ranges of the regional tidal scheme: red - exposed at the lowest 10% of tides, dark blue - exposed when tides are at 70 to 80% of their maximum range.

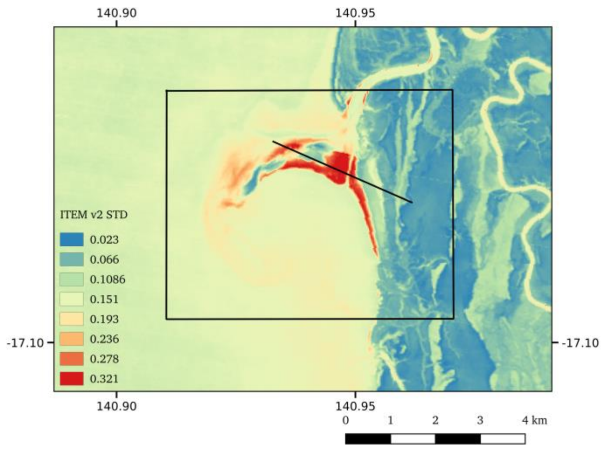

Figure 35. ITEM confidence layer at the mouth of the Gilbert River estuary. The transect represented in Figure 66 is shown in black as well as the coastal change detection (Figure 70) bounding box.

5.7.2 Flinders River (Norman River)

The low (Figure 36) and high (Figure 37) tide image composites for the Flinders River estuary show that bottom currents have eroded channels into the extensive low-tide flats.

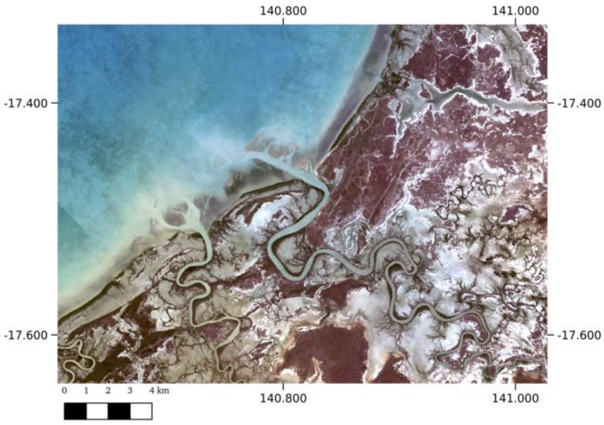

Figure 36. LOT composite image of the Flinders River estuary.

Figure 37. HOT composite image of the Flinders River estuary.

Intertidal extent modelling shows that the tidal influence is fairly uniform across the Flinders River estuary coastline (Figure 38). The confidence layer associated with the tidal extent modelling shows that minimal long-term change is evident in this region (Figure 39).

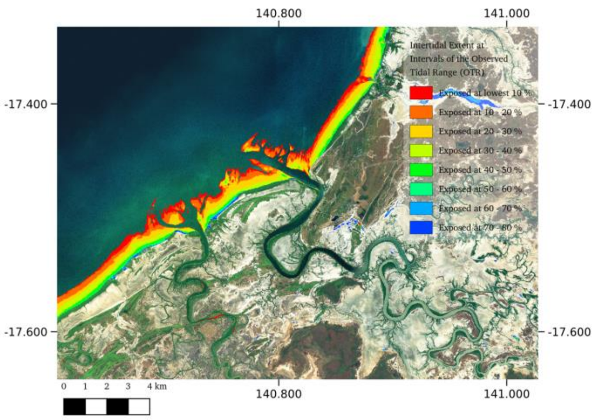

Figure 38. Tidal extent at the mouth of the Flinders River. The colour coding represents exposed land at varying percentage ranges of the regional tidal scheme: red being land exposed at the lowest 10% of tide heights, dark blue being land exposed when tide heights are at 70 to 80% of their maximum range.

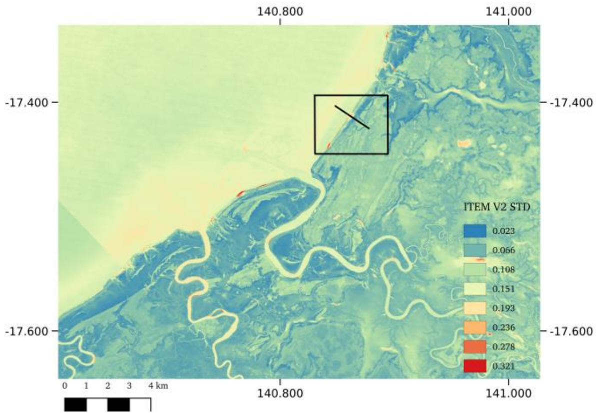

Figure 39. ITEM confidence layer for the Flinders River estuary. The transect represented in Figure 66 is shown in black. The bounding box highlights a region of significant coastal mangrove habitat dieback over the 2015/2016 Austral summer.

5.7.3 Roper River

The low (Figure 40) and high (Figure 41) tide image composites for the Roper River estuary show extensive tidal flats in and around the delta.

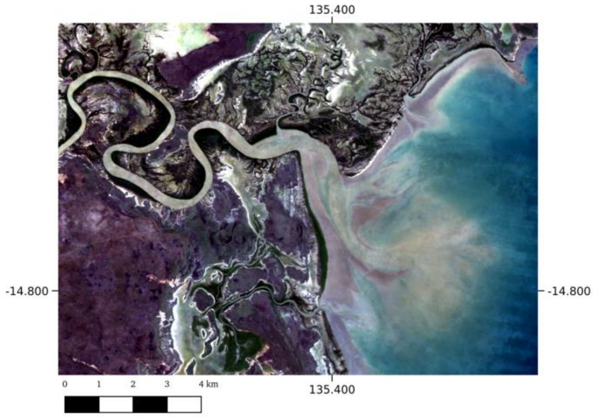

Figure 40. LOT composite image of the Roper River estuary.

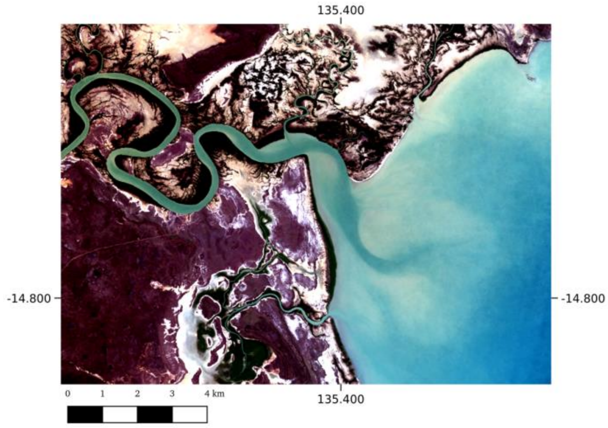

Figure 41. HOT composite image of the Roper River estuary.

Intertidal extent modelling shows the broad tidal zone at the mouth of the Roper River (Figure 42). Notably, the large sand bank in the mouth of the river (Figure 40) only appears in the model when tides are at their lowest 0 to 20% in height. The confidence layer (Figure 43) shows this to be a region with higher uncertainty around the river mouth and adjacent coastlines, likely a reflection of the dynamic character of the mouth of this large river.

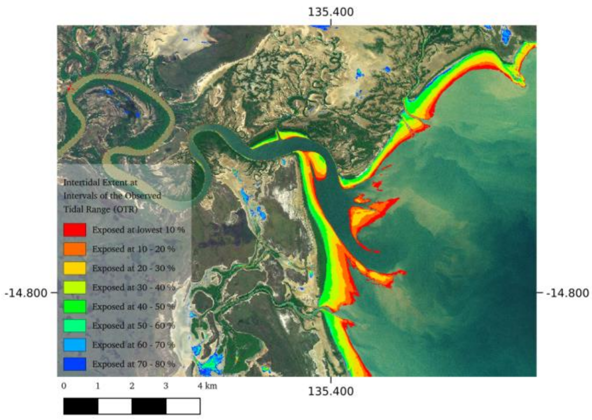

Figure 42. Tidal extent at the mouth of the Roper River. The colour coding represents exposed land at varying percentage ranges of the regional tidal scheme: red being land exposed at the lowest 10% of tide heights, dark blue being land exposed when tide heights are at 70 to 80% of their maximum range.

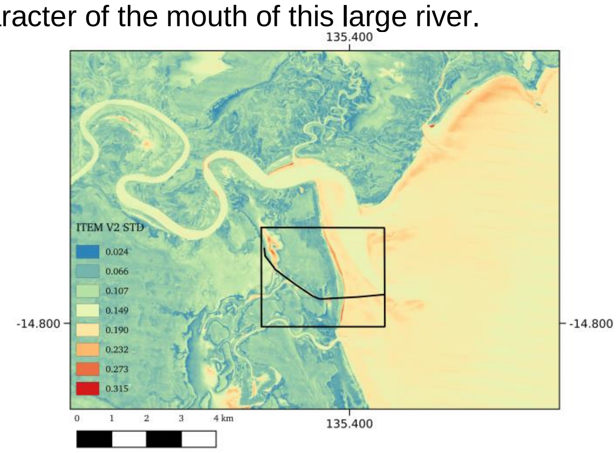

Figure 43. ITEM confidence layer for the Roper River estuary. The change detection highlighted in Figure 68 is represented by the black box. The transect represented in Figure 70 is shown in black.

5.7.4 McArthur River

The low (Figure 44) and high (Figure 45) tide image composites for the McArthur River estuary show that at low tide, there are extensive areas of exposed sand and mud banks whose topography is heavily influenced by the river channel flow.

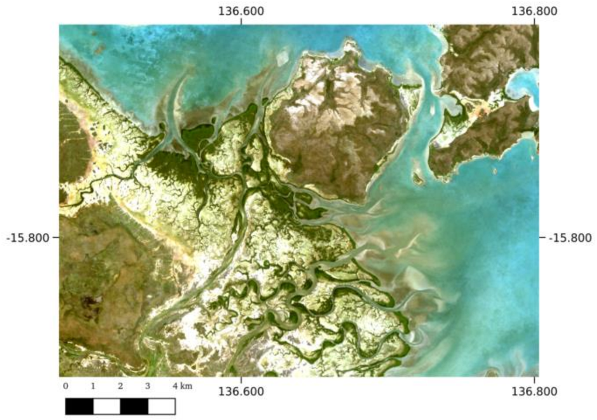

Figure 44. LOT composite image of the McArthur River estuary.

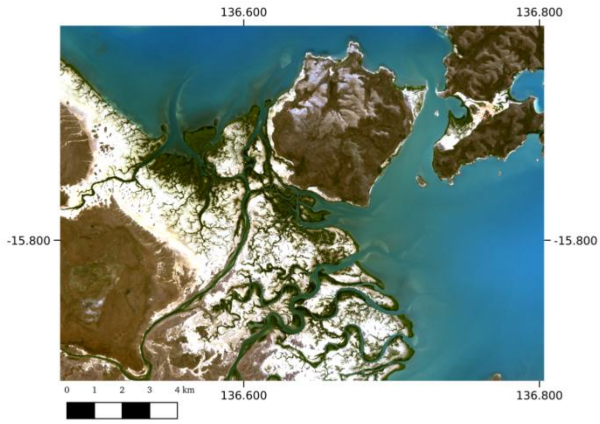

Figure 45. HOT composite image of the McArthur River estuary.

Intertidal extent modelling (Figure 46) shows that the McArthur River estuary is a dynamic region with sand bank morphology that is highly influenced by the estuary. Despite this, the ITEM confidence layer indicates this to be an area with generally long-term stability (Figure 47). The area within the bounding box shows some of the highest variability in the region.

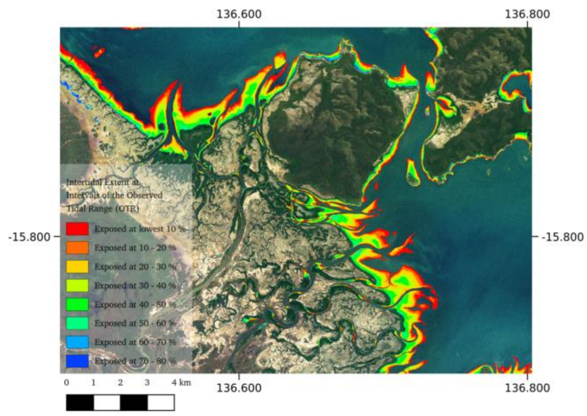

Figure 46. Tidal extent at the mouth of the McArthur River. The colour coding represents exposed land at varying percentage ranges of the regional tidal scheme: red being land exposed at the lowest 10% of tide heights, dark blue being land exposed when tide heights are at 70 to 80% of their maximum range.

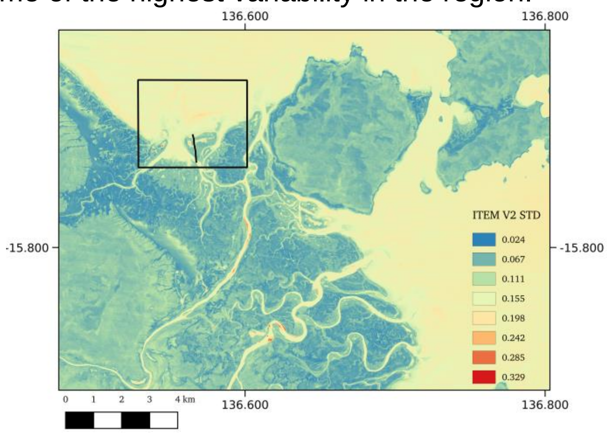

Figure 47. ITEM confidence layer for the McArthur River. The change detection highlighted in Figure 62 is represented by the black box. The transect represented in Figure 71 is shown in black.

5.7.5 Darwin Harbour

The low (Figure 48) and high (Figure 49) tide image composites of Darwin Harbour show wide areas of sandbank and beach that are exposed at low tide.

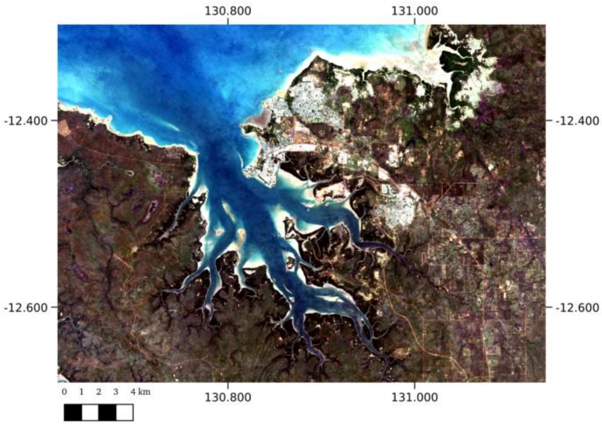

Figure 48. LOT composite image of Darwin Harbour.

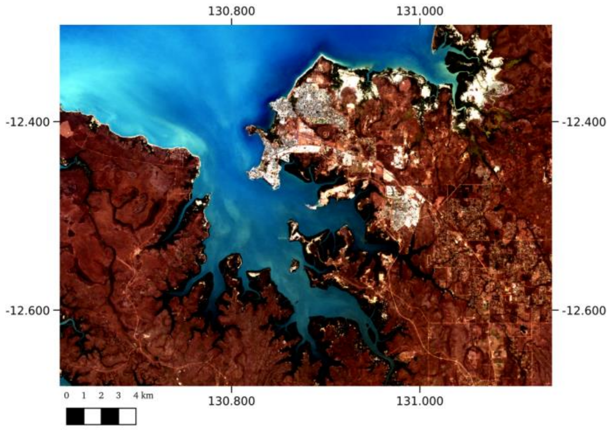

Figure 49. HOT composite image of Darwin Harbour.

Intertidal extent modelling (Figure 50) closely mirrors the exposed areas of sandbank and beach in the Darwin Harbour LOT (Figure 47). The confidence layer (Figure 51) shows localised areas of variability, including changes related to the port development in the eastern harbour, but general long-term stability in the region.

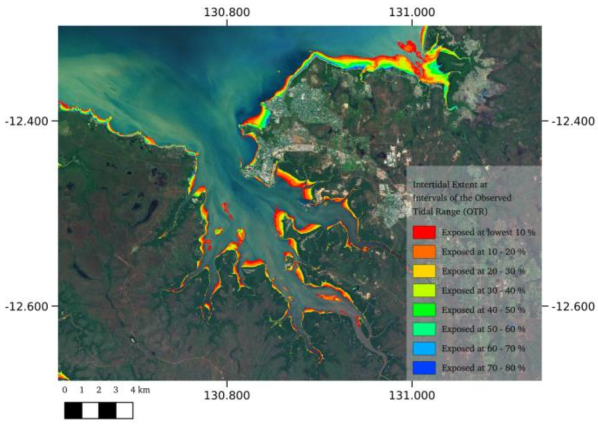

Figure 50. Tidal extent in and around Darwin Harbour. The colour coding represents exposed land at varying percentage ranges of the regional tidal scheme: red being land exposed at the lowest 10% of tide heights, dark blue being land exposed when tide heights are at 70 to 80% of their maximum range.

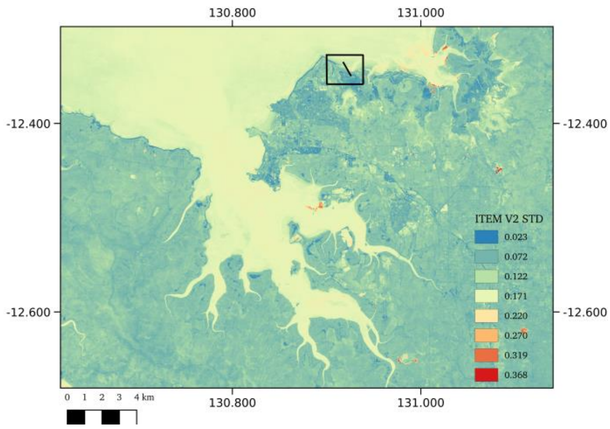

Figure 51. ITEM confidence layer for Darwin Harbour. Analyses for the regions in black are not shown.

5.7.6 Daly River

The low (Figure 52) and high (Figure 53) tide image composites for the Roper River estuary indicate that large areas of sandbank and beach are exposed at low tide. However, the reflectance of highly turbid waters may be interfering with the sand/mud signal at this site. Consequently, the low tide composite may be an average of both low tide areas and highly turbid water.

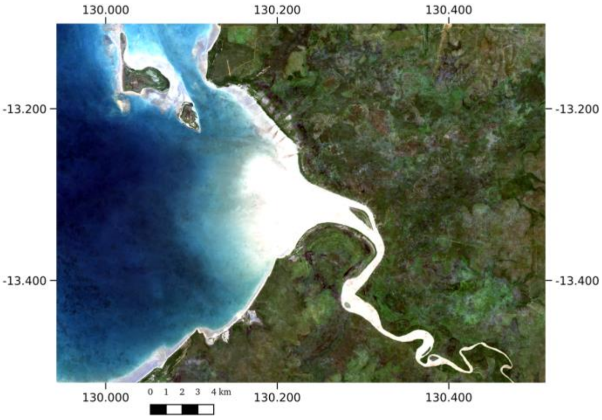

Figure 52. LOT composite image of the Daly River estuary.

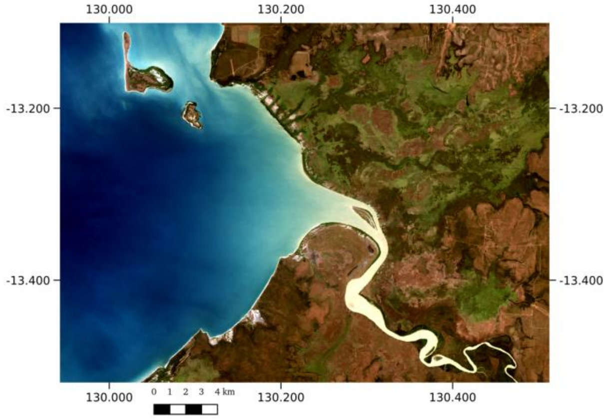

Figure 53. HOT composite image of the Daly River estuary.

Intertidal extent modelling (Figure 54) shows that the intertidal areas either side of the Daly River mouth are fairly uniformly distributed. Like the composites, ITEM at this site is possibly biased by high levels of water turbidity mobilised in the river mouth. The confidence layer (Figure 55) likewise indicates lower confidence in the depiction of the intertidal area in the river mouth.

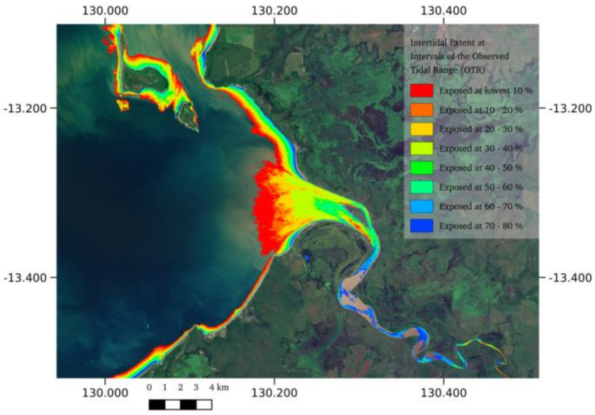

Figure 54. Tidal extent at the mouth of the Daly River. The colour coding represents exposed land at varying percentage ranges of the regional tidal scheme: red being land exposed at the lowest 10% of tide heights, dark blue being land exposed when tide heights are at 70 to 80% of their maximum range.

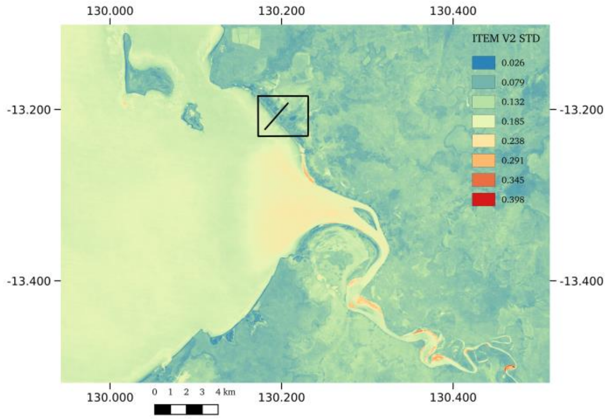

Figure 55. ITEM confidence layer for the Daly River estuary. Analyses for the region in black are not shown.

5.7.7 Keep River

The low (Figure 56) and high (Figure 57) tide image composites for the Keep River estuary show that large areas of sand/mud bank are exposed inside the estuarine channel at low tide.

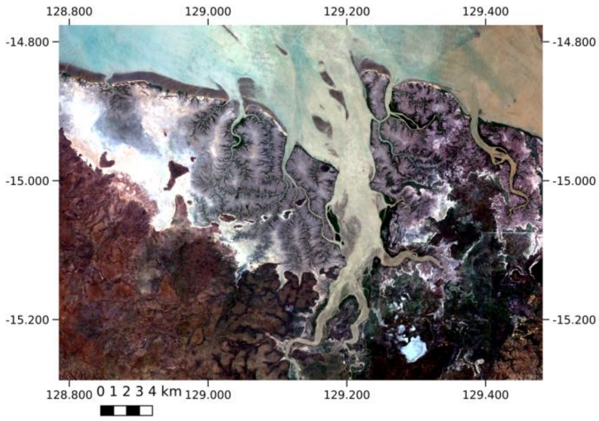

Figure 56. LOT composite image of the Keep River estuary.

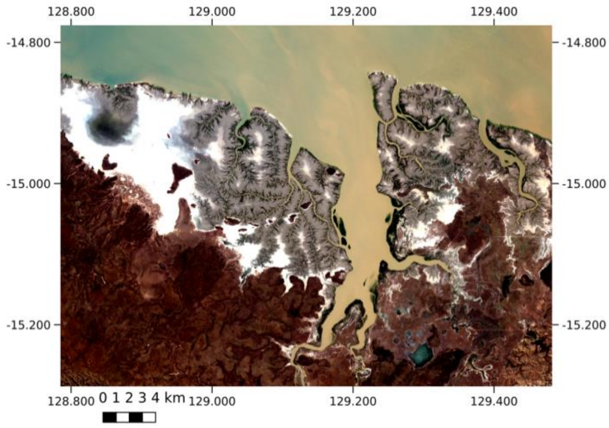

Figure 57. HOT composite image of the Keep River estuary.

Intertidal extent modelling (Figure 58) shows extensive tidal areas in the Keep River mouth and along the open coastline. Within the outer estuary, the modelling is somewhat 'patchy' and ITEM at this site may be biased by high levels of turbidity (Figure 59). Down-river are regions where high uncertainty is possibly related to long-term geomorphic variability (Figure 59).

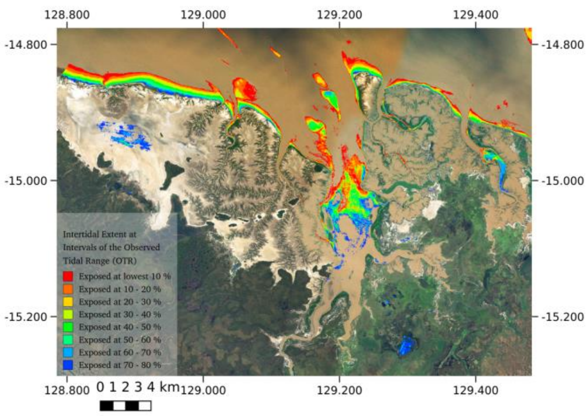

Figure 58. Tidal extent at the mouth of the Keep River. The colour coding represents exposed land at varying percentage ranges of the regional tidal scheme: red being land exposed at the lowest 10% of tide heights, dark blue being land exposed when tide heights are at 70 to 80% of their maximum range.

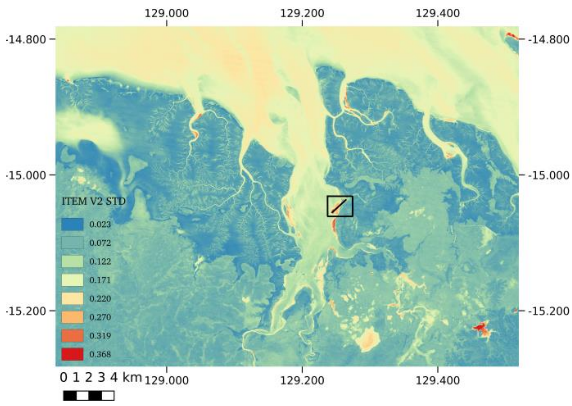

Figure 59. ITEM confidence layer for the Keep River estuary. The change detection highlighted in Figure 63 is represented by the black box. The transect represented in Figure 63 is shown in black.

5.8 Geomorphological Change

The same method used to generate the high and low tide image composites can be used to profile coastal change by altering the tidal and date ranges to the composite input datasets. In these dynamic, tidal environments, real change is visible by creating a time series of composite images where the effects of tide height are removed.

The ITEM confidence layers in Section 5.7 clearly showed regions of coastal change were evident in the Gilbert, Roper and Keep Rivers. The McArthur River also showed areas with slightly elevated standard deviation values. Geomorphological change has been investigated at these sites by creating 6-year composites using data from the mid-tide range (40^{th} to 60^{th} percentiles of observed tide heights). Unless noted otherwise, false colour images are displayed which highlight vegetated area (green), sand/mud sediment (beige) and water/saturated sediment (blue).

5.8.1 Gilbert River

To test whether the modelled tidal uncertainty seen in Figure 35 was due to geomorphological change, composite images of the mid-tide range were compiled for every 6 years from 1988 to the present. The Gilbert River sandspit was an area of dynamic change during this time (Figure 60). The overall shape of the sandspit elongated and migrated towards the coastline, progressively closing the channel that existed between the sand bar and coastline. Simultaneously, the vegetated area on the sandspit expanded towards the coastline, consistent with the trend seen in Figure 51.

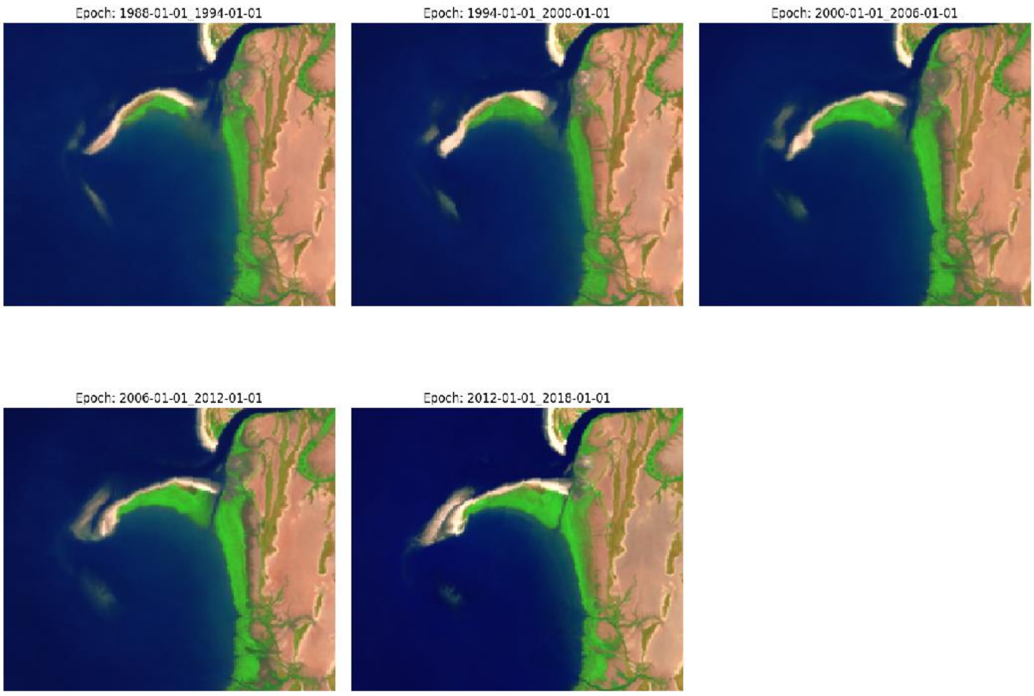

Figure 60. Geomorphic change at the Gilbert River estuary. Composite images of the mid-tide range for the area identified by the bounding box in Figure 35. The figure in the top left represents data composited between Jan 1988 and Jan 1994, increasing in 6-year increments from left to right, top to bottom. The bottom right figure represents data between Jan 2012 and the present.

5.8.2 Roper River

The 6-yearly composite images in Figure 61 show significant expansion of the vegetated communities in both directions along the coastline between 1988 and the present. The inland area in the northwest corner of these composite images changes from water dominated between 1988 and 2000 to mixed water and vegetation dominated between 2000 and the present.

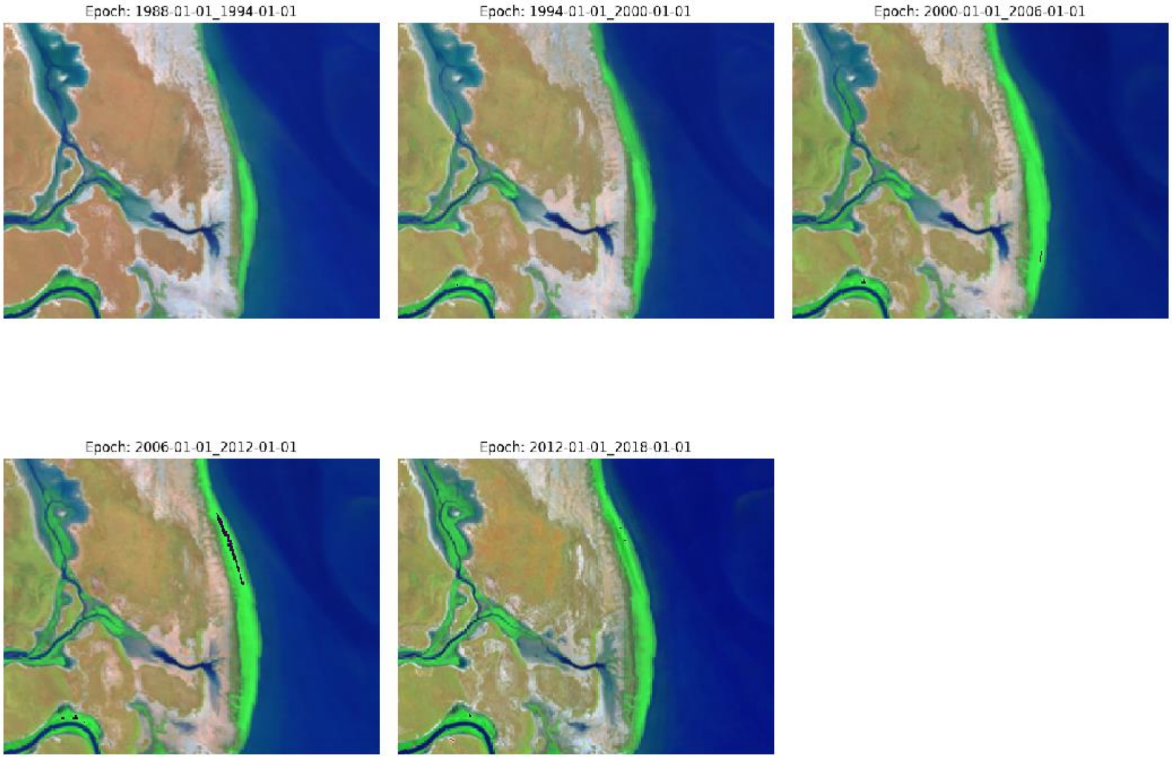

Figure 61. Composite images of the mid-tide range for the area identified by the bounding box in Figure 29. The figure in the top left represents data composited between Jan 1988 and Jan 1994, increasing in 6-year increments from left to right, top to bottom, to the bottom right figure representing data between Jan 2012 and the present.

5.8.3 McArthur River

The 6-yearly composite images for this part of the McArthur River shows that vegetation infills the central island in these composites over time. Of note is the significant colonisation over time by vegetation on the two small islands that sit just offshore. This suite of change over time composite images suggest that this has been an area of extensive vegetation extension over the last 30 years or that perhaps it is an environment recovering from a significantly damaging event or events such as the successive severe cyclones that made landfall in this area over 1984 (TC Kathy) and 1985 (TC Sandy).

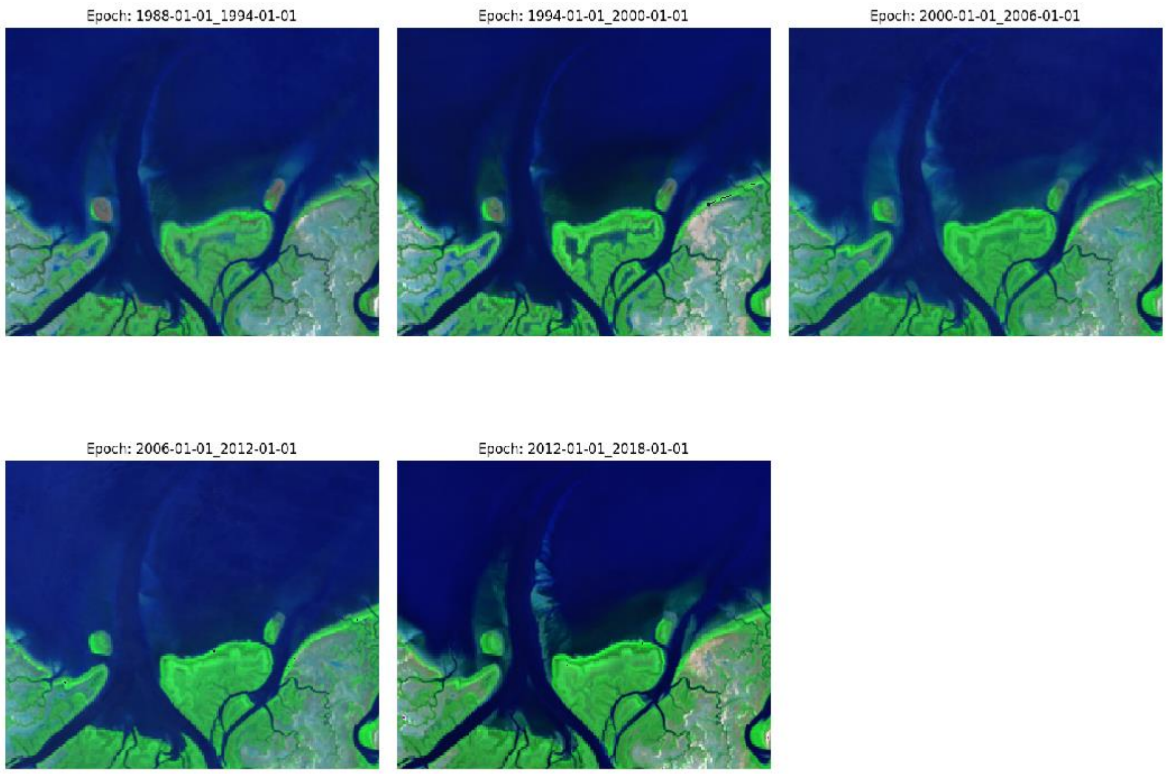

Figure 62. Composite images of the mid-tide range for the area identified by the bounding box in Figure 48. The figure in the top left represents data composited between Jan 1988 and Jan 1994, increasing in 6-year increments from left to right, top to bottom, to the bottom right figure representing data between Jan 2012 and the present.

5.8.4 Keep River

The true colour 6-year composites (Figure 63) for this part of the Keep River estuary show significant geomorphological and vegetation extent change over time. While the coastline appears unchanged over time, the island undergoes significant change in both shape and the extent of vegetation cover. From the first composite image between 1988 and 1994, the vegetation cover on the island appears to decrease while sediments build up, expanding the island between 1994 and 2006. From this time onwards, vegetation expands considerably on the island, which continues to grow. In the final composite (2012 to the present), further sedimentation is evident in the northwest corner of the image, which in turn may be colonised by vegetation in the future.

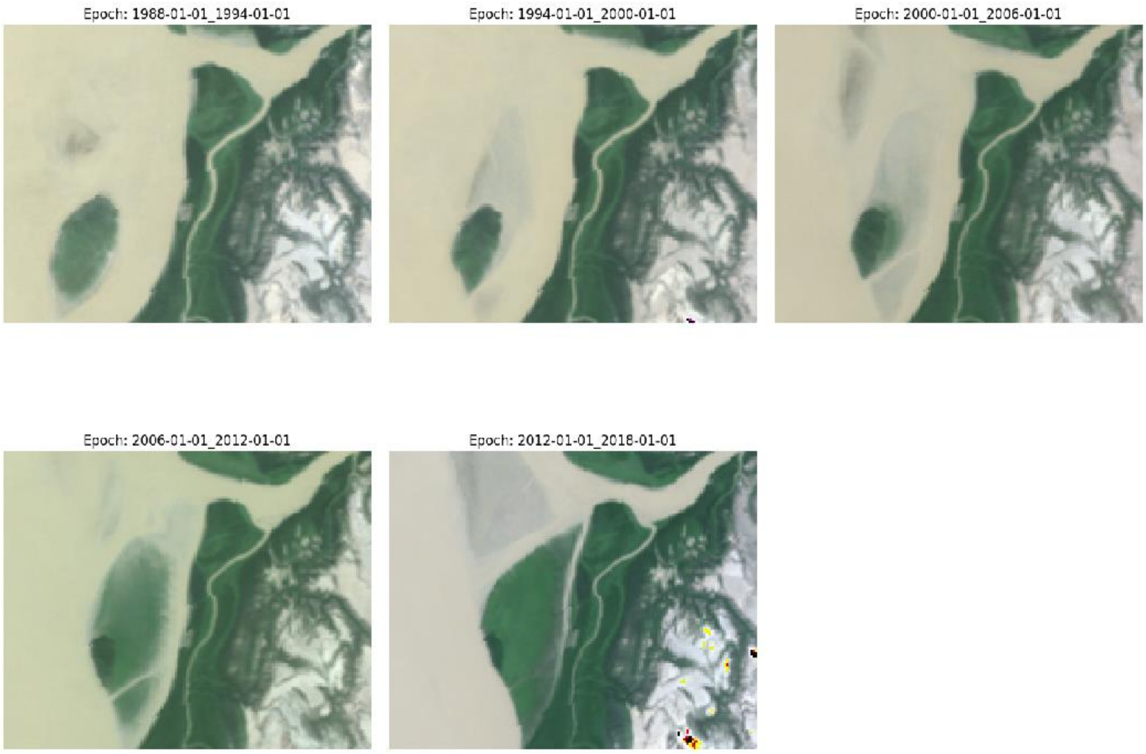

Figure 63. True colour composite images of the mid-tide range for the area identified by the bounding box in Figure 60. The figure in the top left represents data composited between Jan 1988 and Jan 1994, increasing in 6-year increments from left to right, top to bottom, to the bottom right figure representing data between Jan 2012 and the present.

5.9 Mangrove Habitat Change

Across a given geographical transect, a Hovmoller plot is a useful way to represent how a landscape has changed over time. In this work, the calculated NDVI for every imaged pixel over a given transect is plotted for the 30-year length of the DEA archive. Essentially, the NDVI index represents pixels that are calculated to show water (blue), sand/mud (beige) or vegetation (green). NDVI Hovmoller plots have been used in this work to characterise sediment and vegetation change over time. In these tropical, estuarine environments, the vegetation in the selected transects usually represents mangrove unless identified otherwise by the Global Mangrove Watch (GMV) mask (Thomas *et al.* 2015)

Event based mangrove habitat change is also reported for a major mangrove dieback event that occurred in Australia's north over the Austral summer of 2015/2016 (Duke *et al.* 2017). The average annual NDVI over modelled mangrove areas (Thomas *et al.* 2015) is compared before and after the dieback event with areas of major change highlighted as either dieback or mangrove extension.

Some of the worst affected areas in this dieback event occurred in the Gulf of Carpentaria. For this reason, mangrove habitat change in the Gilbert, Flinders, Roper and McArthur Rivers has been investigated. Based on the significant geomorphological change observed in the Keep River, this site has also been investigated for mangrove habitat change.

5.9.1 Gilbert River

Mangrove dieback at the southern end of the Gilbert River estuary during the 2014–2016 dieback event is highlighted by the difference in vegetation greenness over mangrove areas between those years, with the deficit shown in red (Figure 66).

The transect shown in Figure 64 is represented on the x-axis in Figure 65, which is a Hovmoller plot showing how water, sand/mud and vegetation has changed across the transect between 1988 and the present (y-axis). The 2015/16 dieback highlighted in Figure 60 can be seen in the lower-most part of the Figure 66 with vegetated area changing to sand (as represented by NDVI). Notable is the expansion of the mangrove area across this transect during the previous 30 years, and mangrove dieback on the landward side of the transect for about 6 years from 1995 onwards.

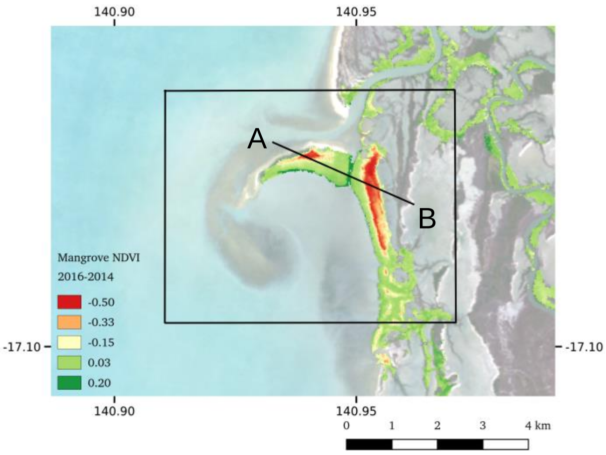

Figure 64. Mangrove dieback at the southern end of the Gilbert River estuary. Relative change in the calculated NDVI of mangrove areas between 2016 and 2014 is shown overlaid on a semi-transparent view of LOT. The transect represented in Figure 61 is shown in black between 'A' and 'B'.

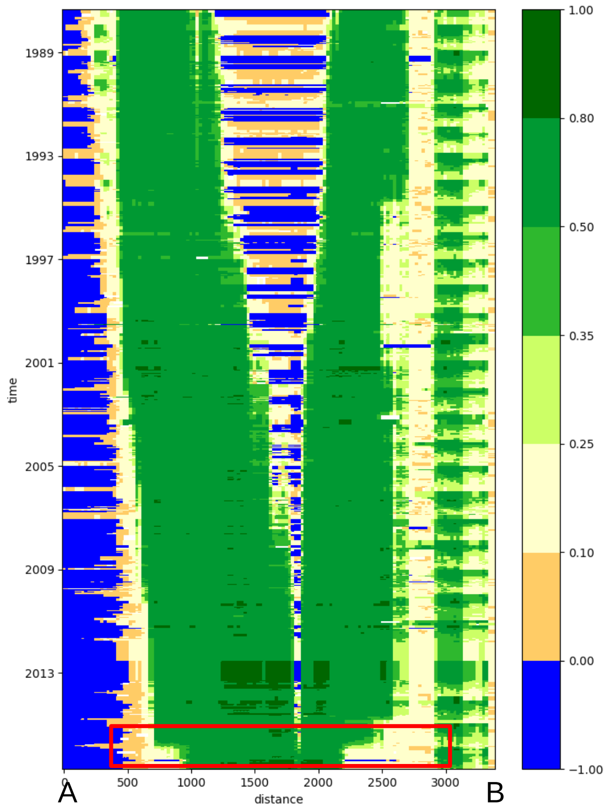

Figure 65. The transect in Figure 60 is represented on the x-axis of this Hovmoller plot, y-axis is time, colour is NDVI. The 2015–16 dieback event is highlighted in the red box.

5.9.2 Flinders River (Norman River)

Mangroves in the Flinders River region were severely impacted in the 2015/16 dieback event. The transect in Figure 66 is shown on the x-axis of Figure 67, clearly illustrating the dieback from this event. Furthermore, Figure 68 shows that mangroves have not been a permanent feature of this transect over the last 30 years. The early years of the Hovmoller plot show little to no vegetation is detected on the coastal fringe of the transect. This may be an artefact of the transect position (possibly consisting of a portion of the time-series) or may be reflective of the greater vegetation pattern of this coastline.

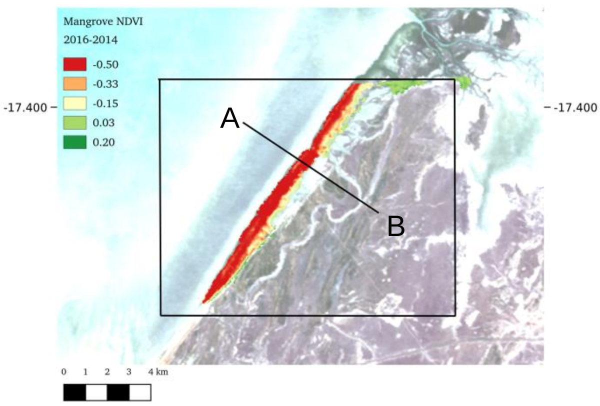

Figure 66. Mangrove dieback in the Flinders River estuary. The detailed Hovmoller transect line (Figure 67) is overlaid upon the transparent LOT image of the site with the relative 2016–2014 change in calculated NDVI in mangrove areas.

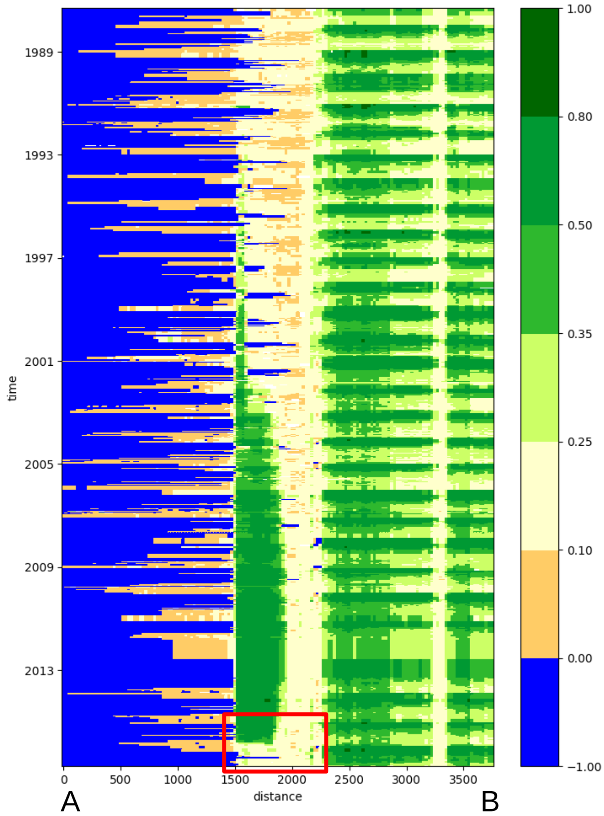

Figure 67. The Flinders River estuary transect detailed in Figure 66 is represented on the x-axis of this NDVI Hovmoller plot. The 2015–2016 dieback event is highlighted in the red box.

5.9.3 Roper River

Mangrove dieback at the Roper River estuary is highlighted by the difference in vegetation greenness over mangrove areas around 2014–2016, with the deficit shown in red (Figure 68). The Roper River coastline is a known region of extensive dieback and this is strongly reflected in the relative change in vegetation greenness at the southern side of the estuary mouth.

The Hovmoller plot (Figure 69) of the transect shown in Figure 67 demonstrates the dieback on the open coast observed at this location between 2014 and 2016. In the 30-year history shown in this plot (Figure 69), the 2014/2016 coastal dieback event is the most extensive. The upstream areas of mangrove have expanded over the last three decades.

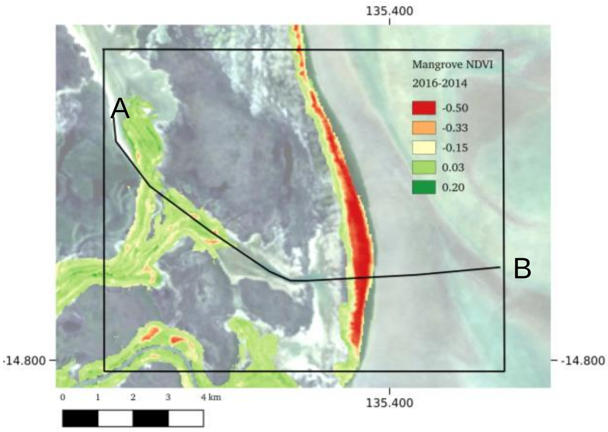

Figure 68. Mangrove dieback in the Roper River estuary. The detailed Hovmoller transect line (Figure 69) is overlaid upon the transparent LOT image of the site with the relative 2016–2014 change in calculated NDVI in mangrove areas.

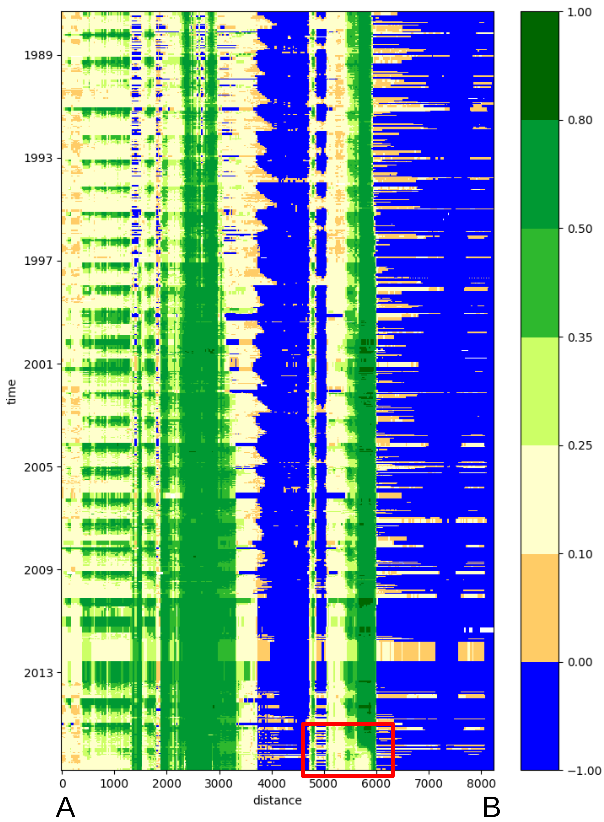

Figure 69. The Roper River estuary transect detailed in Figure 68 is represented on the x-axis of this NDVI Hovmoller plot. The 2014–2016 dieback event is highlighted in the red box.

5.9.4 McArthur River

Mangrove dieback at the McArthur River estuary during the 2014–2016 dieback event appears to affect certain zones to a greater degree than others (Figure 70). The seaward fringing mangrove population appears unaffected by the event, while the population located inward of the seaward fringe shows evidence of dieback.

The Hovmoller plot of the transect shown in Figure 71 shows this site to have a history of both low vegetation and mangrove extension over the 30-year history shown (Figure 70). Two severe tropical cyclones made landfall in close proximity to this site in 1984 (TC Kathy) and 1985 (TC Sandy) and the denuded areas in the transect may have suffered from these events. Mangroves on the fringes of this transect appear stable over the length of this record. Interestingly, the same region of the transect that suffered dieback over 2014–2016 also denuded and re-vegetated periodically up to around 2001 suggesting this might be an area vulnerable to change.

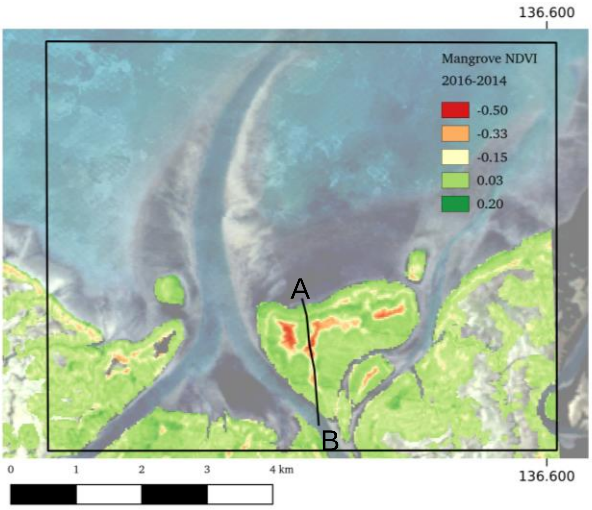

Figure 70. Mangrove dieback in the McArthur River estuary. The detailed Hovmoller transect line is overlaid upon the transparent LOT image of the site with the relative 2016–2014 change in calculated NDVI in mangrove areas.

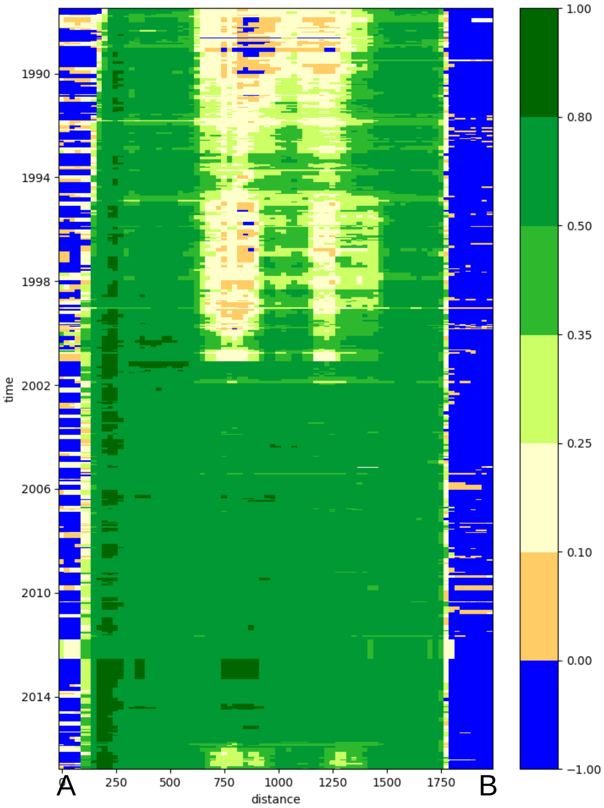

Figure 71. The McArthur River estuary transect detailed in Figure 52 is represented on the x-axis of this NDVI Hovmoller plot.

5.9.5 Keep River

Mangrove dieback at the Keep River estuary is limited to the fringing population only, as illustrated in Figure 72. However, the Hovmoller plot of the transect shown in Figure 72 shows that the mangroves on the island near the central western margin of the estuary have undergone significant movement over the last 30 years (Figure 73). The Hovmoller plot indicates the channel between the mainland coast and the island has been gradually filled in and been colonised by mangrove. Presumably, there has been a significant movement of sediment mass associated with the mangrove change.

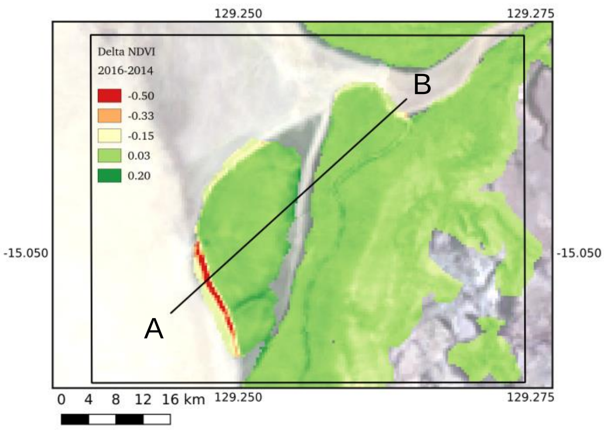

Figure 72. Mangrove change in the Keep River estuary. The detailed Hovmoller transect line is overlaid upon the transparent LOT image of the site with the relative 2016–2014 change in calculated NDVI in mangrove areas.

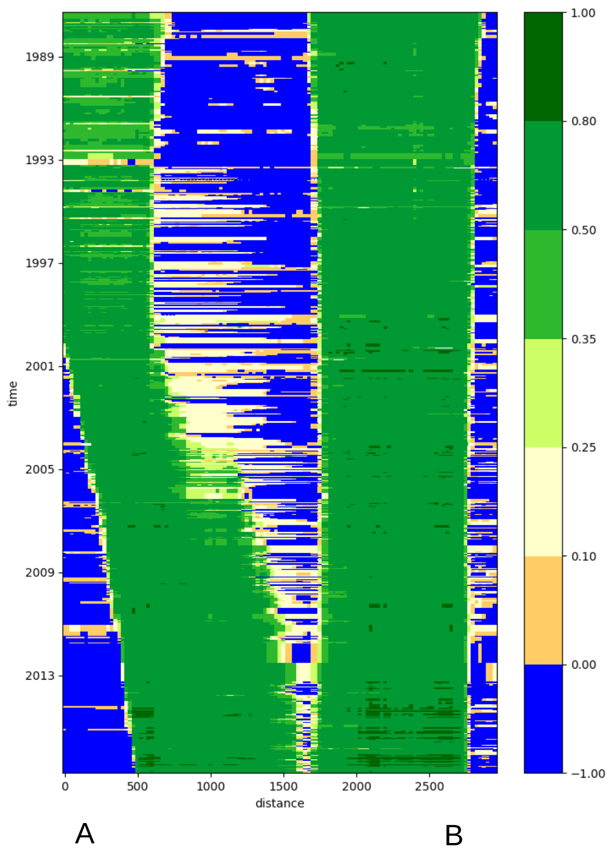

Figure 73. The Keep River estuary transect detailed in Figure 72 is represented on the x-axis of this NDVI Hovmoller plot.

5.10 Conclusions

The case study estuaries examined in this project are known areas of biological importance for Threatened and Migratory marine species of Northern Australia. The image products and analysis tools employed in this study demonstrate the potential utility of Digital Earth Australia for mapping the extent and dynamics of key coastal and estuarine habitats utilised by these species. To better inform the management of these species, a key next step in this approach is to utilise ground-validation data to enable these habitats to be robustly classified and quantified, providing important baseline information and enabling their extent and condition to be monitored.

In Northern Australia, cloud interference can make it difficult to obtain clear satellite imagery. In this study, it has been demonstrated that this issue can be overcome using the geometric median of surface reflectance values from imagery subsets to produce composite imagery of the coast. In the case studies of estuarine and coastal environments, the geomedian approach, combined with imagery sorting based on tide height, produces clear and crisp image composites of high and low tide for the first time. These images depict the maximum observed tidal extent and provide an excellent basis upon which to undertake coastal and estuarine habitat mapping and classification.

Tide-tagging of satellite imagery allows any tide induced change to be removed from change-detection analyses. For example, image composites of coastline change, such as those observed in Figure 63, clearly depict the intertidal extent because the DEA compositing approach provides robust measures of average reflectance values for each set of co-located pixels across the tidal range. In contrast, using a traditional approach would produce considerably blurred coastal features due to high variability between observations. Application of ITEM further improves our understanding of the extent and morphology of the intertidal environment as well as the distribution of tidal currents and circulation, based on these physical characteristics of the intertidal area.

Another important advantage of utilising the DEA is the ability to undertaken change detection using a fully processed (atmospherically and geometrically calibrated), high density (several hundreds of observations per pixel), three-decade long time series. The 30 years of data contained in the DEA Landsat archive enables investigation of event-based changes on the landscape (floods, fires, cyclones and dieback), as well as more gradual changes that can be difficult to detect, such as changes in coastal morphology due to sediment erosion and deposition, and the revegetation of areas stripped by cyclonic wind (e.g. Figure 65 and Figure 60). The results of the analysis of the Landsat time series in the case study estuaries clearly depict the dynamic nature of some areas, including large-scale rapid island growth and mangrove expansion (e.g. Keep River and Gilbert River estuaries), gradual long-term expansion of mangrove (Flinders River and McArthur River estuaries), relatively stable mangrove (Darwin Harbour and Daly River estuaries), and estuaries with areas of rapid recent dieback of mangrove (Roper River and Flinders estuaries). This information is important for the management of key species as well decisions around coastal developments. With Landsat and new satellite images (e.g. Sentinel 2) continually being added to the DEA, this time-series analysis approach could be developed into an effective habitat extent and condition monitoring tool.

Moving forward, the strength of these approaches will lie in their combination with field data. As threatened species 'hotspots' are further identified, tailored investigations can characterise the environment and assess how habitat change may have affected the species distribution over time. Field data that validates the interpretations from satellite data will be crucial to characterise the back-catalogue of imagery over the same region, establish accurate baselines, characterise and classify the landform dynamics of key coastal areas, and enable an ongoing habitat monitoring capability to be developed. Where appropriate, such a set of field measurements could be used to extrapolate across satellite observations over the greater region. Using this approach, predictions could be generated of potential areas of critical habitat for Threatened and Migratory marine species that are currently not documented.

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6. FISHERIES BYCATCH

KEY POINTS

- Commercial fisheries operating across the North Marine Bioregion were reviewed and summarized, and fishing effort for each fishery was mapped.
- An examination of issues and needs in relation to commercial fisheries bycatch interactions with Threatened and Migratory marine species was undertaken through a dedicated workshop.
- Issues identified included: knowledge gaps in species' habitat use and population connectivity, data collation and a lack of consistent bycatch data, improving species identification, improving logbook recording, improving safe release and handling, and understanding post-release survivorship of discarded fauna.
- Sawfishes were consistently identified as a group requiring a better understanding of interactions, post-release survivorship, and population structure in relation to fisheries.
- Overall, across commercial fisheries operating in the North Marine Bioregion, the reporting of Threatened and Migratory marine species bycatch is insufficient and inconsistent; improved species identification, logbook reporting, and implementation of the National Bycatch Reporting System are recommended management priorities.

6.1 Introduction

Marine species, including sharks and rays, turtles, seabirds, Dugong, and cetaceans, are unintentionally caught (bycatch) throughout the North Marine Bioregion by a variety of fisheries and fishing methods. These fisheries are managed by the Commonwealth, Northern Territory, or Queensland, may operate broadly across the region or with concentrated effort, and employ various management actions to ensure the sustainable use of resources, and mitigation of bycatch. Reported bycatch from these fisheries includes many Threatened and Migratory marine species listed under the *EPBC Act*. The identification of knowledge gaps to direct potential future research is required to further mitigate these interactions.

Of the pressures operating on the Northern Seascape, fisheries bycatch was selected for closer examination due to known interactions with Threatened and Migratory marine species, and its inclusion among priority actions in the Recovery Plans of priority species groups, namely sawfishes and marine turtles. We did not consider other bycatch issues, such as non-Threatened and Migratory marine species, and undersized commercial species.

Actions listed in the *Recovery Plan for Marine Turtles in Australia* (DEE 2017) include:

- Engage in, and implement, bi- and multi- lateral agreements to improve the protection of Australia's marine turtles through best practice fisheries management throughout their range;
- Promote and implement best practice and continued innovation of turtle bycatch mitigation in all Australian fisheries;
- Quantify fishery interactions by species, and where necessary, improve reporting processes;
- Design reporting frameworks to quantify the cumulative impacts of all fishing pressure on any given stock. Depending on range, this will require consideration of recreational, state/territory, Commonwealth and international fisheries;
- Support and expand research collaborations with commercial fishers on improving management of bycatch; and,
- Quantify post-release mortality of live caught turtles, and where necessary, improve success rates.

The *Sawfish and River Sharks Multispecies Recovery Plan* (DoE 2015) lists the objective:

- Reduce, and where possible, eliminate adverse impacts of commercial fishing on sawfish and river shark species.

This objective includes the following actions in relation of interactions between commercial fisheries and sawfish:

- Ensure actions (for example, changes to management arrangements and fishing practices) to reduce levels of interaction with, and mortality of, sawfish and river shark species are adopted and evaluated in commercial fisheries;

- Consider new management arrangements to reduce bycatch rates by commercial fishers;

- Improve the ability of fishery monitoring programs to provide accurate (validated) data on the nature and extent of fishery interactions with sawfish and river shark species; and,

- Promote cooperation and understanding between agencies and commercial operators to improve recovery efforts for sawfish and river shark species through, for example, strategic education processes and facilitating research.

Actions in the current Recovery Plans common to both species groups include quantifying fishery interactions, improving reporting, and quantifying post-release mortality. Given this clear articulation of issues, we set out to examine fisheries interactions in commercial fisheries in the North Marine Bioregion, and to identify priority research opportunities through engagement with stakeholders and research end-users in a dedicated workshop.

6.2 Objectives

- Understand interactions between commercial fisheries in the North Marine Bioregion and *EPBC*-listed Threatened and Migratory marine species; and,
- Examine research needs for understanding interactions and their impacts, and research into mitigation measures.

These objectives were considered for *EPBC*-listed Threatened and Migratory sharks and rays, turtles, and cetaceans (as well as specifically for sawfishes). Birds were not considered due to limited interactions with commercial fisheries. The geographic region of interest was the North Marine Bioregion and includes the Commonwealth-managed Northern Prawn Fishery, and State/Territory fisheries (Queensland and Northern Territory). These objectives were considered for commercial fisheries, and were not considered for recreational or Indigenous fisheries. The recreational and Indigenous fishing sectors are likely to have unique issues which require consideration and scoping in the context of Threatened and Migratory marine species in the North Marine Bioregion.

6.3 Methods

All fisheries operating across the North Marine Bioregion were reviewed and summarized, and fishing effort for each fishery was mapped, and broad interaction data summarized. A bycatch workshop with regional stakeholders and research end-users assessed research and mitigation priorities.

Effort and bycatch data for fisheries in the NT were requested from the Department of Primary Industry and Resources aggregated by year, location (60 nm grid), and total net days fished (effort), with data dating from 2006 to 2018. We used data from years to 2017, as data for 2018 is still incomplete. Fine-scale resource extraction data for Queensland from 2011 to 2014 were also obtained but at a finer 6 nm resolution. Restrictions on effort data detail due to there being fewer than 5 vessels operating meant that fishing intensity over time could not be mapped, however we were still able to derive maps of the extent of fishery effort.

Bycatch data were provided by the Commonwealth Northern Prawn Fishery (data from 2008 to 2016), as well as logbook data from Queensland fisheries for Gulf of Carpentaria Species of Conservation Interest (data from 1997 to 2017). Bycatch data were provided for only three NT fisheries (NT Barramundi net fishery, Demersal (finfish) trawl fishery, and Timor Reef fishery).

6.4 Fisheries and Interactions

6.4.1 Commonwealth Fisheries

Northern Prawn Fishery

The Northern Prawn Fishery (Figure 74) is a Commonwealth-managed fishery operating across the North Marine Bioregion, with effort concentrated in the Gulf of Carpentaria. Otter trawl gear is used to target banana, tiger, and endeavour prawns. Management is through input controls, particularly limited entry, individual transferrable effort units, gear restrictions, and spatial and seasonal closures (largely to protect nursery grounds for juvenile prawns). Bycatch Reduction Devices and Turtle Exclusion Devices are compulsory on all vessels in the fishery, and their use has significantly reduced bycatch, including of Threatened and Migratory marine species. In 2016, interactions with priority species recorded in logbooks included at least 202 sawfish (only 1 identified to species level – Dwarf Sawfish) and 50 turtles (2 Flatback Turtles, 6 Green Turtles, 3 Olive Ridley Turtles, 39 unidentified to species level). Observer coverage is high in the NPF, and there have been significant improvements in the accuracy and reliability of data collected in the crew-member observer program since 2011. The effectiveness of the NPF crew-member observer program varies from species to species.

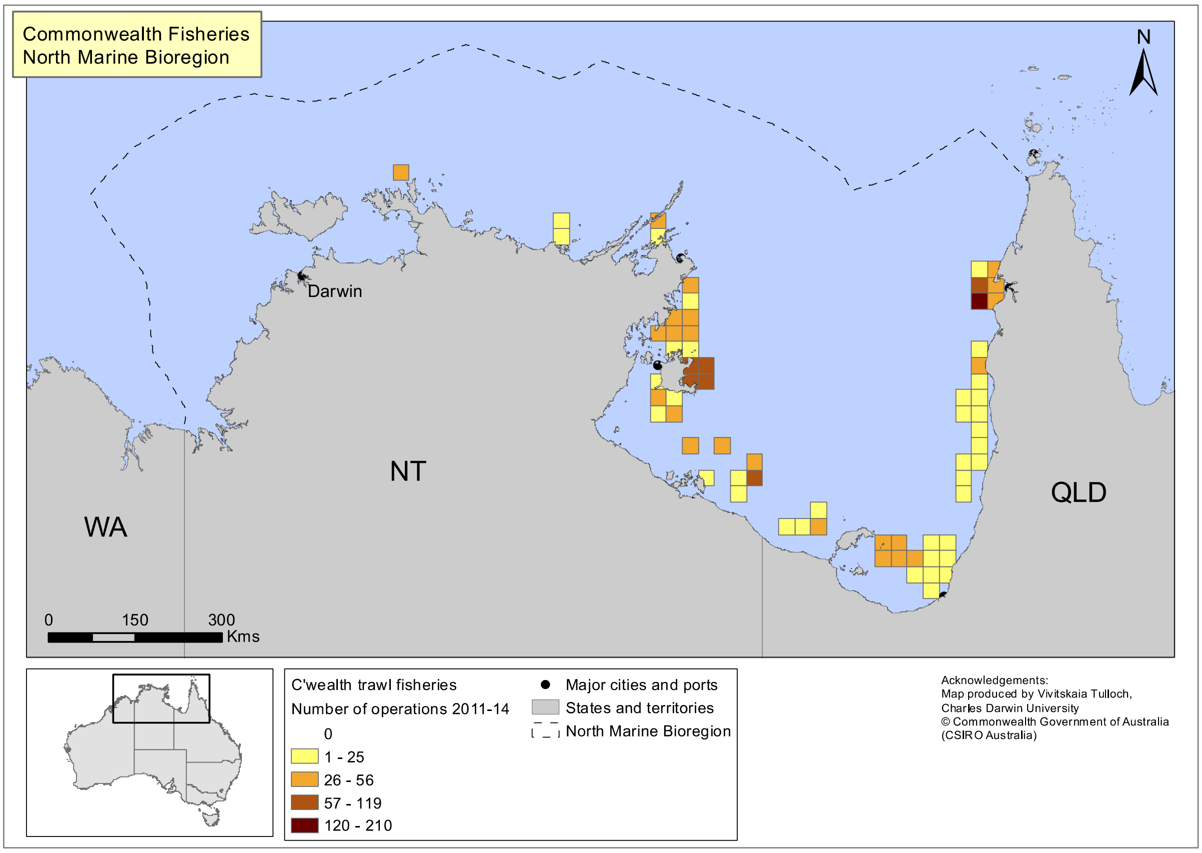

Figure 74. Commonwealth Northern Prawn Fishery effort within the North Marine Bioregion, 2011–2014.

6.4.2 Northern Territory Fisheries

Coastal Line Fishery

The Coastal Line Fishery (Figure 75) is a Northern Territory (NT)-managed fishery operating across the NT, with effort concentrated around rocky reefs. Several gear types are used, including rod and line, hand lines, cast nets (for bait only), scoop nets, gaffs, droplines, and fish traps which are used to primarily target Black Jewfish and Golden Snapper. Management actions include input controls, including gear restrictions, and spatial restrictions on droplines and fish traps. There are also output controls in the form of catch limits on targets species. While there are no specific management controls for bycatch interactions, the targeted hook and line fishing gear used presents little risk of interaction with Threatened and Migratory marine species. There have been no reported interactions with priority species in the last five years, which has been verified by a low level of observer coverage (<5% of total fishing effort).

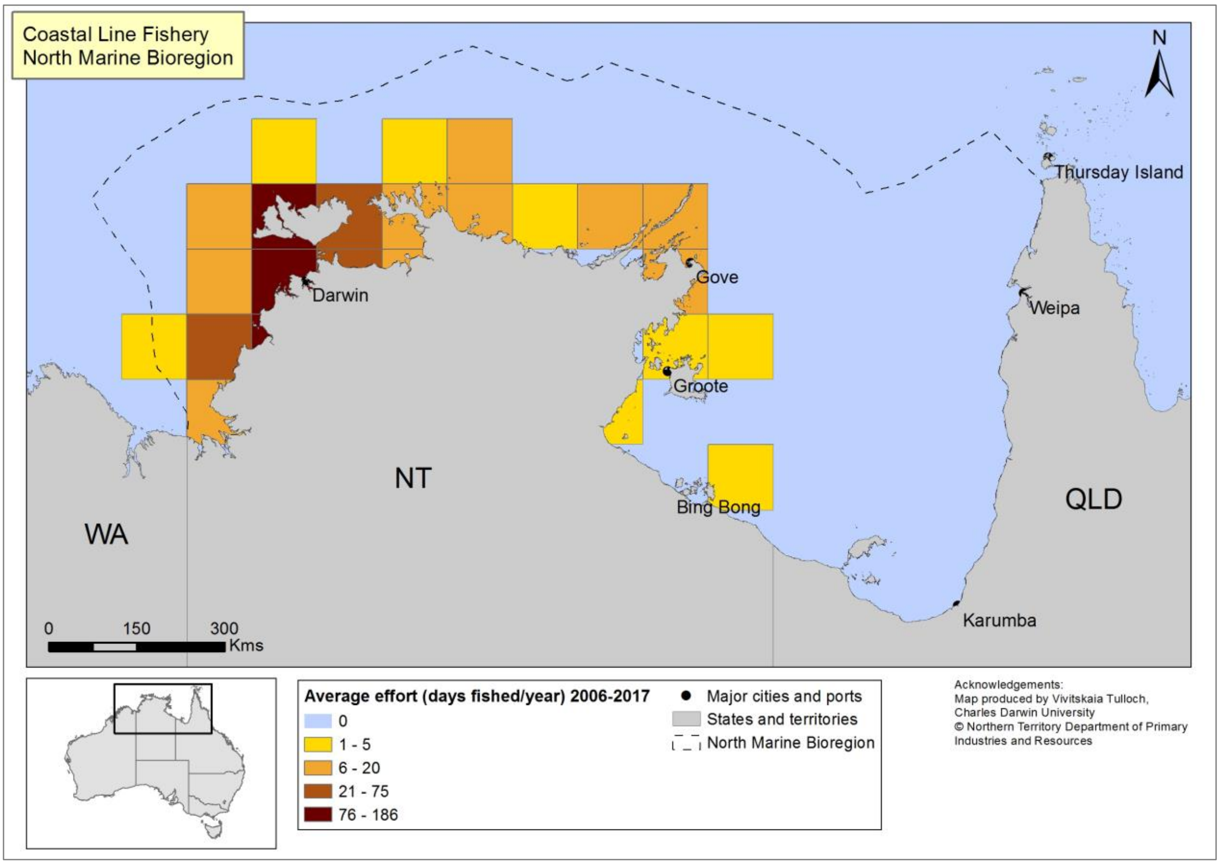

Figure 75. NT Coastal Line Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Coastal Net Fishery

The Coastal Net Fishery (Figure 76) is a NT-managed fishery, concentrated around two discrete zones: Darwin from Cape Hotham to Native Point and Cape Ford to Cape Dooley; and Borroloola from Bing Bong Creek and Pelican Spit.). Gillnets and cast nets are used to target a range of species, including mullets, Blue Threadfin, sharks, and Queenfish. Management is through gear restrictions and low licence numbers. The only specific bycatch management is the restriction of fishing gear to seine nets which allows the release of unwanted catch while it is still in the water. While the relatively small footprint of this fishery limits the risk of interactions with Threatened and Migratory marine species and there have been no reported interactions with protected species in the last five years, there has been no observer coverage to verify this.

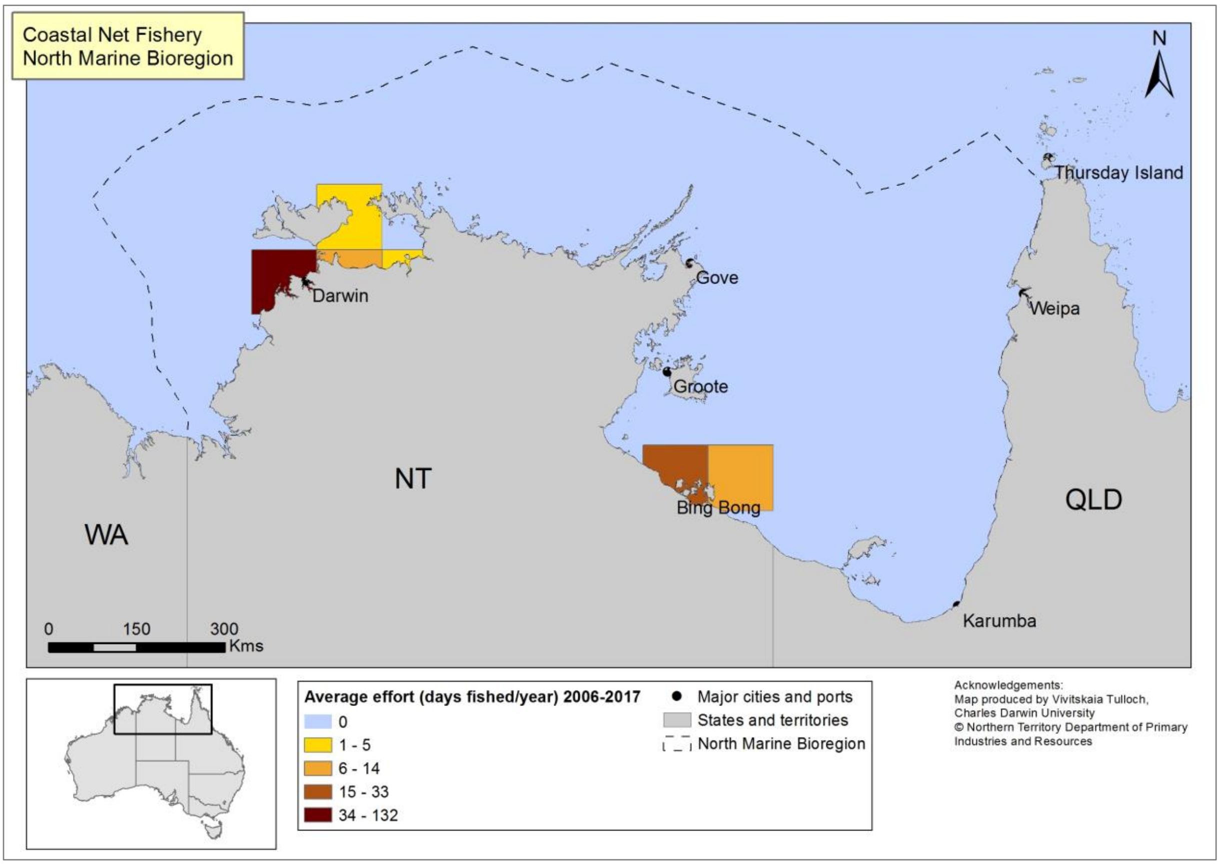

Figure 76. NT Coastal Net Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Bait Net Fishery

The Bait Net Fishery (Figure 77) is a NT-managed fishery, is concentrated in two sections, to the west of Darwin and waters in the vicinity of Cobourg Peninsula. Bait net, cast net, or scoop net are used to target all fish species to be used as bait, with exceptions of Barramundi, Threadfin Salmon, Spanish Mackerel, and Mud Crab. Management is through input control, including gear restrictions, and spatial closures. There are no specific bycatch management arrangements. The nature of the fishery and the gear utilized minimizes the risk of interactions with Threatened and Migratory marine species, and there are no reported interactions with these species. However, there has been no observer coverage to verify these reports.

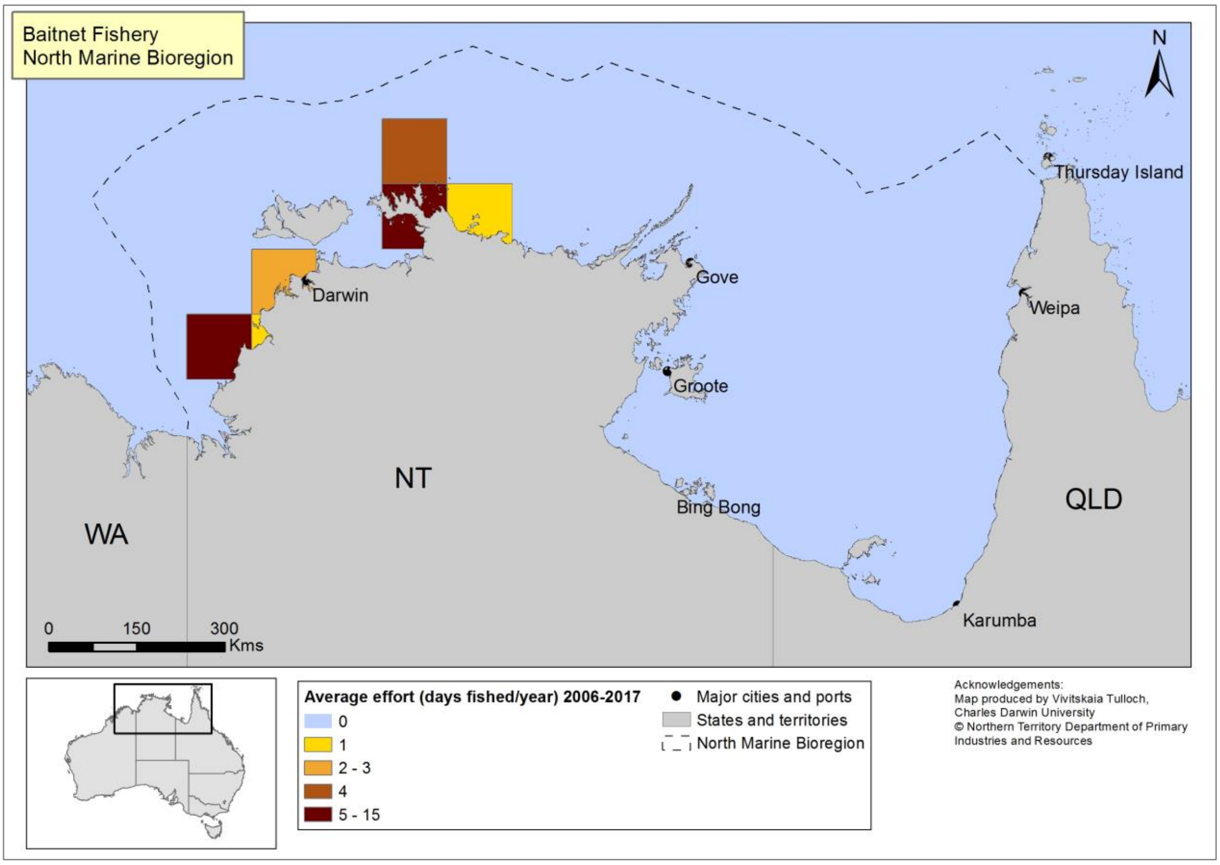

Figure 77. NT Bait Net Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Restricted Bait Fishery

The Restricted Bait fishery (Figure 78) is a NT-managed fishery operating across the NT. This fishery uses a variety of bait nets (gillnets) up to 100m in length to catch fish for use as crab bait in the Mud Crab Fishery. These nets may only be set in the open sea within 3 nm of the coast and the fisher must attend the net at all times. Commercial fishers appear to be increasing the use of purchased bait and decreasing the amount of time spent netting for bait. There are no specific bycatch management arrangements in the fishery, and while there have been no reports of protected species interactions in the last five years, between 1994 and 2004 there were 35 reported sawfish captures. There has been no observer coverage in this fishery to verify reported interaction levels.

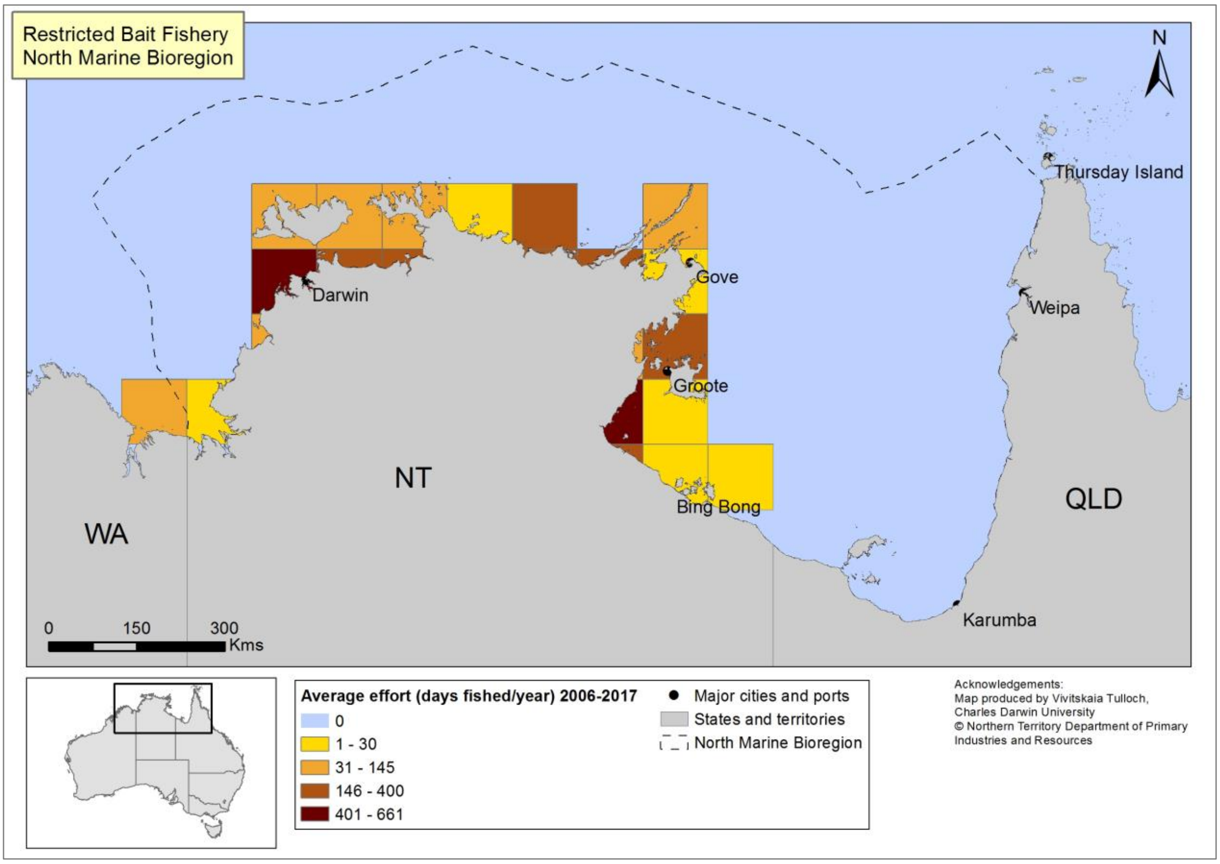

Figure 78. NT Restricted Bait Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Spanish Mackerel Fishery

The Spanish Mackerel Fishery (Figure 79) is a NT-managed fishery operating throughout the NT. Spanish Mackerel are targeted using trolled lures or baited lines. Management action includes catch-sharing arrangements between user groups. The primary fishing gear used in this fishery presents little risk of interaction with Threatened and Migratory marine species, and there were no reported interactions in the last five years. The near zero interactions reported by fishers has been verified by a low level (<5% of total effort) of observer coverage.

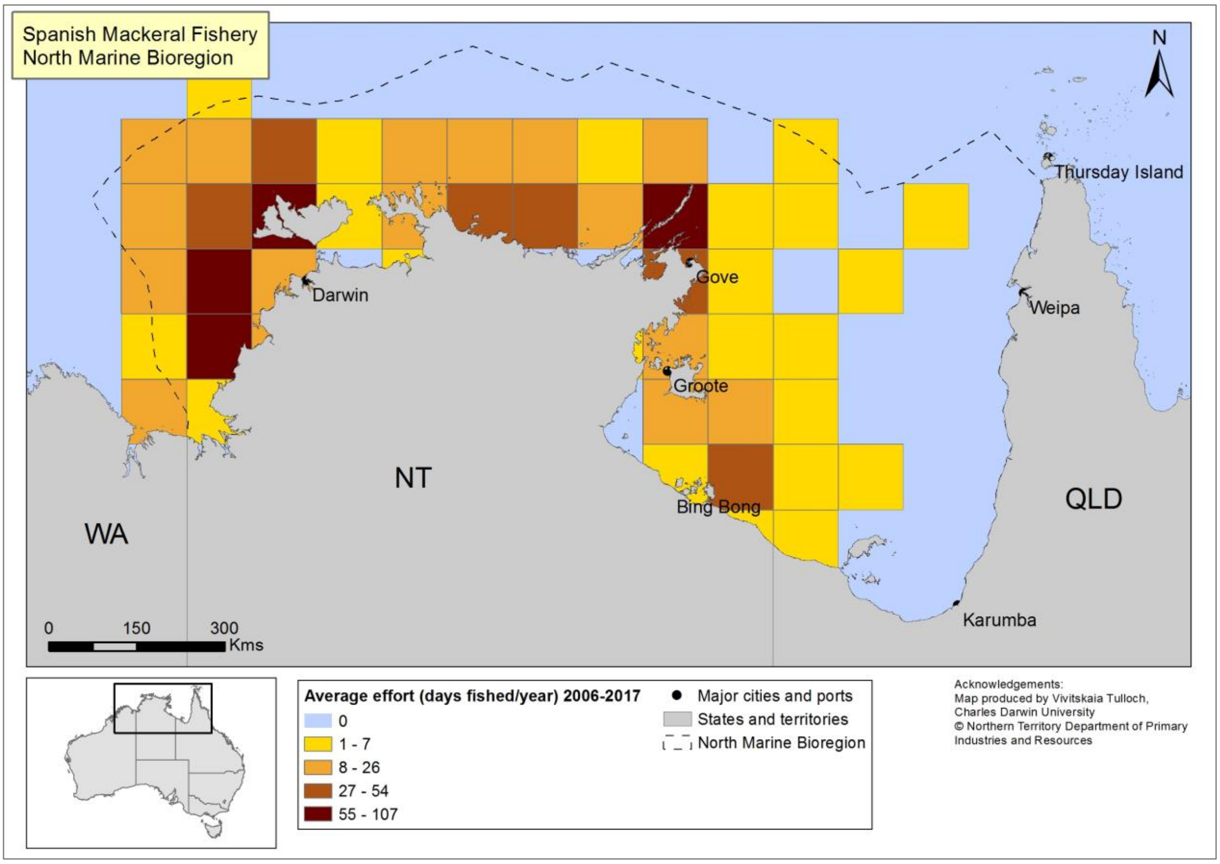

Figure 79. NT Spanish Mackerel Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Offshore Net and Line Fishery

The Offshore Net and Line Fishery (Figure 80) is a NT-managed fishery operating throughout the North Marine Bioregion. Demersal and pelagic longlines, as well as pelagic gillnets are used to target Australian Blacktip Sharks, Common Blacktip Sharks, and Grey Mackerel. Management action includes input controls, including gear restrictions. The amount of bycatch depends strongly on location and season. Risk of interactions with Threatened and Migratory marine species is considered low given that the fishery operates beyond the geographical range of many of these species. Logbooks from 2015 reported interactions with 27 sawfish, 13 turtles, 1 mobulid ray, and 1 dolphin during the course of 588 days of fishing. In conjunction with catch logbook data, a coordinated Observer Program regularly compares and validates information submitted by the operators. Analysis of observer reports and logbook information has verified correct correlation between the observed catch compositions and quantity, and the corresponding logbook information regarding catch trends. Target observer coverage is currently set at 7% based on the expert opinion of the members of the Northern Stock Assessment Group (NSAG). Specific bycatch management includes not allowing bottom set nets in the fishery.

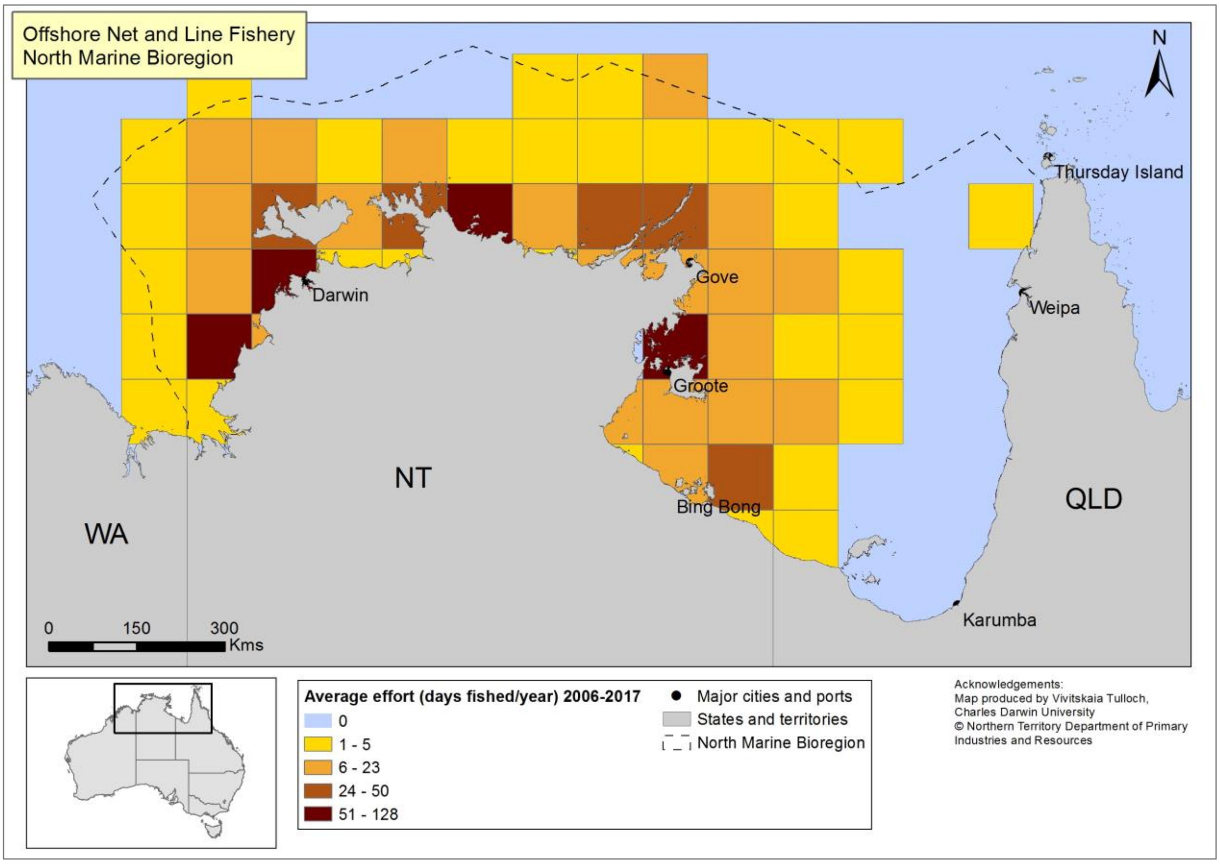

Figure 80. NT Offshore Net and Line Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Demersal Fishery

The Demersal Fishery (Figure 81) is a NT-managed fishery operating across the NT. A variety of gear, including fish traps, hand lines, droplines, and demersal trawl nets are used to target a range of tropical snappers. Management action includes individual transferrable effort units and input control through spatial gear restrictions. Bycatch reduction devices such as Turtle Exclusion Devices and grids are mandatory in the fishery so as to reduce interactions with Threatened and Migratory marine species, while increasing the value of landed product. The Demersal Fishery operates beyond the geographic range of many Threatened and Migratory marine species and so the risk of interaction with this group of species is low. The proportion and composition of bycatch in the trawl component of this fishery is routinely verified by on-board observers, with 31 fishing days observer coverage in 2015. Fishery observers reported 8 interactions over 31 days of fishing in 2015 including sea snakes, Narrow Sawfish, and a grey nurse shark. The Finfish Trawl Fishery (Figure 82) merged with the Demersal Fishery after the 2012 season.

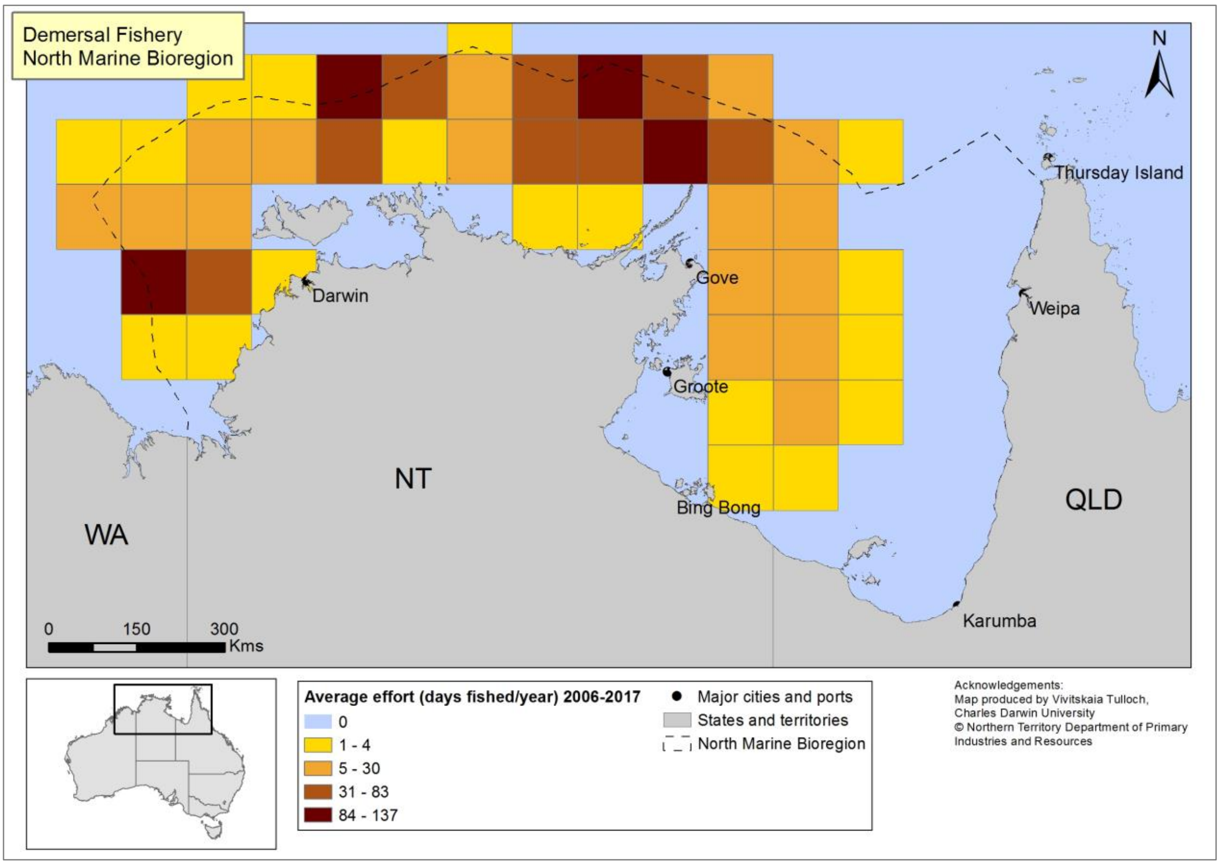

Figure 81. NT Demersal Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

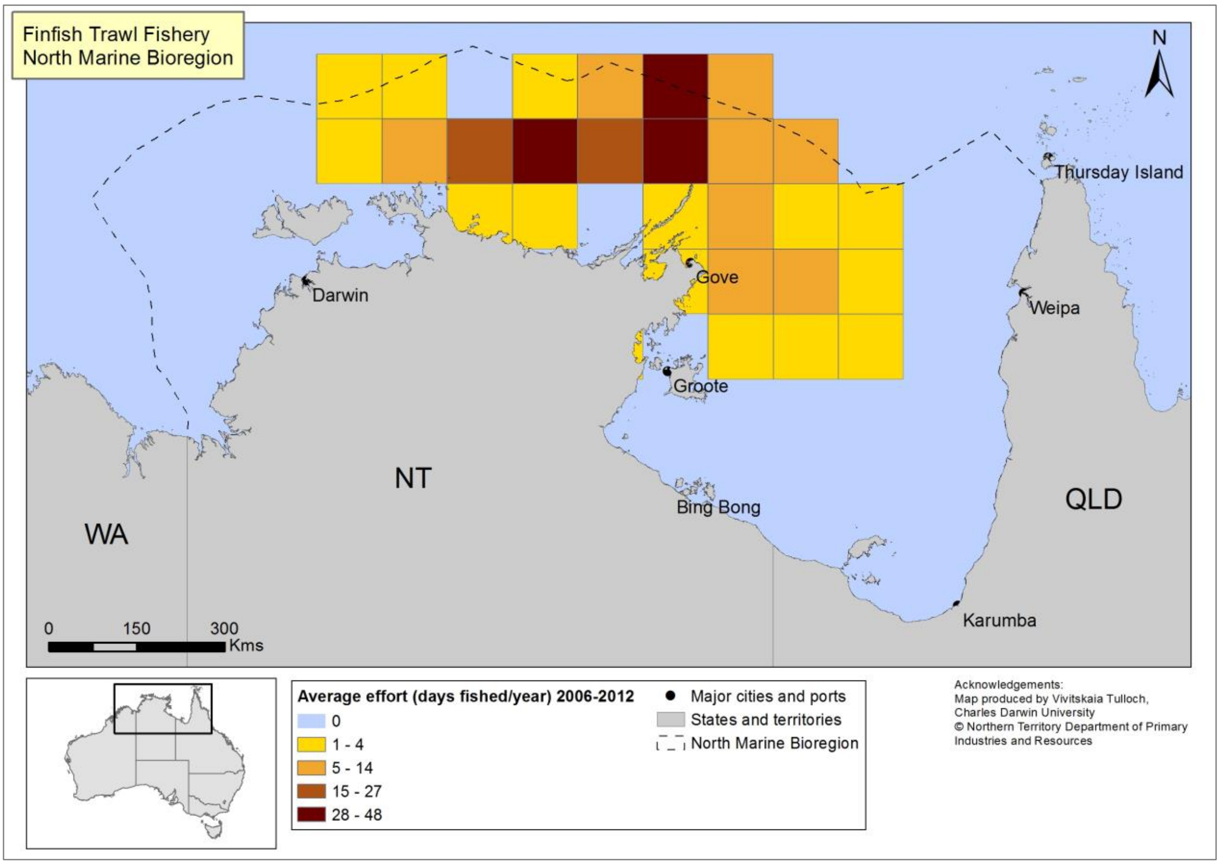

Figure 82. NT Finfish trawl fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2012, where fishery was operational.

Barramundi Fishery

The Barramundi Fishery (Figure 83) is a NT-managed fishery with effort concentrated in coastal waters throughout the NT. Gear including gillnets, and baited hooks and artificial lures target Barramundi and King Threadfin. Management is through input controls, individual transferrable effort units, gear restrictions, and spatial and seasonal closures. The commercial sector is excluded from many estuarine systems and consists of relatively few licensees (14). Guidelines are in place through Dugong Exclusion Zones to protect seagrass beds and avoid capture of dugongs and crocodiles. These factors, in conjunction with restrictions on the length and operation of gillnets, limit the risk of interactions with Threatened and Migratory marine species. Risk of interactions is thus considered low, despite almost 100 interactions in 2015. Most interactions were with Estuarine Crocodile and sawfish, and almost all were released alive. However, observer coverage is low (5–10% of total days fished and are not conducted every year), and previous research based on observer data has shown ~50% sawfish mortality in gillnets in this fishery (Field *et al.* 2008).

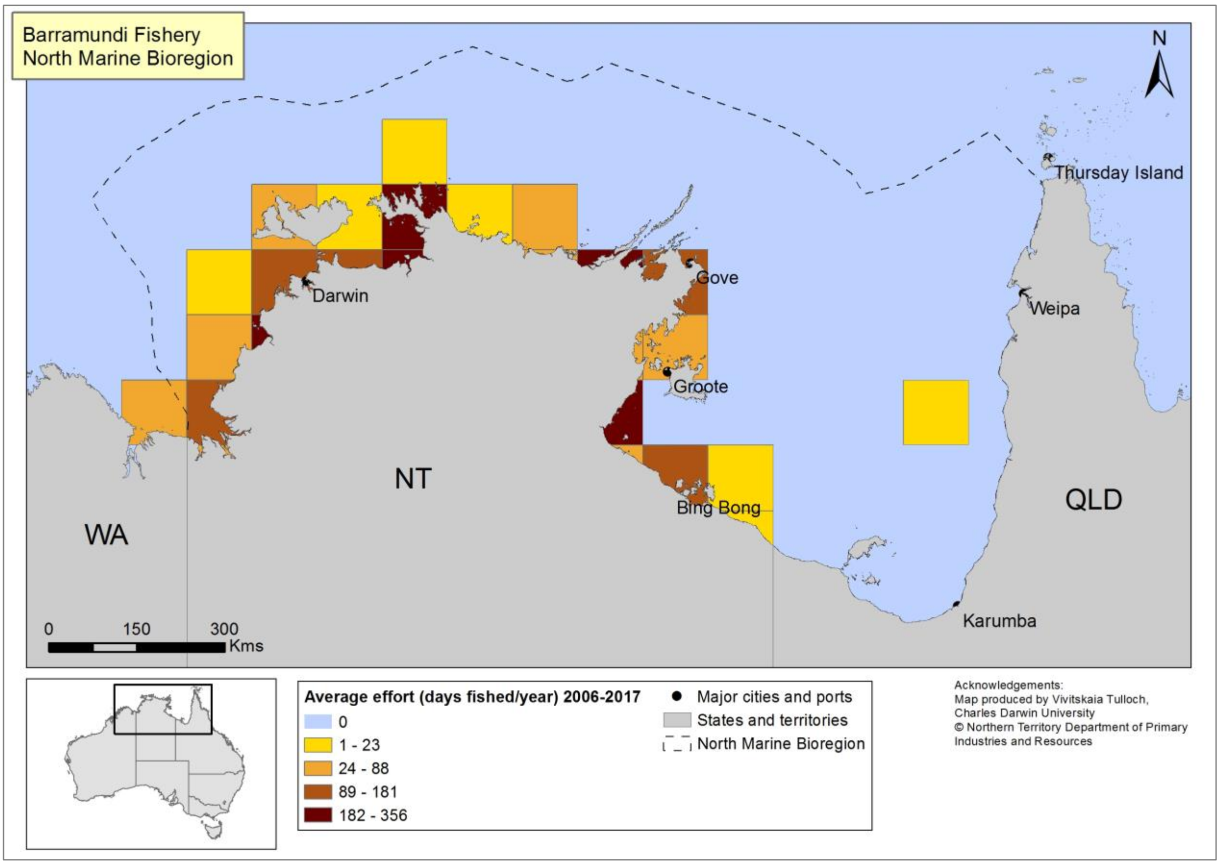

Figure 83. NT Barramundi Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Mud Crab Fishery

The Mud Crab Fishery (Figure 84) is a NT-managed fishery operating in coastal waters across the NT, with effort concentrated in the Gulf of Carpentaria and a small number along the Arnhem Land coast and the Darwin area. Baited pots and bait nets (gillnets) are used to target Mud Crabs and some bait fishes. Management action includes input control, particularly limited entry, gear restriction, and spatial closures. Gear use by this fishery is highly selective, and interactions with Threatened and Migratory marine species is limited. There have been no reported interactions with priority species in the last five years.

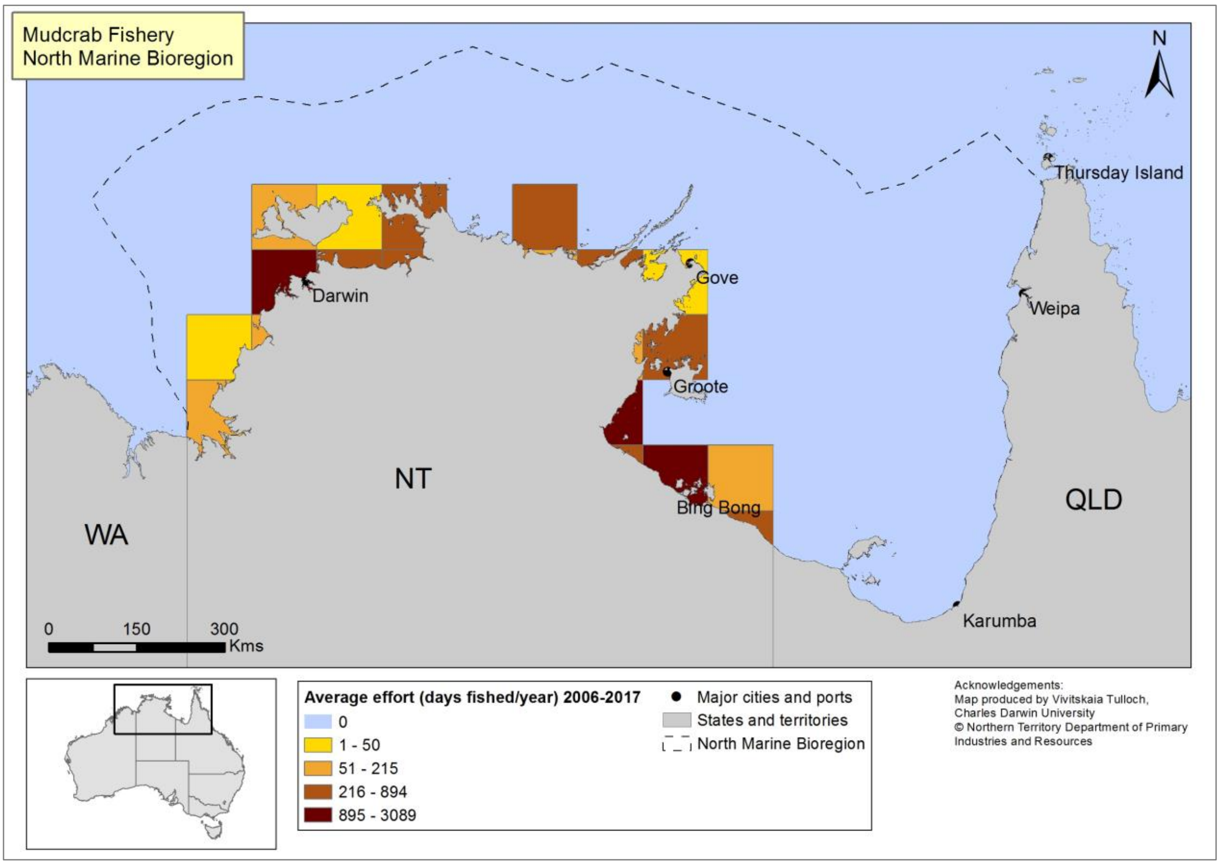

Figure 84. NT Mud Crab Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Mollusc Fishery

The Mollusc Fishery (Figure 85) is a NT-managed fishery with a very limited footprint. Molluscs can only be collected by hand in intertidal waters. There is only one commercial license allocated for this fishery, which may be bought, sold, or leased, and effort is managed with some spatial restrictions. Given the nature of the fishery, there have been no reported interactions with Threatened or Migratory marine species.

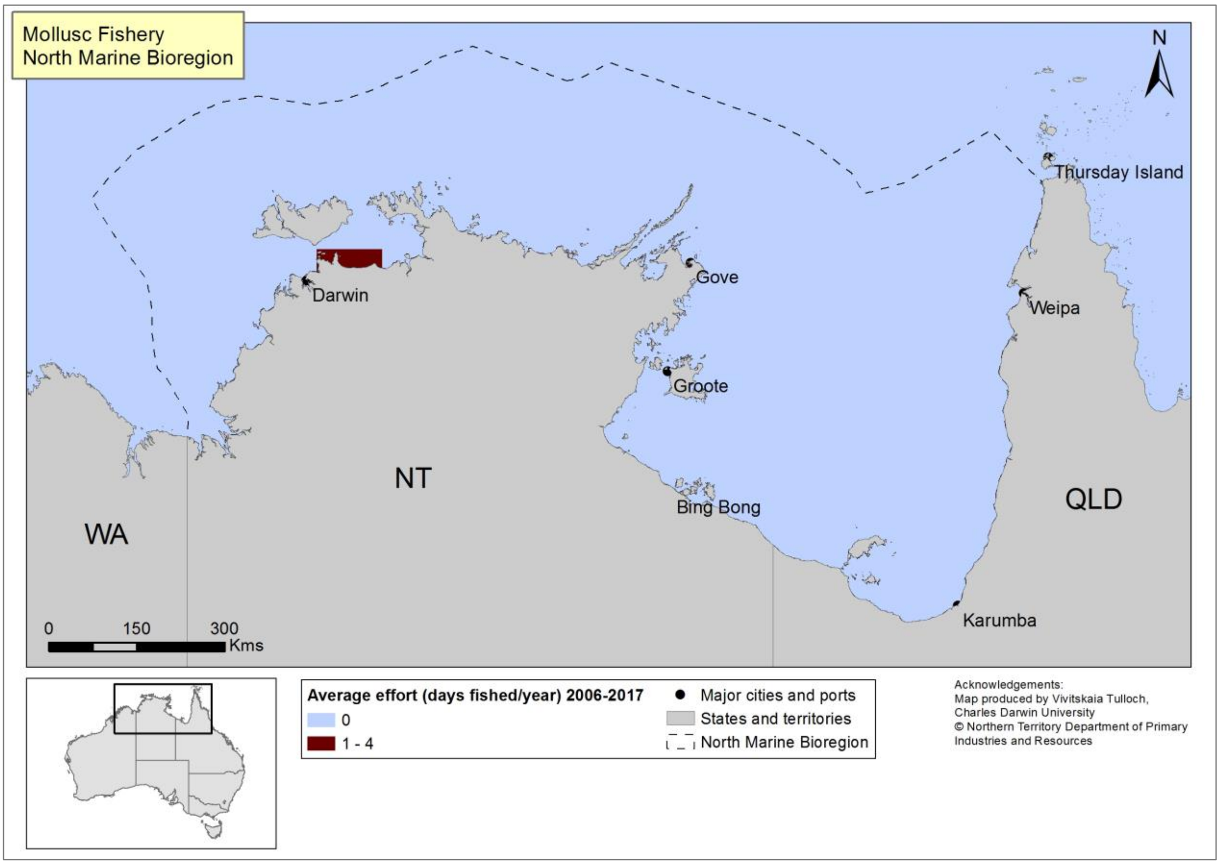

Figure 85. NT Mollusc Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Aquarium Fish/Display Fishery

The Aquarium Fish/Display Fishery (Figure 86) is a NT-managed fishery operating across the NT, to the outer limit of the Australian Fishing Zone (AFZ). Multiple gears, including nets, hand pumps, freshwater pots, and hand-held instruments are used to collect a wide variety of fish, invertebrates, coral rubble, and substrates ("live rock"). Management is through input controls, particularly limited entry, recreational fishing controls (e.g. minimum legal sizes, personal possession limits), spatial closures, as well as compliance with international standards (e.g. CITES regulations). Fishing methods are very selective, and there have been no reported interactions with priority species in the last five years.

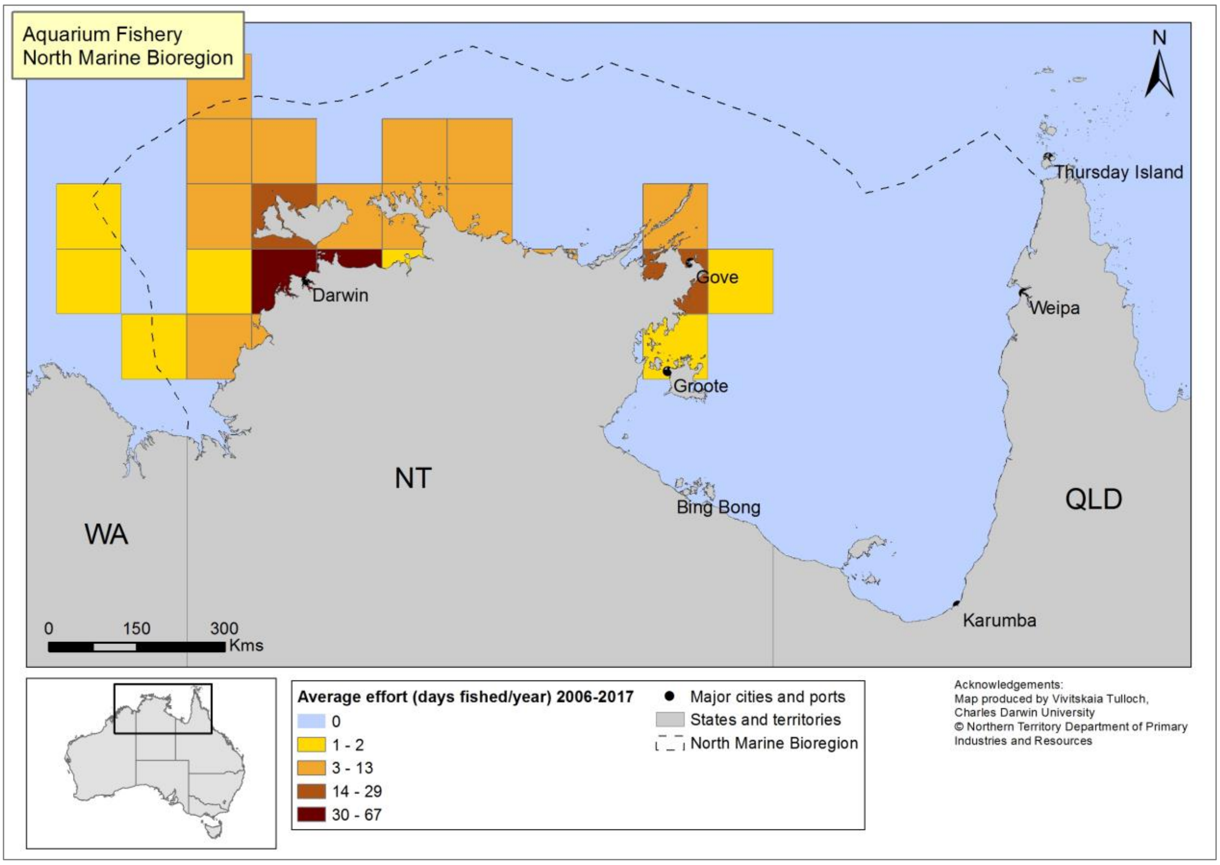

Figure 86. NT Aquarium Fish/Display Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Trepang (Sea Cucumber) Fishery

The Trepang Fishery (Figure 87) is a NT-managed fishery operating across the NT, with most effort concentrated along the Arnhem Land coast (Cobourg Peninsula to Groote Eylandt). Hookah diving (hand capture) is the only method used to capture Sandfish, a type of Sea Cucumber. Management includes limited licenses, minimum legal size, and effort is generally restricted to the dry season with improved water clarity. The highly selective method of this fishery limits interactions with Threatened and Migratory marine species. There have been no reported interactions with priority species in the last five years

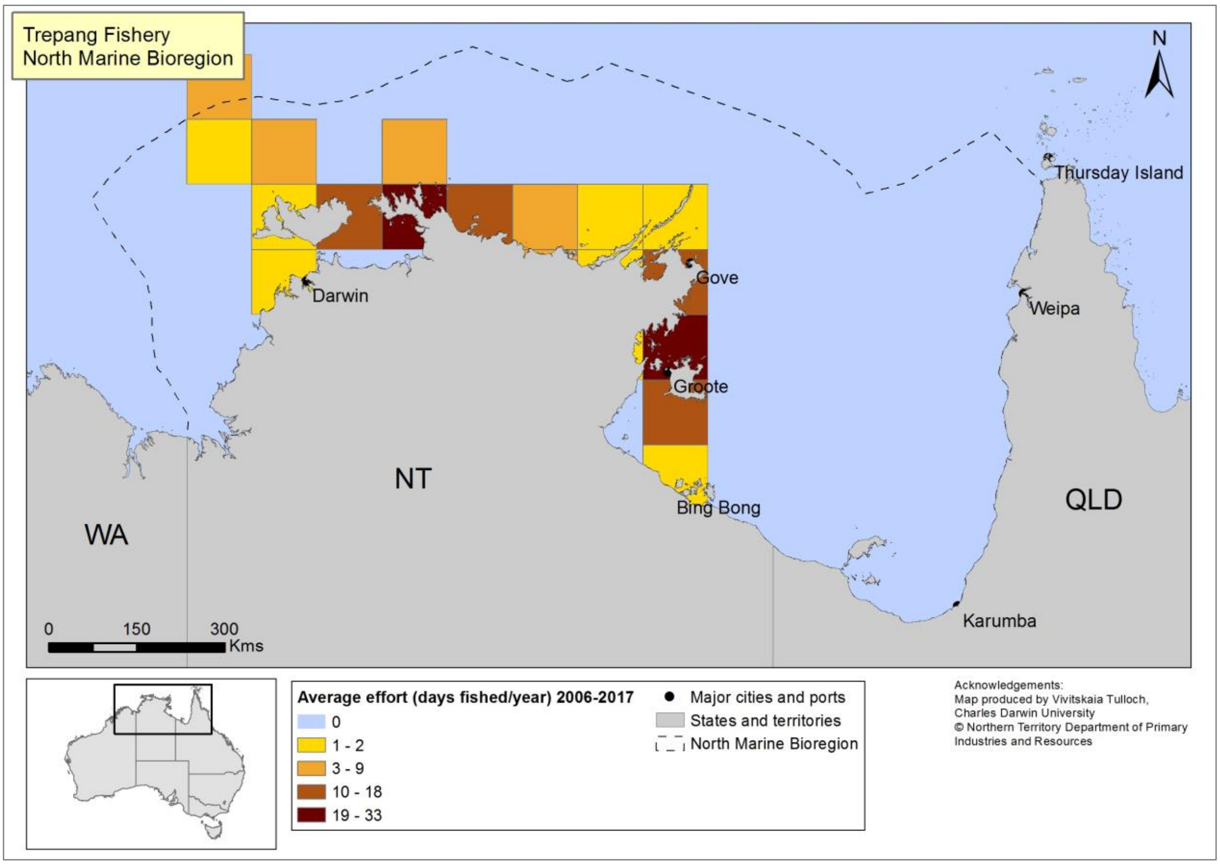

Figure 87. NT Trepang Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Timor Reef Fishery

The Timor Reef Fishery (Figure 88) is a NT-managed fishery which operates off the northern Top End. A variety of gear, including baited traps, hand lines, droplines, and demersal longlines, are used to target tropical snappers. Management is through individual transferrable effort units. This fishery operates beyond the coastal range of some of the priority threatened species, and the primary gear used (fish traps) has minimal risk of interaction with these species. There have been no reported interactions with priority species in the last five years. More recently, a permitted trawl vessel has been operating in this fishery. The same bycatch reduction devices as outlined for the Demersal Fishery are also required. As a consequence of this new gear in the fishery, there have been interactions with Threatened and Migratory marine species (Narrow Sawfish, sea snakes, Whale Shark, Scalloped Hammerhead, and pipefish). These interaction levels have been quite low and have been verified by a relatively high level of observer coverage.

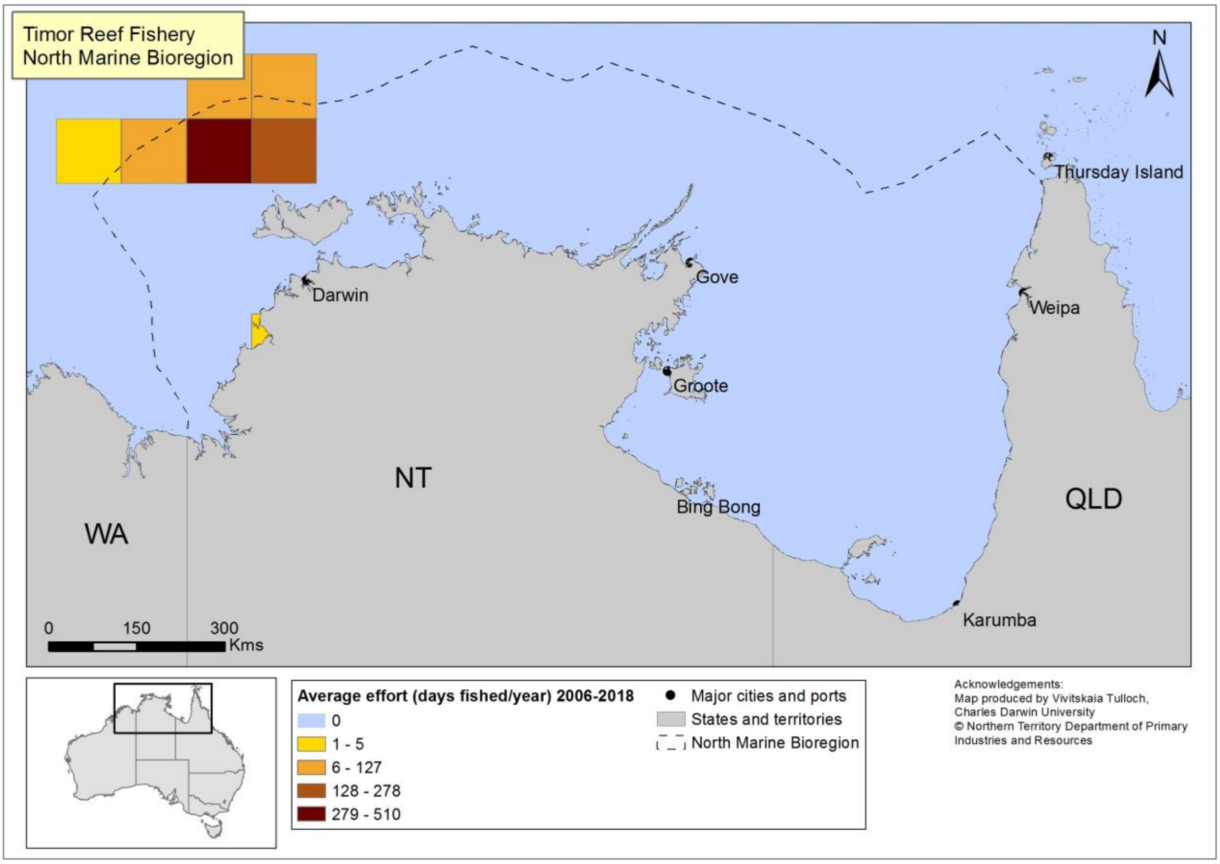

Figure 88. NT Timor Reef Fishery effort within the North Marine Bioregion. Effort dated from 2006 to 2017, where fishery was operational.

Summary of NT Fisheries Effort

The effort varies vastly from fishery to fishery (average annual effort ranging from 4 to 9,850 days fished), as such the 5 colour codes used in the NT Fishery Effort figures presented above represent a wide range of effort from one figure to the next. Table 11 provides a summary of the effort data, to indicate the relative effort across the region, and Figure 89 shows the cumulative Northern Territory fisheries effort (reproduced from Figure 15A in the Pressures chapter, but included here in the context of this review of fishing effort).

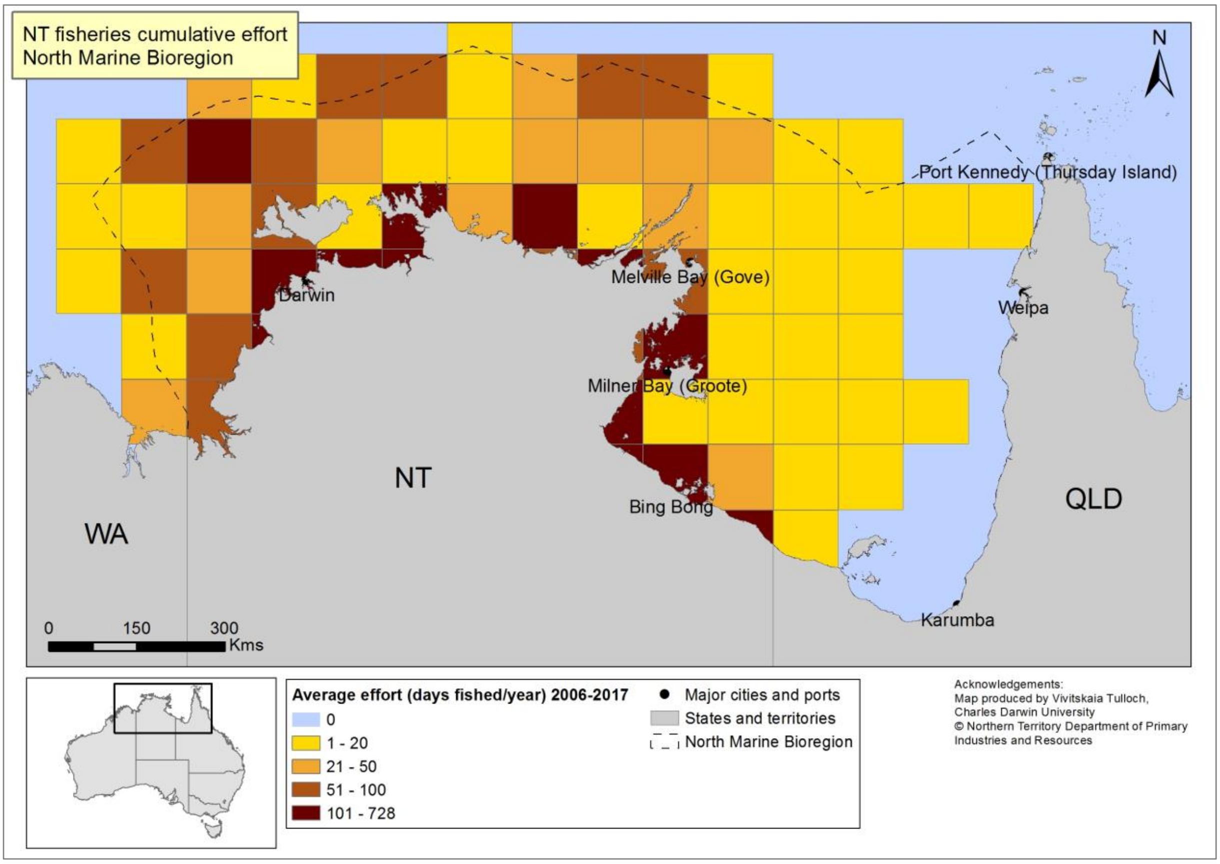

Figure 89. Cumulative fishing pressure map for NT fisheries (Department of Primary Industry and Resources), calculated from the average of the days fished per effort ID and grid square, summed across all fisheries, where dark areas indicate high historical pressure, and lighter areas indicate lower pressure.

Table 11. Summary of effort across 14 NT Fisheries, giving the annual average across each fishery (2006 – 2017) and the total cumulative effort from 2006 – 2017, calculated by summing the total effort for all years (data provided by NT Department of Primary Industry and Resources).

Fishery	Primary Fishing Gear Type	Average of Days fished across fishery (2006–2017)	Sum of Days fished across fishery (2006–2017)
Coastal line	Vertical line	593	7121
Coastal net	Gillnet	154	1847
Bait net	Gillnet	13	79
Spanish Mackerel	Troll line	859	10313
Offshore Net and Line	Pelagic gillnet	757	9087
Demersal	Trawl	785	9416
Barramundi	Gillnet	2681	32168
Mud Crab	Pot	9850	118203
Mollusc	Hand collection	4	4
Aquarium Display	Multiple gear types	186	2227
Trepang	Hand collection	102	1122
Restricted Bait	Gillnet	2182	26189
Finfish Trawl (to 2012)	Trawl	257	1802
Timor Reef	Trap; trawl	1036	12429

6.4.3 Queensland Fisheries

Line Fishery

The Queensland (QLD)-managed Gulf of Carpentaria Line Fishery (Figure 90) operates from Slade Point near the tip of Cape York Peninsula to the QLD-NT border. Trolling gear, bottom handlines, and drop lines are used to target predominately Spanish Mackerel, as well as demersal fin fish such as snappers. Management is through input control, particularly individual transferrable effort units, gear and catch restrictions, and spatial closures. The primary fishing gear used in this fishery presents low risk of interaction with Threatened and Migratory marine species.

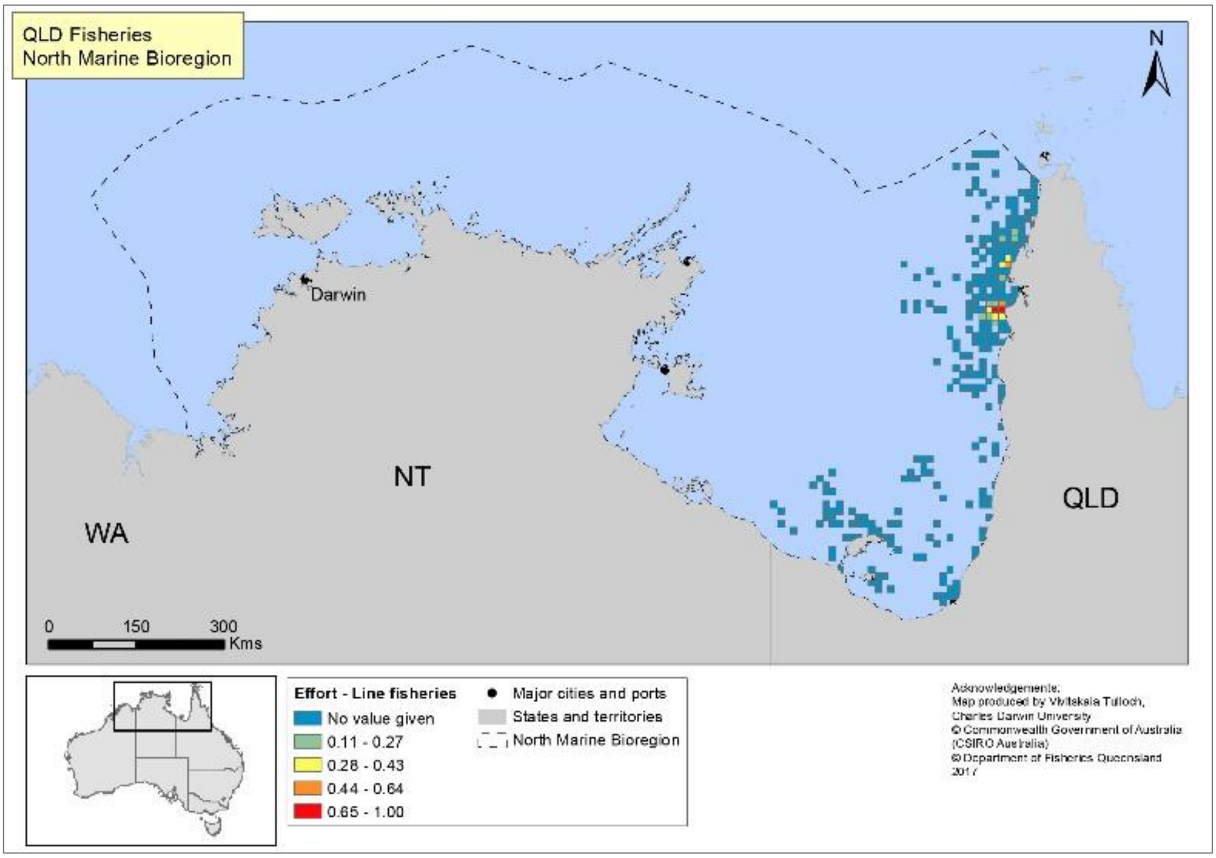

Figure 90. QLD Line Fishery effort (standardised to 0–1) within the North Marine Bioregion, from 2002 to present. Due to fisheries effort confidentiality issues, spatial effort information were not provided for the majority of the fishery extent, these cells are identified as “no value given” (blue).

Net Fishery

The QLD-managed Net Fishery (Figure 91) operates from Slade Point near the tip of Cape York to the QLD–NT border, in tidal waterways, as well as estuaries and the foreshore. This fishery includes a commercial inshore and offshore net fishery, commercial bait netting, and recreational fishing. Mesh nets, as well as hook and line, are used to target a variety of species, including Barramundi, King Threadfin, tropical sharks, Grey Mackerel, and Mangrove Jack. Cast and seine nets are also used to catch baitfish species, Management is through input controls, including limited entry, boat, gear and catch restrictions, and spatial and temporal closures. Interaction records show that the fishery interacts with dugongs, dolphins (particularly inshore dolphin species), guitarfish, marine turtles, Green, Narrow, Dwarf and Largetooth Sawfish, and Estuarine Crocodiles. The Department of Agriculture and Fisheries (DAF) note that there are also likely interactions with Speartooth Sharks, whales and seabirds, although there are no recent interaction records for these species. These interactions require investigation as the fishery's footprint overlaps with the range and habitat of several Threatened and Migratory marine species, and interactions are likely a concern for species such as sawfishes.

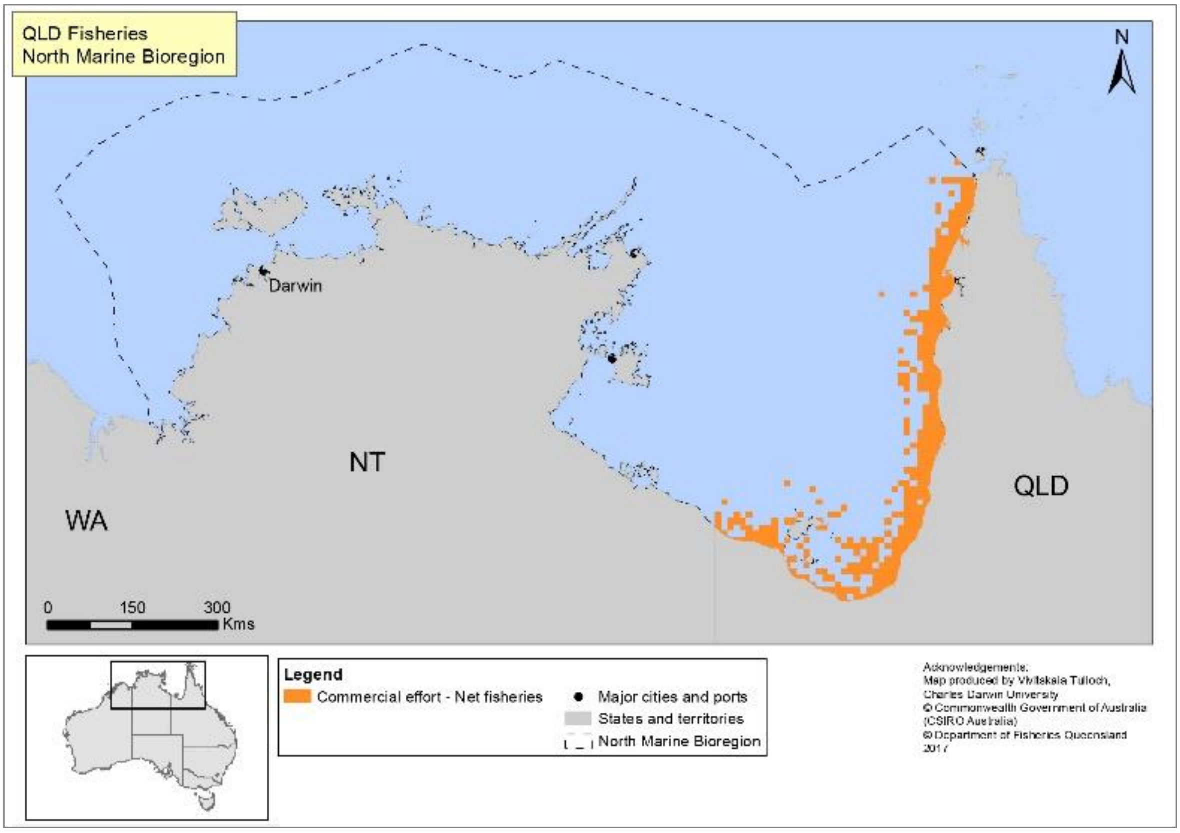

Figure 91. Extent of the QLD Net Fishery within the North Marine Bioregion. Effort data were provided from 2002 to present, where fishery was operational. Due to fisheries confidentiality, fine-scale detail of fishing effort cannot be shown.

Trawl Fishery

The Queensland-managed Gulf of Carpentaria Development Finfish Trawl Fishery (Figure 92) operates in the North Marine Bioregion throughout the Gulf of Carpentaria, beyond 25 nautical miles from the QLD coast to the boundary of the Australian Fishing Zone in the north and the NT border in the west. Otter trawl gear is used to target Crimson and Saddletail Snapper. This fishery operates under developmental fisheries permits, and management action includes input controls, particularly limited entry, individual transferrable effort units, gear restriction, and spatial and seasonal closures. Interaction records show that the fishery interacts with guitarfish, Green, Narrow and Largetooth Sawfish, and Estuarine Crocodiles.

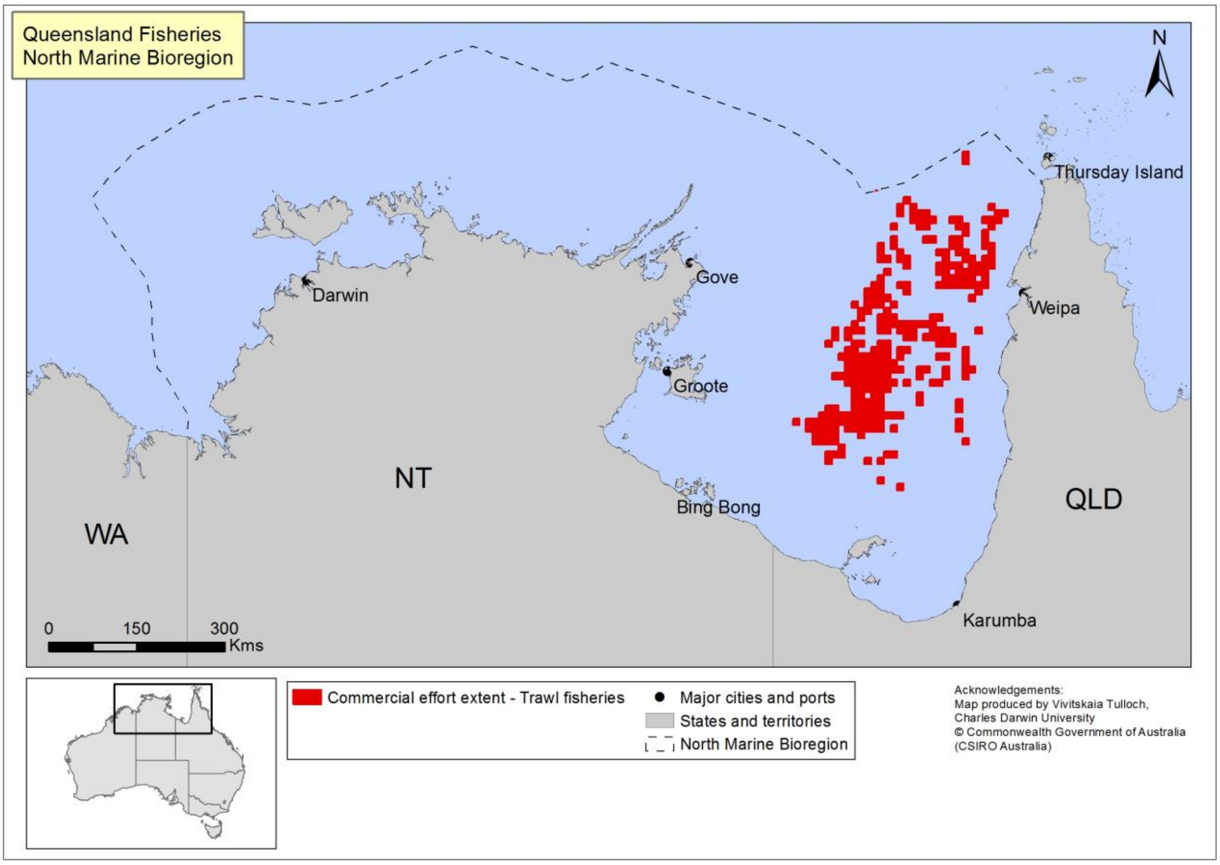

Figure 92. Extent of the Queensland Trawl Fishery within the North Marine Bioregion. Effort data were provided from 2002 to present, where fishery was operational. Due to fisheries confidentiality, fine-scale detail of fishing effort cannot be shown.

Summary of Queensland Fisheries Effort

Figure 93 shows the cumulative Queensland fisheries effort (reproduced from Figure 15B in the Pressures chapter, but included here in the context of this review of fishing effort).

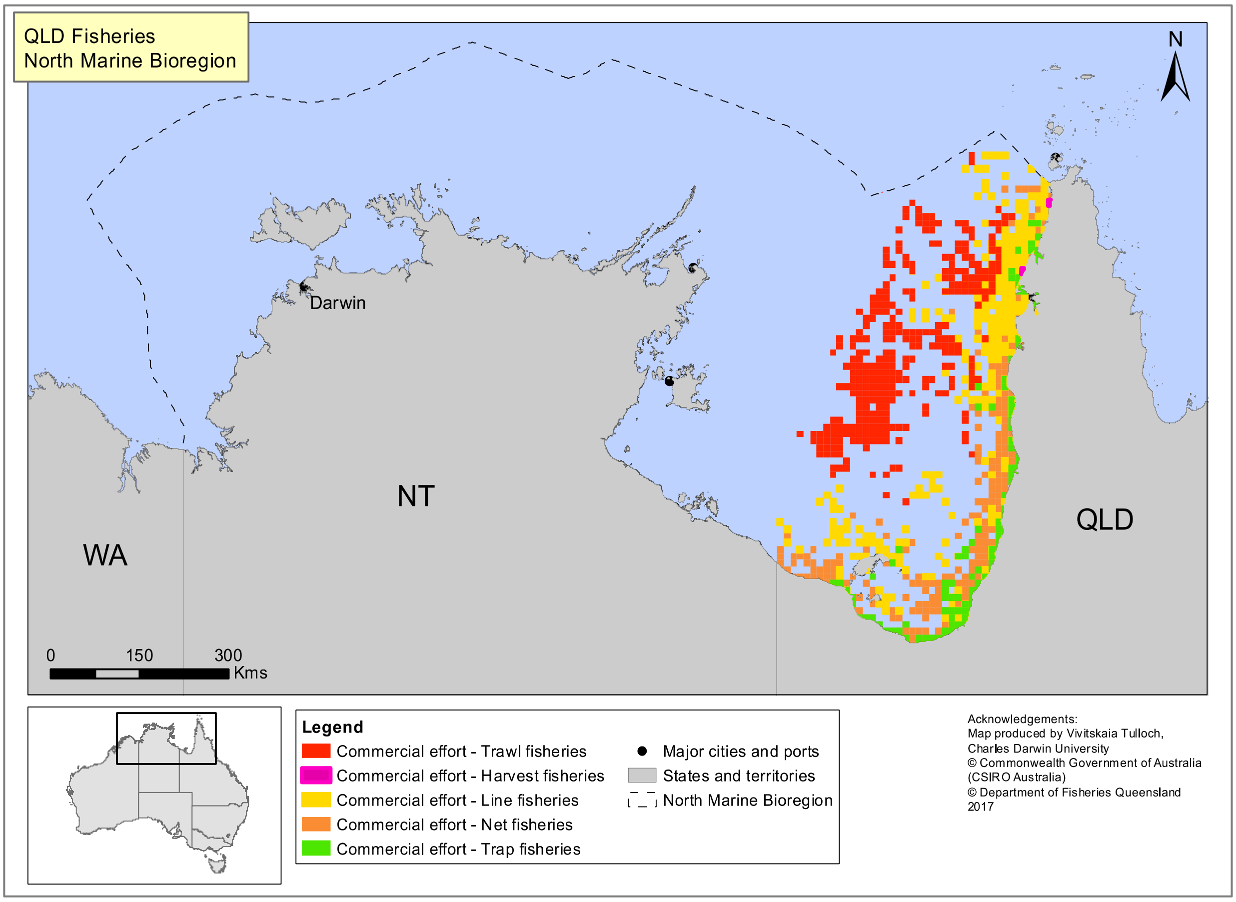

Figure 93. Cumulative fishing pressure map for QLD fisheries (Department of Agriculture and Fisheries), identifying spatial extent of fishery effort only, due to restrictions on data (low vessel numbers).

6.5 Key Issues Identified in the Fisheries Bycatch Workshop

A variety of fisheries in the North Marine Bioregion have the potential to interact with Threatened and Migratory marine species (summarized above). Most interactions occur in trawl and net fisheries (see Synthesis chapter), with the highest level within the Commonwealth-managed Northern Prawn Fishery (the region’s largest fishery).

A one-day workshop was held in Canberra on 08 September 2017 to examine key issues and research needs for understanding interactions with commercial fisheries and their impacts on Threatened and Migratory Species in the North Marine Bioregion. Representatives from the following project partners and research end-users were in attendance: Australian Fisheries Management Authority (AFMA), Charles Darwin University (CDU), Commonwealth Scientific and Industrial Research Organisation (CSIRO), Department of Agriculture and Water Resources (DAWR), Department of the Environment and Energy (DoEE), Fisheries Research and Development Corporation (FRDC), NESP Marine Biodiversity Hub (NESP MBH), Northern Prawn Fishery Industry (NPF Industry), Northern Territory Fisheries, and Queensland Fisheries.

The starting point for discussions at the fisheries bycatch workshop were the 16 priority species identified by work undertaken for the Species component of the project (Table 1). However, the group also considered the full list of ~80 Threatened and Migratory marine species found in the North Marine Bioregion to identify any additional priority species. Consequently, two additional species were considered priorities due to known or suspected interactions with commercial fisheries, namely:

1. Leatherback Turtle *Dermochelys coriacea*: as this species is known from the Northern Territory and has the potential to interact with fishing gear; and,
2. Narrow Sawfish *Anoxypristis cuspidata*: as there is a high number of fisheries interactions and concerns over identification and recording.

Hammerhead sharks (including the Winghead Shark *Eusphyra blochii*) were also considered, however, there is currently an active NESP project specifically for hammerheads in Northern Australia, which fisheries agencies have provided data for.

Key issues and needs identified at the fisheries bycatch workshop are summarised in Table 12 and discussed below.

Table 12. Key issues and needs in relation to Threatened and Migratory marine species bycatch in commercial fisheries in the North Marine Bioregion as identified at the project fisheries bycatch workshop.

Key Issue	Need
Knowledge gaps in species' habitat use	Need to understand habitat use and movement ecology to understand potential for interactions
Knowledge gaps in population connectivity	Need to understand how populations are delineated and connected both within Australia, and between Australia and neighbouring countries
Data collation	Need to collate and understand existing data to prioritise future research and resources
Species identification	Need to improve species identification through industry training
Logbook recording	Need to improve logbook recording through improved species identification and industry training
Safe release and handling	Need to encourage best practice methods for handling and release through industry training
Post-release survival	Need to understand post-release fate of discarded species
Cumulative impacts	Need to understand cumulative impacts of commercial, recreational, and Indigenous interactions

In addressing the issues and needs outlined in Table 12, it was recognised that:

- Industry involvement has been highlighted as a key component for the most effective information sharing;
- Continued fisheries independent surveys and research are needed to better understand stock structure and recruitment;
- For some species, avoidance of capture is unlikely (sawfishes), and efforts should focus on mitigation (including potential spatial management). It is possible that certain characteristics of fisheries currently in place to increase capture efficiency of target species (e.g. moving nets off the seafloor) may also act as inherent mitigation measures for species at risk; and,

- Cumulative impacts over the entirety of a species' range is required to assess if changes in conservation status are needed.

6.5.1 Knowledge Gaps and Data Collation

The workshop recognised and acknowledged that there are large knowledge gaps in species' habitat use and population connectivity (both within and outside of Australian waters), as well as species' interactions with fisheries. An understanding of existing data is required to address key concerns and direct research and resource prioritization.

It was highlighted that a collation of all relevant research from national and international stakeholders and sources is required on topics that should include, but not limited to:

Species ecology:

- Abundance;
- Critical habitat and hotspots;
- Movement and population connectivity;
- Recruitment; and,
- Stock structure.

Fisheries:

- Fishing methods;
- Spatial and temporal effort of fleet;
- Species interactions with gear (e.g. avoidance, behaviour in net);
- Mitigation, including methods deemed as both successes and failures (e.g. closures, changes in gear, deterrents);
- Best practice methods;
- Observer coverage; and,
- Co-operation (or lack of) with fishers.

The Northern Seascapes scoping project addressed some of these topics to some degree, but was not a comprehensive review of all of these topics.

Regular biological sampling (e.g. fin clips) has been recommended during capture and release. These samples are critical to understand population connectivity. The Northern Seascapes project is working with NPF Industry to obtain tissue samples from Narrow Sawfish to assess population structure and connectivity, and consider if the NPF is interacting with a single or multiple populations of the species.

National Bycatch Reporting System

The FRDC has progressed the development of a National Bycatch Reporting System with the recent release of a new report (Kennelly 2018). The aim was to develop a framework to report ongoing and more robust estimates of bycatch and discards across Australian fisheries jurisdictions, and the report included a case study of Northern Territory commercial fisheries. One of the key recommendations was that 'Substantial effort needs to focus on better ways to monitor interactions with TEP (Threatened, Endangered and Protected) species, perhaps by embracing current work occurring in the field of Electronic Monitoring using video and/or still photography to augment and audit industry-based reporting' (Kennelly 2018).

6.5.2 Improved Species ID, Logbook Recording, Safe Release and Handling

There are concerns over species identification and the lack of available data on bycatch. At sea, large animals are not often landed on deck, making identification to the species level difficult (particularly for sawfishes). Additional challenges include the use of multiple logbooks and inconsistencies with logbook recordings, minimal (to no) observer coverage, particularly on small vessels, and a lack of cooperation between jurisdictions for data sharing.

Industry Training

To improve species identification, particularly those species identified as high risk, educating and reinforcing effective training for skippers and crew over time is required. In particular, the need for improved identification of sawfish species has been noted. CSIRO has supplied some skippers with cameras, complete with GPS and dated photos to photograph bycatch. This information will be later analysed for validation of identification at sea. There is an emphasis in fostering trust with industry to encourage reporting of interactions. It should be stressed that this collection of information will not always result in penalties (e.g. closures). Feedback of data to industry should be improved.

Safe Release

Best practice methods for handling and release should be encouraged. It was suggested that an accredited course should be offered for skippers and crew, which may also assist with improved species identification. At present, there is no handling guide for sawfish in NT, and the implementation of such could be complemented with a tagging study to better understand species movement. To reduce the likelihood of injury, attempts are being made to tie fish to the side of vessels for release rather than hauling catch on deck.

A study examining handling practices in Commonwealth-managed commercial fisheries (Bruce *et al.* 2014) found that fisher desire to release shark and ray bycatch was high, but was ‘constrained by the need to conduct fishing operation safely and in an economically efficient manner’. This study concluded that significant improvements through the introduction of ‘improved handling practices’ are unlikely beyond what is already happening at sea.

6.5.3 Understanding Post-Release Survival

Across species, there is a lack of information on post-release survival of discarded individuals. Highlighted species of concern included all sawfishes and Olive Ridley Turtles in the Northern Territory.

Research is needed to understand the full effects of post-release survival. Current implementations include reporting on condition (alive, dead, injured) coupled with photographic evidence and attaching cameras to nets for observation. Tagging studies (e.g. fin tags for turtles; satellite tagging of released individuals) are required to monitor post-release across all life history stages.

Without good data on interactions in all fisheries across the North Marine Bioregion, it is difficult to assess the cumulative impact of commercial fisheries. Furthermore, this chapter did not assess interactions with recreational fisheries, or Indigenous harvest, which would need to be included in any holistic analysis of the impact of fishing activities on Threatened and Migratory marine species in Northern Australia.

6.5.4 Sawfishes

In the context of the broad topics outlined above, workshop participants focused discussion on sawfishes as a group of particular interest. Several knowledge gaps specific to sawfish were identified:

- Population size and structure;
- Habitats of importance to different life history stages;
- Life history movements and the effects of barrages, habitat loss and modification;
- Spatial overlap with fisheries;
- Level of interactions across all fisheries (commercial, recreational and Indigenous); and,
- Post-release survival survivorship across all life history stages.

This information is required for future assessments (e.g. risk analysis) and the importance of a high level of confidence in the data has been emphasised. Clear messages of the importance of sawfish research were expressed by research end-users.

It is unlikely that fisheries interactions are to be avoided given the spatial distribution overlap with fishing effort and the species' attraction to the fishing resources as a food source. There was general consensus that management improvements were needed to limit the number of interactions. Current resources are not successful in mitigating all interactions and alternatives, such as deterrents (e.g. electrical currents), trialling of new gear and modifications of gear, assistance with escapement, need to be explored.

Four species of sawfishes co-occur across Northern Australia, and although life cycles, habitat, and presumably diet differ between species, they all interact with commercial fisheries in the area. On account of high capture rates, Narrow Sawfish has been proposed to be used as a proxy for other sawfish; improving survival of Narrow Sawfish may increase overall survival for all sawfish species.

6.6 References

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7. SYNTHESIS

The Northern Seascapes Scoping Project set out to undertake a situational analysis of *EPBC*-listed Threatened and Migratory marine species in the North Marine Bioregion, to understand gaps in knowledge for these species, historical and ongoing pressures acting on the marine environment, Indigenous priorities and interests in terms of these species, and to undertake a proof of concept for characterising and monitoring the condition and change in extent of coastal habitats.

In this synthesis chapter, we bring together several components of the project to:

- Summarize species gaps;
- Present composite species occurrence maps for the four major taxa groups of interest:
  - Sharks and sawfishes;
  - Marine turtles;
  - Shorebirds; and,
  - Marine mammals;
- Present a pressure-species interaction risk assessment;
- Present the intersections between pressures and species distribution gaps;
- Overlay future pressures with proposed development to produce an ongoing/proposed development map;
- Synthesize Indigenous interest and capacity; and,
- Rank North Marine Bioregion sub-regions as a prioritisation exercise to direct future research focus.

7.1 Species Gap Analysis

In this project, a gap analysis for 16 agreed priority Threatened and Migratory marine species (Table 13) was undertaken to identify where information was lacking within the North Marine Bioregion. The gap analysis was first conducted on information collated from the Species Profile and Threats Database (SPRAT) and distribution maps. This was then updated with new information and data found in the peer-reviewed literature, grey literature, unpublished data, and open access databases (see Chapter 2).

Table 13. The 16 priority species selected for the project, and their final overall gap classification after considering the impact of new knowledge and data. Species are ranked from low to high and colour-coded to aid interpretation (red: low score = large knowledge gaps; orange; medium score = moderate knowledge gaps; green: high score = low knowledge gaps). See Table 4 for gaps and recommendations.

Common name	Species
Dwarf Sawfish	***Pristis clavata***
Green Sawfish	***Pristis zijsron***
Speartooth Shark	***Glyphis glyphis***
Northern River Shark	***Glyphis garricki***
Largetooth Sawfish	***Pristis pristis***
Australian Humpback Dolphin	***Sousa sahulensis***
Hawksbill Turtle	***Eretmochelys imbricata***
Australian Snubfin Dolphin	***Orcaella heinsohni***
Dugong	***Dugong dugon***
Olive Ridley Turtle	***Lepidochelys olivacea***
Red Knot	***Calidris canutus***
Curlew Sandpiper	***Calidris ferruginea***
Great Knot	***Calidris tenuirostris***
Greater Sand-Plover	***Charadrius leschenaultia***
Lesser Sand-Plover	***Charadrius mongolus***
Eastern Curlew	***Numenius madagascariensis***

Dwarf and then Green Sawfish had the most data gaps, indicating that these were the most poorly-known of the selected priority species in the North Marine Bioregion, and as such are a priority for research. These were followed (in order of data gaps) by the other sharks and sawfishes, inshore dolphins, Hawksbill Turtle, Dugong, Olive Ridley Turtle, and shorebirds. Research assessing the relevance and impact of pressures was identified as a gap for all species. New data identified during the project can fill data gaps for all 16 species, and the analysis of these datasets can improve the accuracy of distribution maps, but new data collection is still required for all sharks and sawfishes, Hawksbill Turtle, and inshore dolphins to improve data coverage for distribution modelling and mapping.

The gap analysis identified numerous new datasets, both published and unpublished, that are currently not incorporated into SPRAT profiles and distributions (see Table 5). This provided an opportunity to begin compiling and analysing this information to fill current data gaps, as well as identify targeted research needs for the future.

7.2 Species Composite Maps

For each priority species, we created occurrence values by grid cell, where presence rankings as identified through the SPRAT process (see Table 14) were re-scaled between 0 and 1, and the inverse of this value used as the revised occurrence ranking so that the distribution attributes describing "known" occurrence were given a higher value than those that were "likely" or "may occur". We then created four composite species data maps for each of the species groupings (sawfishes and sharks; turtles; shorebirds; marine mammals) by summing over all species the group, and re-scaling the values for the species in each group between 0 and 1, to identify areas of high probability of occurrence (1) versus low probability (<0.1) (Figures 94–97). Re-scaling was conducted to derive a unitless value that could be combined with the re-scaled pressures value to quantitatively identify areas of overlap between species distributions and pressures (see Section 7.4).

To find areas where there is still uncertainty in species distributions, we then revised the composite maps by changing values for each species where the SPRAT presence was "known" (rankings between 21 and 28; Table 14) to zero, and then recalculating the composite values (Figures 94–97). This left only categories listed under "likely" or "may occur" (SPRAT rankings 31–46), and allowed us to quantitatively rank areas where surveys might improve knowledge of the distribution of that species (where higher values identify areas where all priority species in that grouping are more likely to occur, but have not yet been observed, versus low values that contain more uncertainty).

Table 14. Rankings for each presence attribute as devised for the SPRAT species distributions.

RANK	PRESENCE
21	**Breeding known** to occur within area
22	**Roosting known** to occur within area
23	**Foraging**, feeding or related behaviour **known** to occur within area
24	**Congregation** or **aggregation known** to occur within area
25	**Migration** route **known** to occur within area
26	**Species** or species habitat **known** to occur within area
28	**Translocated population likely** to occur within area
31	**Breeding likely** to occur within area
32	**Roosting likely** to occur within area
33	**Foraging**, feeding or related behaviour **likely** to occur within area
34	**Congregation** or **aggregation likely** to occur within area
35	**Migration** route **likely** to occur within area
36	**Species** or species habitat **likely** to occur within area
41	**Breeding may** occur within area
42	**Roosting may** occur within area
43	**Foraging**, feeding or related behaviour **may** occur within area
44	**Congregation** or **aggregation may** occur within area
45	**Migration** route **may** occur within area
46	**Species** or species habitat **may** occur within area

7.2.1 Sharks and Sawfishes

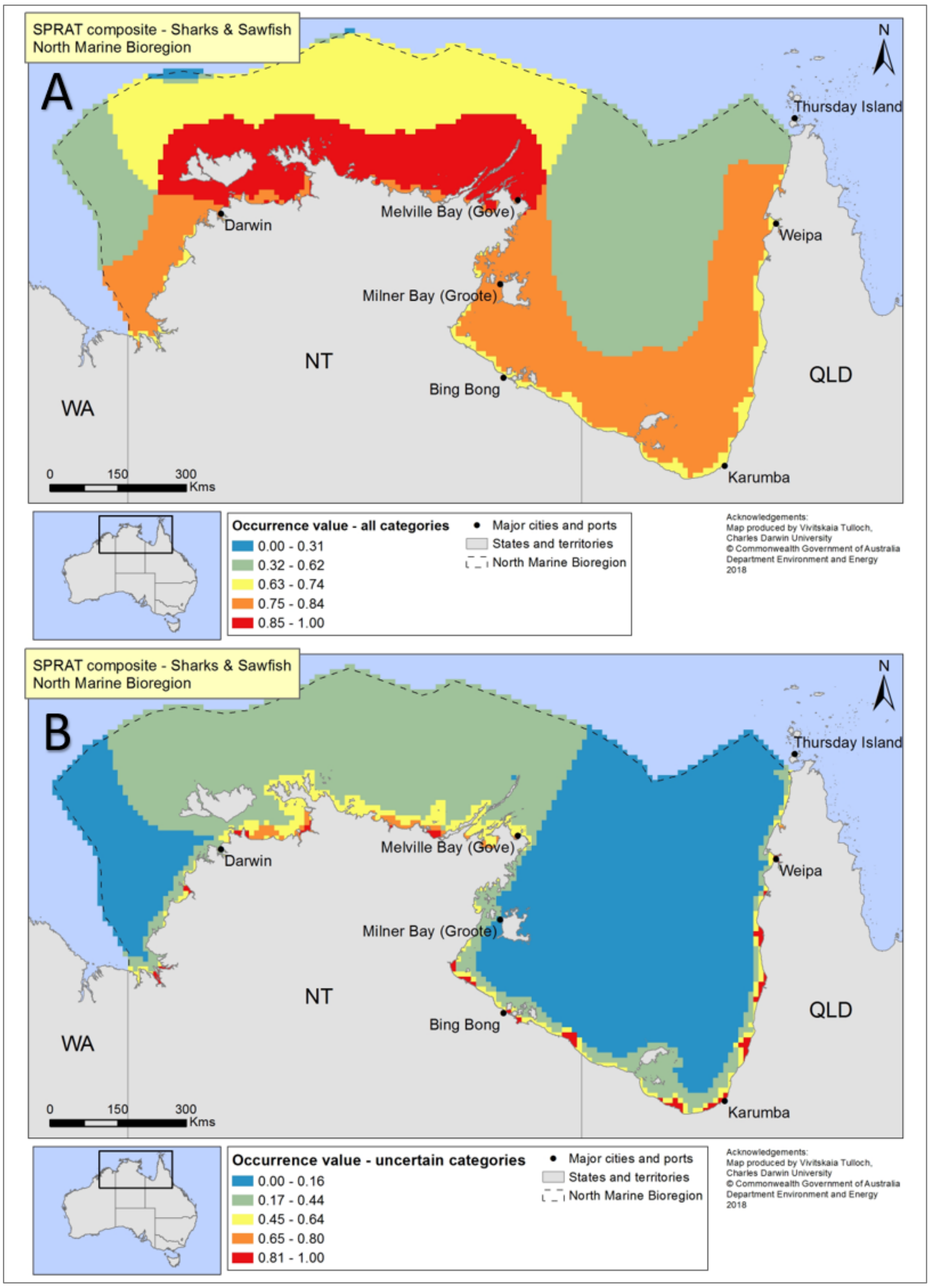


Figure 94. Composite species distribution maps for sharks and sawfishes (Northern River Shark, Speartooth Shark, Dwarf Sawfish, Largetooth Sawfish, Green Sawfish) from SPRAT rankings for (A) all SPRAT categories, and (B) for uncertain categories only (“may occur” and “likely”), which were summed for all 5 priority shark and sawfish species, then re-scaled between 0 and 1. Scales between the two map types are not directly comparable.

7.2.2 Marine Turtles

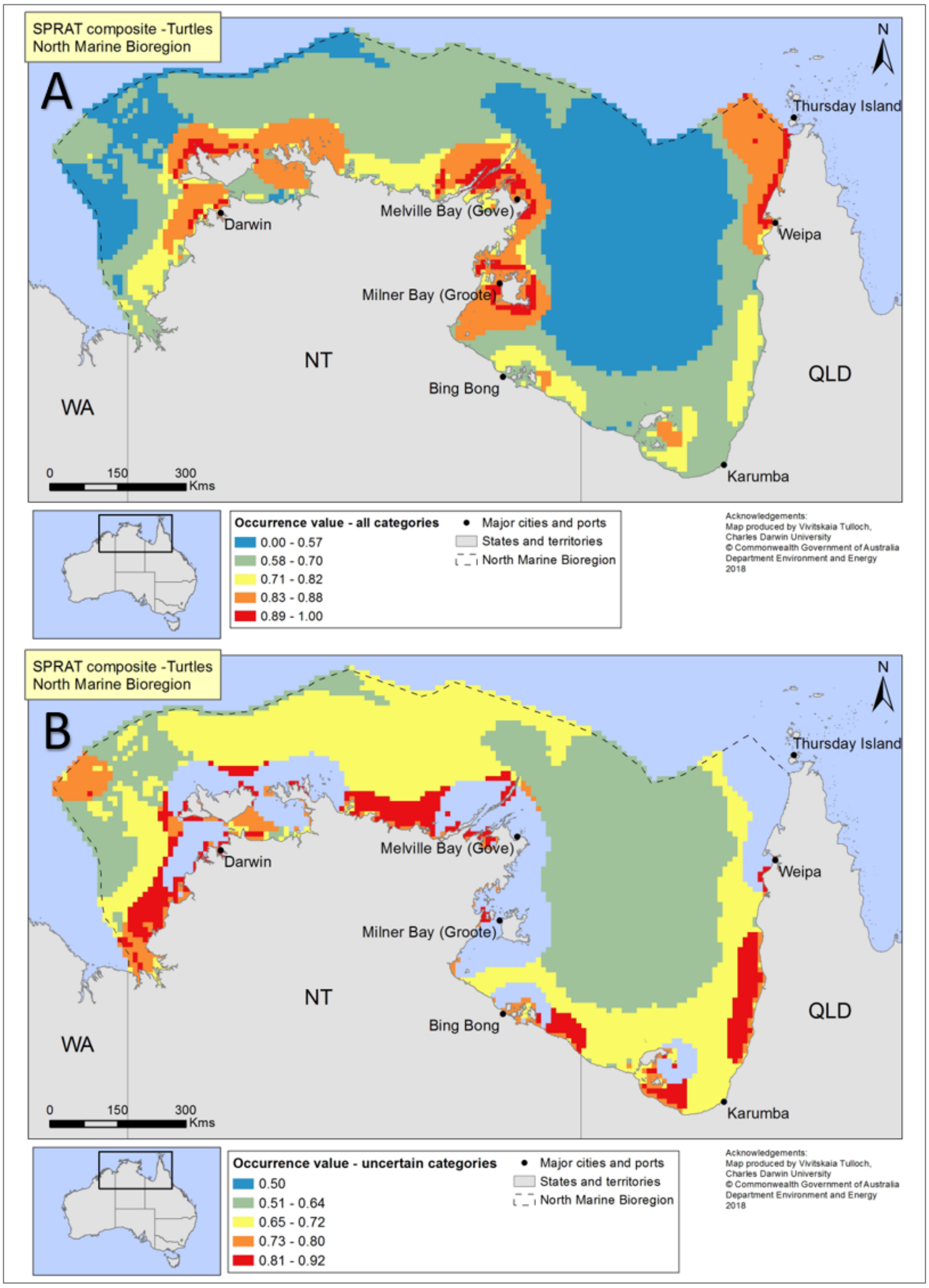


Figure 95. Composite species distribution maps for marine turtles (Hawksbill Turtle, Olive Ridley Turtle) derived from SPRAT rankings for (A) all SPRAT categories, and (B) for uncertain categories only ("may occur" and "likely"), which were summed for the 2 priority species, then re-scaled between 0 and 1. Scales between the two map types are not directly comparable.

7.2.3 Shorebirds

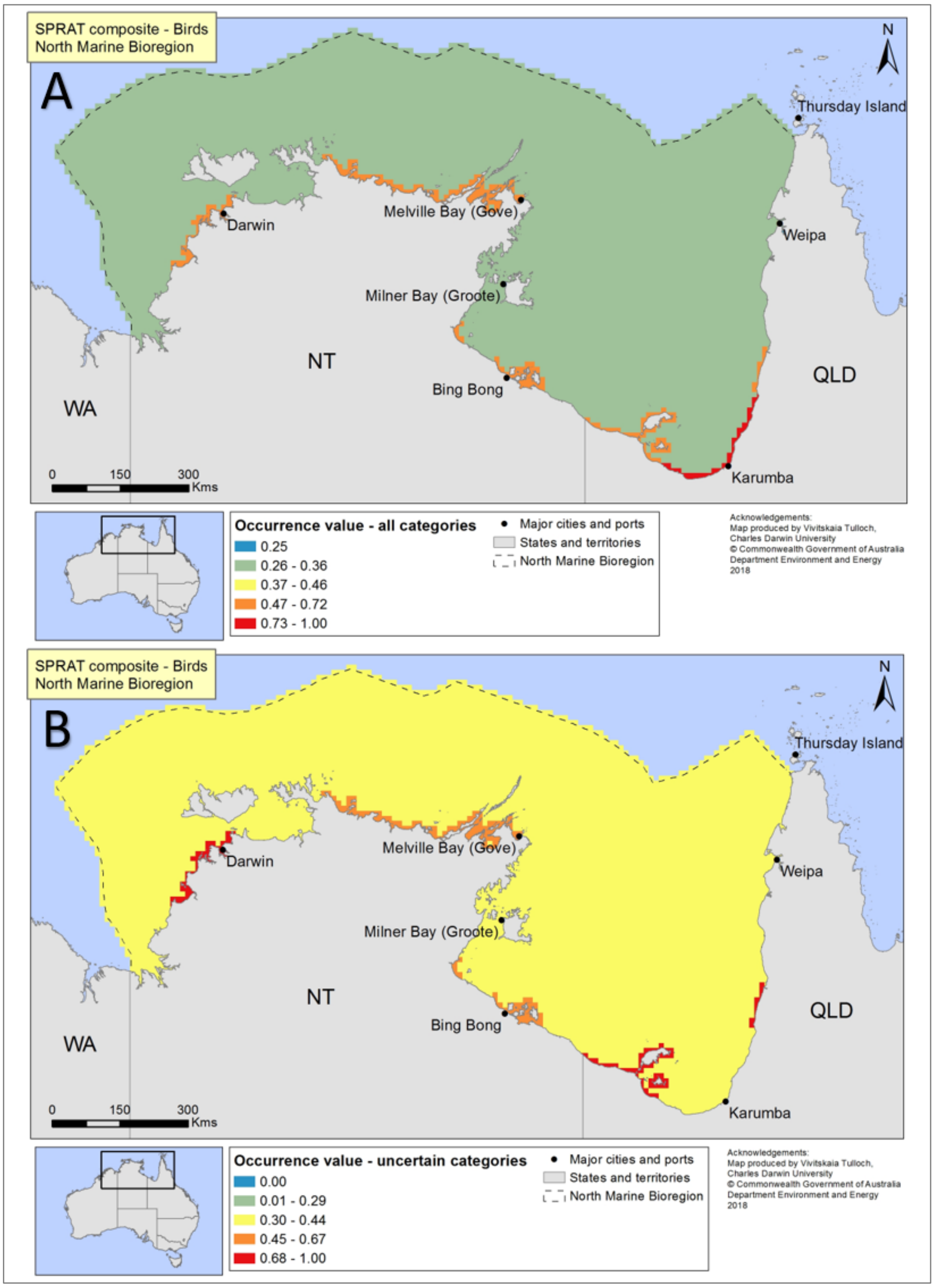


Figure 96. Composite species distribution maps for shorebirds (Red Knot, Curlew Sandpiper, Great Knot, Greater Sand-Plover, Lesser Sand-Plover, Eastern Curlew) derived from SPRAT rankings for (A) all SPRAT categories, and (B) for uncertain categories only ("may occur" and "likely"), which were summed for all 6 priority shorebird species, then re-scaled between 0 and 1. Scales between the two map types are not directly comparable.

7.2.4 Marine Mammals

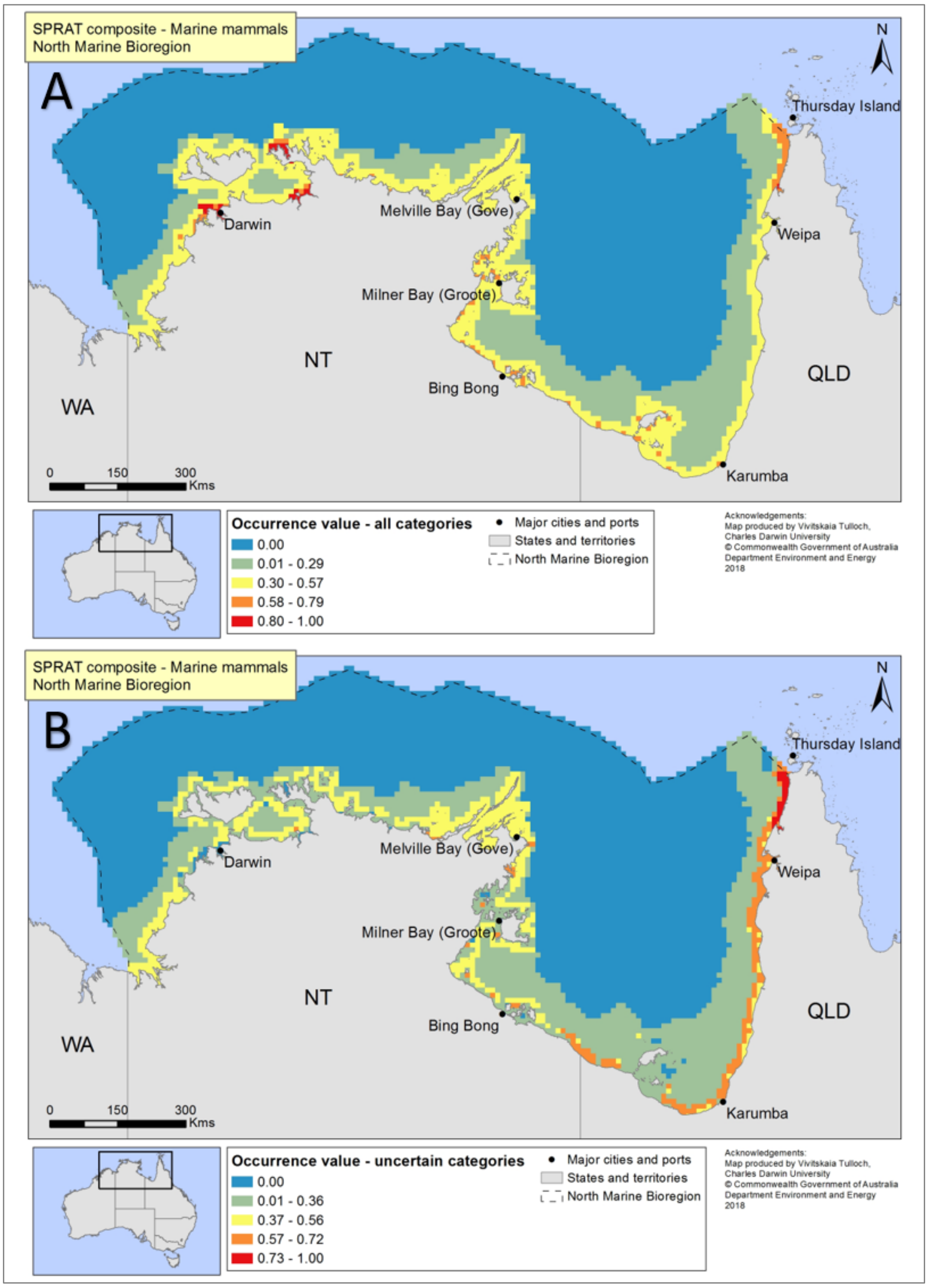


Figure 97. Composite species distribution maps for marine mammals (Dugong, Australian Snubfin Dolphin, Australian Humpback Dolphin) derived from SPRAT rankings for (A) all SPRAT categories, and (B) for uncertain categories only ("may occur" and "likely"), which were summed for the 3 priority mammal species, then re-scaled between 0 and 1. Scales between the two map types are not directly comparable.

7.3 The Interaction between Species and Pressures

To bring together three components of the project – species (Chapter 2), pressures (Chapter 3), and fisheries bycatch (Chapter 6) – we conducted a preliminary pressure-interaction risk assessment. We determined the temporal likelihood of each pressure co-occurring with a species in the North Marine Bioregion, and the consequences of that pressure for the species (Tables 15–18). We assessed the 16 priority species, as well as a selection of other species to broaden the taxonomic scope of this exercise, bringing the total number of species assessed to 27. This information can then be combined with the spatial distribution and intensity of pressures, and spatial information on species distribution and density, to determine relative or cumulative impacts on priority species.

Pressures were as follows: fishing bycatch (by gear: line, trawl, net, trap, recreational), ship-strike and vessel disturbance, Indigenous harvest, marine debris (entanglement or ingestion), chronic pollution (e.g. runoff), acute pollution (e.g. sewage dump, chemical dump), dredging and port development, coastal development, climate change (sea-level rise, climate warming and variability), habitat loss (seagrass), terrestrial predation, light pollution, and seismic noise interference. The majority of these pressures were mapped within the North Marine Bioregion as part of the pressures component of this project (Chapter 3).

The risk matrix was based on an established risk assessment framework used in Recovery Plans including Recovery Plan for Marine Turtles (DEE 2017).

Definitions used for the risk assessment (Table 15) are as follows:

- Likelihood of pressure occurring:
    - Almost certain – expected to occur every year
    - Likely – expected to occur at least once every five years
    - Possible – might occur at some time
    - Unlikely – such events are known to have occurred on a worldwide basis but only a few times
    - Unknown – it is currently unknown how often the incident will occur
- Consequences of pressure:
    - No long-term effect – no long-term effect on individuals or stock
    - Minor – individuals are affected, but no effect at stock level
    - Moderate – stock recovery stalls or reduces

- Major – stock declines
- Catastrophic – stock at risk of extinction

Table 15. Risk assessment matrix framework.

	Consequences				
Likelihood of occurrence (relevant to species)	No long-term effect	Minor	Moderate	Major	Catastrophic
Almost certain	Low	Moderate	Very high	Very high	Very high
Likely	Low	Moderate	High	Very high	Very high
Possible	Low	Moderate	High	Very high	Very high
Unlikely	Low	Low	Moderate	High	Very high
Unknown	Low	Low	Moderate	High	Very high

Levels of risk and the associated priority for action are defined as follows:

- Very High – immediate additional mitigation action required;
- High – additional mitigation action and an adaptive management plan required, the precautionary principle should be applied;
- Moderate – obtain additional information and, where multiple threats receive a moderate rating, develop additional mitigation action if required; or,
- Low – monitor the threat occurrence and reassess threat level if likelihood or consequences change.

We used information from the peer-reviewed literature (largely using information contained within the SPRAT profiles and referenced literature), expert opinion, and quantitative data to develop the likelihood and consequence values for each species. Information on the spread and intensity of pressures developed in Chapter 3 of this report were used to guide the assessment values for "likelihood of occurrence" on a regional basis. Impacts or the "consequences of pressures" on the 27 species were estimated from literature reviews.

Quantitative data were obtained on historical interactions between species and pressures for the following pressures (Table 17):

- Commercial fishing interactions (bycatch and entanglements – NPF Industry, NT Fisheries, Queensland Fisheries, and AFMA);
- Marine debris interactions (including derelict fishing gear); and,
- Ship-strike and stranding data – Incidental stranding records from NT and Qld, and Commonwealth fisheries.

Commercial fisheries effort and interactions (bycatch and strandings due to entanglements) were provided for "Threatened, Endangered and Protected Species" (TEPS; incorporating Threatened and Migratory marine species of interest to this project) by State/Territory and Commonwealth fisheries, with information on species, year, fishery, and spatial location of interaction.

There is only one Commonwealth-managed fishery currently operating in the North Marine Bioregion with reported interactions, the Northern Prawn Fishery (NPF). Interaction data for priority species were provided for 2008 to 2016 by the NPF Industry. Queensland fisheries interaction data with Species of Conservation Interest (SOCI) were acquired from the Department of Agriculture and Fisheries for the Gulf of Carpentaria for the years 1997–2017. Interactions were provided by fishery, species and year, but due to their confidentiality policy there were no spatial information included with each interaction. Effort data have been previously collated by the NESP Marine Biodiversity Hub and are shown in the pressures section of this project (Chapter 3, Figure 15B). Northern Territory fisheries effort data were obtained for all active fisheries for the years 2006–2017, but interaction data were provided for a smaller number of fisheries due to inconsistencies in reporting effort over time between the various fisheries.

We used fisheries effort data, or the spread of fishing pressure (as shown in Chapter 3), to parameterize the regional "likelihood" component of the risk assessment for fisheries impacts. Fisheries interaction, including strandings and ghost net interactions, were used to parameterize the "consequences" component.

We used the best available information to assess impacts of marine debris on the priority species. Information on the spread and impacts of marine debris were obtained from Department reports and consultancy reports (ANZECC 1996, Ceccarelli 2009), as well as peer-reviewed literature. Many types of plastic debris have been recorded in incidents with marine wildlife in Australian waters, affecting survival and fitness of turtles, dolphins, and seabirds in particular (Ceccarelli 2009). Most records involve derelict fishing nets (Limpus *et al.* 1999), with the number of records for this type of plastic debris almost an order of magnitude greater than the second most common type, crab pot gear (Ceccarelli 2009). Surveys show that most derelict nets found in northern Australian waters are from foreign (notably Asian) fisheries

(Kiessling and Hamilton 2003). Of these, large mesh drift, gill, and trawl nets are having some of the greatest impacts on wildlife, especially turtles (Leitch 2001). A lack of detail on which plastic types are generally recorded makes it difficult to determine which types of plastic are of most concern.

Information on ghost nets was obtained from spatial modelling work conducted at CSIRO (Wilcox *et al.* 2013) on interaction rates between ghost nets and turtles in the Gulf of Carpentaria, and the peer-reviewed literature (Laist 1987) and extrapolated for other species based on likely impacts.

The risk assessments were undertaken for each species separately to account for the differences in exposure to threats and the species ability to withstand impacts. This could be further refined by stock if necessary. The impact of each pressure has been assessed assuming that existing management measures continue to be applied appropriately.

A summary of species falling in the risk category ‘Very High’ is provided in Table 16. The complete results of the risk analysis are shown in Table 18.

This pressure risk matrix is an important synthesis product as part of this project within the North Marine Bioregion. It provides vital information, to be combined with outputs from the cumulative pressure mapping, and species distribution information when it becomes available, to help guide future management of the North Marine Bioregion. We note, however, that this is a provisional output, and that some pressures (such as Indigenous harvest) included here were not spatially explored in detail in the Pressures component of this project (Chapter 3). A complete assessment will require structured expert elicitation, which was beyond the scope of this project. These risk assessments however are a crucial component of effective decision-making and management of species and systems under pressure and provide information on where further research should focus. Linking risk assessment outputs with cumulative pressure maps and information on species distributions can help managers and decision-makers understand both where the risks are, but also whether intervention in that area is likely to be successful (given that Scales between the two map types are not directly comparable. Here are potentially several pressures impacting any one species).

Table 16. Priority species and pressures classified as Very High in the pressure-species risk assessment (see Table 18 for the full risk analysis).

Common name	Species	Pressure
Dwarf Sawfish	***Pristis clavata***	**Trawl fishing** **Net fishing**
Green Sawfish	***Pristis zijsron***	**Trawl fishing** **Net fishing**
Green Turtle	***Chelonia mydas***	**Entanglement**
Leatherback Turtle	***Dermochelys coriacea***	**Climate warming/variability**
Hawksbill Turtle	***Eretmochelys imbricata***	**Entanglement**
Olive Ridley Turtle	***Lepidochelys olivacea***	**Sea-level rise** **Climate warming/variability**
Flatback Turtle	***Natator depressus***	**Entanglement**
Great Knot	***Calidris tenuirostris***	**Port development/dredging** **Coastal development**

Table 17. Summary of fisheries interaction data for the 27 species for which the preliminary pressure-interaction risk assessment was undertaken. Includes commercial fisheries in Queensland and the Northern Territory (NT), stranding data from the NT, and Ghostnet entanglements as reported in Wilcox *et al.* (2013).

			Fisheries Data								Stranding data	Wilcox *et al.* (2013)	
			QLD developmental finfish trawl	QLD inshore finfish net	QLD mud crab	NT Barramundi (net)	NT Finfish Demersal Trawl	NT Timor Reef Trawl	NT Timor Reef Trap	Commonwealth NPF Fishery	NT strandings	Ghostnets	TOTALS
Species	**Common name**	**Class**	**2001-2017**	**2001-2017**	**2001-2017**	**2003-2011**	**2000-2017**	**2014-2017**	**2000-2017**	**2008-2016**	**1997-2017**	**2005-2009**	
Calidris ferruginea	Curlew Sandpiper	bird											**0**
Calidris tenuirostris	Great Knot	bird											**0**
Charadrius leschenaultia	Greater Sand-Plover	bird											**0**
Charadrius mongolus	Lesser Sand-Plover	bird											**0**
Numenius madagascariensis	Eastern Curlew	bird											**0**
Calidris canutus	Red Knot	bird											**0**
Orcaella heinsohni	Snubfin Dolphin	cetacean		1							4		**5**
Pseudorca crassidens	False killer whale	cetacean									6		**6**
Sousa sahulensis	Indo-Pacific Humpback Dolphin	cetacean									8		**8**
Crocodylus porosus	Saltwater Crocodile	croc	2	19	3	3					4		**31**
Manta alfredi	Inshore Manta Ray	ray				1	2*		1*				**1**
Manta birostris	Giant Manta Ray	ray					2*		1*				**0**
Mobula eregoodootenkee	Longhorned Pygmy Devil Ray	ray											**0**
Mobula japonica	Japanese Devil Ray	ray											**0**
Mobula thurstoni	Bentfin Devilray	ray		1									**1**

Glyphis garricki	Northern River Shark	sawfish											**0**
Pristis clavata	Dwarf Sawfish	sawfish		9		20				6			**35**
Pristis pristis	Largetooth Sawfish	sawfish	1	15	1		1			18			**36**
Pristis zijsron	Green Sawfish	sawfish	2	8		30				384			**424**
Glyphis glyphis	Speartooth Shark	shark				1							**1**
Dugong dugon	Dugong	sirenia		1							27		**28**
Caretta caretta	Loggerhead Turtle	turtle								23	6		**29**
Chelonia mydas	Green Turtle	turtle		7			5			105	88	14	**219**
Dermochelys coriacea	Leatherback Turtle	turtle		5						2			**7**
Eretmochelys imbricata	Hawksbill Turtle	turtle		9			1			8	64	35	**117**
Lepidochelys olivacea	Olive Ridley Turtle	turtle		1						47	34	53	**135**
Natator depressus	Flatback Turtle	turtle		2			10			44	28	3	**87**

Table 18. Risk analysis for priority species (VH, very high; H, high; M, moderate; L, low). *Note the fishing categories represent multiple fisheries. NPF, Northern Prawn Fishery.

Species	Fishing*						Vessel	Marine debris		Pollution		Habitat modification			Climate change		Other		
	Line	Trawl (includes NPF)	Net	Trap	Recreational	Hunting/indigenous harvest	Ship/ Boat strike	Entanglement (ghostnets, lost	Ingestion	Chronic - runoff	Acute - sewage outfall, contaminants	Port development/ dredging	Coastal development	Seagrass loss	Sea-level rise	Climate warming / variability	Predation by feral land animals	Light pollution	Seismic
Curlew Sandpiper	L	L	L	L	L	L	L	L	L	M	M	H	H	L	H	L	L	L	L
Great Knot	L	L	L	L	L	L	L	L	L	M	M	VH	VH	L	H	L	L	L	L
Greater Sand-Plover	L	L	L	L	L	L	L	L	L	M	M	H	H	L	H	L	L	L	L
Lesser Sand-Plover	L	L	L	L	L	L	L	L	L	M	M	H	H	L	H	L	L	L	L
Eastern Curlew	L	L	L	L	L	L	L	L	L	M	M	H	H	L	H	L	L	L	L
Red Knot	L	L	L	L	L	L	L	L	L	M	M	H	H	L	H	L	L	L	L
Snubfin Dolphin	M	H	H	L	L	L	M	M	H	L	L	L	L	L	L	H	L	L	M
False Killer Whale	M	H	H	L	L	L	M	M	M	L	L	L	L	L	L	H	L	L	H
Indo-Pacific Humpback Dolphin	M	H	H	L	L	L	M	M	H	L	L	L	L	L	L	H	L	L	M
Estuarine Crocodile	L	M	M	M	M	L	L	L	L	L	L	L	L	L	M	M	M	L	L
Inshore Manta Ray	L	H	H	L	L	L	L	M	L	L	L	L	L	L	L	L	L	L	L

Species	Fishing*						Vessel	Marine debris		Pollution		Habitat modification			Climate change		Other		
	Line	Trawl (includes NPF)	Net	Trap	Recreational	Hunting/indigenous harvest	Ship/ Boat strike	Entanglement (ghostnets, lost	Ingestion	Chronic - runoff	Acute - sewage outfall, contaminants	Port development/ dredging	Coastal development	Seagrass loss	Sea-level rise	Climate warming / variability	Predation by feral land animals	Light pollution	Seismic
Giant Manta Ray	L	H	H	L	L	L	L	M	L	L	L	L	L	L	L	L	L	L	L
Longhorned Pygmy Devil Ray	L	L	H	L	L	L	L	M	L	L	L	L	L	L	M	M	L	L	L
Japanese Devil Ray	L	L	H	L	L	L	L	M	L	L	L	L	L	L	M	M	L	L	L
Bentfin Devil Ray	L	L	H	L	L	L	L	M	L	L	L	L	L	L	M	M	L	L	L
Northern River Shark	M	M	M	L	M	L	L	M	L	L	L	L	L	L	L	L	L	L	L
Dwarf Sawfish	L	VH	VH	L	M	L	L	M	L	L	L	L	L	L	L	L	L	L	L
Largetooth Sawfish	L	M	M	L	M	L	L	M	L	M	M	M	M	L	L	L	L	L	L
Green Sawfish	L	VH	VH	L	M	L	L	M	L	M	M	M	M	L	L	L	L	L	L
Speartooth Shark	M	M	M	L	M	L	L	M	L	M	M	M	M	L	L	L	L	L	L
Dugong	L	L	H	L	L	M	M	M	L	M	H	L	L	H	L	H	L	L	M
Loggerhead Turtle	M	M	M	M	M	L	M	H	H	M	M	M	M	M	L	H	L	M	M
Green Turtle	L	M	M	M	M	H	M	VH	M	M	H	M	M	M	M	M	M	L	M
Leatherback Turtle	M	M	H	H	M	L	M	M	H	L	L	L	L	L	H	VH	M	L	L

Species	Fishing*						Vessel	Marine debris		Pollution		Habitat modification			Climate change		Other		
	Line	Trawl (includes NPF)	Net	Trap	Recreational	Hunting/indigenous harvest	Ship/ Boat strike	Entanglement (ghostnets, lost	Ingestion	Chronic - runoff	Acute - sewage outfall, contaminants	Port development/ dredging	Coastal development	Seagrass loss	Sea-level rise	Climate warming / variability	Predation by feral land animals	Light pollution	Seismic
Hawksbill Turtle	M	M	M	M	M	H	M	VH	M	M	L	L	L	L	H	H	H	L	M
Olive Ridley Turtle	M	M	H	L	M	M	M	VH	M	M	H	L	L	L	VH	VH	H	M	L
Flatback Turtle	L	M	M	M	M	M	M	VH	M	H	H	M	M	M	H	H	H	M	M

*see Table 17 for interaction data used to evaluate risk for the 27 species

7.4 Intersections Between Pressures and Species Distribution Gaps

We produced four composite species-pressure data maps for each of the species groupings (sharks and sawfishes, turtles, shorebirds, marine mammals) showing the intersection between the SPRAT distribution gaps in knowledge, and the current/on-going pressures and future development map (Figure 98–101). The intersection was calculated by adding the re-scaled ongoing pressures value in each grid cell to the composite re-scaled SPRAT occurrence value for "likely to occur" and "may occur" categories (summed for all species and re-scaled between 0 and 1). The focus for this scoping exercise was to identify areas where more information would be most useful and not the "known to occur" areas where the likelihood of impact might be expected to be the greatest. Likelihood and consequence of impact can be determined applying the impact categories in Table 18, but was beyond the remit of this scoping study.

We limited our analyses to anthropogenic drivers with pre-existing coverage across the North Marine Bioregion or those for which we could assemble or develop coverage across the region. Although many regional-scale data, and data with a global scope but incomplete coverage, exist for a variety of specific human activities, inclusion of these data would bias comparisons across the entire region and so were excluded. Long-term future commercial fisheries effort is difficult to predict spatially. We assumed that the most recent 5 years of fishing effort likely inform approximately where future effort might be. This is likely to underestimate true future effort for some fisheries, but is the best estimate given existing data.

Mapping the intersection between pressures and species distribution gaps highlights regions where there are high cumulative pressures as well as areas where the species distribution is still uncertain, and could be improved with more surveys.

7.4.1 Sharks and Sawfishes

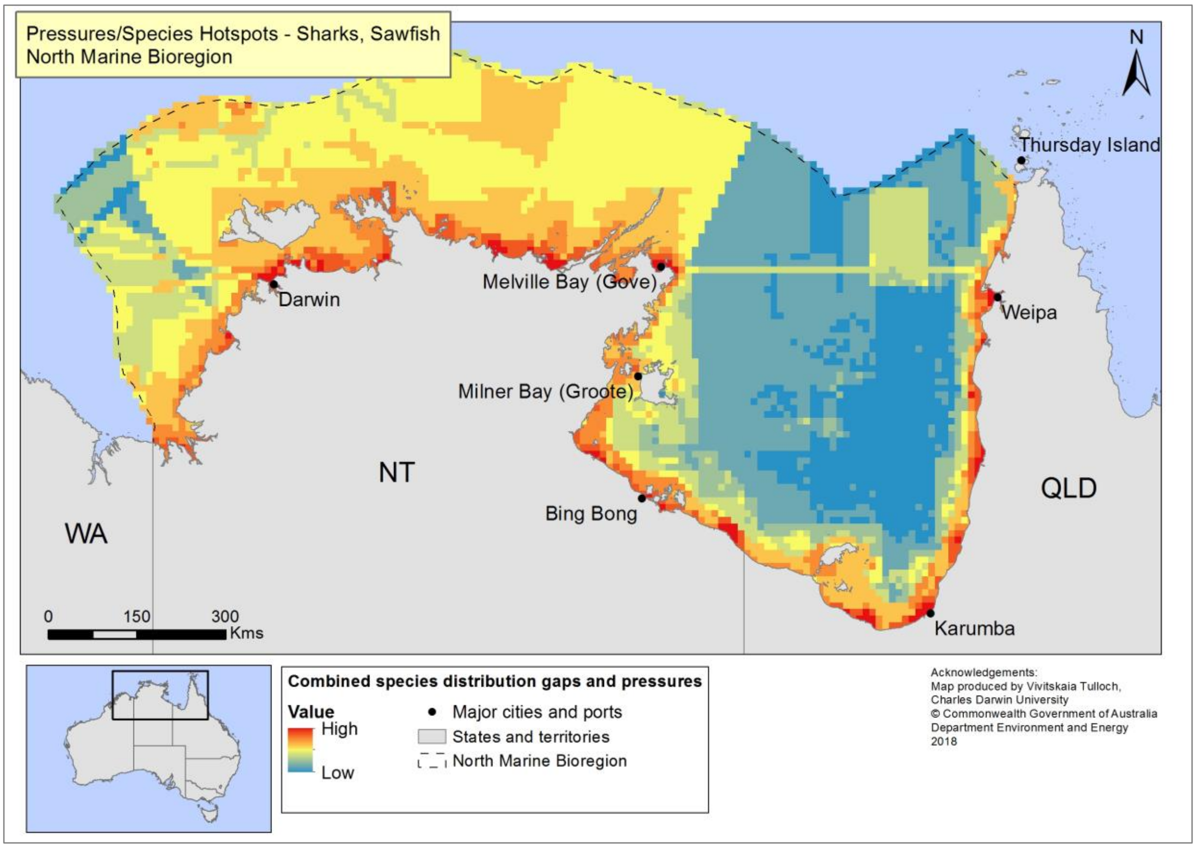


Figure 98. Hotspots of overlap between ongoing pressures and gaps in priority shark and sawfish species distributions (Northern River Shark, Speartooth Shark, Dwarf Sawfish, Largetooth Sawfish, Green Sawfish), derived by adding the re-scaled distribution values for uncertain SPRAT categories, and the re-scaled ongoing cumulative pressure values.

7.4.2 Marine Turtles

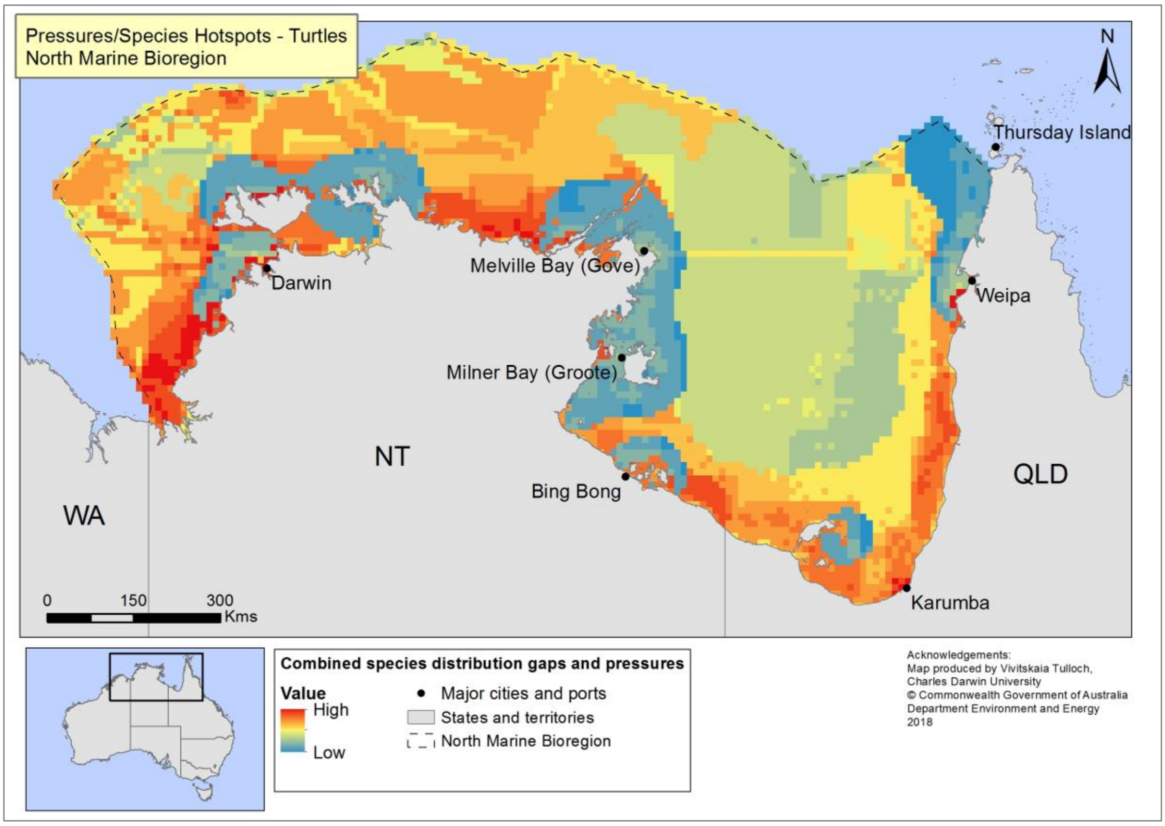


Figure 99. Hotspots of overlap between ongoing pressures and gaps in priority turtle species distributions (Hawksbill Turtle, Olive Ridley Turtle), derived by adding the re-scaled distribution value for uncertain SPRAT categories, and the re-scaled ongoing cumulative pressure values.

7.4.3 Shorebirds

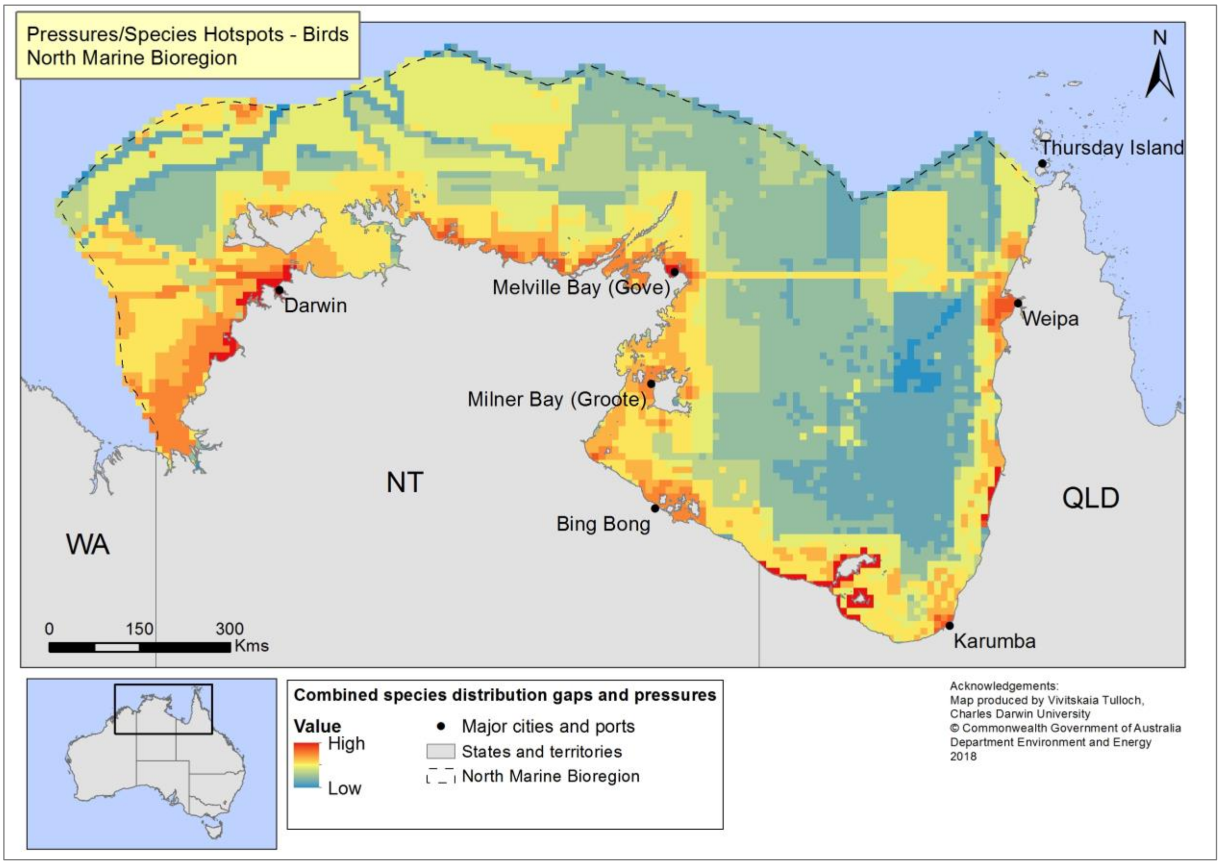


Figure 100. Hotspots of overlap between ongoing pressures and gaps in shorebird species distributions (Red Knot, Curlew Sandpiper, Great Knot, Greater Sand-Plover, Lesser Sand-Plover, Eastern Curlew), derived by adding the re-scaled distribution value for uncertain SPRAT categories, and the re-scaled ongoing cumulative pressure values.

7.4.4 Marine Mammals

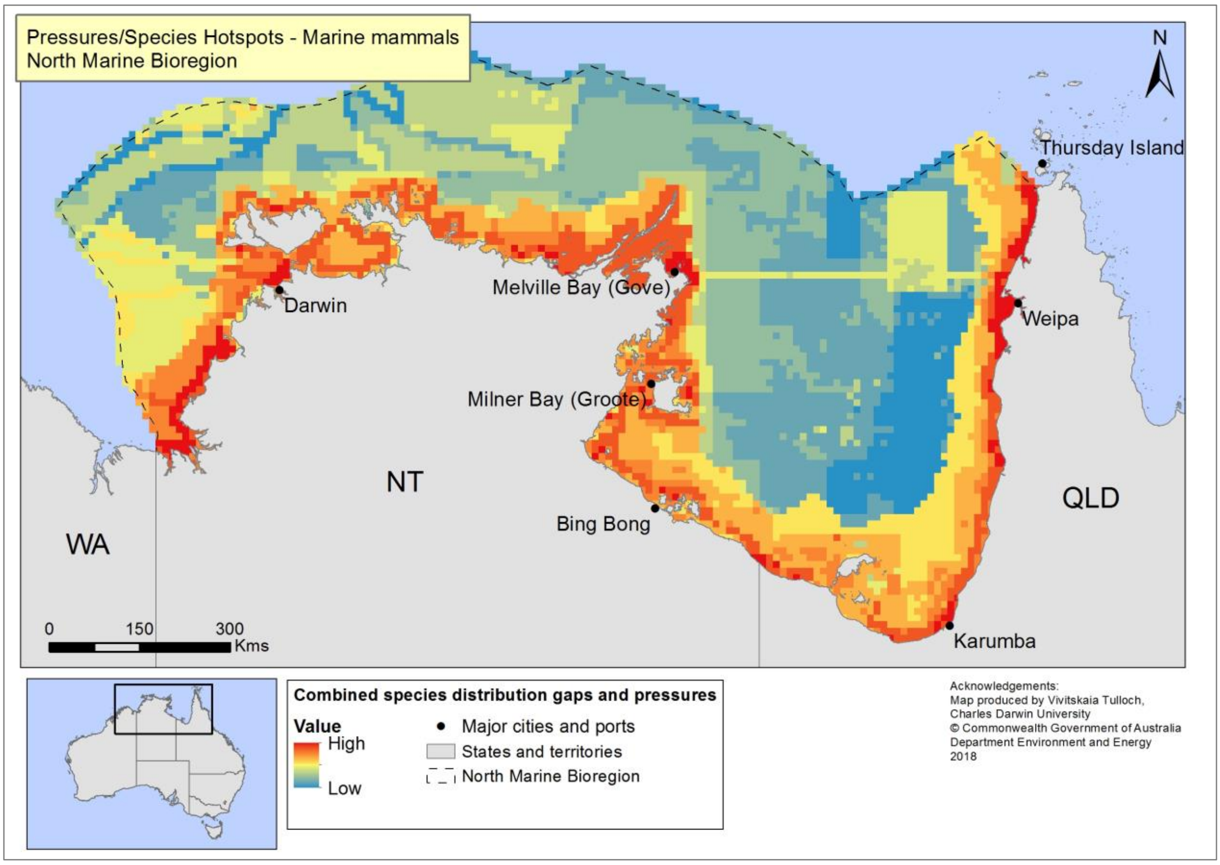


Figure 101. Hotspots of overlap between ongoing pressures and gaps in priority marine mammal species distributions (Dugong, Australian Snubfin Dolphin, Australian Humpback Dolphin), derived by adding the re-scaled distribution value for uncertain SPRAT categories, and the re-scaled ongoing cumulative pressure values.

7.5 Ongoing and Proposed Development

A diverse array of pressures operate across the North Marine Bioregion, which are known to interact with, or potentially interact with, Threatened and Migratory marine species. The ongoing pressure hotspot map derived using the additive model presented in Chapter 3, revealed high future pressure risk across most of the coastal Northern Territory and parts of western Cape York in Queensland (Figure 102). Pressure was lower away from coastal areas, including much of the Gulf of Carpentaria and Arafura Sea, but was higher in the Timor Sea in the south-western part of the North Marine Bioregion (Figure 102).

This analysis indicates the areas of highest ongoing cumulative pressure. Combining this analysis with the risk assessment will provide an indication of where and how each species is likely to interact with increasing development and climate change in Northern Australia. The predictive capacity of this exercise, or fore-sighting, could be improved by developing specific future scenarios (e.g. following the 5 development scenarios identified in the Northern Australia Audit) and predicting the environmental consequences on the Threatened and Migratory marine species in the North Marine Bioregion.

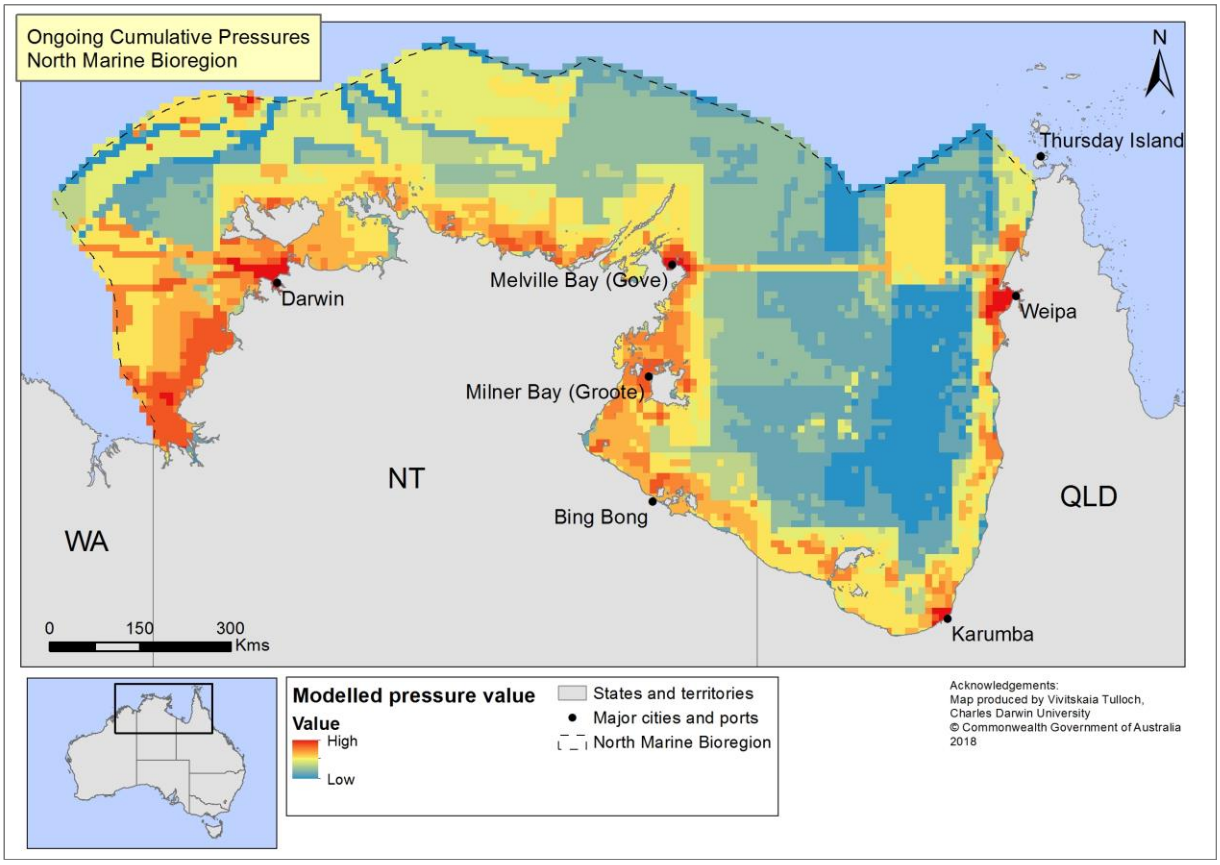


Figure 102. Cumulative ongoing and future pressure hotspots map, derived by adding current ongoing and future pressure risk metrics in each grid cell. This figure identifies hotspots of multiple current ongoing and future pressures (red) versus regions of low ongoing and future pressures (blue) (reproduced from Chapter 3).

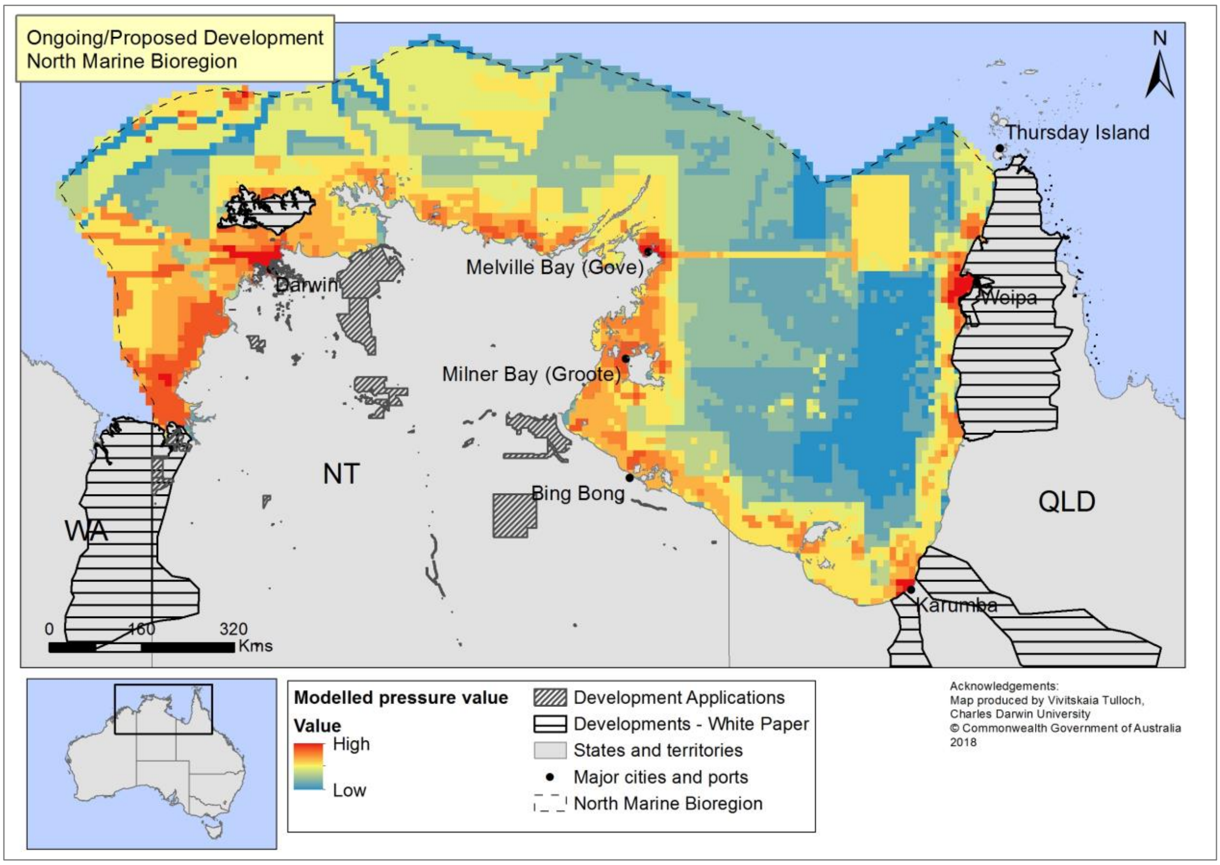


Figure 103. Cumulative ongoing and future pressure hotspots map, overlaid with proposed and potential development in northern Australia displayed as Northern Territory development applications (Digital Cadastral Database; http://www.ntlis.nt.gov.au), and potential developments extracted from the White Paper on Developing Northern Australia (Commonwealth of Australia, 2015) (Table 8).

7.6 Indigenous Interests and Capacity

Findings from the consultation phase found that Indigenous sea country custodians and managers throughout the North Marine Bioregion clearly have an interest in bolstering their knowledge about one or more Threatened and Migratory marine species; and whilst only specific species or taxa groups representing Threatened or Migratory marine species are indicated in Figure 104 all groups aspire to maintain or increase their capacity to manage the sea country under their care. Therefore, groups such as the Yirralka Rangers may not have a specific species or taxa groups that they are focussed on, rather they have expressed an interest in marine biodiversity mapping and research generally. Furthermore, it important to note that in some cases the species of interest are already being examined through existing research or monitoring programs, for example at the time the Mapoon Land and Sea Rangers were consulted they had recently been or were presently engaged in several research partnerships (see Table 10). Equally important was the message that, in addition to the effort on identifying the focal and priority species, and where they occur, the engagement process for planning and delivering collaborative research requires further consideration. The Species component of this project revealed that there has been quite a significant research effort across several species/taxa groups in the North Marine Bioregion in recent years. Some of this research may address some current communities' concerns, if the information is actually communicated to those key research end users in a format that is meaningful.

Of the wide diversity of Threatened and Migratory marine species occurring in the North Marine Bioregion, marine turtles were the most commonly discussed group. In the Cape York region, there is significant research effort already underway on turtles, primarily supported by Western Cape Turtle Threat Abatement Alliance (WCTTAA). Research on marine turtles in the Northern Territory would also be welcomed as groups there recognised a number of pressures acting on these species. Dugong were also a species that almost all communities expressed some concern about even though there is a vast body of traditional ecological knowledge on them across Northern Australia. People have questions about the sustainability and health of local populations.

Sawfish were also a group of considerable interest. Traditional Owners from the Tiwi Islands were eager to see sampling for sawfish as part of NESP Project A1, but unfortunately were unable to schedule fieldwork before that project concluded. Sawfish research is being carried out in two communities (Kowanyama and Mapoon) on Cape York with Sharks and Rays Australia. Continuation of the Largetooth Sawfish work with Malak Malak, Numbulwar Numburindi, and Yugul Mangi Rangers is desired by communities, with a demonstrated capacity to partner on sawfish research, and produce meaningful outputs and outcomes.

A number of communities have been investing in efforts to understand and manage shorebirds and/or seabirds. In the Southern Gulf significant shorebird sites have been protected under the East Asian-Australasian Flyway partnership. Ranger groups there, and others in Cape York are undertaking regular shorebird monitoring, and TOs are interested in further research to understand species distribution and population dynamics. There are concerns about the sustainability of customary seabird harvesting, as these species are now subjected to additional pressures such as predation by feral animals.

Working in the Gulf section of the Arnhem area would also take advantage of existing positive relationships, including the relationship between the South East Arnhem Land (SEAL) IPA ranger groups and NESP researchers; and potentially the good working relationship between the SEAL rangers and their neighbours from adjoining IPAs to the north, the Yirralka and Dhimurru Rangers.

Across the Top End and Arnhem regions of the NT, there is currently a focus on commercial fishing licensing, as described previously for Maningrida and the Tiwi Islands. In the greater Darwin area, where many of the pressures acting upon Threatened and Migratory marine species are most evident, there is a keen interest in Threatened and Migratory marine species, however there are also many other pressing concerns for Traditional Owners of a highly urbanised environment. Any new marine research in the Darwin region must involve the Larrakia Rangers, and at a minimum, attempt to engage with Kenbi Rangers. Between the Western Australian border and the Darwin region there are few coastal communities, the largest being Wadeye.

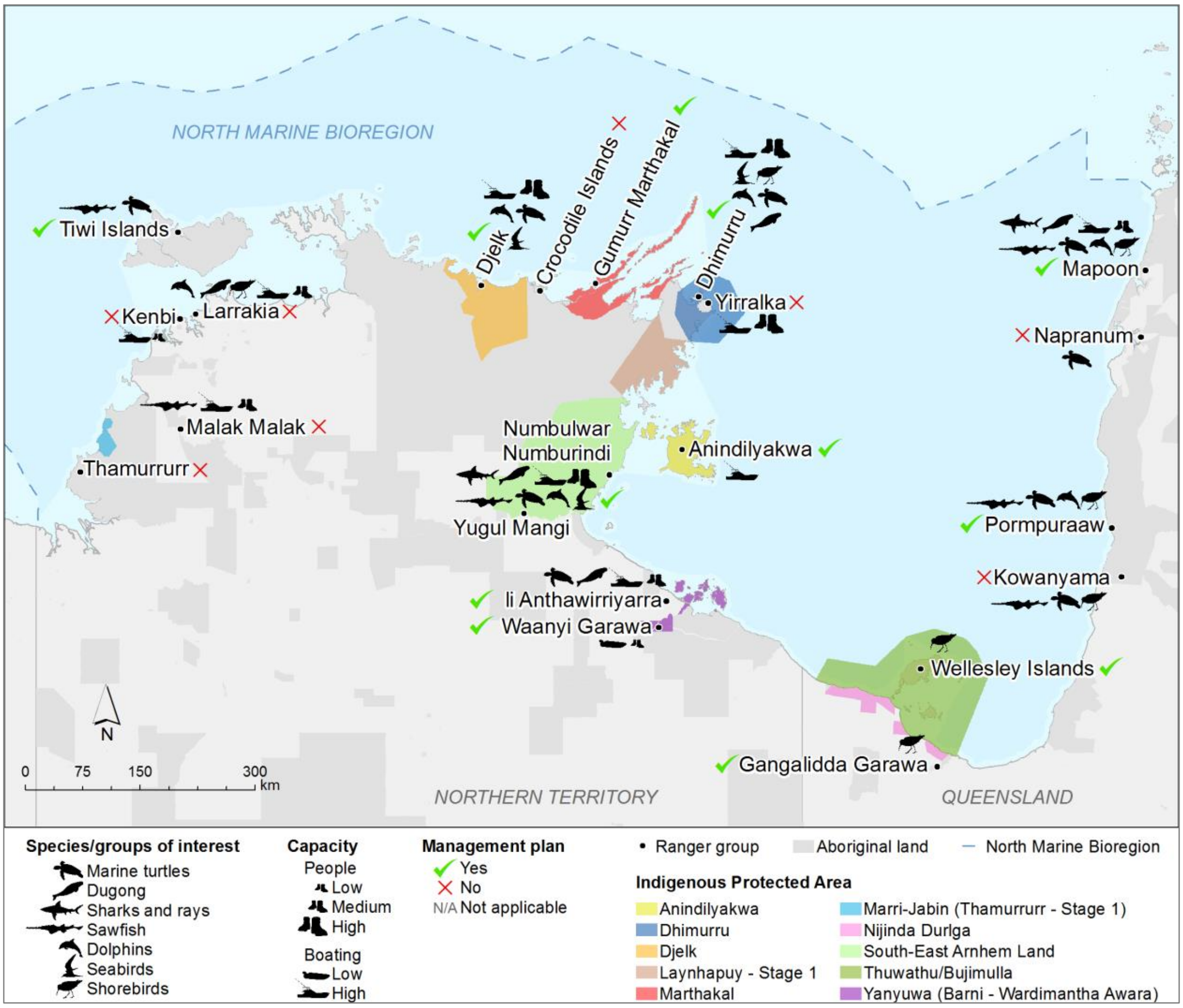


Figure 104. Indigenous ranger group capacity, species/taxa groups of interest to communities and existence of Management Plans. This information was determined through the Desktop Review (Appendix E) and/or community consultations (Chapter 4) (current at end of 2017). Capacity includes approximate number of rangers, with Low representing 1-5 Rangers, Medium 6-10 and High more than 10 Rangers, Low indicates group has no boats or small vessels, high indicates multiple vessels and staff trained to pilot vessels. A Management Plan may be an IPA Management Plan, Sea Country Plan, Healthy Country Plan or similar (Table 9).

Though there was interest expressed by all communities engaged, there are two critical factors that differ from community to community: 1) capacity and 2) suitability of the proposed project timeframe. Whilst we have attempted to provide an approximate representation of ranger group ‘assets’, this does not necessarily indicate capacity to be involved in future research endeavours as some groups such as Mapoon may currently have a fully allocated workplan. The Desktop Review and community consultations revealed current interest and existing capacity relating specifically to marine turtles, dugong, shorebirds and seabirds, and sawfishes, and largely within the Gulf of Carpentaria sector of the Arnhem area (primarily through the Numbulwar Numburindi and Yugul Mangi Rangers, and quite likely Dhimurru), and the Daly River region of the Top End (through the Malak Malak Rangers). The limited project timeframe, and other priorities and commitments of various communities and their ranger groups precluded understanding marine species priorities across the entire North Marine Bioregion, but the results presented here provide a sound platform to continue engagement in appropriate geographical locations in 2018, and beyond**.**

7.7 Project Conclusions: Priority Research Regions

7.7.1 Aims and Methods

We aimed to identify which areas within the North Marine Bioregion were a higher priority for future Threatened and Migratory marine species research. We did this by synthesising the information collated in the chapters of the report and qualitatively ranking each attribute between 1 and 5 based on the project outputs and expert judgement.

To undertake this analysis, we divided the North Marine Bioregion into 5 coarse spatial-scale sub-regions based on State/Territory borders, major rivers, and the boundaries of Indigenous lands (Figure 105):

- **Top End:** Encompassing the western part of the Northern Territory, from the Western Australia/Northern Territory border (the western boundary of the North Marine Bioregion) eastwards to a longitudinal line extending northwards from the mouth of the East Alligator River. Major features of this region include the Timor Sea, Keep River, Victoria River, Daly River, Darwin Harbour, Van Diemen Gulf and the Alligator Rivers, the Tiwi Islands, and Cobourg Peninsula;

- **Arnhem:** Encompassing the eastern part of the Northern Territory, from a longitudinal line extending northwards from the mouth of the East Alligator River eastwards to a longitudinal line extending northwards from the Northern Territory/Queensland border, north of a latitudinal line extending eastwards from the mouth of the Roper River. Major features of this region include the Arafura Sea, Arnhem Land, the Wessel Islands, Nhulunbuy, Groote Eylandt, and the Roper River;

- **Western Gulf:** Encompassing the south-western Gulf of Carpentaria, from a latitudinal line extending eastwards from the mouth of the Roper River to its intersection with a longitudinal line extending northwards from the Northern Territory/Queensland border. Major features of this region include Limmen Bight, Maria Island, Limmen Bight River, McArthur River, and the Sir Edward Pellow Group of islands;

- **Southern Gulf:** Encompassing the south-eastern Gulf of Carpentaria, from a longitudinal line extending northwards from the Northern Territory/Queensland border to the Staaten River. Major features of this region include the Wellesley Islands, and the numerous rivers of the southern Gulf of Carpentaria (including the Flinders, Norman, and Gilbert Rivers); and,

- **Cape York:** Encompassing the eastern Gulf of Carpentaria from a longitudinal line extending northwards from the Northern Territory/Queensland border, and a latitudinal line extending westwards from the Staaten River, to Slate Point on north-western Cape York. Major features of this region include western Cape York, Weipa, the Mitchell River, and the Port Musgrave-Wenlock River-Ducie River system.

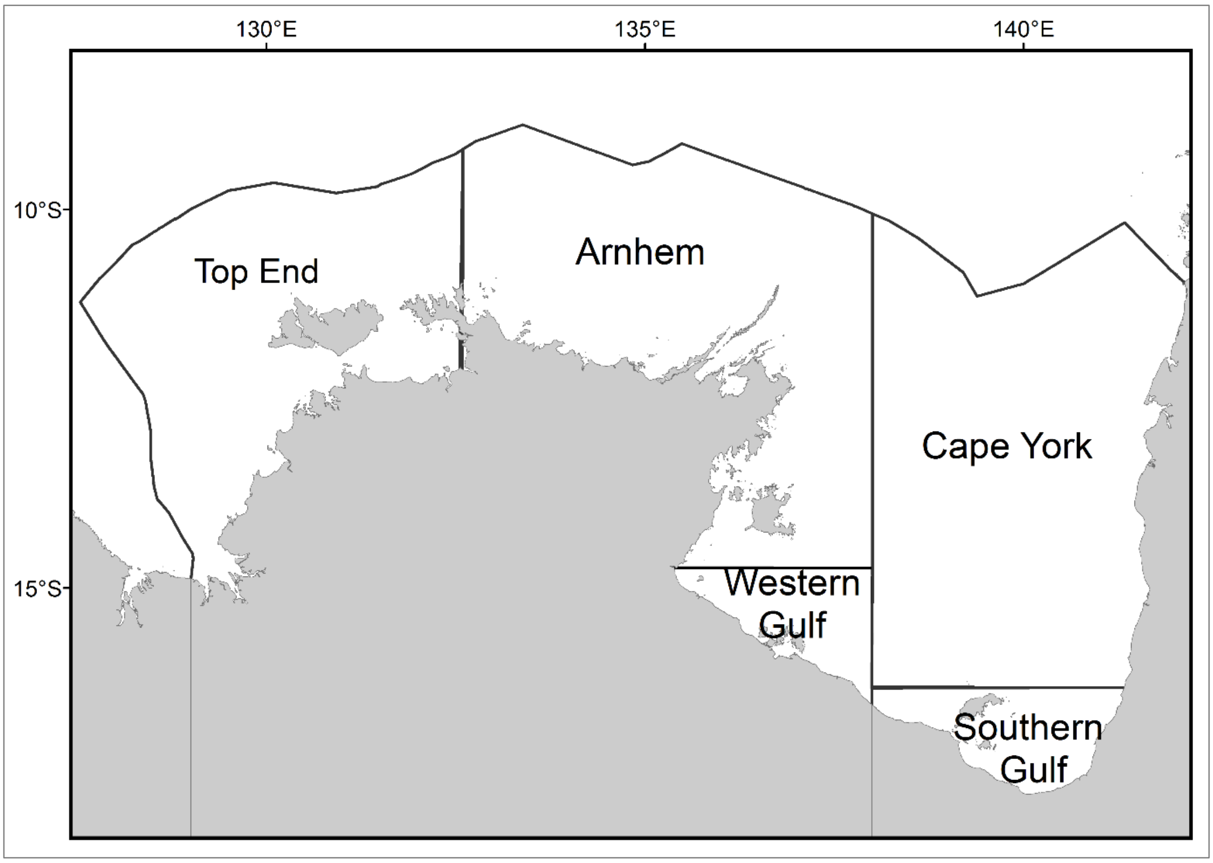


Figure 105. Sub-regions within the North Marine Bioregion used to rank project attributes and prioritise future research.

We ranked each of 11 project attributes, consisting of 4 species knowledge gap attributes, 3 pressures and development attributes, and 4 pressures-species overlap attributes, on a relative scale of 1 to 5, where 1 is low priority and 5 is high priority.

For the species knowledge gap attributes, we ranked (in relative terms) each sub-region for each species by the percentage of grid cells with new data (where new data overlapped with the 'likely' and 'may occur' categories in the SPRAT high resolution distribution). A ranking of 1 was given to the sub-region with the highest percentage of grid cells with new data and 5 given to the sub-region with the lowest). When two sub-regions had the same percentage of new data, both received an average rank value (e.g. if two sub-regions were tied at ranks 2 and 3, both received the value of 2.5). We then averaged (and rounded) the scores for all species in a group (sharks and sawfishes, marine turtles, shorebirds, marine mammals) and ranked the average scores between 1 and 5. If the average score between two sub-regions were tied we then considered the amount of "known" areas identified in each sub-region. The sub-region with more "known" areas (areas where occurrence data already exists) received the lower score (e.g. we considered this area as having a higher amount of data), and consequently, a smaller data gap.

For the pressure, and the pressure-species overlap attributes, we converted all pressure hotspots and pressure-species distribution hotspots maps (Figures 94–101) for each species group (sharks and sawfishes, marine turtles, shorebirds, marine mammals) to rasters, and then performed a zonal statistics calculation in GIS using the 5 sub-regions to obtain a quantitative estimate of the mean value in each of the five regions.

For the current development attribute, we ranked the sub-regions by the number and extent of ongoing *EPBC* referrals (from Figure 25), and for the future development attribute, we ranked the sub-regions by the number and extent of proposed developments as extracted from the Northern Territory Digital Cadastral Database, and the White Paper on Developing Northern Australia (from Figure 103).

7.7.2 Results and Project Conclusions

Overlays of proposed and potential future development in northern Australia highlighted potential impacts on the North Marine Bioregion largely in the greater Darwin area, the Keep-Victoria River region, the Tiwi Islands, Van Diemen Gulf, south-western Gulf of Carpentaria, south-eastern Gulf of Carpentaria, and along western Cape York.

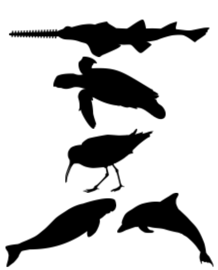
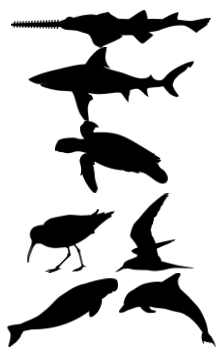
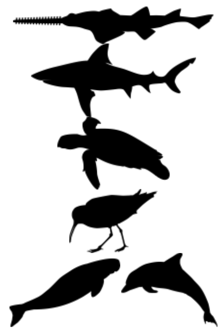
Bringing together the species, pressures, and development aspects of this project, and qualitatively ranking the five North Marine Bioregion sub-regions suggests that the Southern Gulf of Carpentaria (Queensland) and the Top End (Northern Territory) are the two sub-regions of highest priority for future research effort on Threatened and Migratory marine species (Table 19). These are followed by the Western Gulf, Arnhem, and Cape York sub-regions (Table 19).

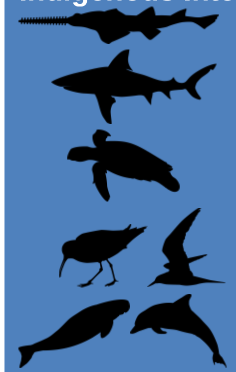
Figure 106 provides a way to visualise these rankings. The Southern Gulf is characterised by a high pressure footprint and poor knowledge (green icons in Figure 106). The overall ranking of Cape York is a result of relatively lower pressures and lower overlap between pressures and species gaps, however knowledge gaps in that sub-regions are relatively high (orange icons in Figure 106).

Of the Southern Gulf and the Top End, Indigenous interest in, and capacity to work on, Threatened and Migratory marine species is far greater in the Top End than the Southern Gulf. Top End Indigenous communities and groups considered during this project outlined interests in sawfishes, marine turtles, shorebirds, and marine mammals, while interest in the Southern Gulf centred on shorebirds (Table 19).

The information gathered and the analysis undertaken in the scoping project demonstrate that there is an overall paucity of the most fundamental data for species in the region of interest. Advances have been made in understanding some species groups, but decision-making in terms of assessing the impact of development on species in the north is often made by inference (e.g. determining a species is likely to occur in location *x* based on its occurrence in location *y* with similar habitat). What this work has demonstrated is that there is a need for an efficient method to collect this fundamental data. A combination of species distribution modelling and on-ground surveys, can begin to provide better knowledge of the distribution and presence of northern species to inform decision-making. Building the capacity of, and partnering with, people who have a vested interest in maintaining their presence in certain locations (including Indigenous Ranger Groups and engaged industries such as the Northern Prawn Fishery) is a pathway forward to advance baseline knowledge in light of the Northern Australian development focus.

Table 19. The five North Marine Bioregion sub-regions, ranked from 1–5 (relative ranking) against project attributes. Final ranking is the average ranking score calculated from the 11 individual attribute ranking scores. Existing NESP Marine Biodiversity Hub collaborations with Indigenous Ranger Groups, as well as Indigenous taxa interests resulting from engagement during the project are shown. *Sharks = sharks & sawfishes.

Attribute	Top End	Arnhem	Western Gulf	Southern Gulf	Cape York
Species Knowledge Gaps – Sharks*	1	2	5	4	3
Species Knowledge Gaps – Turtles	3	2	1	5	4
Species Knowledge Gaps – Shorebirds	3	1	2	5	4
Species Knowledge Gaps – Mammals	1	3	2	5	4
Pressures	5	2	3	4	1
Current Development	5	2	3	1	4
Future Development	5	1	2	3	4
Pressures-Species Overlap – Sharks*	3	2	4	5	1
Pressures-Species Overlap – Shorebirds	3	2	4	5	1
Pressures-Species Overlap – Turtles	4	2	3	5	1
Pressures-Species Overlap – Mammals	3	2	4	5	1
Final Ranking	**3.3**	**1.9**	**3.0**	**4.3**	**2.5**
Indigenous Collaborations	*	*			
Indigenous Interests					



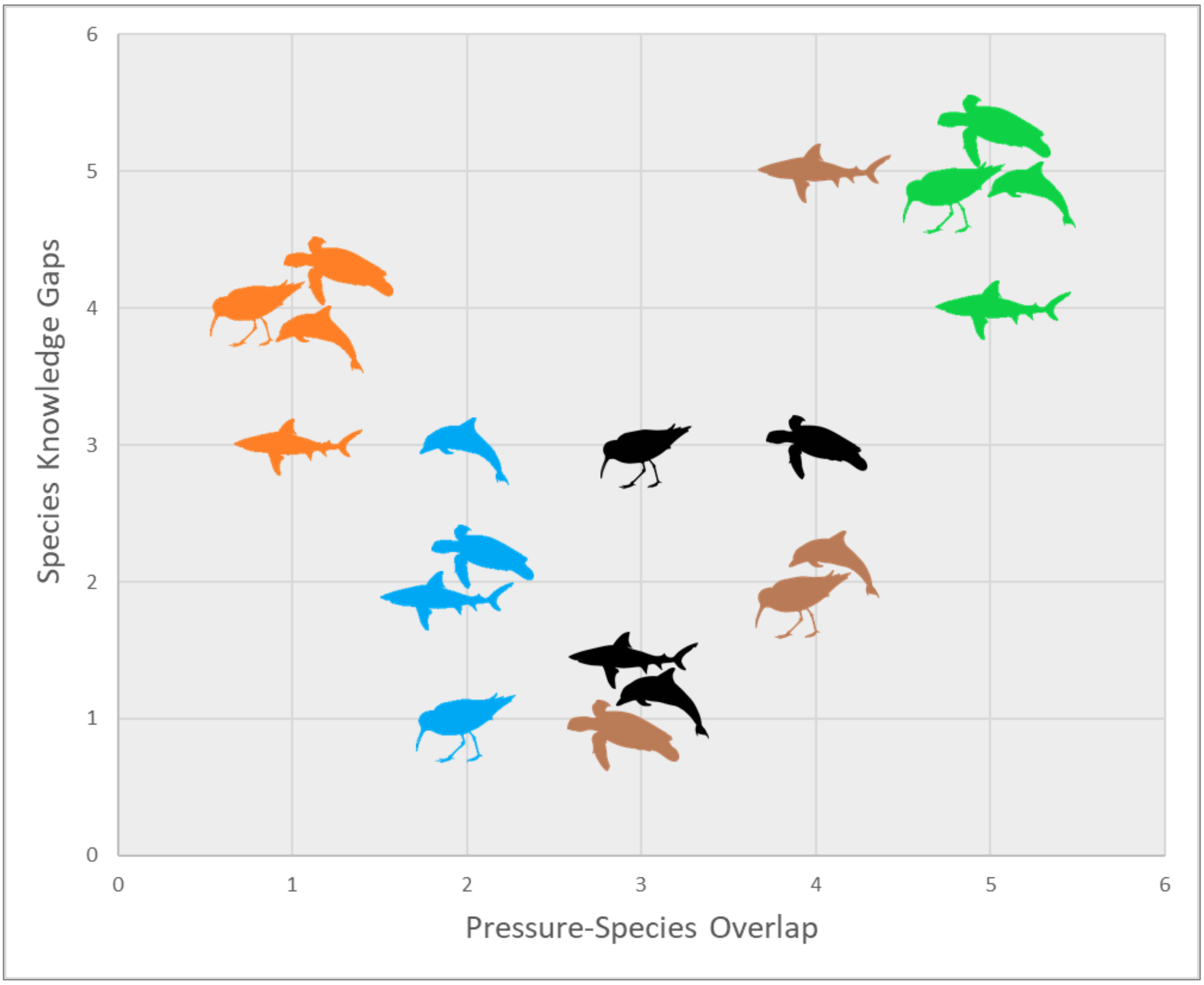


Figure 106. Species knowledge gap/pressure-species overlap plot for sharks and sawfishes, turtles, shorebirds and marine mammals for the five North Marine Bioregion sub-regions (Top End, black; Arnhem, blue; Western Gulf, brown; Southern Gulf, green; Cape York, orange; colours used here are not related to those in Table 19).

7.8 Project Data

Data generated from this project are stored in the Integrated Marine Observing System's Australian Ocean Data Network catalogue, and the associated metadata records can be accessed here:

http://catalogue.aodn.org.au/geonetwork/srv/eng/metadata.show?uuid=ea9d4c1f-0385-448e-adfe-c0782567baa9

7.9 References

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Queensland Department of Agriculture and Fisheries (QLD DAF)	Tony Courtney Ian Jacobsen

APPENDIX B – INFORMATION USED TO DEVELOP SPRAT CATEGORIES

Summary of the information used by ERIN (Environmental Resources Information Network, DoEE) to develop the SPRAT distribution categories for each of the priority species as summarised from information obtained from ERIN. The source of the data in the SPRAT database is largely State and Territory wildlife atlases, the Atlas of Living Australia (ALA), Birdlife Australia's Birdata and museums.

Date	Species	Observation point data	Other data	SPRAT distribution categories			
				Known	Likely	May	All
Mar 2017	Red Knot (*Calidris canutus*)	SPRAT database and ALA	Geographic range descriptions and habitat information sourced from available scientific literature and recent academic research.	The preferred habitat of the species within 1km of recently confirmed observations and expert validated locations	The suitable habitat of the species occurring within its broader environmental range and has been defined by detailed habitat mapping (NVIS 2012, Geoscience Australia 2012, CAMRIS).	The broader environmental range that could provide habitat for the species and has been defined by the bounding envelope of known sightings - representing migratory routes and overfly areas.	A conservative buffer has been applied to the known, likely and may extents
Aug 2016	Curlew Sandpiper (*Calidris ferruginea*) Eastern curlew (*Numenius madagascariensis*)	As above	As above. Habitat mapping: muddy shorelines (OzCoasts Smartline 2009); foreshore flats, lakes, reservoirs, coastal swamps and settling ponds (Geodata Topo250K); coastal marine seagrass (CAMRIS); and, mangroves (NVIS 2016).	The preferred habitat of the species within 1km of recently confirmed observations and is comprised of detailed habitat mapping as detailed left	The suitable habitat of the species occurring within its broader environmental range and has been defined by detailed habitat mapping within 5km of historic records (post-1966).	The broader environmental range that could provide habitat for the species and has been defined by statistical modelling of regional population groups (Delaunay-Alpha Hull analysis).	As above
Nov 2009	Great Knot (*Calidris tenuirostris*) Greater Sand-Plover (*Charadrius leschenaultii*) Lesser Sand-Plover (*Charadrius mongolus*)	As above	GIS shape files provided by BA - National Shorebird Feeding and Roosting Area, National Shorebirds Areas (1:100,000) and National Shorebird Count Areas (1:100,000). Where available, the distribution is a combination of the SPRAT profile distribution with the above data (BA 2008). It describes the known	BA shape files where the species has an average bird sighting (presence) greater than 0. The known feeding area is the intersection of the species distribution with feeding habitat and feeding area of the National Feeding and Roosting Map. The	Combine the SPRAT likely and may occur with the National Feeding and Roosting Map. Roosting Likely and Foraging Likely areas are the intersections of the National Feeding and Roosting Map with the		

			important areas in which migratory birds congregate to feed and roost in Australia.	Known roosting area is the intersection of the species distribution with roosting or feeding and roosting categories of the National Feeding and Roosting Map. The Known area is the rest of the area that this species was recorded but with no specific habitat type mentioned.	Sprat distribution of this species which has only Likely to occur habitat). The Likely to occur area is the likely area with no specification of roosting or feeding.		
Nov 2011	Dugong (*Dugong dugon*)	DEWHA and State government and museum databases (NT Fauna, Qld EPA Wildnet and ANHAT), NOO (?)	BIAs	Observation point records buffered by 10 km; GBRMPA Dugong Protection Areas A&B (unbuffered); and, Ashmore Reef Nature Reserve (with 10 km buffer). Distribution (except for NOO data areas) delimited at 40 m bathymetry	Seagrass beds occurring from Shark Bay, WA to Moreton Bay, Qld buffered by 10 km; observation data points buffered by 10 km; and, NOO data low density areas (unbuffered), in addition to known areas. Distribution (except for NOO data areas) delimited at 40 m bathymetry.	40 m bathymetry from Shark Bay, WA to Qld/NSW border.	
Feb 2013	Australian Snubfin Dolphin *(Orcaella heinsohni*)	SPRAT database and ALA	Location and habitat descriptions in the SPRAT Profile (DSEWPaC 2012) and the Threatened Species Nomination Form (April 2011).	The preferred habitat of the species within the immediate area (10km) of recently confirmed observations.	The suitable habitat of the species occurring within its broader environmental range and has been defined by regional seagrass mapping (CAMRIS).	The broader environmental range that could provide habitat for the species and has been defined by a 10km seaward buffer of Australian coastline data (SmartLine 2012).	A conservative buffer has also been applied to the known, likely and may extents
May 2013	Australian Humpback Dolphin (*Sousa sahulensis*)	As above	BIAs	The preferred habitat of the species within the immediate area (5km) of recently confirmed observations.	The suitable habitat of the species occurring within its broader environmental range and has been defined by the 15m bathymetric zone that occurs within 5km of the coast and within 20km of coastal estuaries.	The broader environmental range that could provide habitat for the species and has been defined by the 50m bathymetric zone that occurs within 50km of the coast down to the 25th latitude on the west coast	As above

						and the 34th latitude on the east coast.	
Nov 2012	Hawksbill Turtle (*Eretmochelys imbricata*) Olive Ridley Turtle (*Lepidochelys olivacea*)	Observation records and nesting locations from the SPRAT database (DSEWPaC 2012), QLD marine turtle migration & nesting data (QLD EPA 2009), NT coastline biodiversity survey data (NRETAS 2008)	BIAs	The known breeding extents were created by incorporating sandy beach areas that occur within 10km of nesting locations. The known foraging extents were created by selecting reef and seagrass area features within 20km of all known breeding areas, BIAs and observation records. The known inter-nesting extents were created by buffering known breeding areas by 20km. The known to occur extent was created by buffering the known breeding and foraging areas by 50km.	The likely breeding extents were created by incorporating all remaining sandy beach areas that occur within the broad geographic range of the species. The likely foraging extent includes all remaining reef and seagrass areas within the broad geographic range of the species. The likely to occur extent comprises key marine geomorphic features (including continental shelves, seamounts, coastal zones and pinnacles) within the broad geographic range of the species.	The may occur extent represents the broad geographic range of the species and comprises the marine environment that contains observation records, nesting locations and suitable habitat features.	
May 2015 to Nov 2016	Northern River Shark (*Glyphis garricki*) Speartooth Shark (*Glyphis glyphis*), Dwarf sawfish (*Pristis clavata*) Largetooth Sawfish (*Pristis pristis*) Green Sawfish (*Pristis zijsron*)	SPRAT database and ALA	Geographic range descriptions and habitat information sourced from available scientific literature and recent academic research.	The preferred habitat of the species within the immediate area of recently confirmed observations and expert validated locations.	The suitable habitat of the species occurring within its broader environmental range and have been defined by hydrological, bathymetric and marine geomorphic features mapping (Geoscience Australia).	The broader environmental range that could provide habitat for the species and have been defined by hydrological, bathymetric and marine geomorphic features mapping (Geoscience Australia).	A conservative buffer has also been applied to the known, likely and may extents

APPENDIX C – SPECIES INFORMATION FOR GAP ANALYSIS

Summary information for the species gap analysis (NMB, North Marine Bioregion).

Species	Records and distribution	Population sampled	Critical habitats	Data type	Threats	BIA	Recovery plans	Average	Sum	Gap Score classification	Gaps identified
Glyphis garricki Northern River Shark, New Guinea River Shark	Rare - 10 locations in NT. Probably small population. Very little of the coastal area designation as 'known'. No records for massive marine region designated as 'may occur'. The recent recognition that the species is primarily estuarine, rather than freshwater.	Not specified, likely immature	Unknown	Tracking (1 study), some data from fisheries by-catch, limited research surveys	Thought to be bycatch in fisheries and recreational fishing, habitat modification. Considerable progress to reduce bycatch but mostly unknown if it is having an impact. As distribution and critical habitats are poorly defined, this also means that the ability to manage threats in these areas as reduced.	No BIA	Sawfish and River Sharks Multispecies Recovery Plan and in plan for the North Marine Bioregion.	1.4	10	LOW	Very little data available for SPRAT profile and map - checked information on species card for NT. Need to determine the distribution, abundance and status of the species across the NT; monitor and limit the impacts of fishing in estuarine areas. The Fisheries Division of the NT Department of Primary Industry and Fisheries is currently studying the distribution and abundance of the species.
Glyphis glyphis Speartooth Shark	Rare - Recorded for 5 rivers NT, 3 rivers QLD. Very little of the coastal area designation as 'known'. No records for massive marine region designated as 'may occur' using bathymetry mapping	Mostly juveniles, subadults	Unknown	Small number of catch records from studies, NT fisheries bycatch – coarse-scale	Thought to be recreational fishing, bycatch Barramundi fishery, habitat loss - Not monitored. As distribution and critical habitats are poorly defined, this also means that the ability to manage threats in these areas as reduced.	No BIA	Sawfish and River Sharks Multispecies Recovery Plan and the marine bioregional plan for the North Bioregion	1.3	9	LOW	Lack of data on distribution, movements and habitat use, no information on mature individuals

Pristis clavata Dwarf Sawfish, Queensland Sawfish	Few records for NT - Fitzroy, May and Robinson Rivers. Very little of the coastal area designation as 'known'. Very large marine area categorised as 'known habitat' but seems large extrapolation using bathymetry and from three sharks captured in marine waters of King Sound. Could also include fisheries bycatch data (unclear).	Adults, juveniles but limited number	Nursery identified in WA. Not much information for NT.	Some tracking, some data from fisheries catch, limited research surveys	Thought to be bycatch in commercial and recreational net fishing, habitat degradation, indigenous harvesting - not monitored. As distribution and critical habitats are poorly defined, this also means that the ability to manage threats in these areas as reduced.	No BIA	Sawfish and River Sharks Multispecies Recovery Plan and included in the Marine bioregional plan for North and Northwest	1.3	9	LOW	Little information on distribution, population size and structure, ecology. No critical habitats have been identified in the NMB
Pristis Pristis Largetooth Sawfish	Limited - Known from several drainages of NT but likely to be widely distributed. A large extrapolation of the marine areas of the whole NMB for distribution map of the 'known habitat' using bathymetry. Unclear where this data comes from but may include fisheries bycatch data points.	Mostly juveniles, subadults	Only Fitzroy River has been identified as nursery	Tracking data in localised areas and limited catch records from published studies and bycatch records from fisheries - insufficient	Thought to be gillnet and net fishing, recreational and barramundi fishing bycatch, shark fin trade, habitat modification. Not monitored.	No BIA	Sawfish and River Sharks Multispecies Recovery Plan and included in the Marine bioregional plan for North and Northwest	1.6	11	MED	Very little data on population size and trends; no data for ecology, distribution and movements of adults. Not much information on bycatch records, overall distribution and threats in the NMB

Pristis zijsron Green Sawfish, Dindagubba, Narrowsnout Sawfish	Records indicate that the species occurred along the east coast of Queensland and NSW prior to the 1960s. Little known about distribution in WA and NT (Buffalo Creek only). Very little of the coastal area designation as 'known'. A large extrapolation of the marine areas of the whole NMB for distribution map of the 'known habitat' using bathymetry. May include fisheries bycatch data points, but unclear.	Adults, juveniles	Unknown	Catch records (incidental and fisheries), 1 adult tracked	Thought to be fishing pressure, habitat degradation and indigenous harvesting-not monitored. As distribution and critical habitats are poorly defined, this also means that the ability to manage threats in these areas as reduced.	No BIA	Sawfish and River Sharks Multispecies Recovery Plan and included in the Marine bioregional plan for North and Northwest	1.4	10	LOW	Little information on the distribution to allow identification of critical habitats and management (impact of threats). Almost no information on the biology, ecology, population and threats to the species.

Eretmochelys imbricata Hawksbill Turtle	Nesting beaches identified. Surveys such as Chatto of nesting beaches in whole of NT. Inter-nesting areas mapped from simple buffering of points and little data from foraging grounds. Massive marine area designated as 'likely' and 'may occur' habitat but with no or few actual data and developed using observed habitat associations.	Females at nesting beaches mostly	Significant areas for nesting sites have been identified but no foraging areas	Monitoring of beaches has identified nesting beaches. Flipper tag return data. Bycatch from fisheries. Limited data in offshore environment	Habitat alteration (beach erosion), bycatch fisheries and shark control, boat strikes, predation of nests, ingestion marine debris, artificial light. These are all identified and some studies and mitigation for some threats. As foraging grounds are not well understood, understanding the impact of threats in these areas is thus reduced.	Only nesting areas identified as BIA	Recovery Plan for Marine Turtles in Australia (2017). Included in the temperate East, North and Northwest marine regional plans	2.1	15	MED	Lack of data on movement to identify foraging area, inter-nesting and migration corridors to identify and protect critical habitat. Most data from adult females on nesting grounds, need data from males and younger individuals and outside the nesting grounds.
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle	As above	Females at nesting beaches mostly	Significant areas for nesting sites have been identified but no foraging areas	As above	Commercial and recreational fishing (Trawling, gillnets, longline, pot fishing and ghost nets); coastal infrastructure and development; Indigenous harvest; feral animal predation; and climate change. As foraging grounds are not well understood, understanding the impact of threats in these areas is thus reduced.	Only nesting areas identified as BIA	Recovery Plan for Marine Turtles in Australia (2017). Included in the Marine bioregional plan for the North Marine Region and Marine bioregional plan for the North-west Marine Region.	2.1	15	MED	Lack of data on movement to identify foraging area, inter-nesting and migration corridors to identify and protect critical habitat. Most data from adult females on nesting grounds, need data from males and younger individuals and outside the nesting grounds.

Calidris canutus Red Knot, Knot	Long-term monitoring and sightings by bird conservation agencies and groups. Although the whole marine area is designated as 'may occur', most of the NMB coast is classified as 'known to occur' suggesting good spatial coverage of data and studies.	Although distribution is only for the non-breeding season, breeding occurs outside of Australia.	Foraging sites identified in NT with counts (monitoring)	Numbers(surveys), banding, published studies	Habitat loss, human disturbance, pollution, invasive species. Identified but largely not monitored.	Bird Important Areas identified for multiple species	Recovery Plan not required, approved conservation advice provides sufficient direction. Significant management and research is being undertaken	2.7	19	GOOD	Need to understand the impacts of threats and need species-specific BIAs
Calidris ferruginea Curlew sandpiper	While there appears to be long-term data there many gaps in the NMB - Area of Occupancy defined but with low confidence, i.e. the distribution is made up of 'likely' and 'may occur categories and no 'known to occur'.	As above	Foraging sites identified. Kakadu National Park	Counts (surveys), time series, banding, published studies	Habitat alteration and loss, human disturbance. Identified but largely not monitored.	Bird Important Areas identified for multiple species	No - Recovery Plan not required (SPRAT). Included in the Important Bird Areas	2.4	17	GOOD	Spatial data gaps in NMB. Lack of information on threats and possible impacts on population and biologically important areas.
Calidris tenuirostris Great Knot	While there appears to be long-term data there many spatial gaps in the NMB. There are some areas designated as 'known to occur' in the distribution but it is mostly gaps or made up of 'likely' and 'may occur categories.	As above	Foraging sites identified in NT with estimate of numbers	Counts (surveys), banding, published studies	Habitat loss - foraging grounds. Identified but largely not monitored.	Bird Important Areas identified for multiple species	No - Recovery Plan not required (SPRAT). Included in the Important Bird Areas	2.4	17	GOOD	Spatial data gaps in NMB. Identification of areas of overlap with threats and impacts on populations and identification of biologically important areas - but ongoing efforts

Charadrius leschenaultii Greater sand plover, Large sand plover	Counts from surveys in some areas, but major geographical gaps in NMB	As above	Some foraging sites identified but not monitored between Eighty Mile Beach and Darwin	Counts(surveys), banding, published studies	Habitat loss, human disturbance, pollution, invasive species. Identified but largely not monitored.	Bird Important Areas identified for multiple species	No - Recovery Plan not required (SPRAT).	2.3	16	MEDI	Spatial data gaps in NMB - need for more data collection and identification of foraging areas and BIAs
Charadrius mongolus Lesser Sand Plover, Mongolian Plover	Counts from surveys in some areas but major geographical gaps in NMB	As above	Very few foraging sites around NT and QLD	Counts (surveys), banding, leg flagging, published studies	Habitat loss, human disturbance, pollution, invasive species. Identified but largely not monitored.	Bird Important Areas identified for multiple species	Recovery Plan not required (SPRAT). The species does not rely on the habitat of ecological communities listed under the EPBC Act.	2.3	16	MED	Spatial data gaps in NMB. Identification of areas of overlap with threats and identification of biologically important areas - but ongoing efforts

Numenius madagascariensis	Eastern Curlew	Long-term monitoring and sightings by bird conservation agencies and groups. Although the whole marine area is designated as 'may occur', most of the NMB coast is classified as 'known to occur' suggesting good spatial coverage of data and studies.	As above	Important foraging areas in the NT (counts) Darwin, Millingimbi to Buckingham Bay area, the Roper and Limmen Bight River mouths and the Port McArthur area.	Banding, numbers (long term survey), satellite tracking and geolocation, published studies	human disturbance, habitat loss and degradation from pollution, changes to the water regime and invasive plants	Bird Important Areas identified for multiple species	Recovery Plan not required, as the approved conservation advice for the species provides sufficient direction to implement priority actions and mitigate against key threats. Australian Government has prioritised resource allocation to support the species recovery effort	2.7	19	GOOD	Reasons for decline not fully understood - human disturbance in several habitats used for roosting, foraging when wintering in Australia not monitored

Dugong dugon Dugong	Occur in coastal and island waters from Shark Bay in WA across the northern coastline to Moreton Bay in QLD. Much of the NT section of NMB is 'know to occur' but there appears to be no data inputs for the QLD section of the NMB distribution with mostly 'likely' and 'may occur' categories in the distribution.	All(sightin gs)	Sea grass (foraging) areas well defined but no information on relative importance of these areas. No info on breeding important areas	Some aerial surveys (not regular) and observation s	Habitat degradation, pollution, entanglement and incidental bycatch in fishing, shark control programs (nets), vessel strike, anthropogenic noise and acoustic disturbance, climate change	No BIA	There is no adopted Recovery Plan for this species. Included in the Marine bioregional plan for the North and North-west	2.0	14	MED	More information on habitat use, distribution movement, impact of threats, population trend and distribution in the NT (so far, most data only for specific locations surveyed). Identify BIAs
Orcaella heinsohni Australian Snubfin dolphin	Much of the NT section of NMB is 'know to occur' but there appears to be no data inputs for the QLD section of the NMB distribution with mostly 'likely' and 'may occur' categories in the distribution.	All (sightings)	Unknown	Stranding, museum specimens, observation s from ALA etc	Incidental capture in gillnets, including shark nets, habitat degradation, and competition with fisheries, pollution, pathogens	BIA identif ied for a few locati ons in the NT	No Recovery Plan. Included in the marine bioregional plans for the North and North-west	1.9	13	MED	Limited data throughout the range to estimate distribution, population size and trends. More information on overlap and potential impacts of threats

Sousa sahulensis Indo-Pacific Humpback Dolphin	In NMB data only available for a few selected locations (Top End, parts of Arnhem and top of Cape). Very little 'known to occur' on the distribution and most of coast has no distribution. Unclear whether they do not occur there or a result of lack of survey effort though we found new data points in these areas so seems bit of both.	All (sightings)	Unknown	counts, strandings, museum records observations from ALA etc	Habitat loss and degradation, being caught as by-catch, water pollution, underwater noise, floods, vessel traffic, overfishing of prey resources, wildlife tourism	No BIA	No recovery plan. Included in the marine bioregional plan for the North, Temperate East and North-west	1.6	11	MED	Not much data for the distribution, population and movements (only very localised data and mostly low-quality data). Need for long-term data for population trend, threats and robust distribution map to assess threats. BIAs not identified.

APPENDIX D – PRESSURES AND FISHERIES DATA COLLATION

Data acquired, interpolation, and data availability

Data	Type	Source	Metadata	Contact
Aquaculture infrastructure	Pollution	Pearling, mariculture industry	Collated as part of Project C1 national-scale pressures	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment Contact: Piers Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au
Bycatch and SOCI interaction - QLD	Interaction	Department of Agriculture and Fisheries	Calculated effort by gear	Ashley Lawson, Qfish
Bycatch and TEPS interaction - NT	Interaction	Department of Primary Industries and Resources	Calculated effort by gear	Thor Saunders, NT Fisheries
Cables	Habitat modification	CSIRO	Collated as part of Project C1 national-scale pressures. None active, one decommissioned	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment Contact: Piers Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au

Data	Type	Source	Metadata	Contact
Cyclone activity	Climate	Camris	This database presents an index of the intensity, frequency and density of cyclone occurrence in the Australian region. It has been derived from data held in CSIRO CAMRIS database and originally collected by the Bureau of Meteorology from 1958 - 1990. The cyclone_density code in the coverage represents: 1 Australia, 2-23 the nominal index of cyclone density/intensity, as per the Bureau of Meteorology cyclones database. The Coastal and Marine Resources Information System (CAMRIS), is a small-scale spatial analysis system developed in collaboration by several divisions of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), as part of the CSIRO Coastal Zone Program. CSIRO (2015): Australian Region Cyclone Intensity and Frequency Index - CAMRIS. v1. CSIRO. Data Collection. http://doi.org/10.4225/08/55148491CB988	http://doi.org/10.4225/08/55148491CB988
Defence activities - spoil dumping - boat	Pollution	Department of Defence, www.hydro.gov.au	Information on the dumping at sea of hazardous substances was obtained from the Department of Defence online at http://www.hydro.gov.au/n2m/dumping/dumping.htm and digitized. This information has been made public through Australian Notices to Mariners since 1982. The Environment Protection (Sea Dumping) Act 1981 covers current Government policy with respect to dumping at sea. For more information on Sea Dumping regulations and the permits required under the Environment Protection (Sea Dumping) Act 1981 refer to Environment Australia's web site at www.ea.gov.au/coasts/pollution/dumping/index.html	http://www.hydro.gov.au/n2m/dumping/dumping.htm
Defence activities - spoil dumping - other	Pollution	Department of Defence, www.hydro.gov.au	Information on the dumping at sea of hazardous substances was obtained from the Department of Defence online at http://www.hydro.gov.au/n2m/dumping/dumping.htm and digitized. This information has been made public through Australian Notices to Mariners since 1982. The Environment Protection (Sea Dumping) Act 1981 covers current Government policy with respect to dumping at sea. For more information on Sea Dumping regulations and the permits required under the Environment Protection (Sea Dumping) Act 1981 refer to Environment Australia's web site at www.ea.gov.au/coasts/pollution/dumping/index.html	http://www.hydro.gov.au/n2m/dumping/dumping.htm

Data	Type	Source	Metadata	Contact
Defence activities - spoil dumping - ammo	Pollution	Department of Defence, www.hydro.gov.au	Information on the dumping at sea of hazardous substances was obtained from the Department of Defence online at http://www.hydro.gov.au/n2m/dumping/dumping.htm and digitized. This information has been made public through Australian Notices to Mariners since 1982. The Environment Protection (Sea Dumping) Act 1981 covers current Government policy with respect to dumping at sea. For more information on Sea Dumping regulations and the permits required under the Environment Protection (Sea Dumping) Act 1981 refer to Environment Australia's web site at www.ea.gov.au/coasts/pollution/dumping/index.html	http://www.hydro.gov.au/n2m/dumping/dumping.htm
Port infrastructure and dredging risk	Pollution	NT Government	The threat to coastal marine habitats (e.g. seagrass) from port infrastructure and dredging was assessed based on the locations of ports in Australia provided by the Australian Customs & Border Protection Service (http://data.gov.au/dataset/australian-ports), and Australian shipping routes. We predicted that there was a high risk to seagrass habitat when there was a port located in a grid cell, a moderate risk in cells adjacent to a high cell, and a low risk in cells adjacent to moderate, using shipping routes to determine the direction of risk. We considered that there was no exposure to the threat of port infrastructure and development and hence no risk in all other grid cells.	https://nt.gov.au

Data	Type	Source	Metadata	Contact
Fisheries effort - Commonwealth	Resource extraction	AFMA	Collated as part of Project C1 national-scale pressures. This data set contains summaries of AFMA log book data on effort distribution for Commonwealth fisheries in the North Marine Bioregion, Australian Exclusive Economic Zone. The only fishery operating in this region is the Northern Prawn Trawl Fishery. The logbook data has been recorded and submitted to AFMA by commercial fishers. The data has been aggregated to produce summaries of total effort by gear type (summarised across fishery), over 5-year periods and at a 0.1 degree resolution where 5 boats or more operate. All effort information has been removed for areas where <5 boats operate and these areas are mapped to a 1 degree resolution. The 5-year periods (1996–2000, 2001–2005 and 2006–2010) correspond to State of Environment (SoE) Reporting, required under the *EPBC Act 1999*. The most recent reporting period (2011–14) is a 4-year period. Each is labelled by the years aggregated (i.e. 2001–2005) and the gear type. Notes: 1. Care needs to be taken when interpreting the fishing effort maps because in areas where there are <5 boats operating only the fishing footprint is displayed, consistent with the AFMA Information Disclosure Policy. The fishing footprint indicates that fishing occurred but does not provide information about the intensity of effort (number of operations etc). 2. Legal fishing by foreign flagged vessels occurred in the 1980s and early 1990s in the Australian Fishing Zone. These are shown as areas of higher effort in trawl maps prior to 1990 north of Arnhem Land. 3. Trawl effort maps are missing Torres Strait Prawn Fishery data prior to 2004. Disclaimer: The data provided by AFMA may contain errors or be incomplete. AFMA makes no warranty or representation that the data is accurate or complete. Those who choose to use this data should make their own enquiries as to its accuracy and completeness and AFMA assumes no liability for any errors or omissions in the data provided, or for any decision by a person who chooses to rely on the data. Field descriptions for shapefiles: CSQ_CODE: C-Squares code. 1 degree and 0.1 degree grids used CSQ_RESLN: C-Squares resolution of current polygon VESSELS: Number of vessels OPERATIONS: Number of operations HOURS: Effort in hours from start and end time HOOKSSET: Total hooks set NUMLINES: Number of lines deployed NETLENGTH: Gillnet Net Length Fishery Aggregations	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment Contact: Piers Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au
Fisheries catch and effort - NT	Resource extraction	NT Fisheries, Department of Primary Industries and Resources	Metrics developed of average effort by fishery, and summed effort across all fisheries, since 1980	Thor Saunders, NT Fisheries

Data	Type	Source	Metadata	Contact
Fisheries catch and effort - QLD	Resource extraction	QLD fisheries	Metrics of average annual effort (hours fished), by gear, since 2011 (Trawl, Harvest, Line, Net, Trap)	Department of Agriculture and Fisheries
Flood plumes	Pollution	Landsat	Digitized flood plumes from Landsat imagery	Jon Brodie
Garbage spills	Pollution	AMSA	Collated as part of Project C1 national-scale pressures. This data contains summaries at 0.1 deg of all suspected and confirmed garbage pollution events reported to, or suspected by AMSA. Data on the date, geographic location, source type and ship type was provided by AMSA. This data was summarised over the entire period (1970–2016) at 0.1 degree resolution and the count of the number of incidents produced. http://www.amsa.gov.au/environment/major-historical-incidents/index.asp Contact: Piers K Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment
Harmful substance spills	Pollution	AMSA	Collated as part of Project C1 national-scale pressures. This data contains summaries at 0.1 deg of all suspected and confirmed harmful substance pollution events reported to, or suspected by AMSA. Data on the date, geographic location, source type and ship type was provided by AMSA. This data was summarised over the entire period (1970–2016) at 0.1 degree resolution and the count of the number of incidents produced. http://www.amsa.gov.au/environment/major-historical-incidents/index.asp Contact: Piers K Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment
Oil and gas infrastructure	Resource extraction	http://www.nopta.gov.au/spatial-data/spatial-data.html; https://www.business.qld.gov.au/industry/mining/mining-online-services/qdex-data	Collated as part of Project C1 national-scale pressures	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment

Data	Type	Source	Metadata	Contact
Oil spills	Pollution	AMSA	Collated as part of Project C1 national-scale pressures. This data contains summaries at 0.1 deg of all suspected and confirmed oil pollution events reported to, or suspected by AMSA. Data on the date, geographic location, source type and ship type were provided by AMSA. This data was summarised over the entire period (1970–2016) at 0.1 degree resolution and the count of the number of incidents produced. http://www.amsa.gov.au/environment/major-historical-incidents/index.asp Contact: Piers K Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment
Recreational boating QLD	Pollution	Modelled (CSIRO CMAR)	Developed by Judy Upston, modified as per recreational boating NT.	Judy Upston, CSIRO
Recreational boating NT	Pollution	Modelled	We obtained numbers of trailer registrations for NT collected by the Dept of Infrastructure, Planning and Logistic (as of 30 Aug 2017) and QLD. We assumed that boat owners in landlocked regions of Alice, Katherine and Tennant regions use their boats locally in rivers, lakes, streams, and do not travel to the coast regularly for recreational or fishing purposes. For other regions (Darwin, East Arnhem, West Arnhem), we allocated current numbers of trailer registrations to respective population areas from the National Census 2011 remuneration data. Average distance travelled by boat size for each region was derived from the “National Boating Usage Study – Preliminary Survey Report” (http://www.trpa.org/wp-content/uploads/2009-National-Marine-Safety-Committee-Boat-usage.pdf). We created a model of average boats per distance from shore, based on survey data and number of boats, calculating standardized number of boats per distance and boat length for each state. For those regions with multiple boat ramps, we allocated number of trailers and population density evenly between each ramp. We developed four spatial buffers for each boat ramp out to 30 nautical miles, and modelled recreational boating for each buffer based on the number of registered trailers, population density and buffer distance from shore. QLD data was verified and updated based on work currently being done by Judy Upston.	Viv Tulloch-McShane, CDU

Data	Type	Source	Metadata	Contact
Relative petroleum prospectivity of the North marine planning region	Resource extraction	Geoscience Australia	This dataset is a subset of the Sedimentary Basins dataset developed by Geoscience Australia. It represents those sedimentary basins in the North commonwealth marine planning region that are considered to be prospective for petroleum, and it has been attributed with a rating describing the relative prospectivity of different areas. This interpretive data on relative petroleum prospectivity is derived from Geoscience Australia's internal quantitative basin evaluation work, modified in some cases after consultation with their own internal experts on particular basins. The classification terms used represent a simplified qualitative assessment of petroleum prospectivity, and are subject to future change as new data are gathered and interpreted. We applied an index between 0 and 1 based on the range of prospectivity attributes within the dataset (low, low-medium, medium, medium-high, and high), and then spatially joined the data to the north australian grid to derive a relative index of future prospectivity to the North Marine Bioregion. The information has been provided to DEWHA in good faith, as an input to bioregional marine planning and MPA development in the North marine planning region. It should not be taken as a definitive Geoscience Australia view of the petroleum prospectivity of these areas. The Sedimentary Basins dataset itself provides outlines for the maximum extent of Australian geological provinces and their components, including sedimentary, igneous, metamorphic provinces, both onshore and offshore. These data were compiled as part of Geoscience Australia's integrated digital information system to provide improved accessibility and knowledge relating to the petroleum and minerals geology and prospectivity, and to provide a national stratigraphic and tectonic framework for Australia. The current Sedimentary Basins dataset is not complete for Australia, and covers only offshore sedimentary provinces and a selection of sedimentary and igneous provinces in onshore eastern Australia	http://www.environment.gov.au/fed/catalog/main/home.page

Data	Type	Source	Metadata	Contact
Sea level rise risk to coastal habitats	Climate	ACEAS	Method - An increase in sea level can have a negative effect on seagrasses if the shoreline is hardened and they cannot colonise new habitats, also seagrasses can be lost on the deeper edge if light becomes limiting to growth (Waycott *et al.* 2007, Saunders *et al.* 2013). Saunders *et al.* (2013) modelled the impact of sea level rise on a large embayment in Queensland and found that the area of seagrass declined by 17% with a 1.1. m rise in sea level. Obviously, these predictions are location specific but we used these as a guide to categorise the likelihood of the risk. Dataset on the projected departure from global mean (A1B scenario) at 2070 (mm) from 17 model simulations was used (http://www.cmar.csiro.au/sealevel/sl_proj_regional.html) to quantify sea level increase. If no increases were predicted, then no risk was assigned, <50 mm was low, 50–200 moderate, and >200 mm a high likelihood.	https://acef.tern.org.au/geonetwork/srv/eng/main.home?uuid=0419a746-ddc1-44d2-86e7-e5c402473956
Sea surface temperature - variance of change	Climate	CSIRO CMAR	The physical climate defines a significant portion of the habitats in which biological communities and species reside. It is important to quantify these environmental conditions, and how they have changed, as this will inform future efforts to study many natural systems. We present the results of a statistical summary of the variability in sea surface temperature (SST) time-series data for the waters surrounding Australia, from 1993 to 2013. We partition variation in the SST series into annual trends, inter-annual trends, and a number of components of random variation. We utilise satellite data and validate the statistical summary from these data to summaries of data from long-term monitoring stations and from the global drifter program. The spatially dense results show clear trends that associate with oceanographic features. Noteworthy oceanographic features include: average warming was greatest off southern West Australia and off eastern Tasmania where the warming was around 0.6 C per decade for a 20-year study period, and; insubstantial warming in areas dominated by the East Australian Current but this area did exhibit high levels of inter-annual variability (long-term trend increases and decreases but does not increase on average). The results of the analyses can be directly incorporated into (biogeographic) models that explain variation in biological data where both biological and environmental data are on a fine-scale. Contact: Piers Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment

Data	Type	Source	Metadata	Contact
Sea surface temperature - annual variance	Climate	CSIRO CMAR	The physical climate defines a significant portion of the habitats in which biological communities and species reside. It is important to quantify these environmental conditions, and how they have changed, as this will inform future efforts to study many natural systems. We present the results of a statistical summary of the variability in sea surface temperature (SST) time-series data for the waters surrounding Australia, from 1993 to 2013. We partition variation in the SST series into annual trends, inter-annual trends, and a number of components of random variation. We utilise satellite data and validate the statistical summary from these data to summaries of data from long-term monitoring stations and from the global drifter program. The spatially dense results show clear trends that associate with oceanographic features. Noteworthy oceanographic features include: average warming was greatest off southern West Australia and off eastern Tasmania where the warming was around 0.6 C per decade for a 20-year study period, and; insubstantial warming in areas dominated by the East Australian Current but this area did exhibit high levels of inter-annual variability (long-term trend increases and decreases but does not increase on average). The results of the analyses can be directly incorporated into (biogeographic) models that explain variation in biological data where both biological and environmental data are on a fine-scale. Contact: Piers Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment

Data	Type	Source	Metadata	Contact
Sea surface temperature - change in SST	Climate	CSIRO CMAR	The physical climate defines a significant portion of the habitats in which biological communities and species reside. It is important to quantify these environmental conditions, and how they have changed, as this will inform future efforts to study many natural systems. We present the results of a statistical summary of the variability in sea surface temperature (SST) time-series data for the waters surrounding Australia, from 1993 to 2013. We partition variation in the SST series into annual trends, inter-annual trends, and a number of components of random variation. We utilise satellite data and validate the statistical summary from these data to summaries of data from long-term monitoring stations and from the global drifter program. The spatially dense results show clear trends that associate with oceanographic features. Noteworthy oceanographic features include: average warming was greatest off southern West Australia and off eastern Tasmania where the warming was around 0.6 C per decade for a 20-year study period, and; insubstantial warming in areas dominated by the East Australian Current but this area did exhibit high levels of inter-annual variability (long-term trend increases and decreases but does not increase on average). The results of the analyses can be directly incorporated into (biogeographic) models that explain variation in biological data where both biological and environmental data are on a fine-scale. Contact: Piers Dunstan CSIRO Marine and Atmospheric Research piers.dunstan@csiro.au	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment
Seismic exploration	Pollution	Geoscience Australia	Collated as part of Project C1 national-scale pressures.	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment
Seismic historical exploration	Pollution	Geoscience Australia, ARC files	Collated as part of Project C1 national-scale pressures.	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment
Sewage outfalls	Pollution	www.cleanocean.org; https://www.outfalls.info	Estimated dispersal distance from mixing zone as a rough approximation based on license information from National Outfall Database providers. Estimated minimum 500m dispersal buffer from sewage outfall.	John Gemmill

Data	Type	Source	Metadata	Contact
Shipping lanes	Pollution	AMSA	This data is a combination of records held by the Australian Maritime Safety Authority. From 1999 to 2011 Australia shipping was tracked through the Australian Ship Reporting System (AUSREP). From 2012 onward this changed to the Automatic Identification System (AIS). The data presented here are summaries of the tracks of vessels between the points identified by either AUSREP or AIS, summarised to the number of KM per 0.1 deg grid square. The AIS is a Very High Frequency (VHF) radio broadcasting system which enables AIS equipped vessels and shore-based stations to send and receive identifying information. This information can: be displayed on a computer or chart plotter aid in situational awareness provide a means to assist in collision avoidance. The International Maritime Organization (IMO) defines AIS as a ship and shore-based broadcast system, operating in the VHF maritime band. The AIS can handle over 2,000 reports per minute and may update information as often as every two seconds. https://www.amsa.gov.au/navigation/services/ais/ Australian Ship Reporting System (AUSREP) is a ship reporting system designed to contribute to the safety of life at sea and is operated by the Australian Maritime Safety Authority (AMSA) through the Australian Rescue Coordination Centre (RCC Australia) in Canberra. Participation in AUSREP is mandatory for certain ships but most other commercial ships participate voluntarily. Shipmasters send a position report each day at a convenient time nominated by the ship, the maximum time between any two reports is not to exceed 24 hours. The data is used as reference material only, designed to indicate shipping lanes and the number of vessels moving through Australian waters. AUSREP commenced in 1973 in line with Australia's obligations under the International Convention for the Safety of Life at Sea (SOLAS) as a ship reporting system and is operated by AMSA through the RCC Australia in Canberra. https://www.operations.amsa.gov.au/Spatial/DataServices/MapProduct Contact: Piers Dunstan CMAR - CSIRO Marine and Atmospheric Research Piers.Dunstan@csiro.au	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment

Data	Type	Source	Metadata	Contact
Population pressure	Pollution	CENSUS Australia, Australian Bureau of Statistics http://www.abs.gov.au/	Data from Australian Bureau of Statistics - Australian Population Grid 2011 and ASGC (Edition 2006) Urban Centres and Localities (UC/L) Digital Boundaries, Australia. Data were transformed by summing population numbers at sites >100 people and creating buffer of 20 km around population centre to account for pollution and habitat degradation from human use. Buffers were weighted by population, by summing the population in each buffer, transforming the numbers using the square root and normalising to 1. Australian Population Grid 2011 presents the first population grid produced by the Australian Bureau of Statistics. The grid presents Usual Resident Population (URP) data from the 2011 Census of Population and Housing using 1 km^2 grid cells across Australia. The 1 km^2 resolution of the grid also offers a measure of population density for Australia. The data has been modelled from Mesh Block level URP values. ASGC digital boundaries represent Urban Centre/Locality (UC/L), Section of State (SOS), Section of State Range (SOSR). Date of effect of the UC/L and SOS Structures is 8 August 2006, the date of the 2006 Census of Population and Housing. Copyright Commonwealth of Australia administered by the ABS. Reference: Statistical Geography Vol 1: Australian Standard Geographical Classification (ASGC) 2006 (ABS Cat. No. 1216.0). Statistical Geography Vol 3: Australian Standard Geographical Classification (ASGC) 2006 Urban Centres/Localities (ABS Cat. No. 2909.0). Custodian: ABS Geography Section: geography@abs.gov.au.	CENSUS Australia, Australian Bureau of Statistics http://www.abs.gov.au/
Urban development	Pollution	Australian Bureau of Statistics	Collated as part of Project C1 national-scale pressures.	https://www.nespmarine.edu.au/project/project-c1-improving-our-understanding-pressures-marine-environment

Data	Type	Source	Metadata	Contact
Seagrass threats 2016	All	Canto, R., Kilminster, K., Lyons, M., Roelfsema, C., McMahon, K. 2016. Spatially explicit current and future threats to seagrass habitats in Australia	Spatially explicit current and future threats to seagrass habitats in Australia created 2015. This mapped dataset is a compilation of spatially explicit, nation-wide threats to seagrass based on current pressures and projected future climate change pressures. In addition, the value of this mapped dataset can potentially extend to assess threats to other coastal habitats. Current threats in this mapped dataset include urban/agricultural runoff, industrial pollution, sediment resuspension, port infrastructure and dredging, shipping accidents, oil and gas accidents. Future threats in this mapped dataset include modelled increase in sea surface temperature for 2070, modelled increase in total annual rainfall for 2070 and modelled increase in sea level rise for 2070. All threats in this mapped dataset are given as a single ArcGIS polygon shapefile composed of 10 x 10 km coastal grid cells. All 10 threat layers were put together as one shapefile. In this shapefile, each 10 x 10 km grid cell/polygon will have the following attribute corresponding to a specific threat layer: 2070temp - increase in sea surface temperature risk, 2070seaL- sea level rise risk, 2070rn - change in rainfall risk, Industry - industrial pollution risk, Oilgas - Oil and gas accident risk, Port - port infrastructure and dredging risk, Resuspen - sediment resuspension risk, Shipping - shipping accident risk, ChrSedNut - chronic sediment nutrient load risk, AcuSedNut - acute sediment nutrient load risk. Each grid cell/polygon will have a risk value (high risk =4, medium risk=3, low risk=2 or no risk=1) for each of the 10 risk layers. Important Note: The risk values for the 10 threat layers were generated for all coastal grid cells with and without seagrass presence. In order to view risk for grid cells with seagrass, a seagrass presence / absence layer (Canto *et al.* 2016a, Canto *et al.* 2016b, Canto *et al.* 2016c, Canto *et al.* 2016d, Canto *et al.* 2016e, Canto *et al.* 2016f, Canto *et al.* 2016g) was added as indicated by the “SG” attribute. This is done by doing a query/filter function where grid cells with “SG value =1” are shown. This data is under TERN Attribution- Licence (TERN-BY). This licence requires the following: 1) that the original creator must be credited, and the source linked to by the data user. More information can be found regarding the data licence at http://www.tern.org.au/TERN-s-Data-Licences-pg22188.html. The data author requests attribution in the following manner: Canto, R., Kilminster, K., Lyons, M., Roelfsema, C., McMahon, K. 2016. Spatially explicit current and future threats to seagrass habitats in Australia	ttps://acef.tern.org.au/geonetwork

Data	Type	Source	Metadata	Contact
Industrial pollution risk to coastal habitats	Pollution	ACEAS and ports of Australia	The industrial pollution layer was generated from the industrial class cover of the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) 2005–2006 land use map derived from an AVHRR satellite image (http://adl.brs.gov.au). This industrial pollution layer assumes that with more industrial land use in a 10 x 10 km grid cell, the greater chance of industrial pollution reaching the marine environment, either through direct runoff, groundwater contamination or atmospheric deposition. In this approach, we only considered the grid cells that were adjacent to the coast, and not those further inland, hence the limitation is that we capture industrial pollution from direct run-off and groundwater contamination, but not from surface run-off from catchments further inland. The percentage of the terrestrial grid cell adjacent to the coast that contained industrial pollution was calculated, based on the number of pixels within each cell (total of 100). If the terrestrial grid cells adjacent to the coastal grid cell contained no industrial land-use, then it was considered to have no exposure to industrial pollution. If <2% of the grid cell was industrial this was categorised as low likelihood (=low risk), 2–10% was considered a moderate likelihood (=medium risk), and >10% a high likelihood (=high risk). Buffers were created adjacent to any moderate or high likelihood cells. Any marine grid cell adjacent to a high-risk cell was considered a moderate risk, and those adjacent to a moderate risk cell were considered a low risk. If any grid cell was allocated more than one risk category, then the highest category was maintained.	ttps://acef.tern.org.au/geonetwork

River discharge - acute sediment and nutrient risk	Pollution	Canto, R., Kilminster, K., Lyons, M., Roelfsema, C., McMahon, K. 2016. Spatially explicit current and future threats to seagrass habitats in Australia	This threat layer was derived by considering the catchment condition moderated by the likelihood of large pulses of flow along river channels as well as the total volume of the flow. Specifically, the disturbance of the catchment (as identified in the National Estuary Audit 2000, n=974 estuaries http://www.ozcoasts.gov.au/search_data/estuary_search.jsp) was used to describe catchment condition. As sediment and nutrient loads are strongly linked to catchment clearing and land use, we assumed that catchments that were near pristine and largely unmodified would pose a low risk to seagrasses in terms of sediment and nutrient loads. Similarly, the highest risk would be from catchments which are extensively modified, with a moderate risk from those moderately modified. We considered that estuaries receiving very pulsed streamflow were more susceptible to acute nutrient and sediment loads. To determine the pulse regime, streamflow data from the Australian Bureau of Meteorology was supplemented by the Western Australian Department of Water Data (bom.gov.au and water.wa.gov.au) which described the daily flows from the period 1990–1999 from 241 stream gauging stations Australia-wide. Gauging stations within 250 km of the coast were ‘moved’ to the nearest point on the Australian coastline linked to the appropriate waterway, and estuaries matched with their nearest streamflow. We then calculated a pulse metric based on the number of days which daily streamflow was >1SD above the mean daily streamflow (determined on ln(ML+0.01) of daily data for each gauging station). If the pulse metric was <25th percentile, then streamflow was more constant so acute risk assumed to be zero. If the pulse metric was within the 25th–75th percentile, the acute risk was assumed to be reduced and acute risk greatest for estuaries where the pulse metric >75th percentile. The risk of acute sediment and nutrient risk for each estuary was determined based on the catchment condition and pulse metric as summarised in Table 1 of Canto *et al.* (2016), where 4 is high risk, 3 moderate risk and 2 low with one indicating no risk. Once the risk values were generated for each estuary point location, the spatial extent of the influence of the threat was considered based on annual streamflow. Areas with higher annual streamflow would have greater sediment and nutrient risks than those which received less annual streamflow. The annual flow data was derived from the same dataset as above and the metric defined as ln (annual flow, ML)). Areas receiving streamflow of 20 333 ML/yr or less, were in the lowest 25th percentile, and the spatial extent of impact was considered small. A medium extent of impact was assigned for flow between 20,333 ML/yr and 181,680 ML/yr (25th – 75th percentiles) and >181,680 ML/yr was assigned a large extent of impact. The spatial extent was estimated based on both the risk of acute sediment and nutrient risk in the estuary (1–4 above) and the streamflow category (Figure 1 of Canto *et al.* (2016)). For low risk cells a small streamflow generated no buffer, a moderate stream flow had a	https://acef.tern.org.au/geonetwork

Data	Type	Source	Metadata	Contact
			buffer of 1 10x10 km cell around the estuary at low risk, and the high stream flow generated a buffer of 2 10x10 km cells around the estuary. For moderate and high-risk cells, the size of the buffer varied, and the buffer dropped down one risk category. A small flow generated a buffer of 1 10x10 km cell around the estuary, a medium flow generated a buffer of 2 10x10 km cells and a high flow buffer of 4 10x10 km cells	
Light pollution	Pollution	NOAA	We obtained the 2013 DMSP-OLS raster image of radiance-calibrated night time light data from the National Centres for Environmental Information - Version 4 DMSP-OLS Nighttime Lights Time Series (formally National Geophysical Data Center (NGDC)). The files are cloud-free composites made using all the available archived DMSP-OLS smooth resolution data for calendar years. In cases where two satellites were collecting data - two composites were produced. The products are 30 arc second grids, spanning -180 to 180 degrees longitude and -65 to 75 degrees latitude.	https://www.ngdc.noaa.gov/eog/dmsp/downloadV4composites.html

APPENDIX E – *EPBC* REFERRALS

Introduction

Northern Australian growth and development has been recognized as an increasingly important asset to the country. Over the past decade, the population of Northern Australia has grown at a faster rate than that of the Australian average, and the economy of Northern Australia has sustained significant growth beyond the rest of the nation, now contributing to 11.7% of the Australian Gross Domestic Product (GDP). With this growth, improvements in infrastructure are required to link Northern Australia to the south of the country and to further advance economic opportunities.

To understand the location and industries most likely to affect *EPBC*-listed Threatened and Migratory marine species across the North Marine Bioregion (Commonwealth marine areas, Northern Territory, and Queensland Gulf of Carpentaria), referrals between the period 2000 and 2016 which triggered Threatened and Migratory marine species were analysed from data provided by the Environment Standards Division of the Department of the Environment and Energy.

This data (*EPBC Act* referrals for the years 2000–2016) showed that:

- There was a total of 550 triggers, representing 67 of the ≈80 Threatened and Migratory marine species;
- The majority of triggers were from the Northern Territory;
- The majority of triggers related to turtles, with all five species represented; and,
- Thirteen industry types were represented, the bulk being exploration for minerals, oil and gas, and mining.

This analysis of EPBC referrals provides the background for a spatial analysis of *EPBC* referral data as part of the Pressures Chapter of this report (see Chapter 3).

Jurisdictions and Locations

A total of 550 unique triggers were identified. The majority of triggers originated from the Northern Territory (NT, 51%), followed by Commonwealth marine areas (CWM, 27%), and Queensland (QLD, 22%). Across the region, nearly half of the triggers occurred in locations within the Australian Exclusive Economic Zone (EEZ, 48%), followed by the coastline (36%), and inland waterways (16%) (Table E1).

Table E1. The jurisdiction and broad location of the number of *EPBC Act* referrals (proportional breakdown of triggers in brackets).

Jurisdiction	Commonwealth	Northern Territory	Queensland
	148 (0.27)	282 (0.51)	120 (0.22)
Location	**Within EEZ**	**Coastline**	**Waterways**
	265 (0.48)	199 (0.36)	86 (0.16)

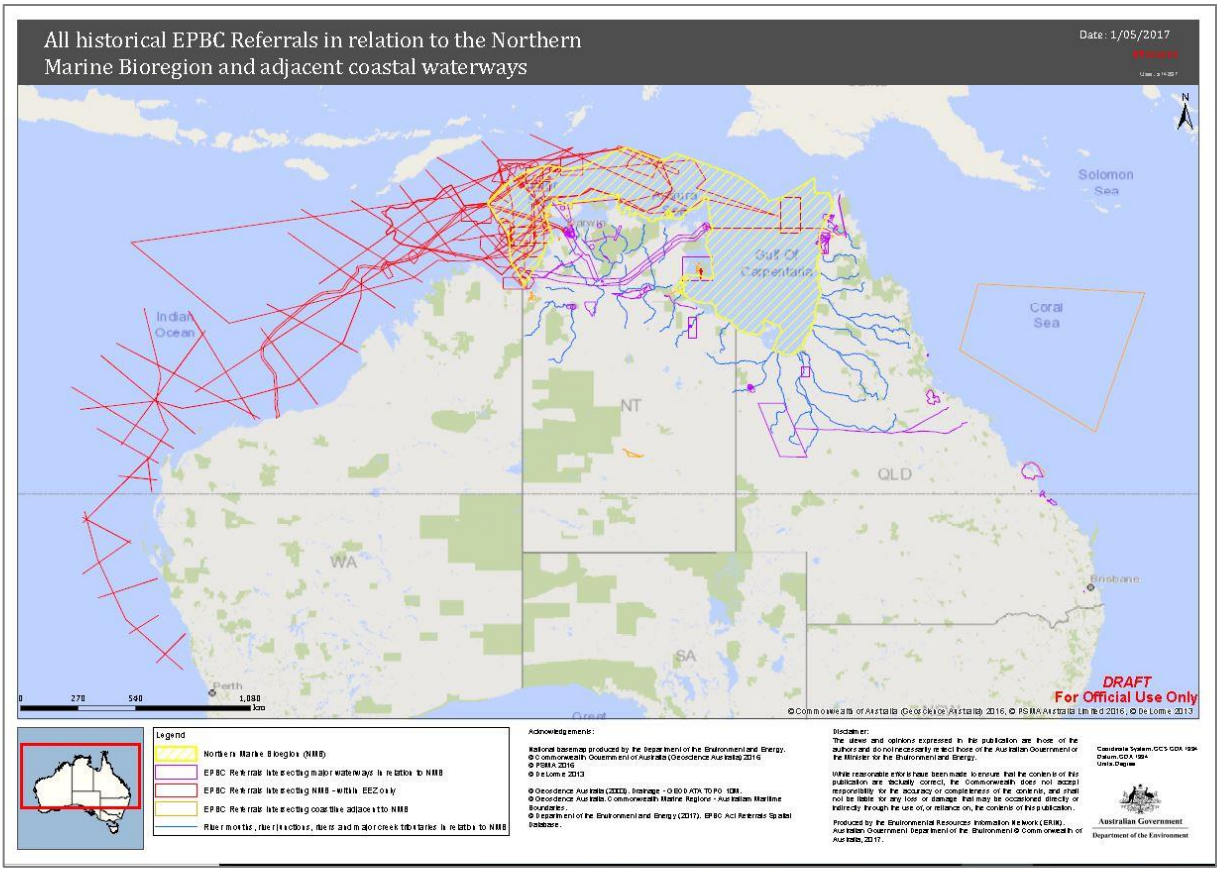

Figure E5. Historical *EPBC* referrals (covering the years 2000–2016) in the North Marine Bioregion and adjacent coastal waterways, mapped as the extent of their geographic footprint. Credit: Department of the Environment and Energy; Source:

http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7BC65F30AC-CD38-4EC6-BD62-2A0D37C661EE%7D

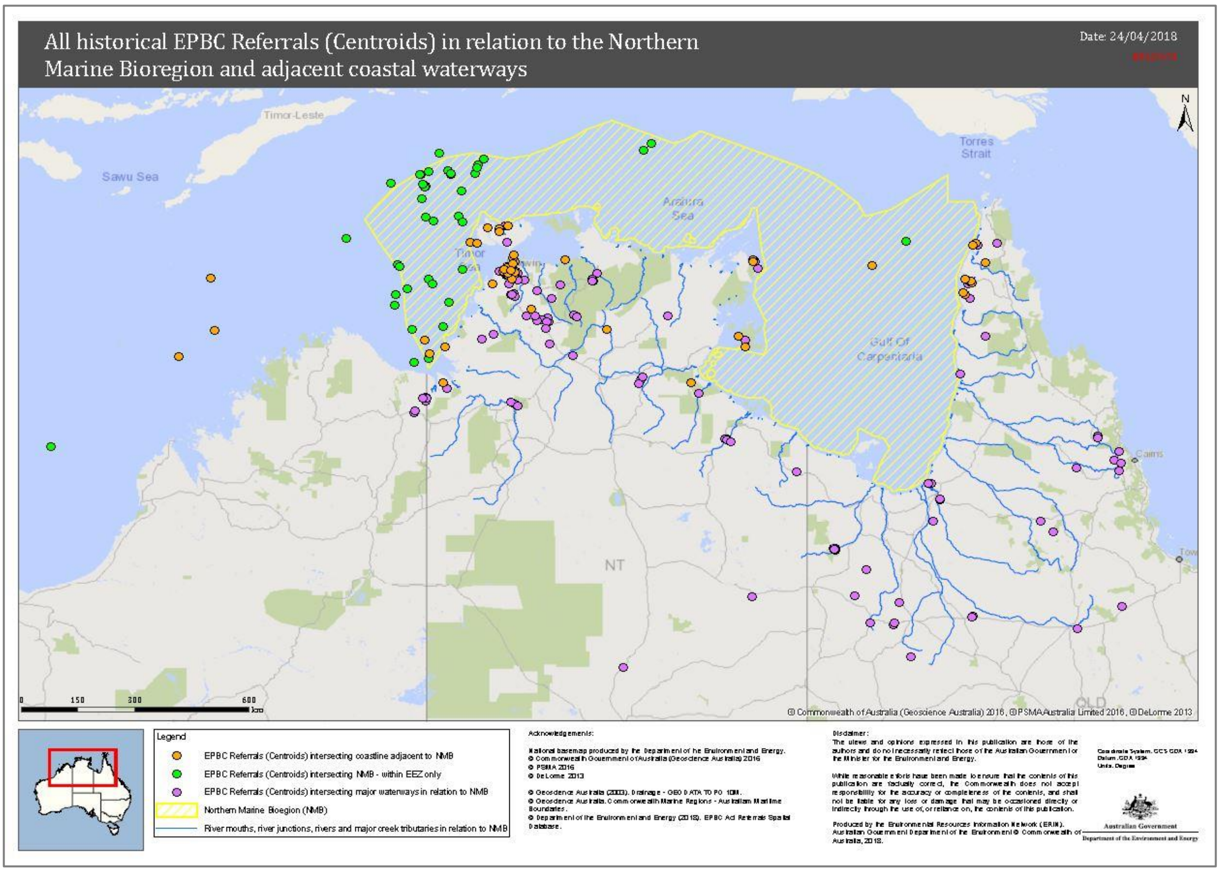

Figure E6. Historical *EPBC* referrals (covering the years 2000–2016) in the North Marine Bioregion and adjacent coastal waterways, mapped as centroids. Credit: Department of the Environment and Energy; Source:

http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7BC65F30AC-CD38-4EC6-BD62-2A0D37C661EE%7D

Industry Types

Within the referrals, 17 industries were recognized. Due to the small number of instances for some industry types, several industries were grouped together, resulting in a total of 13 industries. Industry types that were grouped together included: *Commonwealth* and *Commonwealth Development* (referred to as *Commonwealth*); *Energy Generation and Supply (Renewable)* and *Energy Generation and Supply (Non-renewable)* (referred to as *Energy Generation and Supply*); and *Waste Management (Sewage)* and *Waste Management (Non-Sewage)* (referred to as *Waste Management*). Most triggers initiated from industries for Exploration (minerals, oil, and gas; 35%) or Mining (27%) (Table E2). Table E3 presents the complete species list, in order of number of triggers (highest to lowest), by industry type.

Table E2. Breakdown of *EPBC Act* referrals by industry.

Industry	Number of Referrals	Proportion of Total Referrals
Aquaculture	17	0.03
Commercial Development	16	0.03
Commonwealth	49	0.09
Energy Generation and Supply	27	0.05
Exploration (minerals, oil, and gas)	194	0.35
Manufacturing	16	0.03
Mining	150	0.27
Residential Development	5	0.01
Science and Research	5	0.01
Telecommunications	2	<0.01
Transport	42	0.08
Waste Management	17	0.03
Water Management and Use	9	0.02

Triggered Species

Sixty-seven Threatened and Migratory marine species were identified across six animal groups. These included 35 species of birds (52%), 16 species of cetaceans (whales and dolphins, 24%), 9 species of sharks (including sawfishes) (13%), 5 species of turtles (7%), the Estuarine Crocodile (2%), and the Dugong (2%) (Figure E1). Of the 550 triggers, 211 were prompted by turtles (38%), 135 by cetaceans (25%), 118 by birds (21%), 73 by sharks (13%), 11 by the Estuarine Crocodile (2%), and 2 by the Dugong (<1%) (Figure E1).

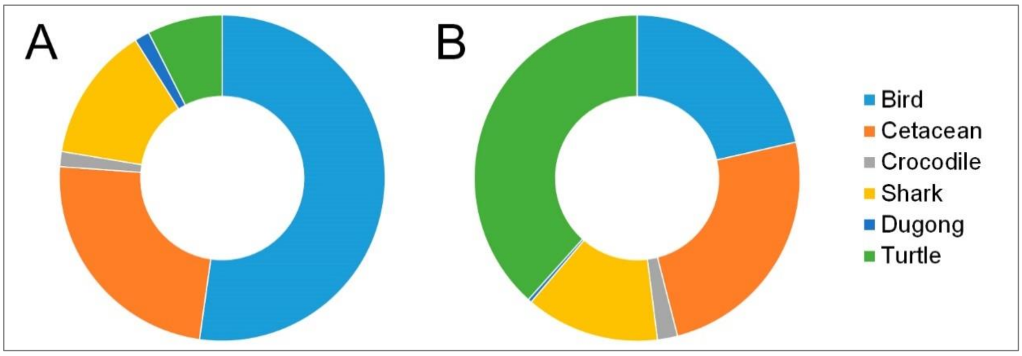

Figure E1. Proportional breakdown of the 550 triggers by (A) number of species per animal group, and (B) number of triggers per animal group.

All five species of turtles (Green Turtle, Olive Ridley Turtle, Hawksbill Turtle, Loggerhead Turtle, and Leatherback Turtle) were amongst the top 10 triggered species. Three species of cetaceans (Humpback Whale, Blue Whale, Killer Whale), and two species of sharks (Green and Dwarf Sawfish) were also included in the top 10 species (Table E4). Table E5 provides the complete species list.

Table E3. Complete species list, in order of number of triggers (highest to lowest), by industry type (AQ, Aquaculture; CM, Commercial Development; CW, Commonwealth; EG, Energy Generation and Supply; EX, Exploration (minerals, oil, and gas); MA, Manufacturing; MI, Mining; RD, Residential Development; SR, Science and Research; TL, Telecommunications; TR, Transport; WS, Waste Management; WT, Water Management and Use).

Species	*N*	Industry												
		AQ	CM	CW	EG	EX	MA	MI	RD	SR	TL	TR	WS	WT
Green Turtle	52	4	3	2	4	17	2	12	0	1	0	4	3	0
Olive Ridley Turtle	47	3	4	2	3	15	1	12	0	2	0	3	2	0
Hawksbill Turtle	41	3	3	2	3	15	1	9	0	0	0	3	2	0
Loggerhead Turtle	40	1	3	2	2	15	1	10	0	0	0	3	3	0
Humpback Whale	37	0	0	3	2	27	0	1	0	2	1	1	0	0
Leatherback Turtle	31	0	1	2	2	13	1	6	0	0	0	3	3	0
Blue Whale	26	0	0	1	2	21	1	0	0	0	1	0	0	0
Green Sawfish	23	0	0	1	1	4	1	12	1	0	0	1	1	1
Dwarf Sawfish	21	0	0	1	1	1	1	13	1	0	0	1	1	1

Species	*N*	Industry												
Killer Whale	19	0	0	1	0	17	0	0	0	0	0	0	1	0
Sperm Whale	16	0	0	1	1	14	0	0	0	0	0	0	0	0
Largetooth Sawfish	14	0	0	1	2	0	1	7	1	0	0	1	0	1
Bryde's Whale	11	0	0	0	0	9	0	2	0	0	0	0	0	0
Estuarine Crocodile	11	3	1	0	0	1	0	6	0	0	0	0	0	0
Curlew Sandpiper	10	1	1	1	0	0	1	3	1	0	0	1	0	1
Eastern Curlew	9	0	0	1	0	0	1	4	1	0	0	1	0	1
Speartooth Shark	6	0	0	0	1	0	0	5	0	0	0	0	0	0
Little Curlew	6	1	0	1	0	0	1	3	0	0	0	0	0	0
Indian Ocean Bottlenose Dolphin	6	0	0	0	0	2	1	0	0	0	0	2	1	0
Streaked Shearwater	6	0	0	0	0	4	0	2	0	0	0	0	0	0
Antarctic Minke Whale	6	0	0	0	0	6	0	0	0	0	0	0	0	0
Oriental Pratincole	5	1	0	1	1	0	0	1	0	0	0	0	0	1
Southern Right Whale	4	0	0	1	0	3	0	0	0	0	0	0	0	0
Latham's Snipe	4	0	0	0	0	0	0	4	0	0	0	0	0	0
Oriental Plover	4	0	0	1	1	0	0	2	0	0	0	0	0	0
Longfin Mako	4	0	0	0	0	3	0	1	0	0	0	0	0	0
Asian Dowitcher	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Bar-tailed Godwit	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Black-tailed Godwit	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Common Sandpiper	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Great Knot	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Greater Sand-Plover	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Indo-Pacific Humpback Dolphin	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Grey Plover	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Grey-tailed Tattler	3	0	0	1	0	0	0	1	0	0	0	1	0	0

Species	*N*	Industry												
Lesser Frigatebird	3	0	0	0	0	0	0	3	0	0	0	0	0	0
Lesser Sand-Plover	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Little Tern	3	0	0	0	0	0	0	3	0	0	0	0	0	0
Marsh Sandpiper	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Pacific Golden Plover	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Red Knot	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Sharp-tailed Sandpiper	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Terek Sandpiper	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Whimbrel	3	0	0	1	0	0	0	1	0	0	0	1	0	0
Broad-billed Sandpiper	3	0	0	1	0	0	0	1	0	0	0	0	0	1
Pin-tailed Snipe	3	0	0	1	0	0	0	1	0	0	0	0	0	1
Swinhoe's Snipe	3	0	0	1	0	0	0	1	0	0	0	0	0	1
Dugong	2	0	0	0	0	0	0	1	0	0	0	1	0	0
Great Frigatebird	2	0	0	0	0	0	0	2	0	0	0	0	0	0
Shortfin Mako	2	0	0	0	0	2	0	0	0	0	0	0	0	0
Little Ringed Plover	2	0	0	1	0	0	0	1	0	0	0	0	0	0
Pectoral Sandpiper	2	0	0	1	0	0	0	1	0	0	0	0	0	0
Ruddy Turnstone	2	0	0	1	0	0	0	0	0	0	0	1	0	0
Sanderling	2	0	0	1	0	0	0	0	0	0	0	1	0	0
Wandering Tattler	2	0	0	1	0	0	0	1	0	0	0	0	0	0
Largetooth Sawfish	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Australian Snubfin Dolphin	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Eastern Reef Egret	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Wood Sandpiper	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Dwarf Sperm Whale	1	0	0	0	0	1	0	0	0	0	0	0	0	0
False Killer Whale	1	0	0	0	0	1	0	0	0	0	0	0	0	0

Species	*N*	Industry												
Minke Whale	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Pygmy Killer Whale	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Great White Shark	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Pygmy Sperm Whale	1	0	0	0	0	1	0	0	0	0	0	0	0	0
Northern River Shark	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Sei Whale	1	0	0	0	0	0	1	0	0	0	0	0	0	0
Sum	**550**	**17**	**16**	**49**	**27**	**194**	**16**	**150**	**5**	**5**	**2**	**43**	**17**	**9**

Table E4. The 10 most triggered *EPBC*-listed species.

Species	*EPBC* Threatened Status	*EPBC* Migratory Status	*n* triggers
Green Turtle	Vulnerable	Migratory	52
Olive Ridley Turtle	Endangered	Migratory	47
Hawksbill Turtle	Vulnerable	Migratory	41
Loggerhead Turtle	Endangered	Migratory	40
Humpback Whale	Vulnerable	Migratory	37
Leatherback Turtle	Endangered	Migratory	31
Blue Whale	Endangered	Migratory	26
Green Sawfish	Vulnerable	Migratory	23
Dwarf Sawfish	Vulnerable	Migratory	21
Killer Whale	Not listed	Migratory	19

Table E5. Complete species list, in order of number of triggers (highest to lowest), by location of triggers (EEZ, within EEZ; CL, coastline; WW, waterways), and jurisdiction of triggers (CW, Commonwealth marine areas; NT, Northern Territory; QLD, Queensland).

Species	Status	N triggers	Locale			Jurisdiction		
			EEZ	CL	WW	CW	NT	QLD
Green Turtle	Vulnerable	52	23	21	8	17	26	9
Olive Ridley Turtle	Endangered	47	22	16	9	14	24	9
Hawksbill Turtle	Vulnerable	41	18	15	8	12	22	7
Loggerhead Turtle	Endangered	40	20	13	7	14	18	8
Humpback Whale	Vulnerable	37	32	4	1	23	10	4
Leatherback Turtle	Endangered	31	18	10	3	11	15	5
Blue Whale	Endangered	26	25	1	0	18	7	1
Green Sawfish	Vulnerable	23	5	11	7	2	14	7
Dwarf Sawfish	Vulnerable	21	2	11	8	1	13	7
Killer Whale	Migratory	19	18	1	0	11	7	1
Sperm Whale	Migratory	16	15	1	0	9	6	1
Largetooth Sawfish	Vulnerable	14	0	7	7	0	10	4
Bryde's Whale	Migratory	11	9	2	0	4	6	1
Estuarine Crocodile	Migratory	11	2	5	4	0	6	5
Curlew Sandpiper	Critically Endangered	10	1	7	2	0	8	2
Eastern Curlew	Critically Endangered	9	1	5	3	0	6	3
Speartooth Shark	Critically Endangered	6	1	1	4	0	1	5
Little Curlew	Migratory	6	1	4	1	0	3	3
Indian Ocean Bottlenose Dolphin	Cetacean	6	2	4	0	0	6	0
Streaked Shearwater	Migratory	6	4	1	1	2	3	1
Antarctic Minke Whale	Migratory	6	6	0	0	2	4	0
Oriental Pratincole	Migratory	5	0	3	2	0	3	2
Southern Right Whale	Endangered	4	3	1	0	2	2	0

Species	Status	N triggers	Locale			Jurisdiction		
Latham's Snipe	Migratory	4	1	1	2	0	1	3
Oriental Plover	Migratory	4	1	2	1	0	3	1
Longfin Mako	Migratory	4	3	0	1	2	1	1
Asian Dowitcher	Migratory	3	1	2	0	0	2	1
Bar-tailed Godwit	Migratory	3	1	2	0	0	2	1
Black-tailed Godwit	Vulnerable	3	1	2	0	0	2	1
Common Sandpiper	Migratory	3	1	2	0	0	2	1
Great Knot	Critically Endangered	3	1	2	0	0	2	1
Greater Sand-Plover	Migratory	3	1	2	0	0	2	1
Indo-Pacific Humpback Dolphin	Migratory	3	1	2	0	0	2	1
Grey Plover	Migratory	3	1	2	0	0	2	1
Grey-tailed Tattler	Migratory	3	1	2	0	0	2	1
Lesser Frigatebird	Migratory	3	1	0	2	0	0	3
Lesser Sand-Plover	Endangered	3	1	2	0	0	2	1
Little Tern	Migratory	3	1	1	1	0	1	2
Marsh Sandpiper	Migratory	3	1	2	0	0	2	1
Pacific Golden Plover	Migratory	3	1	2	0	0	2	1
Red Knot	Endangered	3	1	2	0	0	2	1
Sharp-tailed Sandpiper	Migratory	3	1	2	0	0	2	1
Terek Sandpiper	Migratory	3	1	2	0	0	2	1
Whimbrel	Migratory	3	0	3	0	0	3	0
Broad-billed Sandpiper	Migratory	3	0	2	1	0	2	1
Pin-tailed Snipe	Migratory	3	0	2	1	0	2	1
Swinhoe's Snipe	Migratory	3	0	2	1	0	2	1
Dugong	Migratory	2	1	1	0	0	1	1
Great Frigatebird	Migratory	2	1	0	1	0	0	2
Shortfin Mako	Migratory	2	2	0	0	2	0	0

Species	Status	N triggers	Locale			Jurisdiction		
Little Ringed Plover	Migratory	2	0	2	0	0	2	0
Pectoral Sandpiper	Migratory	2	0	2	0	0	2	0
Ruddy Turnstone	Migratory	2	0	2	0	0	2	0
Sanderling	Migratory	2	0	2	0	0	2	0
Wandering Tattler	Migratory	2	0	2	0	0	2	0
Largetooth Sawfish	Vulnerable	1	1	0	0	0	0	1
Australian Snubfin Dolphin	Migratory	1	1	0	0	0	0	1
Eastern Reef Egret	Migratory	1	1	0	0	0	0	1
Wood Sandpiper	Migratory	1	1	0	0	0	0	1
Dwarf Sperm Whale	Cetacean	1	1	0	0	0	1	0
False Killer Whale	Cetacean	1	1	0	0	0	1	0
Minke Whale	Cetacean	1	1	0	0	0	1	0
Pygmy Killer Whale	Cetacean	1	1	0	0	0	1	0
Great White Shark	Vulnerable	1	1	0	0	1	0	0
Pygmy Sperm Whale	Cetacean	1	1	0	0	0	1	0
Northern River Shark	Endangered	1	0	1	0	0	1	0
Sei Whale	Vulnerable	1	1	0	0	1	0	0
Sum		**550**	**265**	**199**	**86**	**148**	**282**	**120**

The majority of triggered species are listed as Migratory under the *EPBC Act* (39 species, 58%). Ten species are listed as Vulnerable (15%), eight as Endangered (12%), six as Other (in this case, species were listed as *Cetacean*; 9%), and four as Critically Endangered (6%) (Figure E2).

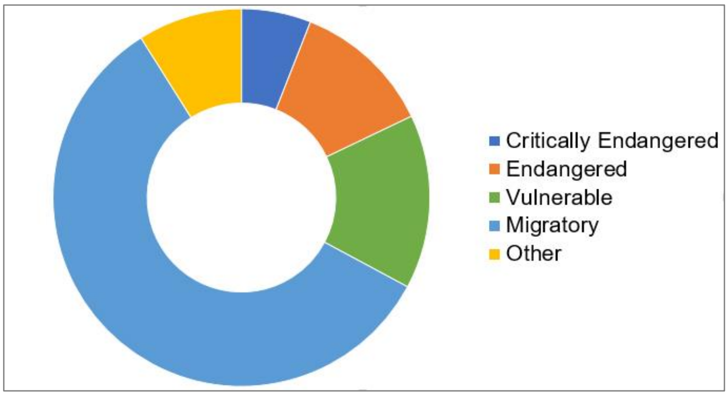

Figure E2. Triggered species as listed by their *EPBC Act* listing.

Triggers for most species originated in the Northern Territory, with the exception of the cetaceans where half of the triggers came from Commonwealth marine areas. There were no instances from Commonwealth marine areas for the Estuarine Crocodile or the Dugong (Figure E3). For cetaceans, turtles, and the Dugong, most triggers were found to occur within the Australian EEZ. Triggers for birds occurred mostly from the coastline, while triggers for the Estuarine Crocodile and sharks were roughly equally distributed across the three locations (EEZ, coastline, waterways) (Figure E3). Birds, sharks, and the Estuarine Crocodile were most affected by mining proposals, whereas cetaceans and turtles were more affected by exploration (mineral, oil and gas). Dugong were equally affected by mining and transport (Figure E4).

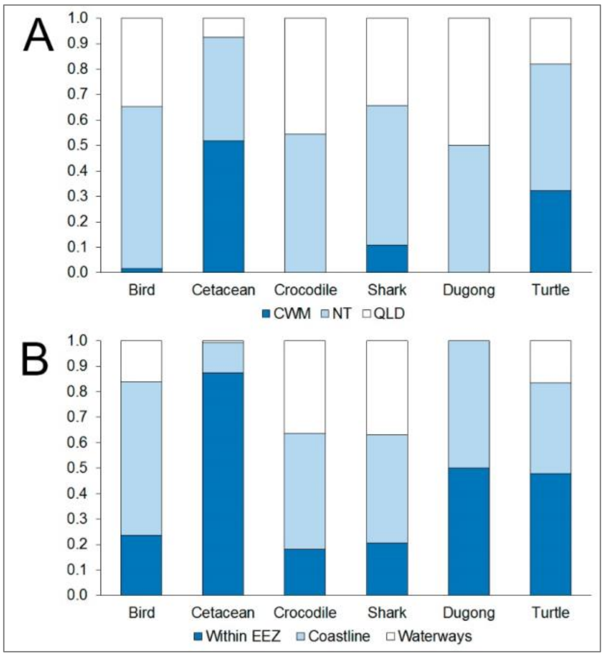

Figure E3. By animal group, the proportion of triggers by (A) jurisdiction (Commonwealth marine areas, CWM; Northern Territory, NT; Queensland, QLD), and (B) location (within EEZ, Coastline, Waterways).

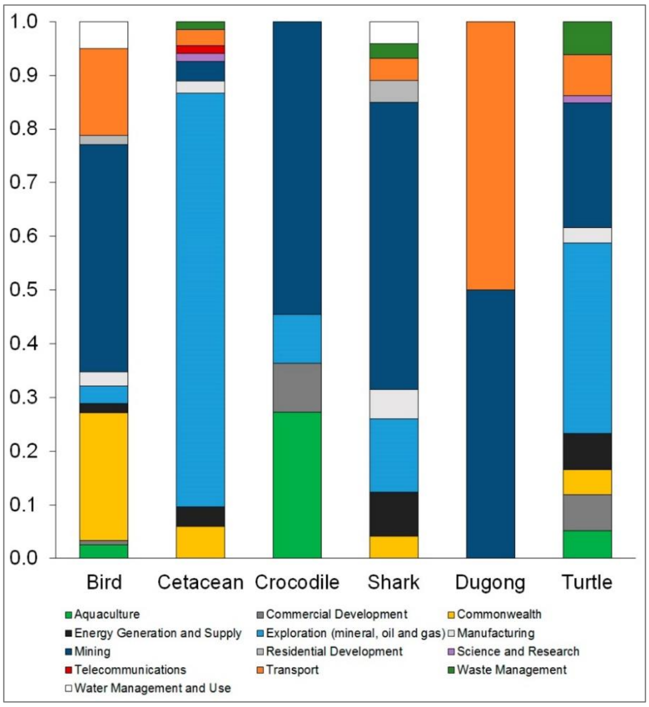

Figure E4. For each animal group, the proportion of triggers initiated by the identified industries.

The Current Development Landscape

In addition to the broad analysis of triggers presented above, the Department of the Environment and Energy provided additional information pertinent to understanding development patterns in the North Marine Bioregion. These related to groundwater resources; current water, mineral, and energy assessments; resource developments; and current agricultural developments.

Groundwater Resources in the Northern Territory

Figure E5 below shows the distribution of all (known) groundwater bores in the Northern Territory. While ongoing work being conducted by Geoscience Australia may discover a new groundwater resource, the current distribution provides a very good indication as to where groundwater resources are located. It is apparent that the groundwater resource on the eastern side of the Northern Territory is limited. This is because the groundwater resources here are located within fractured rocks which means that finding groundwater can be very hit and miss (many fractures needed in the one place).

In terms of infrastructure, the highest density of bores (red dots in Figure E7) are largely around the Barkly Highway and the Stuart Highway (and associated railway line). Hence it has been suggested that any further development is likely to use this existing infrastructure.

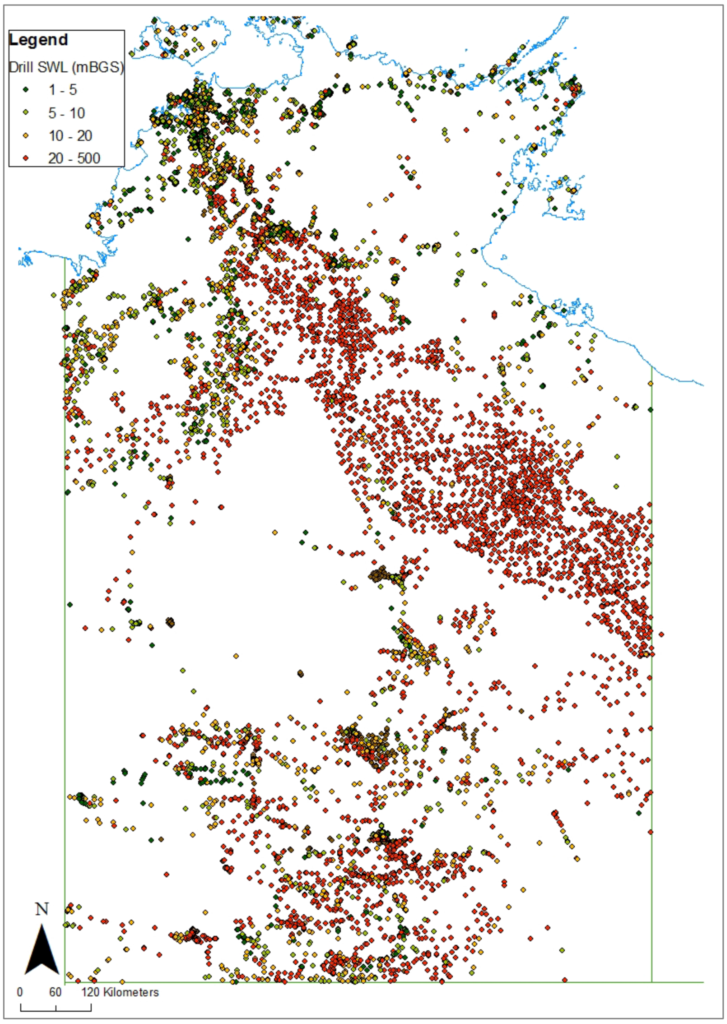

Figure E7. Groundwater bores in the Northern Territory. Source: Gough, T. (2011). Northern territory Groundwater Stocktake. Water Assessment Section, Water Resources Division. Department of Land and Resource Management.

Current Water, Mineral and Energy Assessments

Northern Australia Water Resource Assessment

CSIRO are currently conducting assessments in the Fitzroy River catchment (WA – Kimberley region) and Mitchell River catchment (Qld – western side of Cape York). An assessment is also underway in the Northern Territory in the Finniss, Adelaide, Mary, and Wildman River catchments (Darwin catchments). These projects are due for completion in June 2018.

As there is no assessment being conducted on the eastern side of the Northern Territory, there is limited prospect of large-scale agricultural development that would require new infrastructure in the short to medium term.

Exploring for the Future

Geoscience Australia are conducting petroleum, mineral, and groundwater assessments across Northern Australia. In the Northern Territory, the focus is on the Barkly region. This is a 4-year program and due for completion at the end of 2020. Consequently, it is unlikely that there would be any future development requiring new infrastructure in the short to medium term.

Geological and Bioregional Assessments

Whilst the final regions are still to be determined, the Beetaloo Sub-Basin in the Northern Territory (Barkly region) is likely to be an area of investigation (see shale gas discussion below).

Agricultural Resource Assessment

CSIRO also conducted assessments in the Flinders and Gilbert River catchments in Qld (western side of Cape York). These have been completed.

LNG Plants – Darwin

Two Liquified Natural Gas (LNG) facilities have been built in the Port of Darwin. Of particular note is the Ichthys Project, which will export up to 8.9 million tonnes of LNG and 1.6 million tonnes of liquefied petroleum gas per annum mostly to southeast Asia. This will result in a significant increase in shipping.

Shale Gas

Given that the NT Government recently lifted its moratorium on hydraulic fracking, the Beetaloo Sub-Basin containing an extensive gas resource could quickly be brought into production. The most likely initial production area (based on current knowledge) is close to the Stuart Highway, which is already serviced by a gas pipeline. Further, another pipeline is being built, and is due for completion at the end of 2018, between Tennant Creek and Mt Isa, which would allow this gas to service the eastern gas market. Hence, it is highly unlikely that any development would be required along the eastern Northern Territory coastline.

Existing Mines

There are several existing mines on the eastern side of the Northern Territory, for example, the McArthur River (Lead, Zinc) and Merlin (Diamonds) mines. The McArthur River mine is currently going through an EIS process, however, this is to extend production life rather than increasing production. Thus, there is unlikely to be any need to increase infrastructure (or shipping) requirements.

Other Mineral Prospects

In the general eastern Northern Territory area, there are several mineral prospects, including the Reward/Teena (Lead, Zinc) and the Highland Plains (Phosphate, Iron). These prospects are in exploration or mine preparation stage, respectively, with the later not coming on line for at least four years. Export will be out of the existing Port Karumba and would likely result in a small increase in shipping traffic.

Ord River Irrigation Scheme – Stage 3 Expansion

This expansion involves the release of a further 6000ha of land, close to the Ord River, which will be used for irrigated agriculture on top of the recent Stage 2 (Weaber Plain) expansion. These two expansions may impact on water quality and the exported produced will increase shipping traffic out of Wyndham (outside but close to the North Marine Bioregion).

Project Sea Dragon Stage 1 Prawn Aquaculture Project

This project is a large-scale, integrated, land-based prawn aquaculture project with a number of components (Figure E8) on the western side of the Northern Territory. The ‘grow out’ facility is located in the south-eastern side of the Joseph Bonaparte Gulf bounded by the Victoria and Keep Rivers. The core breeding centre is located southwest of Darwin. The ‘grow out’ facility may impact on water quality in the region and the export of prawns will increase shipping traffic out of Wyndham. Prawns will also be exported through Darwin. It is important to note that this is only Stage 1 and there is likely to be significant expansion in the future.

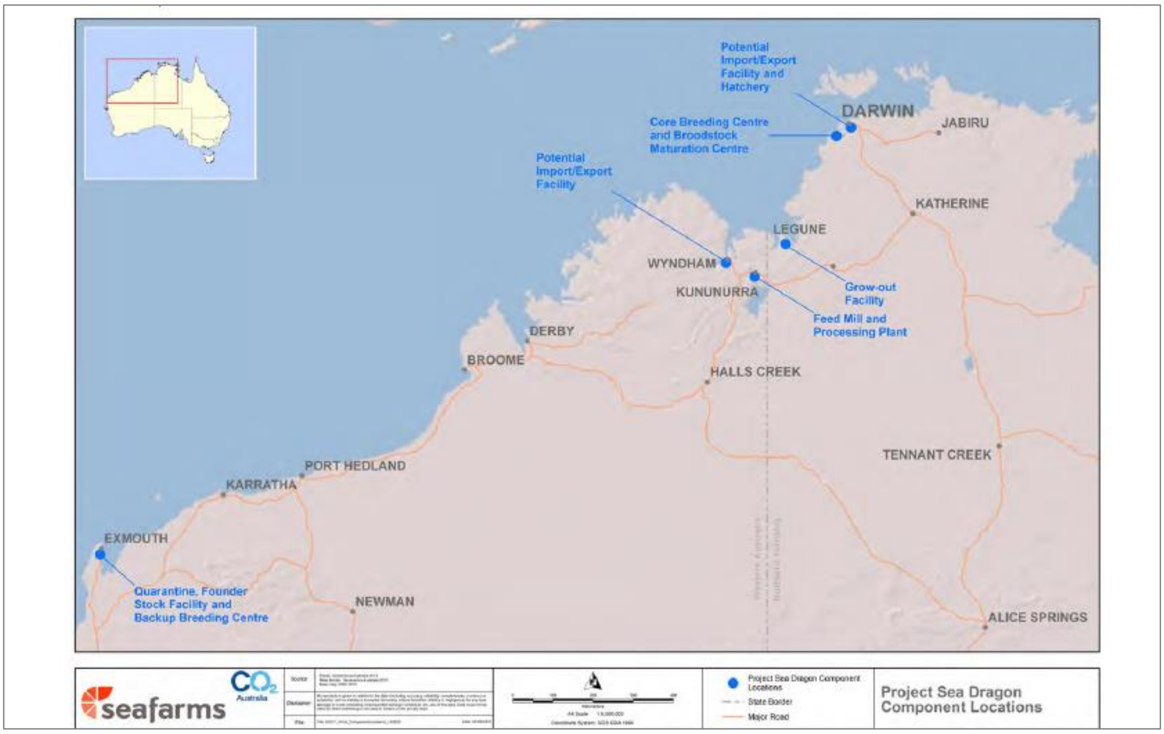

Figure E8. Project Sea Dragon Component Locations. Source: Project Sea Dragon Environmental Impact Statement – Executive Summary.

APPENDIX F – INDIGENOUS PRIORITIES: DESKTOP REVIEW

Introduction

Indigenous Australians have been the custodians of the seascapes of this country for millennia, continuing up to the present day. However, since European settlement, Indigenous governance and management of (land and) sea country has been significantly eroded, leaving much sea country unmanaged. New governance and management systems, interests and needs are emerging across Australia as dramatically changed circumstances, pressures, opportunities and information needs demand critical thinking for protecting and managing healthy coastal and marine environments.

Substantial legal Indigenous rights exist in coastal and marine country in this project area under various legislative instruments (e.g. *Aboriginal Land Rights (Northern Territory) Act 1976* (Cwlth), *Native Title Act 1993*, (Cwlth), *Northern Territory Sacred Sites Act, Aboriginal Land Act* (NT)), built largely on recognition of customary rights and interests. Additionally, historical engagement, extant knowledge systems, familiarity and recognised essential livelihood needs, strongly suggest collaborative approaches between Indigenous people and western science are needed in the complex interplay of anthropogenic and natural processes affecting coastal and marine environments, including their human capital.

Aboriginal and Torres Strait Islanders recognise the need to apply these different knowledge systems collaboratively to manage their sea country into the future, and demand recognition and respect for their rights and interests in the manner and operation of these collaborations. Whilst local knowledge systems/interests substantially overlap with formal science, for instance in identifying conservation targets, what these targets mean to traditional custodians may differ dramatically from the targets as objects of scientific research. In Indigenous accounts of their sea country certain ontological characteristics are common, for instance:

- Sea country is continuous with the land – local language is equally derived from it and defines it, creation stories travel between and through land and sea, traditional ownership and customary estates equally apply over them, traditional knowledge systems emanate from and influence the health of each; and,
- Indigenous people do not distinguish themselves from their land or sea country – their ancestral and spiritual essences are in and animate the land and sea scapes; plants, animals and features of those scapes are variously familial, totemic and important agents in ceremonial life.

Furthermore, customary economies based on sea country are significant foundations for community resilience, livelihoods and wellbeing, and tend to be played out through local cultural rules and protocols. In State and cash economies, long histories of engagement in fishing, and other marine industries are common amongst Traditional Owners (TOs) of sea country. Many, such as trading with Macassan fishers, are prior to colonisation by the British.

> "We are not just another stakeholder; we are first Australians whose identity and essence is created in, through and with the sea and its creatures. We wish to contribute to regional and national economic development, in keeping with our time-honoured responsibilities to care for the land and sea.
>
> Our relationship with the sea and its resources is fundamental to our religious, social and economic life and wellbeing. We continue our care and guardianship as our ancestors have done. We have an intimate knowledge of the environment and ecology in the places for which we have rights and responsibilities. We want our children and grandchildren to receive this knowledge so they can look after sea country. We do not come and go like most non-Indigenous people do. We want to continue to stay here permanently. However, it is becoming increasingly difficult to undertake this work because our interests are often ignored or are seen as secondary to non-Indigenous issues of open access, economic exploitation and the welfare of the well known and loved marine animals like turtles, dolphins, dugong and whales" (Dhimurru 2006).

This desktop review shows the broader Indigenous treatment of sea country within which obligations to country and its wildlife are described and actions to meet those obligations are set out. It is through this broader contextual lens that engagement with Indigenous sea country managers over Threatened and Migratory marine species can be made meaningful and fruitful.

Objectives

This report aims to provide a brief overview of marine animal species of importance to Indigenous communities in the Northern Territory, including the Gulf of Carpentaria and western Cape York (collectively encompassing the North Marine Bioregion), based primarily on a desktop study of readily available written materials. Following this desktop component, information from this review will be considered alongside the outcomes of consultations with Indigenous community members/groups to provide a more comprehensive view of 'priority' marine fauna for future research. To effectively inform research and management actions, a complementary purpose in this report (and project more broadly) is to identify local practical responses to species-specific research and management needs, articulated through the kind of social and cultural context summarised above. This includes discussion about appropriate principles for engaging Indigenous individuals and organisations in discussion about and research on their country.

Methods

Information has been drawn primarily from published land and sea country management plans and strategies framed by various Indigenous Land Management (ILM) groups involved in caring for country throughout the Northern Marine Bioregion. In terms of desktop research these cover only parts of the coast and mostly focus on sites or areas where research and conservation efforts are formally supported or being considered. Other material, perhaps with limited emphasis on relevant research but indicating practical interests, aspirations and concerns, have also been included. It is essential, as attempted here, to recognise the significant effort that people have already committed to articulating their aspirations and plans for caring for country into the future.

Where available, Indigenous Protected Area (IPA) Management Plans and other Sea Country plans should be recognised as incorporating (to greater or lesser extent) local and traditional knowledge, customary protocols and other enabling and empowering features of resilient communities, adapted to deliver agreed environmental management outcomes. They are generally developed over a period of several years through extensive, considered and representative consultation with all the appropriate Traditional Owners and other relevant community members. They clearly articulate community desires with regard to sea country matters, set in the context of an ongoing commitment to continue the ancestral custodianship of their traditional estates, using both traditional and contemporary approaches to manage sea country for their people and for all Australians. They are a primary resource for anyone interested in working in land and sea country. For example, the Dhimurru sea country plan (2006) explains that "We wish to be understood as not only the traditional custodians and managers of our sea country, but also as contemporary and future managers." It details the intent of the plan as follows:

"Our Sea Country Plan:

- Lets everybody know what our sea country means to us and explains how we look after it, both in keeping with traditions and through our contemporary work at Dhimurru;
- Makes clear the concerns we have for our sea country and its management; and,
- Suggests to others with interests in our sea country how we can work together for sustainable management in ways that respect and acknowledge our rights and interests and those of other users."

Aboriginal people have a clear interest in research relating to their sea country. It is important to consider not only what future research should be conducted, but how. In cross-cultural research the partnerships underlying, and processes adopted in the conduct of projects are of critical importance. Broader issues of communication, access, consent and intellectual property, scale and context, compensation, appropriate use of Indigenous knowledge and governance need to be considered in exploring what is best practice collaborative research. Some communities already have considerable experience working with western scientists, and this experience has enabled them to establish a clear process for managing engagement in research projects. In some cases, communities are driving the research agenda and actively seeking out partnerships to address identified knowledge gaps. Included is a discussion of engagement principles at the end of this review.

Scope and Qualifications

As non-local authors of this remote study, the scope and purpose must be clear, acknowledging; the information bias towards the interests of groups/communities who have an incentive and the capacity to publish, the tendency (given the nature of ILM support) to isolate conservation and other environmental management issues, the unavoidable simplification of the great heterogeneity of ILM interests; and the non-Indigenous authorship in English (not withstanding direct quotes to circumvent this). This desktop review can hint at local perspectives and interests, suggesting overall approach and potential targets for dedicated research and action (a conditional snapshot of the global needs) but cannot replace locally tailored approaches to ascertaining detail and effective collective action (the local context). The sea country plan prepared by Yanyuwa Traditional Owners from southwest Gulf of Carpentaria (near Borroloola) reflects this in affirming that:

> "[it] should not be used to identify people's attitudes to particular issues and proposals or as a basis for redefining development proposals to circumvent the consultation process. This is a critical point and the Yanyuwa community is at a point in their discussions in relation to proposed and actual development where wrongful use of the data presented here could do more harm than good" (Bradley & Yanyuwa families 2007).

Finally, it is worthwhile considering the lens through which we are looking at the research question to underpin an effective approach. The broad aim of this desktop review is to 'get to' Threatened and Migratory marine species important to the traditional custodians and managers of sea country, as prescribed in the Seascapes project on the whole. On the one hand, one may assume that individual species have meaning and value independent of the holistic biocultural landscape in which they are naturally treated by Indigenous society. This is in a sense an artificial view, in which it may be unclear to custodians how their connection (spiritual, economic, ceremonial) to that target species will be treated and understood. Alternatively, recognising co-dependence and connectedness of species within their cultural context that determines their meaning and place, affords greater comfort and value for ILMs when focusing on individual species, being able to contribute theirs to other useful knowledge forms about them. 'Two-way' knowledge can enhance value derived from for example, AQIS and biosecurity contracts, biodiversity surveys and fisheries impact monitoring. Better engagement with people around their knowledge and connection to target species helps them revitalize knowledge and cultural learning. The frame and approach are important. As the delegates of the 2012 National Indigenous Sea Country Workshop explain:

> "Our Estate, including land, sea country, fresh water, spiritual aspects, cultural aspects, and intellectual property; and Aboriginal and Torres Strait Islander Peoples, are intrinsically entwined."

Current Management Arrangements in the North Marine Bioregion

As mooted above, formal arrangements for management of environmental values (particularly Indigenous Protected Areas, IPAs; Table F1; Figure F1) are based on qualities emanating from estate ownership and time immemorial kinship and 'caring for country' obligations, interests and skills. It is therefore important to note that the strongest authority, core capabilities and enabling factors for sea country management are on homelands (or out stations) where traditional ownership, local knowledge systems, livelihood dependence and related well-being outcomes are most keenly manifest. These embedded customary arrangements are seen as best practice by ILMs but are often outside IPAs, ranger groups and National Parks for example, where (other) critical financial, technological, research, service and skill resources are acquired. They continue to be a standard and sounding board for best practice in IPAs and Indigenous ranger groups more generally. Very little published material on homelands based land and sea management is available for this review but IPA plans, and other materials referenced here heavily reflect that background yard stick.

In the Northern Territory, there are six dedicated IPAs encompassing coastal and/or sea country:

- Anindilyakwa;
- Dhimurru;
- Djelk;
- Laynhapuy (Stage 1);
- Marthakal (Stage 1); and,
- South East Arnhem Land.

There are a further three formally proposed, all seaward expansions of existing IPAs (all Stage 2):

- Anindilyakwa;
- Laynhapuy; and,
- Marthakal.

There are aspirations for at least two more: The Crocodile Islands (Gambold 2016) and South East Arnhem Land – Stage 2 (Gambold 2015). In the Western Cape and Southern Gulf region of Queensland there is only one dedicated IPA with sea country: the Thuwathu/Bujimulla IPA; and one formally proposed: The Wik, Wik Way and Kugu. There may well be others in the early stages of planning. A frequently updated map of existing and formally proposed IPAs, along with the Commonwealth funded Indigenous Ranger groups can be found on the Department of Prime Minister and Cabinet's website here https://www.pmc.gov.au/sites/default/files/files/ia/IEB/IPA_WOC_national_map.pdf

Table F1. Existing IPAs within the study area (see also IPA map), and notes whether there is a corresponding Management Plan available.

Indigenous Protected Area	Management Plan available? (Year of publication/ operational period)	Ranger group/s
Anindilyakwa	Yes	Anindilyakwa
Dhimurru	Yes (2015–2022)	Dhimurru
Djelk	Healthy Country Plan (2015–2025)	Djelk
Laynhapuy – Stage 1	No, but publication imminent (sea country extension planned)	Yirralka
Marri-Jabin (Thamurrurr) – Stage 1	No	Thamurrurr
Marthakal - Stage 1	Yes (sea country extension planned) (2015–2020)	Gumurr Marthakal
Nijinda Durlga (Gangalidda) – Stage 1	Yes (2015)	Gangalidda Garawa
South East Arnhem Land	Yes (sea country extension mooted) (2015–2020)	Yugul Mangi and Numbulwar Numburindi Amalagayag Inyung
Thuwatha/Bujimulla (Wellesley Islands)	Yes (2015)	Wellesley Islands
Yanyuwa (Barni-	Sea Country Plan (2007)	li Anthawirriyarra

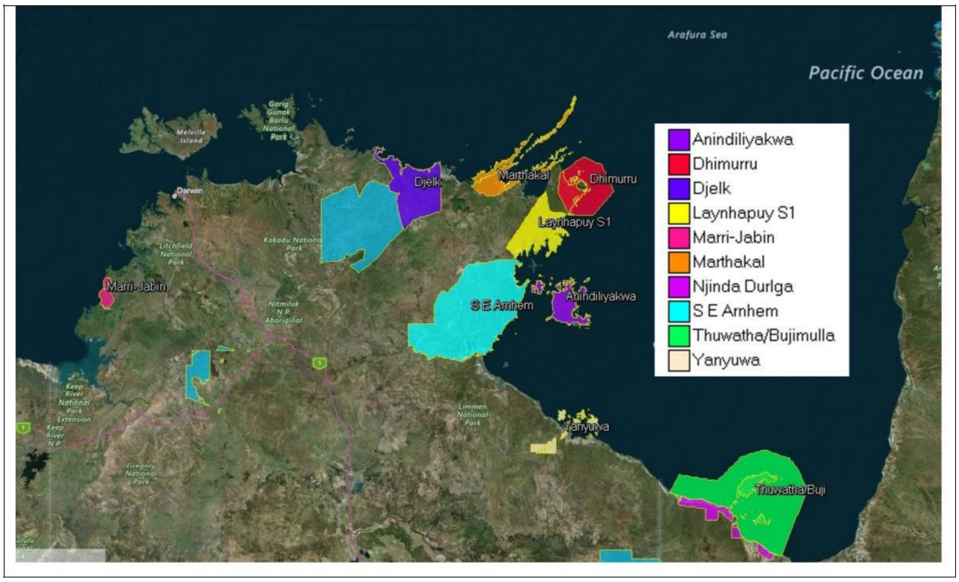

Figure F1. Coastal Indigenous Protected Areas within the North Marine Bioregion.

Whilst IPA management plans are probably the most widely recognised (and possibly the strongest currently existing) vehicles for articulating traditional land owners' commitment to management of their country, there are numerous other arrangements where Traditional Owners may be supported in managing country. Even without dedicating IPAs, many communities have articulated their aspirations in land and sea country (and healthy country) management plans, for example the Mapoon Country Plan 2013–2020 and the *Ngamp inth Wantharr Yumpnham* Pormpuraaw Land and Sea Country Cultural and Natural Resource Management Plan 2010–2015 from Queensland; and the Tiwi Islands Regional Natural Resource Management Plan (2004) from the Northern Territory.

In the Northern Territory, there a number of relevant jointly managed parks including Kakadu (Commonwealth) and Cobourg (Garig Gunak Barlu) Marine Park (Territory). Cobourg (Garig Gunak Barlu) Marine Park is the only marine park declared under the Territory Parks and Wildlife Conservation Act. It is jointly managed by the Northern Territory Government and Traditional Owners through the Cobourg Peninsula Sanctuary and Marine Park Board (CPS & MPB 2011). There is however minimal discussion on the cultural values of animal species in the management plan. Similarly, in the Kakadu National Park Management Plant 2016–2026 there is very little detailed information regarding the cultural values of animals, beyond some general recognition that native animals are integral to the cultural landscape of the park, and the importance of some bush tucker species including Magpie Goose and others. There are some cursory statements around management arrangements which support sustainable harvest of species such as Dugong and marine turtles, as provided for by Native Title legislation.

Important Marine Animals

Marine turtles, Dugong and seagrass are represented in the logo of the li-Anthawirriyarra sea rangers (the ILM group for Yanyuwa people) and Yanyuwa people express the close relationship between these lifeforms thus *walya nyiki-nganji ki-maramanngku* “the dugong and sea turtle they are kin to the sea grass”. The term *walya* includes Dugong and all marine turtles and is one of the most detailed and complex categories in Yanyuwa biological classification, including 16 names for Dugong expressing multiple and contextual meanings, often also defining behaviour and response (Bradley & Yanyuwa families 2007). It can see some parallels with the way western science might consider multiple values inherent in a species, or a food web in which a key animal may have many functions.

And the depth of this interconnectedness extends far beyond what current ecological sciences may identify. Baymarrwaŋa & James (2014) discuss:

> “The Yan-nhaŋu language is a sign of belonging, a spring of knowledge, and a source of ancestral connection to country. Yan-nhaŋu people say ‘We are kin to the sea’ and ‘We care for him/her and she/he keeps us alive’. Here in Yan-nhaŋu language can be seen the complementary relations, the harmonisation of opposites, of *Dhuwa* and *Yirritja*, underlying a holistic world view. The names of places and people, and the everyday words of language reflect the notion of relatedness and the indissoluble connections of people to their sea country.”

> “All the other species that live and visit the (Crocodile) islands are named, sung, painted and danced by people of the islands. All of them are linked to people through kinship. This idea that kinship underpins the Yan-nhaŋu world view; it is just one of the reasons the Yan-nhaŋu people know and care for their sea country. After all, this inheritance sustains life.”

Traditional Owners from the region around Pormpuraaw explain:

> “Remember we do not distinguish between the ‘cultural’ and the ‘natural’ when it comes to resource use and management. We do not look after the Brolga, the Crocodile, the Barramundi, the Savannah Grass or other plants and animals in isolation. These are our Ancestors, our Totems, our Culture, our Country. We remain connected to our Culture, our Country and its Songs across all ‘values’ – from the cultural, the natural and the spiritual – integral to ourselves and our homelands” (Pormpuraaw 2011).

There are also some quite clear and explicit statements of the importance of particular species, for example the Thuwathu/Bujimulla IPA Management plan states “The most important marine mammal is the dugong, which is a major source of food for us as well as being central to our identity as Saltwater people.” (CLCAC, 2015b). The Yanyuwa Sea Country Plan (Bradley & Yanyuwa families 2007) states “The future health of our people and culture depends on taking care of our dugongs”.

The story of the Anindilyakwa Land Council (ALC) logo below, is also indicative of treatment of individual iconic species, some of which are Threatened and Migratory marine species or are closely-related. Though no conclusions can be drawn from this treatment about research priorities, the focus clearly identifies nuanced understanding and interest.

> “In the beginning the island was dark. *Barnimbirra* (morning star) brought daylight to the island and ever since then there has been a day and night. In creation times, *Yumaduwaya* (stingray), *Mungwarra* (Hammerhead Shark) and *Yukwurrirrindangwa* (sawfish), began their journey from the eastern coast of Arnhem Land. On their way to Groote Eylandt they stopped at Bickerton Island where they transformed themselves from human beings into sea creatures. They then continued their journey to Groote Eylandt. On the way, they agreed to go to the centre of the island and decided to enter from the north. *Yukwurrirrindangwa* however, said: “I’ll take a short cut”. After the *Yumaduwaya* had left him, *Yukwurrirrindangwa* set off with a crowd of many different stingrays following him. *Yukwurrirrindangwa* led the way, probably because he was the biggest.
>
> Meanwhile *lirreba* (the tide), was growing big. *Yukwurrirrindangwa* reached Groote Eylandt, came out of the sea, and started to cut his way through the land, using his teeth and nose as he went. As he cut out the land, and threw the earth aside, he created the Angurugu River. He opened a way for himself to travel towards Central Lake. As the water came in, the dirt was stirred up. *Lirreba* grew bigger and bigger and followed close behind *Yukwurrirrindangwa*. The stingrays used *lirreba* to continue following *Yukwurrirrindangwa*. *Yukwurrirrindangwa* then went to the centre of the island where he created Central Hill (*Yandarrnga*)” (Taylor 2016).

Other representations of marine life where they have been presented to the public have been presented, in the form of organisational logos and artworks. In response to increasing use of their sea country and marine resources by commercial and recreational fishers Yolŋu artists in the late 1990s created a collection of paintings to publicly communicate the cultural, spiritual, and economic importance of their sea country:

> “The paintings reveal Yolŋu saltwater country in many states, showing qualities of depth, surface, and the sacred and often dangerous land just below the surface, the profound depths, and the totemic life forms that inhabit these waters” (Dhimurru 2006).

Dugong, marine turtles, whales, stingrays, and Manta Rays are among the marine lifeforms represented in this series of paintings.

It is important to remember that some statements in the various management plans reviewed are likely to reflect a combination of cultural values and a recognition of western conservation values, as alluded to in the prelude to the ‘Statement of Vision’ in the Tiwi Islands Regional Natural Resource Management Strategy (2004):

> “The Tiwi vision is a statement of values placed on the natural values of the Tiwi islands by the majority stakeholders; Tiwi people. It recognises their importance in terms of economic development, while also acknowledging their cultural, spiritual and recreational values. Other also value the Islands’ natural resources, predominantly for contemporary conservation aims. The challenge is to accommodate and protect the variety of values placed on the Tiwi Islands, while acknowledging that it is those who rely on the Islands for their daily living that will be most affected by natural resource management actions both now and into the future” (Tiwi Land Council 2004).

Many of the formal management plans note the known and likely occurrence of species and assemblages of (western) conservation significance. Some refer to them in describing management actions or goals for example in the Djelk Healthy Country Plan the presence of migratory species including seabirds and turtles will be used as an indicator of healthy sea and coasts, which will be measured through population surveys of migratory species, and surveying community members for harvest of seabird and marine turtle eggs (Ansell & Djelk Rangers 2015). This is a clear indication, not only of the willingness to take up new and useful knowledge forms and to embed collaborative action research in local management interests, but also of the importance of good inclusive process, engagement and support for ILMs which provides the confidence to do so.

Dugong and Marine Turtles

> “The future health of our people and culture depends on taking care of our dugongs” (Bradley & Yanyuwa families 2007).

> “The most important marine mammal is the dugong, which is a major source of food for us as well as being central to our identity as Saltwater people” (CLCAC 2015b).

> “We believe our wellbeing and turtle (*miyapunu*) wellbeing are inseparable. To put it another way, we belong to turtles and turtles to us; we sustain them and they us” (Dhimurru 2015).

> “Marine turtles and their eggs continue to be an important part of our traditional food and we are committed to ensuring that we use this resource sustainably” (CLCAC 2015b).

Saltwater people across the north almost universally identify the Dugong as a vitally important part of the cultural and physical landscape, and alongside it often one or multiple marine turtle species. The multi award winning NAILSMA-led Marine Turtle and Dugong Project recognised this fact, bringing together communities across the region to work towards the project vision

“Healthy and sustainable populations of dugong and marine turtles in north Australian waters that support Indigenous livelihoods”. The Australian Government’s Evaluation Performance Story Report (Bessen Consulting Services 2008) concluded the project was a standout success that had outstripped the original expectations, and importantly “From this project, the Australian Government has learnt that Traditional Owners can manage a very large project and achieve the outcomes specified as well as achieving a large number of additional social, cultural, environmental and economic outcomes” (Kennett & Kitchens 2009).

Many documents discuss the threats, concerns and management goals for these species together. This connectedness is further demonstrated in language, such as the Yanyuwa term *walya*, discussed above, which includes Dugong and all marine turtles (Bradley & Yanyuwa families 2007). These two logos of ranger groups from the Gulf region, li Anthawirriyarra rangers from Borroloola (representing Yanyuwa TOs) and the Numbulwar Numburindi rangers from Numbulwar both feature marine turtle and Dugong together.

The most consistently recognised threatening processes in the seascapes of the North Marine Bioregion known to be impacting both marine turtles and Dugong, include entanglement in ghost nets, commercial fishery bycatch, boat strike and in many locations also water quality impacts on seagrass:

“…without seagrass there would be no sea turtles or dugong; but likewise it is said that without the dugong and sea turtle, there would be no seagrass, as the feeding upon it keeps it healthy (Bradley & Yanyuwa families 2007).

Six marine turtle species occur on Yanyuwa country and there are 36 known significant nesting sites. One estimate of the Dugong population in Yanyuwa sea country was 8,000, suggesting it was the largest population in the Northern Territory. Yanyuwa people have expressed a number of very serious concerns about sea turtles on their country including observations of an increasing number of sick turtles and Dugong, and also falling nesting rates on island beaches where previously turtles ‘nearly nested on top of each other’. Yanyuwa people know that seagrass is critical to both Dugong and marine turtles, and have expressed a desire to be involved in any relevant research. Issue 8 of the Yanyuwa Sea Country Plan 2007 clearly articulates community aspirations for monitoring, informed management and sustainable use of Dugong and marine turtles (Bradley & Yanyuwa families 2007).

Marine turtles are known in the lingua-franca of east Arnhem Land as *Miyapunu*, and as indicated above they are a central to the culture of people whose sea country is represented in the Dhimurru IPA. The Rangers regularly record Green, Hawksbill, Olive Ridley and Flatback turtles and are the custodians of internationally significant rookeries of these species; Leatherbacks and Loggerheads are occasionally sighted. Traditional Owners are concerned about the common threats to marine turtle and Dugong, and for nest and turtle hatchling predation by feral pigs is an additional threat. Bycatch is also a focus:

> "Catch reports from fisherman suggest few turtles and sea birds are casualties from fishing. We know this to be untrue because we have reliable off-the-record reports from deckhands and some skippers contradict this, confirming that many are killed" (Dhimurru 2006).

There is clearly a gap in reliable evidence for fisheries management, suggesting the need for independent marine and fisheries researchers with senior traditional custodians' involvement in the research process.' There is also recognition that some young (local) people have disregarded proper cultural protocols when harvesting *miyapunu* so senior TOs and other custodians aim to develop a *miyapunu* management plan to encourage culturally and environmentally sustainable harvest, with the Learning on Country program also playing a role in educating youth (Dhimurru, 2006). Note also Laurie Baymarrwangga's turtle sanctuary and management plan on Murrungga Island – supported by Crocodile Island Rangers (Baymarrwangga and James 2014). One of guiding principles for Dhimurru IPA management is Sustainability – ensuring that Dugong, turtle, fish, and other culturally and economically important species are harvested sustainably for the generations to come (Dhimurru 2015).

Together the adjoining Nijinda Durlga and Thuwathu/Bujimulla IPAs in the Southern Gulf region represent a protected area of some 175,350 hectares. Traditional Owners recognise that they share challenges and are committed to facing them together (CLCAC 2016a). Both Management plans both include considerable discussion about depletion of dugong and marine turtle numbers, it is clearly a pervasive concern for ILM's in the region. Aerial surveys during the late 1990s indicated that about 3,000 Dugongs lived around the Wellesley Islands; two other aerial counts since that time suggested that numbers to remain constant over that period of time. Another survey was conducted in September 2007 and though numbers counted were similar, the researcher involved with all three surveys suspects this number to be very conservative with numbers closer to 5,000 being more realistic (CLCAC 2015). Dugong is an important shared resource in the region. Both plans outline actions relating to monitoring of sick or underweight Dugong, fisheries bycatch issues and impacts on seagrass meadows. Hunting is not a regular activity of Gangalidda people with "most dugong obtained, as it has been done for generations, by trading resources with our Wellesley Island neighbours." (CLCAC 2015a) Reflecting the fact that most Dugong hunting occurs around Wellesley Island, the Thuwathu/Bujimulla IPA management plan (CLCAC 2015b) outlines a proposal to conduct a long-term survey of customary Dugong harvest activities.

Six marine turtle species are found in sea country of the Southern Gulf region. High numbers of nesting Green and Flatback Turtles make the Wellesley Islands an area of international significance. Many unhealthy or dead turtles have been observed in the region (CLCAC 2015a, b). There are concerns that they are being affected by pollution from mining in the region and also by observed seagrass bed dieback. People 'intend to work together with researchers to better understand what is happening to turtles and to protect their feeding grounds and nesting beaches.' Since publication of the 2006 Thuwathu/Bujimulla sea country management plan people have become aware of additional information about these issues such as scientific evidence to suggest that the presence of zinc in the water could affect sense of smell of marine turtles, having an impact on the ability to feed, and recognition of the disease fibropapilloma. Commercial fishery bycatch issues are a concern. Gillnets used in the Barramundi fishery pose a significant threat to Dugong and turtle. There is recognition (and respect for) the demonstrated reduction in the impact of the Northern Prawn Fishery through the introduction of Turtle Exclusion Devices (TEDs). Regarding turtle nesting success there are clear predation impacts of feral pigs and dogs, and possibly an increase in Goanna predation as their other food sources become scarcer. People have also heard about increasing nest mortality in other areas of the Gulf due to nest inundation linked with climate change driven sea level rise and rangers intend to monitor for this. Both the southern Gulf IPA management plans outline numerous complimentary actions intended to contribute to conservation of marine turtles (CLCAC 2015a, b)

One of the nine main targets in the Mapoon Country Plan is *minya/kai kai* (bush meat foods). Dugong and *traina* (marine turtles) feature heavily in this category. There are specific aims and actions described to improve the health of Dugong and turtles including ensuring harvest is done in the right season, respecting old peoples custom and lore, improving turtle hatchling success and ensuring healthy feeding (seagrass) grounds (ML&SP 2013).

Five species of *yimenda* commonly occur across Anindilyakwa sea country: *enuwa* (Flatback), *yijirakamurra* (Olive Ridley), *yimuwarraka* (Green), *dingaluwa* (Hawksbill) and *yinubungwaya* (Loggerhead); the first four are also known to nest there. Given the spiritual and practical value of *yimenda*, Anindilyakwa people possess unique knowledge of locally common species.

Yimuwarraka are a shared totem for four clan groups and are the most valued for their meat. *Enuwa*, *yijirakamurra* and *yinubungwaya* are eaten on occasion. Eggs of *yimenda* species are traditionally dug from nests and consumed. A target in the IPA monitoring and evaluation framework is to establish and undertake annual monitoring of nesting *yimenda*.

Four species of marine turtle are known to occur in the sea country of the Marthakal IPA, *garriwa* (Flatback) *wirrwakunha* (Hawksbill) *dhalwatpu* (Green) and *mududhu* (Olive Ridley). There have also been two recent isolated sightings of the Leatherback Turtle, but there is no language name known for this species, so it is unlikely to be considered culturally important. The Gumurr Marthakal Rangers patrol for ghost nets and marine debris along the coastline. They are monitoring key sea turtle nesting beaches. Where appropriate, the Rangers invoke customary law to manage the customary use of sea turtles; supporting Traditional Owners to regulate hunting in their estates. They are actively educating local people about the conservation status of sea turtles, discouraging take of nesting turtles from beaches, advocating restraint in egg harvest and exposing non-traditional methods of hunting within the local community (Gambold 2016).

All six of the marine turtles of Australia are known to occur in the sea country around Pormpuraaw. The coastline north of the community has an extensive Olive Ridley nesting rookery. Feral pigs were responsible for 90% predation of the Olive Ridley prior to aerial culling operations by ranger staff in 2014. At the time of reporting, predation of nests in the 2016 nesting season was 2 nests. The Pormpuraaw Land and Sea Rangers believe that ongoing culling operations are essential for the long-term sustainability of Olive Ridley populations (CYNRM 2016) and in addition as many individual Olive Ridley nests as possible are protected against predation with aluminium nest protection devices (CYNRM 2016). Thaayorre and Mungkan TOs from the region also recognise the common threats mentioned above, and feel they also impact on Dugong. The turtles may also be facing over-hunting in some areas, and light pollution impacting on nesting behaviour (Pormpuraaw 2010).

The Pormpuraaw Land and Sea Rangers are one of the founding members of the Western Cape Turtle Threat Abatement Alliance (WCTTAA), playing a key role in the reduction of threats to threatened marine turtles nesting on the west coast of Cape York Peninsula. The other ILM members of WCTTAA are Mapoon Land and Sea Rangers, Nanum Wungthim (Napranum) Land and Sea Management Rangers, NPARC/Apudthama Rangers and the Kowanyama Aboriginal Land & Natural Resource Management Office. On beaches monitored by WCTTAA rangers in 2016, turtle egg predation fell below scientifically determined target levels, increasing the chance of maintaining viable turtle nesting populations in future. Participating groups have been involved in a variety of collaborative turtle research and management activities since WCTTAA formed in 2013, it is noted that funding for the Alliance currently expires at the end of 2017 (CYNRM 2017). This is critical work but perhaps only marginally effective unless collaborations to address adult mortality are explored and supported.

In recent years, mainstream society has been questioning people’s right to customary harvest of Dugong and marine turtles. The widely criticised 2003 National Recreational and Indigenous Fishing Survey (Bessen Consulting Services 2008) lead to a belief that customary harvest of turtle and Dugong in Australian waters were unsustainable. Immediately to the north of the North Marine Bioregion in the Torres Strait a journalist claiming to be a researcher secretly filmed hunting activities, selected footage was used as the basis for an inflammatory and deeply divisive television exposé. In addition to creating a completely unwarranted sense of shame for many people about traditional practices that are central to their culture, Marsh and Loban (2017) explained that the deception by the journalist consequently created deep distrust of the scientific research community, when prior to this TOs in the region were actively involved in scientific research projects. Whilst there is a general acceptance that there is a small minority of Indigenous people disregarding correct cultural protocols for harvest of Dugong, marine turtles and turtle eggs (often Aboriginal people from elsewhere, and occasionally younger members of communities) (Dhimurru 2015, Gambold 2016), ILMs are resolutely committed to ensuring customary harvest activities are adhered to and are sustainable, as clearly demonstrated throughout this section. An important issue for management is the erosion of customary knowledge around sustainable hunting and the critical protocols that guide and enforce it. How such knowledge can best be strengthened to avoid further erosion of sustainable practice, is as much a question for Traditional Owners and their ranger groups as it is for researchers serious about effective collaboration in species conservation and protection:

> "Across Northern Australia, there is concern that Traditional Owners are taking too many dugongs, that the rules of customary take are no longer being adhered to and that the use of powered boats makes hunting extremely efficient. While from a cursory glance there is some substance to this argument, we object to the fact that Indigenous people seemed to be targeted as the only factor contributing to the decline in dugong numbers. We are well aware of other pressures exerted on dugongs by ghost nets, pollution, loss of seagrass meadows and other forms of environmental degradation, boat strikes, climate change and other human impacts" (CLCAC 2015b).

> "We do not believe there is an issue with the amount of dugong and turtles that are taken as a food source and for cultural reasons in our waters. However, we understand that discrete areas within the overall landscape of our sea country can be over-utilised for this purpose. To combat this problem, we proposed to close particular areas to hunting on a seasonal basis, or even a permanent basis" (CLCAC 2015b).

> "Marine turtle harvesting is based in strong traditional customs and deep social and cultural associations. The advent of modern boats and hunting tools has allowed far greater access to this resource. There is a resulting imperative for our community to make strong management decisions to ensure sustainability of these traditional resources. However, modern Indigenous hunting is not responsible for the falling numbers of turtles. We understand that worldwide turtle populations are in serious decline as a result of coastal development, commercial fishing, poisoning by and entrapment in marine debris, predation by feral animals and human over-exploitation. Areas such as North East Arnhem Land are by contrast, strongholds for these threatened species" (Gambold 2016).

In the Torres Strait significant research effort was applied to investigate this issue. Contrary to previous findings by Marsh *et al.* (2004), a subsequent re-evaluation by Marsh *et al.* (2015) using multiple lines of evidence, and new research by Hagihara *et al.* (2016) supported the notion that Torres Strait Dugong harvest is sustainable. The status of the foraging Green Turtle population in was less certain than that of the Dugong (Hagihara *et al.* 2016).

Cobourg Marine Park is considered to be one of the most significant areas for Dugong in the Northern Territory. All six marine turtle species are known to occur and there are numerous nesting beaches for Green and Flatback Turtles including what may be the most important

Flatback nesting sites in the Northern Territory (CPSMPB & PWSNT 2011). Coastal and marine areas of Kakadu National Park including *Gardangal* (Field Island) and *Djidbordu* (Barron Island) near the mouth of the South Alligator River, are of great importance to Bininj/Mungguy Traditional Owners; numerous sites of significance are located within and adjacent to the park. Five species of marine turtle occur in the waters adjacent to Kakadu. Gardangal has a small beach which regularly supports nesting Flatback Turtles and is a key site for an annual monitoring programme for this threatened species, and 20 years of survey data are now available for Flatbacks, and Estuarine Crocodiles (KNPBM 2016).

Whales and Dolphins

There are 5 species of *dinginjabena* (dolphin) and two whale species known to occur in the seas of the Anindilyakwa IPA; including the Australian Snubfin Dolphin, Indo-Pacific Humpback Dolphin, Australian Humpback Dolphins, and also the False Killer Whale.

Dinungkwulangwa (Dugong) and *dinginjabena* are significant to Anindilyakwa people. Individuals of several clan groups (for which *dinungkwulangwa* and *dinginjabena* are totems) hold and pass on their associated Dreaming stories. *Dinginjaben*a are no longer considered a resource; however, they were once utilised in a manner similar to *dinungkwulangwa*. A whale ancestral being is represented in a painting by prominent Yolŋu artists included in the collection Saltwater: Yirrkala Bark Paintings of sea country (Dhimurru 2006).

Indo-Pacific Humpback Dolphin, Australian Snubfin Dolphin (referred to as Irrawaddy in the plan), and False Killer Whales, Pilot Whales and a species referred to as 'Roqual' (possibly the Humpback Whale) are known to occur around the Wellesley Islands (CLCAC 2015b). The Australian Snubfin and Indo-Pacific Humpback Dolphins, Short-finned Pilot Whale, Black Whale (likely to be the Killer Whale) are known to occur in Yanyuwa sea country (Bradley & Yanyuwa families 2007). It is considered the Australian Snubfin Dolphin is likely to occur in the sea country around the Dhimurru IPA, and this is supported by number of records showing on Atlas of Living Australia (ALA 2017).

The Pormpuraaw plan notes the occurrence of the Indo-Pacific Humpback, Australian Snubfin (referred to as Irrawaddy in the plan), Common, Risso's, Spotted, and Spotted Bottlenose Dolphins, along with Killer Whale, Bryde's Whale and Blue Whale. Although there is no discussion of their cultural value there are a number of threats noted (PLSM & PASC 2010). Kakadu is home to two inshore dolphin species, the Indo-Pacific Humpback and Australian Snubfin. There is no mention of the cultural significance of these species. Management recognise that illegal fishing using gillnets could pose a threat to these species. Australian Snubfin Dolphins and Bryde's Whales are known to occur in the waters of the Laynhapuy IPA (Laynhapuy 2013).

Shorebirds and Seabirds

Yanyuwa people recognise close kinship ties between seabirds and fish: "To see many birds over the sea country is to know that the country is well, 'They hold the country up when there are no people present" (Una Harvey 2005 in Bradley and Yanyuwa families 2007) (Jack Baju in Bradley & Yanyuwa families 2007):

Kilu-ngabunjama	The tern dives into the sea
Wunjurrkunjurr	The vast open expanse of the ocean
li-walamakamakala	They belong with the sea country
kumba-jajirra	They are the ones that dive into the depths of the sea

There are 33 recorded shorebird nesting colonies on Yanyuwa country; including the world's largest known rookeries of the largest Crested Tern and Roseate Tern. At least 35 migratory bird species to visit Yanyuwa sea country, of which 21 are known to breed.

Mapoon Traditional Owners consider the presence of shorebirds and their nests as indicators of healthy beaches. Vehicles on beaches are recognised as a threat, so rangers patrol beaches educating tourists about rules and protocols designed to protect birds and their nests. Initiated by a collaboration with Birdlife Australia and NAILSMA in 2012, the Mapoon rangers have been undertaking annual shorebird surveys of their coastal country (Jackson *et al.* 2016). The group plans to monitor shorebirds and sea turtles in order to improve knowledge about local impacts of climate change. The Curlew Sandpiper, Red Knot, Bar-tailed Godwit, Lesser Sand-Plover, Greater Sand-Plover, Great Knot, and Eastern Curlew are all known to occur on the Anindilyakwa IPA. Approximately half of the marine and shorebirds are listed as migratory. Many, including species of *dirrkba* (Plover), sandpiper and *yijarra* (Tern), visit the IPA marine zone.

Kakadu National Park supports more than one per cent of the East Asian–Australasian Flyway population, of the following waterbirds: Magpie Goose, Wandering Whistling-duck, Plumed Whistling-duck, Radjah Shelduck, Pacific Black Duck, Grey Teal, Brolga, Black-necked Stork, Marsh Sandpiper, Little Curlew, Common Sandpiper, Australian Pratincole and Sharp-tailed Sandpiper, however the management plan does not explore the values or management aspirations of Traditional Owners, beyond recognising that several are popular bush tucker species.

Dhimurru IPA provides important foraging habitat for breeding aggregations of migratory seabirds such as the Common Noddy, Roseate Tern, the listed marine Crested Tern, Black-naped Tern, Caspian Tern, Brown Booby and Lesser Frigatebirds. But there is concern about potential bycatch issues from commercial fishing, whilst formal records suggest few seabird (and Dugong) mortalities "We know this to be untrue because we have reliable off-the-record reports from deckhands and some skippers that many are killed" (Dhimurru 2006). Bycatch by commercial (and illegal) fishers is identified as a threat to seabirds (also turtles and marine mammals) on the Djelk IPA too. Through Learning on Country and other community events, the Djelk Rangers aim to increase the awareness of conservation issues associated with migratory birds, along with other marine species of conservation concern (Ansell & Djelk Rangers 2015).

The islands of Cobourg Marine Park are a nationally significant breeding site for Crested Terns and regionally significant breeding site for Black-naped Terns; lower numbers of other species including Roseate and Bridled Terns also use these islands to breed (CPS & MPB 2011). There is no mention of the cultural value of these birds. Wellesley Islands are home to large breeding colonies of Crested Tern, Roseate Tern, Brown Booby and Lesser Frigatebird. Adjacent to the islands, the coastal areas of the Nijinda Durlga IPA provide valuable habitat for numerous shorebird species. Four Nationally Important Wetlands are found on Gangalidda country in the Gulf of Queensland, including part of the Southern Gulf Aggregation, which is the largest continuous estuarine wetland of its type in Northern Australia and one of the three most important areas for shorebirds in Australia providing habitat for species listed under international agreements: 22 species under Japan-Australia Migratory Bird Agreement and 31 species listed under the China-Australia Migratory Bird Agreement (CLCAC 2015a). Within the Marthakal – Stage 1 IPA, there are 1,750 km of natural coastline, offering extensive habitat for a variety seabirds and migratory shorebirds; with the extensive tidal flats of Buckingham Bay providing a major stop over point on the East Asian-Australasian Flyway (Gambold 2016).

Sawfishes, Sharks and Rays

Marine and riverine environments within Kakadu National Park provide key habitat for the Northern River and Speartooth Sharks, as well as the Largetooth, Dwarf, and Narrow Sawfishes (KNPBM 2016).

Three species of sawfish are commonly found in Gangalidda traditional waters. Traditional Owners attest to a serious decline in numbers, and point to scientific evidence that suggests that their traditional country includes important nursery grounds for sawfish in general, also highlighting that more research is needed to fully understand the life cycle of sawfish (CLCAC 2015a). It is clear that Gangalidda people are interested in supporting sawfish conservation efforts. They had been in initial discussions with the State level authority on the creation of an unzoned marine park which would include critical habitat for sawfish within their traditional estate and the adjacent Thuwathu/Bujimulla IPA. Despite that particular marine planning process being abandoned they states that they would gladly resume such discussions and that their rangers are eager to work with scientists to ensure the local survival of sawfish species.

Anindilyakwa people have strong traditional connections with *aranjarra* (the cartilaginous fishes). *Yukwurrirrindangwa* (sawfish), *yumaduwaya* (stingray) and *mungwarra* (Hammerhead shark) are significant totemic species which feature in the Anindilyakwa creation story shared earlier. The Speartooth Shark, Green Sawfish, and Dwarf Sawfish are known to occur in the Anindilyakwa IPA, as well as frequently hunted (Saunders & Carne 2010) *amarbirra* (Cow-tail Stingray) and *yilyanga* (Giant Shovelnose Ray). *Malarra* (Manta Ray) and *gawaŋalkmirri* (stingray) are totemic beings represented in painting by prominent Yolŋu artists included in the collection Saltwater: Yirrkala Bark Paintings of sea country (Dhimurru 2006).

Yanyuwa people have observed an overall decline in the number of stingrays.

The painting below (Figure F2; “Berelh”) is by Graham Rostron, a Baraba man living at Korlorbirrahda on the Arnhem Plateau. Graham’s description of this piece is as follows:

> “Berelh is the Kunay word for the flat one, stingray. This is a female one. In the day she stays down in the sand ground, where it is cool. At night she swims around looking for tucker, looking for prawn, crab and other tucker. All night she swims, then goes back and rests herself, she covers herself back up with sand. This stingray is swimming around, she sees the sawfish, the shark and the prawn. The sawfish we call Djenkundamen, he is dangerous when we are hunting so we be careful. The shark, he’s dangerous too, same like crocodile. The shark we call Wamba. The little prawn, he’s a day time, night time man, walking around under the water enjoying himself. These all live in the river where they hunt tucker. They are all tucker for us too on our country.”

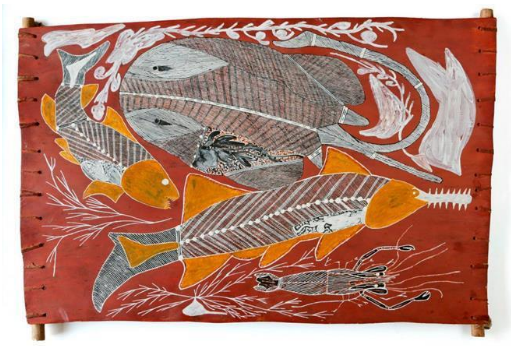

Figure F2. Berelh © Graham Rostron.

Reptiles

Around 20 species of sea snake are believed to occur within the Cobourg Marine Park, including the Critically Endangered Short-nosed Sea snake (CPSMPB & PAWSNT 2011). The Dhimurru IPA is believed to support between 19 and 26 sea snakes. Nineteen species of sea snake are noted as occurring in the seascape adjacent to Pormpuraaw (PLSM & PASC 2010). In these three cases, there is no specific discussion of the value cultural value of sea snakes to the Traditional Owners. For Yanyuwa people there is a sea snake ancestral being (Bradley and Yanyuwa families 2007). Similarly, Anindilyakwa people recognise a songline associated with a sea snake:

> "According to Anindilyakwa tradition, the history of people began with the formation of the land and seascape during the Dreaming. During this time, ancestral creatures travelled across the land and sea along 'songlines'. They sang the country's features – including the plants, animals, hills and rivers – into being and brought Anindilyakwa people to the region. There are various songlines that traverse the islands and sea within the IPA. These include tracks related to *angwura* (fire), *yukwurrirrindangwa* (sawfish), *dumurrengmurra* (sea snake) and *dinginjabena* (dolphin).

To Yolŋu people, the Estuarine Crocodile, known as Bäru is a significant ancestral being. There are strict customs governing the hunting or killing of the species and conservation of Bäru habitat is important to ensure the survival of the species. Extinction of the species would have major consequences for Yolŋu spirituality (Dhimurru 2015). Estuarine Crocodiles are important cultural and totemic species for some clans from the Djelk IPA region. However, consultations revealed they are now perceived as a major threat to safety 'on country' and are restricting access to customary resources. In particular, senior people reported Estuarine Crocodiles in places and numbers that they have never experienced in their lifetimes, and have observed that the increasing numbers have coincided with increasing feral animal numbers. Traditional Owners hope that in 2020 there will have been no further spread of Estuarine Crocodiles beyond 2015 levels, and that the Djelk Rangers have increased their capacity to assist Landowners to manage Estuarine Crocodiles in culturally appropriate ways (Ansell & Djelk Rangers 2015).

Involvement in Marine Research

Indigenous landowners have been active participants in research and management to advance goals - like reduction in greenhouse gas emissions - that sit outside traditional obligations and experience (Russell-Smith *et al.* 2009). They are eager to deploy assets, skills and practices to problems important to other members of Australian society, especially where delivery of those external goals can contribute to meeting customary obligations to country. Communities and Indigenous organisations with the capacity to engage with researchers and commission work have done so. In 2004–2005, the Tiwi Islands rangers and the World Wildlife Fund undertook a multidisciplinary research project, the sea turtle conservation and education project (Whiting *et al.* 2007). In 2008, a partnership between Fisheries staff of the Northern Territory Department of Resources the Anindilyakwa Rangers undertook a survey of the customary harvest of sharks and stingrays; prior to this project the 2003 National Recreational and Indigenous Fishing Survey was the only other survey attempting to evaluate customary harvest of sharks and rays. Many Indigenous ranger groups have contributed to research undertaken by Ghostnets Australia (Gunn *et al.* 2010).

Dhimurru have a long history of involvement in collaborative research and management projects on a diverse range of subjects including: Marine turtle and Dugong conservation and management, ghost net and other marine debris mitigation and removal, distribution of inshore dolphins and Dugongs, seagrass monitoring and mapping, fish abundance and health, crocodile management, cultural mapping, Yellow Crazy Ant control, Northern Quoll relocation, terrestrial biodiversity surveys, management of the endemic Gove Crow Butterfly, ethnozoology of frogs and toads, fire management, and biosecurity. The Malak Malak rangers from the Daly River region have been working with researchers to learn more about the distribution and habitat requirements of the Largetooth Sawfish (Simpfendorfer *et al.* 2016) and the Traditional Owners are eager to contribute to the conservation of the species through a ranger of on-ground management activities (NESP 2016).

Planned Research and Monitoring Directions

Several groups have outlined some specific research and/or monitoring directions. For example, the Mapoon rangers plan to monitor shorebirds and sea turtles in order to improve their knowledge about local impacts of climate change (Mapoon 2013). Anindilyakwa aspire to detect, describe and/or map 1 new species, population or ecological community annually.

In the Dhimurru sea country plan (2006) 'Invitations to stakeholders' section one broad aim is "To extend and develop our role as real partners in monitoring and research on marine creatures and their habitats. This includes both customary and contemporary scientific knowledge and involves careful cooperative management planning at sub-regional, regional and state levels." In the subsequent IPA management plan Dhimurru have identified mapping sea country habitats and marine biodiversity surveys as a high priority before 2020. They also want to investigate all causes of turtle mortality resulting from commercial fishing, and invest in the development of solutions. Dhimurru want to continue to explore and develop 'both ways' approaches to manage and protect threatened species and habitats, and encourage cooperative partnerships for research and management.

Indigenous land managers of the Thuwathu/Bujimulla and neighbouring Nijinda Durlga IPAs point out that there is a serious lack of baseline data in a number of key areas including species population levels and trends and overall habitat health, recognising that without it, it is difficult to assess the effectiveness of the management plan and on-ground actions (CLCAC 2015a, b). Gangalidda people have included a direct call to potential collaborators in their management plan to help fill this gap. "We actively invite scientists involved in research projects applicable to our region, visiting researchers, etc. to work with our rangers in what will be a mutually beneficial arrangement to collect environmental information across the region" (CLCAC 2015a). In addition to a need for baseline information, there was mention of increasing nest mortality in other areas of the Gulf due to nest inundation linked with climate change-driven sea level rise, and they stated an intent to monitor for this (CLCAC 2015a, b).

Principles of Appropriate Engagement in Future Research

The above analysis of documents is an important preliminary step in the process, recognising the work already done by communities to communicate their intent for the ongoing custodianship of their sea country. These documents identify threats, priorities and knowledge gaps; giving an indication of where future research efforts may be of most value to Aboriginal people as legal and customary holders of land and sea country over most of the project area and as the dominant and most affected group outside the larger towns.

As communities continue to build their capacity to engage with the western science community on their own terms, there is growing (two way) research collaborations often driven by Indigenous interests and actions (NAILSMA 2006, Dhimurru 2013, Jackson *et al.* 2015, Dobbs *et al.* 2016, Jackson *et al.* 2016, James & NAILSMA 2016, Simpfendorfer *et al.* 2016, Ens *et al.* 2017). This marks an emerging trend away from research projects primarily founded on non-Indigenous actors, interests and priorities. In these examples of collaborative and cross-cultural research it is the partnerships and processes adopted in the conduct of projects that put them on a good footing for success.

Some key principles of engagement can be summarised as:

- Know and respect local rights, interests and aspirations;
- Where possible, engage local people in the research agenda;
- Discuss value and legacy of research for the respondents and their communities;
- Provide useful information – explaining background and broader context;
- Use opportunity to employ and pass on skills;
- Respect local timeframes;
- Right people, right country;
- Manage expectations;
- Use local language or parlance when reporting back; and,
- Respect "both ways/two knowledge systems*" approaches and existing knowledge systems.

*Two knowledge systems: Maintaining the balance between the Yolŋu and the mainstream worlds and the active practice of both-ways natural and cultural resource management is an important key guiding principle. As one Rirratjingu elder put it "We need to ensure there is balance between Yolŋu and Ŋapaki [western] land and sea management and that Ŋapaki work does not over run Yolŋu ideas" (Dhimurru 2015).

The Dhimurru IPA Management Plan (2015) provides some very clear guidance about future research processes and directions. One of the guiding principles is collaborative relationships – continued development of collaborative relationships with government agencies and other organisations in programs and research to support sustainable use and management of Yolŋu land and seas:

> "From inception, Dhimurru has steadily developed its capacity and participation in research to support land and sea management objectives. In collaboration with university and government agency researchers, we have undertaken many successful collaborative research projects through our 'both-ways' approach to combining Yolŋu and scientific approaches to problem-solving, environmental understanding and policy development."

While Dhimurru are keen to focus on collaborative research that directly supports their identified management priorities, they will also consider approaches from researchers who wish to undertake projects involving Dhimurru IPA and its cultural and natural resources. The proposed research activity:

- Should align with national policy directions and guidelines;
- Be consistent with Dhimurru's Research Protocols;
- Comply with Australian guidelines for the conduct of ethical research involving indigenous people;
- Contribute to the understanding and/or protection of the cultural or natural heritage of Dhimurru IPA; and,
- Contribute to training and capacity-building of Dhimurru staff and Yolŋu people.

Anindilyakwa Traditional Owners support research projects that aim to address knowledge gaps and inform the management of the IPA marine zone. They have a research application available to assist people/organisations to put their proposal forward. In the IPA monitoring and evaluation framework there is a target of 2 environmental research projects (terrestrial and/or marine) to be supported by the ALC LSM Unit, and 30 days participation in projects with researchers/other land managers. Such projects must meet a number of criteria:

- Respect Anindilyakwa culture and traditional rights to natural and cultural resources;
- Benefit and appropriately acknowledge the contributions of Traditional Owners;
- Recognise the rights of Anindilyakwa Traditional Owners to their cultural and intellectual property;
- Provide information that can inform management activities undertaken by the ALC Rangers; and,
- Provide opportunities for ALC Rangers to participate and gain experience and skills.

The Tiwi Land Council have also developed a process for considering research projects including a research application to be completed by the organisation and researcher protocols to be signed by individuals involved in on-ground activities.

As part of the permitting process Parks Australia and the Kakadu Research and Management Advisory Committee have developed research guidelines that outline how Kakadu traditional custodians want to work with researchers. In consultation with the Aboriginal Areas Protection Authority and Traditional Owners, they also intend to develop Indigenous research protocols designed to ensure that research:

- Incorporates traditional custodians' knowledge and perspectives;
- Reflects consultation with traditional custodians depending on expected level of impact;
- Engages with and provides opportunities for collaboration with and employment for traditional custodians; and,
- Is in accordance with the *EPBC Act* and the management plan.

Conclusions and Next Steps

This work focuses on *EPBC*-listed species and related issues, and shows that many of the species accorded this formal significance are also of great importance to Indigenous people. Although the motivations and criteria for assigning significance may be different, there is certainly a strongly shared commitment to ensure that they continue to define north Australian seascapes and maintain their spiritual and instrumental value to Australian society. The research interests identified by Indigenous people reflect the powerful obligations they accept as custodians of country and the lifeforms and ancestors depending on their management of country.

Research "hotspots" may be identified in many ways, potentially as simple as taking a list of *EPBC*-listed species about which multiple Indigenous groups express interest and concern and selecting some sites where those species are abundant and thought to be subject to a known pressure. However, such an approach would not necessarily deliver strong Indigenous engagement/ participation nor the "seascape approach", which would not be plausible without the participation of the Indigenous owners of critical elements of seascapes.

Lists of the favoured - by definition - also exclude. For example, uncritical application of lists may devalue the apparent relevance of the knowledge, interests and particular cultural responsibilities of Traditional Owners and/or authoritative managers of putative hotspots. If genuine Indigenous engagement is to be achieved, this and related issues must influence how research questions are framed, site and species selections are made, would-be collaborators are identified and real benefits generated by participation.

Within limited scope, this desktop assessment has sought identification and comments about *EPBC*-listed migratory and threatened marine species evident in marine management and IPA plans and importantly, to hint at the perspectives from which these species particularly are ascribed value and meaning. The latter broadens the opportunity for useful engagement around research, management and monitoring over the long term.

It is proposed that in the second, consultative phase of this study, known concerns as documented in this report are further explored to deal with both the 'right' engagement and 'seascape' issues. This will involve discussions around questions such as:

- What other animals or places are affected by the pressures you think are affecting (listed species x, y, z)?
- Will these species show effects before or after (listed species y, z)?
- What will happen to them?
- If you watched these animals closely, would they give you warning of problems coming for others, including (listed species y, z)?
- Management actions so far identified to help protect (listed species y, z) are (actions a, b)
- Will those actions also help (unlisted) species that you are worried about?
- Are there other actions that would help them as well other (unlisted) species of concern?
- If you had to choose one or a few actions that would help the most species, what would they be?
    - How would you know whether they were working?
- Are there places with many (listed species x, y, z) where management is good and pressures not too bad?
- What do we need to do to keep them that way?
- Are there places where numbers of (listed species y, z) are good but there are signs or recent changes that worry you?
- Were there places where the numbers of (listed species y, z) aren't all that high but are still really important?
    - What needs to be done to look after these places?
- Because some of these (listed species y, z) move into and out of your country, how will you work with others to make sure they are looked after in all the places they need?
- Do you know enough about where they go and what they need in other places?
    - What additional information about movements do you think would be most useful?

The aim in this further work and final report will be to build on the demonstration of shared interests to support design for optimising opportunities and effectiveness in collaborative research programs that addresses both Indigenous and non-Indigenous values.

Table F2. Summary table.

Species/groups	Significance/ nature of interest	Identified issues/pressures	Potential research questions	Relevant IPAs/communities
Dugong	Powerful cultural affiliations for the majority of groups Customary resource for many groups Indicator of ecosystem health	Overall reduction in numbers Impact of customary harvest (actual, potential and perceived) Resilience to harvest Unhealthy animals observed (underweight, unusual fat colour) Impacts of pollution (marine & terrestrial origin) on animal health and on primary food (seagrass) Non-target mortality including commercial fishery bycatch, ghostnets, and commercial and recreational boat strike Application of traditional law for managing customary harvest	Broad-scale investigation of population status and dynamics, Development of local survey methods, Possible impacts of chemical pollutants on animal health, Impacts of pollution (chemical and sedimentation) on seagrass food source Bycatch levels and mitigation methods	Anindilyakwa Cobourg Dhimurru Djelk Mapoon Marthakal Nijinda Durlga Thuwathu/Bujimulla Yanyuwa Also important in adjacent regions of the Torres Strait and the Kimberley
Marine turtles	Powerful cultural affiliations for majority of groups Customary resource (eggs & adults) for most groups Indicator of ecosystem health Interest in conservation status	Overall reduction in numbers Impact of customary harvest of adults and eggs (actual, potential and perceived) Resilience to harvest Unhealthy animals observed (floaters, fibropapilloma) Impacts of pollution (marine & terrestrial origin) on animal health and on primary food (seagrass)	Broad-scale investigation of population status and dynamics Causes of diseases and illness Possible impacts of chemical pollutants on animal health Ongoing impacts of marine debris and ghostnet Impacts of pollution (chemical & sedimentation) on seagrass food source	Anindilyakwa Apudthama Cobourg Dhimurru Djelk Kowanyama Mapoon Napranum Nijinda Durlga

Species/groups	Significance/ nature of interest	Identified issues/pressures	Potential research questions	Relevant IPAs/communities
		Non-target mortality including commercial fishery bycatch, ghostnets, commercial and recreational boat strike Feral animal impacts on nesting success Climate change (sea level rise affecting nesting) Light pollution affecting nesting Application of traditional law	Bycatch levels and mitigation methods Nesting success: predation rates & mitigation methods, sea level rise, incubation temp, light pollution Customary harvest surveys	Pormpuraaw Tiwi Thuwathu/Bujimulla Yanyuwa Yirralka (Laynhapuy) Also important in adjacent regions of the Torres Strait and the Kimberley
Cetaceans	Dolphins totemic in one region (was also historically a customary resource) Whale an ancestral being Interest in conservation status	Possible bycatch issues (commercial & illegal fishers) Boat strike	Bycatch levels and mitigation methods	Anindilyakwa Dhimurru
Sawfish, Sharks, Rays	Powerful cultural affiliations for some Common customary resource (mainly rays and sharks) Interest in conservation status	Observed reduction in number of rays and Sawfish Commercial fishery bycatch	Population surveys Investigate lifecycle Investigate causes of population reduction Fishery interactions Habitat quality	Anindilyakwa Arnhem/Kakadu Dhimurru Malak Malak Nijinda Durlga Thuwathu/Bujimulla Yanyuwa
Shorebirds	Indicator of healthy beaches Interest in conservation status	Nest mortality (vehicle impacts)	Population surveys Climate change impacts on habitat availability	Djelk Mapoon Napranum

Species/groups	Significance/ nature of interest	Identified issues/pressures	Potential research questions	Relevant IPAs/communities
				Kakadu Thuwathu/Bujimulla
Seabirds	Some species totemic Former customary resource (food & ceremonial items) Indicators of healthy sea country Interest in conservation status	Commercial bycatch Local harvest of eggs Nest mortality (vehicle impacts)	Fishery interactions & mitigation methods Population surveys Interaction between feral numbers and crocodiles Impacts of egg harvest	Anindilyakwa Djelk Yanyuwa
Crocodiles	Powerful cultural affiliations for some Eggs a resource for ILM enterprise	Increasing numbers and expanded range (since cessation of widespread culling) Egg harvest Climate change impact on nesting		Djelk Dhimurru
Sea snakes	Powerful cultural affiliations for two groups			Anindilyakwa Yanyuwa

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