Design and Siting

Phase 2 Final Report

NT Artificial Reefs and Fish Attracting Devices

59918060

Prepared for

NT Department of Primary Industry and Resources

21 June 2018

Cardno®

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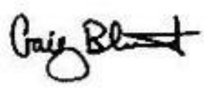

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Document Information

Prepared for	NT Department of Primary Industry and Resources
Project Name	NT Artificial Reefs and Fish Attracting Devices
File Reference	59918060_Ph2_Final_Rev0
Job Reference	59918060
Date	21 June 2018
Version Number	Rev 0
Effective Date	21/06/2018
Date Approved	21/06/2018

Document History

Version	Effective Date	Description of Revision	Prepared by	Reviewed by
Rev A	4 May 2018	Draft for client review	Lachlan Barnes, Craig Blount, John Diplock, Johann Bell, Marcus Lincoln Smith, Doug Treloar, Andrew Bradford, Daryl McPhee, Craig Wilson, William Sokini	Andrew Costen
Rev0	21 June 2018	Final Report	Lachlan Barnes	Craig Blount

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Executive Summary

The Northern Territory (NT) Government has made a commitment to invest in a range of recreational fishing infrastructure projects as a means of expanding, improving and diversifying recreational fishing opportunities to enhance lifestyle activity and tourism. As part of this commitment, the Department of Primary Industry and Resources (DPIR) is investigating the potential of artificial reefs (ARs) and fish attracting devices (FADs) as a part of a 'recreational fishing infrastructure investment plan' to aid in the recovery of at risk reef fish and substantially improve recreational fishing access.

This report presents the results of Phase 2 of the NT Artificial Reefs and Fish Attracting Devices: Design and Siting Study (the study) which build on those provided to DPIR in the Phase 1 report (Cardno 2017). Key components of this phase included incorporation of stakeholder and community feedback into the design of ARs and FADs and additional analysis of spatial data to identify potential AR and FAD deployment areas. In addition, this report identifies potential permitting requirements and ongoing investigations that are recommended to be undertaken prior to the deployment of ARs or FADs.

The objectives of this study included identifying:

- AR design/engineering specifications, including extent, topology and architecture of niche and reef unit/reef field habitat features for NT coastal reef fish communities
- FAD designs and recommending testable FAD designs to go to proof of concept pilot tests
- Identifying potential deployment areas for ARs and FADs.

The study area is situated between Cape Ford, south-west of Darwin, to Point Stuart (east of Darwin) and north of Darwin to the southern coastline of Melville Island and Bathurst Island (approximately 18,048.37 square kilometres). This area is characterised by a tidal range of 8 m, strong currents and turbid waters associated with short period wind waves.

Three types of commercially available AR modules were considered generally suitable for deployment; a 9 t concrete pyramid, 17 t concrete cube and a much heavier (31 t) and taller (~14 m) steel dome. Some modifications to ensure these modules incorporate appropriate internal void space and size and shape (for shelter), vertical relief and upwell potential as well as modifications to ensure stability (slide or over-turn, at various depths) were also recommended and documented. Various module arrangements, such as the incorporation of four modules into a single cluster and the deployment of multiple clusters, are scalable and provide DPIR with flexible deployment options were identified to suit $2M, $5M and $10M deployment budgets.

Two FAD designs incorporating; an anchoring system (facilitating seasonal deployments), a string of oval and purse seine float headgear, GPS locator unit, night light and two styles of headgear and top lines attachments were identified as suitable for deployment. It is considered that these two FAD designs can be constructed and should be incorporated into a proof of concept pilot study. A budget of $1 million over five years would provide DPIR with an opportunity for dry season deployments of twelve FADs spread across six sites. At each site, FADs should be spaced approximately 500 m apart and sites should be spaced at least 10 km apart.

Environmental, social and engineering criteria were examined using multi-criteria analysis (MCA) to identify potential AR and FAD deployment areas. The Round 2 MCA identified 43 (1,993 square kilometres) and 52 areas (1,369 square kilometres) considered to be least constrained for the potential deployment of ARs and FADs respectively. These areas were distributed throughout the study areas generally in the vicinity of Dundee Beach, Bynoe Harbour, Darwin Harbour and in the Van Diemen Gulf.

In consultation with DPIR, a range of performance indicators developed to measure the success of future AR and FAD deployments are identified. To monitor performance, future sampling designs should incorporate appropriate replication, controls and the avoidance of pseudoreplication. As such, DPIR should consider the sampling design of future monitoring program requirements prior to committing to particular AR and FAD deployment configurations.

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Glossary of Terms

Term or Acronym	Definition
AFANT	Amateur Fishermen's Association of the Northern Territory
Amphidromous	Migrating from fresh to salt water, or vice versa at some stage during the life cycle other than during the breeding period
AR	Artificial reef
Benthic organisms	Flora and fauna on/in the bottom sediments of the sea
Decision support system	An approach to solving complicated problems. Consists of four phases; Intelligence, Design, Choice, Implementation
Demersal fish	Fish living close to or in association with the seafloor
DPIR	Department of Primary Industry Resources
EIA	Environmental Impact Assessment
FAD	Fish attracting devices
FIRA	Korea Fisheries Resources Agency
Fit for purpose	Well-equipped or well suited for its designated role or purpose
Grey literature	Publications produced in print and electronic formats, but which is not controlled by commercial publishers
Kurnell density analysis	Calculates a magnitude-per-unit area from a point using a kernel function and search radius (10 km during this study) to fit a smoothly tapered surface to each point. See http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/kernel-density.htm
LAT	Lowest astronomical tide
MBACI	Multiple-Before-After-Control-Impact sampling designs
MCA	Multi-criteria analysis
Mesopelagic	Organisms inhabiting the intermediate depths of the sea, between 200-1000m down
NT	Northern Territory
Oceanodromous	Fish that live and migrate wholly in the sea
PICTs	Pacific Islands Counties and Territories
Pelagic fish	Fish inhabiting the open ocean
SPC	Pacific Community (SPC), the principal scientific and technical organisation in the Pacific region, owned and governed by 26 country and territory members
Study Area	Darwin region, from Cape Scott to the south-west of Darwin to Point Stuart in the East, including the Tiwi and Vernon Islands to the north
SoW	Scope of Works
Target species	Those species that are primarily sought by the fisherman in a particular fishery

1 Introduction

1.1 Purpose

This report presents the methods and results of the *NT Artificial Reefs and Fish Attracting Devices: Design and Siting Study* (the study). Specifically this report includes details relating to the environmental setting of the study area, identification of refined designs and configurations of artificial reef (AR) and fish attracting devices (FADs) considered suitable for deployment, potential AR and FAD deployment areas and the limitations in the existing data and potential monitoring activities.

This study was completed in two Phases (**Figure 1-1**); Phase 1 incorporated the initial collection, collation and analysis of data while Phase 2 incorporated specific stakeholder engagement and community inputs to refine the results of Phase 1 works. Cardno (2017) presents the results associated with Phase 1.

1.2 Background

The Northern Territory Government has made a commitment to invest in a range of recreational fishing infrastructure projects as a means of expanding and improving recreational fishing as a lifestyle activity and tourism feature for the Northern Territory. As part of this commitment, the Department of Primary Industry Resources (DPIR) is investigating the potential for purpose built artificial habitats as a part of an overall 'recreational fishing infrastructure investment plan'.

It is widely accepted that ARs and FADs have the potential to diversify and enhance recreational fishing opportunities. For example, many countries have installed ARs and FADs to enhance artisanal, commercial and recreational fisheries (angling and spearfishing (Baine 2001)). ARs and FADs have historically been constructed using materials of opportunity (e.g. car tyres, pipes, abandoned fishing gears and decommissioned ships) while more recently consideration of construction materials and design has resulted in the development of purpose built devices being deployed (Sherman et al. 2002). These purpose built devices have several benefits over those that consist of materials of opportunity, as they can be engineered to address specific aims, objectives and existing conditions (such as to suit a chosen location in terms of depth, oceanographic conditions, substratum type and habitat preferences of as of particular species).

1.3 Scope

DPIR engaged Cardno Pty Ltd (Cardno) to:

- Identify AR design/engineering specifications, including extent, topology and architecture of niche and reef unit/reef field habitat features for Northern Territory coastal reef fish communities
- Identify and recommend testable FAD designs to go to proof of concept pilot tests
- Identify potential deployment areas for ARs and FADs that incorporate resource sustainability, public safety, accessibility and environmental suitability.

1.4 Tasks

Cardno completed the following tasks to address the study scope:

- Investigated the existing physical, environmental and social characteristics of the study area (see **Figure 1-2)**
- Compiled, examined and summarised existing literature related to AR, FADs and associated risks (environmental, social and engineering)

- Developed and used a decision support system for determining ‘fit for purpose’ ARs and FADs suitable for deployment in the study area
- Developed and used a fit for purpose multi-criteria analysis (MCA) for the identification of potential AR and FAD deployment areas
- Developed and launched a web portal to facilitate the collection of community inputs into the preferred location of ARs and FADs within the study area
- Developed monitoring program objectives, performance criteria and techniques for future AR and FAD deployments
- Identified approval requirements, data gaps and limitations to be addressed by DPIR prior to the deployment of ARs and FADs.

1.5 Report Structure

This report comprises the sections listed below. Where possible tables and figures to help expedite review and relay key messages are included. Supporting information is included in a series of appendices.

- Section 1 – Introduction
- Section 2 – Approach and Methodology
- Section 3 – Environmental Setting
- Section 4 – Artificial Reefs - Results
- Section 5 – Fish Attracting Devices – Results
- Section 6 – Approval Requirements
- Section 7 – Monitoring Considerations
- Section 8 – Further Investigations
- Section 9 – References.

1.6 Assumptions and Limitations

Please note the following qualifications when reading this report:

- It is not the intention of this report to provide definitive AR or FAD designs but rather provide concepts for designs
- Potential AR and FAD deployment areas identified are for DPIR discussion purposes only
- While based on georeferenced data, locations of data reflect inaccuracies associated with the original data sources.

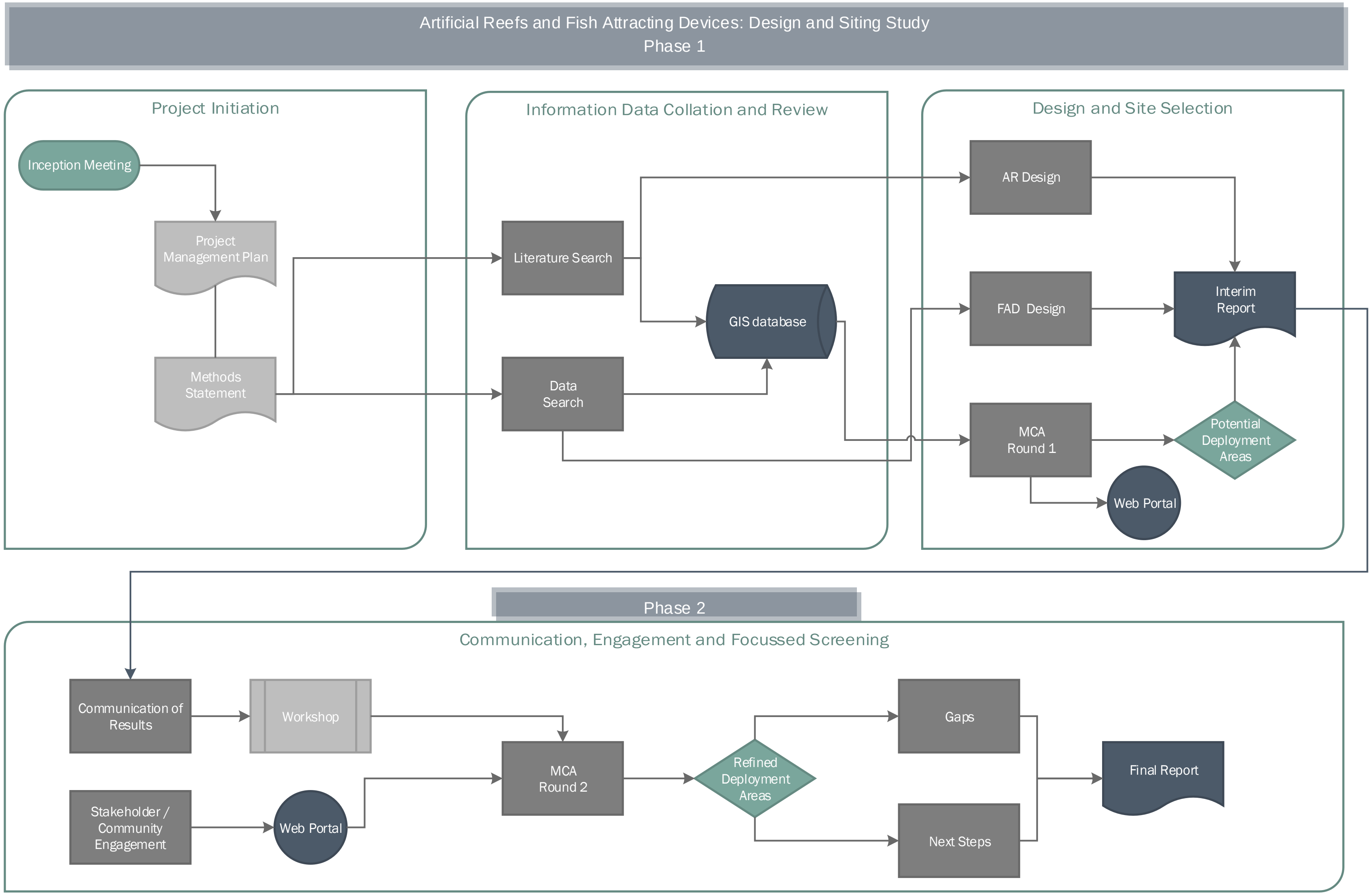

Figure 1-1 Workflow for Phase 1 and 2 of the 'DPIR AR and FAD Design and Siting Study'

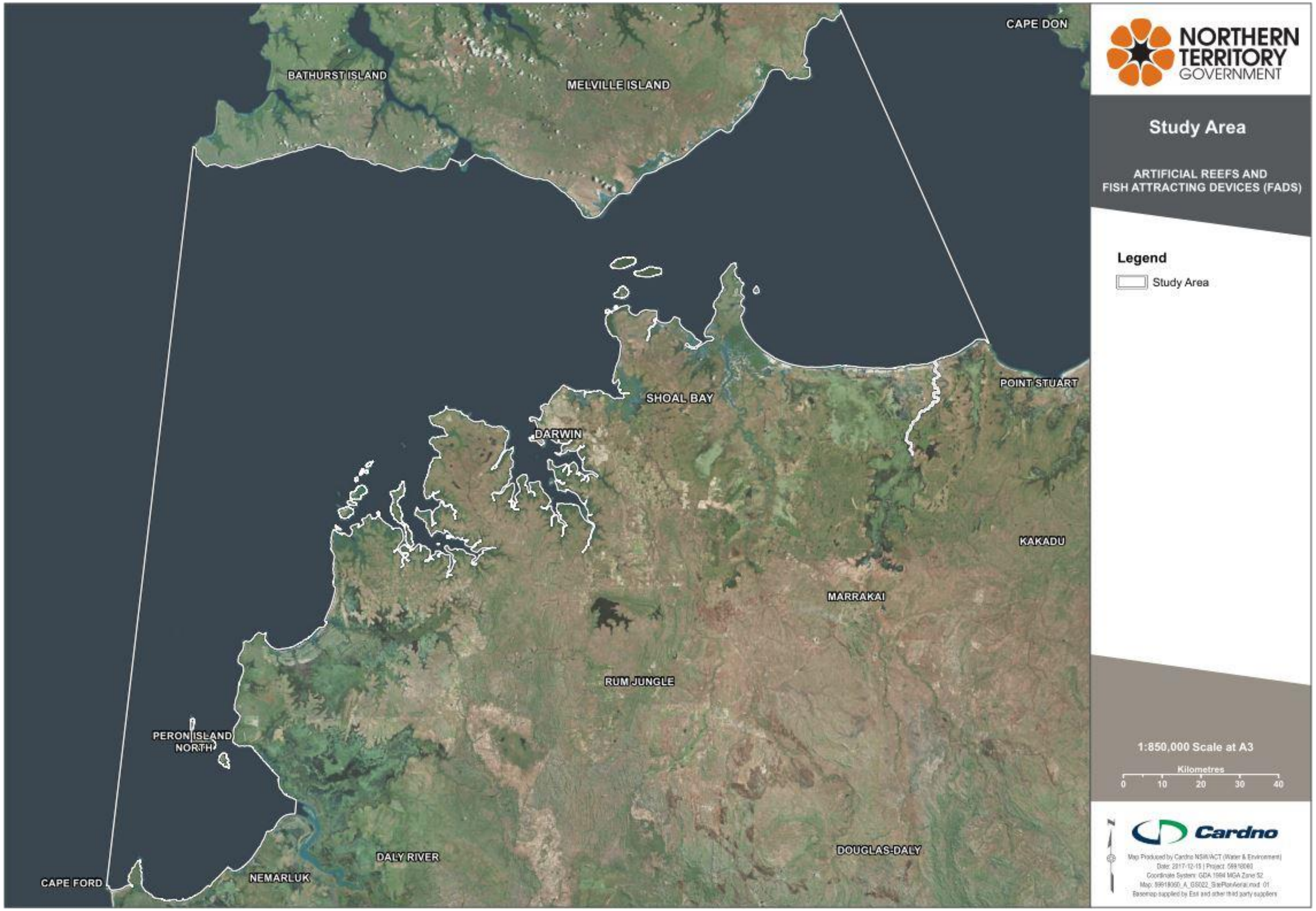

Figure 1-2 Study area

2 Approach and Methodology

2.1 Overview

The approach to develop this report is shown diagrammatically in Figure 1-1 and outlined below. Further detail is included in Appendices (where required).

2.2 Data and Information Collation and Review

This task, largely a desktop exercise, comprised:

- A review information from numerous sources including contemporary peer reviewed and grey literature
- A search for relevant and publicly available information and data
- Sorting electronic data and building a GIS database for this project
- Interrogation of data within the GIS database and development of consolidated maps and figures for use in this report.

A review of the existing literature associated with ARs and FADs are in Appendix A and B respectively.

Information and data compiled during this exercise:

- Provided an overview of the existing environmental and social characteristics of the study area
- Informed the development of a decision support tool.
- Supported the identification of categories and criteria for the Multi-Criteria Analysis (MCA) used to identify potential AR and FAD deployment areas.

2.3 Decision Support Tool - 'Fit for Purpose' AR and FAD Design

Decision support tools are a useful approach to solving complicated problems - i.e. best applied to unstructured or semi-structured problems. Accordingly, Cardno adopted such an approach during this study to identify optimal AR and FAD designs for DPIR.

The decision support tool for this study comprised four steps:

1. *Intelligence* – Searching for the conditions that call for decision
2. *Design* – Developing and analysing possible alternative actions to the solution
3. *Choice* – Selecting a course of action among the possible alternative actions
4. *Implementation* – Adopting the selected course of action in a decision situation.

These steps are summarised in the following sub-sections. Further details are included in **Appendix B** and **Appendix C** and Cardno (2017).

2.3.1 Step 1 - Intelligence

Approach

To help determine potential courses of action, it was important to first understand the functionality of various aspects of AR and FAD structures or their arrangements, with respect to the various types of target fish. This was done through a review of information in technical reports, the internet and research articles (**Appendix B** and **Appendix C**).

Outcomes

An understanding of the various structural components and configurations for ARs and FADs, which can affect properties of attraction, aggregation or production.

2.3.2 Step 2 - Design

Approach

Step 2 included the development of hypotheses regarding the functionality of different structural and or arrangement options for ARs and FADs using information collated during Step 1.

Consultation with experts was undertaken to confirm or refine hypotheses and hence to synthesize key findings from the review in Step 1. Engagement with relevant stakeholders was also undertaken to provide feedback on designs (see Section 2.5).

Outcome

Short list of concept designs for further assessment.

2.3.3 Step 3 - Choice

Approach

Decision makers need to compare and contrast the various options for ARs and FADs. The approach involved comparing options against a suite of 'fit for purpose' criteria that closely reflected the objectives of the program and that considered key findings of the review of existing information. The fit for purpose criteria were:

1. A focus on maximising the potential for aggregation of a diversity of reef (including juveniles) and/or pelagic species that are preferred by recreational fishers
2. Minimisation of attraction of fish from other reefs (for ARs), particularly vulnerable species, so that new aggregations are a result of new production
3. Scale and scale-ability of designs to provide for long-term network development
4. Siting (including configuration) that maximises the potential for recreational fisheries enhancement (including accessibility) and minimises the potential for compromising safety and social, economic or ecological risks
5. Construction, maintenance and deployment/ retrieval costs that are within the given budget and, for ARs, a design life of 30 yrs.

Outcomes

A suite of fit for purpose criteria for ARs and FADs that matched the requirements of the program.

2.3.4 Step 4 - Implementation

Approach

The range of various structural options for individual AR and FAD units and configurations of modules were evaluated against the relevant 'fit for purpose' criteria above and the choices of the optimal designs were justified by their compliance with the criteria as determined through consideration of the key findings in Step 2.

Outcomes

Optimal concept designs for ARs and FADs.

2.4 Identification of Potential AR and FAD Deployment Areas

Cardno used an integrated, multi-criteria analysis approach (MCA) to identify potential AR and FAD deployment areas.

MCA is a type of decision analysis tool used to compare positive and negative effects or values against a list of relevant criteria to determine preferred areas or alignments (Mendoza & Macoun 1999). MCA is particularly applicable to cases where a single-criterion approach (such as cost-benefit analysis) falls short, especially where significant environmental and social impacts cannot be easily assigned monetary values. The key strength of multi -criteria analysis is the 'accountable' manner in which unquantifiable and intangible factors (such as impacts of an activity on marine benthic communities) can be integrated with strictly measurable data.

The MCA included the following steps:

1. Desktop review
2. Identification of evaluation criteria
3. Data review
4. **Round 1** (see Phase 1 report for results (Cardno 2017))
    a. Assign performance weightings (least, slightly, moderately or highly constrained)[1]
    b. Weighting of criteria
    c. GIS analysis.
5. **Round 2** (results presented in this report)
    a. Incorporate additional spatial information and stakeholder feedback (see Section 2.5)
    b. Assign performance weightings (least, slightly, moderately or highly constrained)[2]
    c. Weighting of criteria
    d. GIS analysis

The criteria and rationale used to identify potential AR and FAD deployment areas are listed in **Table 2-1**. Criteria performance weighting and pairwise comparison weighting used in the MCA to identify potential AR and FAD deployment areas is in **Appendix E**. A full description of the MCA methodology, categories and criterion used during the study are included in **Appendix E**.

[1] Performance criteria weightings for up to four categories (least constrained, slightly constrained, moderately constrained and highly constrained) were assigned to characteristics relating to each criterion examined. 'Least constrained' determinations were made for characteristics that were in the opinion of the specialists consulted posed no constraint for the deployment of ARs or FADs. 'Slightly constrained' determinations were made for characteristics that while not restricting were considered less than ideal for the deployment of ARs or FADs. 'Moderately constrained' determinations were made for characteristics that could restrict or were considered to represent an option that would require considerable additional investigation or justification for the potential deployment of ARs or FADs. 'Highly constrained' determinations were made for characteristics where protections through legislation or other regulations prohibits the placement of ARs or FADs or where it is considered non-viable or not consistent with the objectives of the study to deploy ARs or FADs within the study area. Based on the aforementioned, only areas identified as being 'least constrained' were considered potential AR or FAD deployment areas. It is however acknowledged that areas identified as those other than being 'least constrained' may also contain potential AR or FAD deployment locations.

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Table 2-1 Criteria and rationale used to identify potential AR and FAD deployment areas

Constraint	Criteria	Rationale
Environmental	High relief (complex) benthic habitat	Loss of existing high relief benthic habitat is avoided
	Seagrass habitat	Loss of existing seagrass habitat is minimised
	Conservation estate	Impacts on sites with legal conservation status or areas identified as important to threatened species are avoided
Social	Existing use	Impacts to the existing use of the area are minimised
	Wrecks (including war graves)	Wrecks, including known war graves are avoided
	Cultural heritage sites	Cultural Heritage sites are avoided
	Mineral or petroleum exploration areas	Impact on mineral or petroleum exploration activities are minimised
Engineering	Substrate type	**AR:** Areas of rock and corals are avoided **FAD:** Artificial reefs are stable
	Distance from access point or harbour	ARs and FADs are accessible
	Water depth	**AR:** AR is not exposed during low tide **FAD:** FAD is not exposed during low tide
	Interference with existing infrastructure	Interference with marine infrastructure is avoided
	Interference with established shipping channels and 2017 vessel tracks[3]	**AR:** Interference with established shipping channels and 2017 vessel tracking data is minimised **FAD:** Interference with established shipping channels is avoided

During Phase 1 of this project MCAs identified 16 potential AR and 17 potential FAD deployment areas that were larger than 400 ha (Cardno 2017). During Phase 2 of the project, results from the Round 1 MCA were further refined based on feedback received during the stakeholder engagement workshop (specifically the addition of vessel tracking information, the reweighting of criteria pairwise comparisons and subsequent GIS analysis (see **Appendix E)**.

As with all general planning tools and methods, there is still room for modification but, in general terms, it is considered that the model derived during this study was suitable for the broad-scale identification of potential AR and FAD deployment areas (see **Section 4.6** and **Section 5.6** for identified potential AR and FAD deployment areas respectively).

Key site attributes associated with the potential AR and FAD deployment areas identified during the Round 2 MCA are summarised in this report.

[3] Criterion added to MCA following input from the stakeholder engagement workshop (see Section 2.5).

2.5 Stakeholder Engagement Workshop

Following the completion of Phase 1 of the project a stakeholder engagement workshop was undertaken on 5 February 2017 to:

- Examine, discuss and provide general feedback on the results presented in this report
- Provide specific feedback in relation to identified AR and FAD designs and deployment configurations
- Provide specific 'suitability and sensibility' feedback on the outputs of the AR and FAD MCAs
- Prioritise areas of least constraint for the deployment of ARs and FADs within the study area for additional detailed assessment
- Identify criteria to use in more detailed Round 2 MCA assessments to identify potential AR and FAD deployment areas (see **Section 2.4**)
- Provide input for criteria performance weighting and pairwise criteria weighting for the identification of AR and FAD deployment areas.

Feedback received during the stakeholder engagement workshop was incorporated into activities and analyses undertaken during Phase 2 of the study (**Figure 1-1**) and the accordingly the results are presented in this report.

2.6 Community Input – Web Portal

Community input to identify potential AR and FAD deployment sites was collected through a web portal data capture application. The web portal, built in an ArcGIS environment included a base map developed as part of the Phase 1 works (**Appendix F**). The base map identified highly constrained locations considered not suitable for the deployment of ARs of FADs within the study area. The web portal was activated from 18 January 2017 to 19 February 2018.

To increase community and stakeholder awareness of the web portal notification and links to the web portal address were advertised in numerous ways including but not limited to:

- Ministerial announcement and NT Government website (web address)
- Article in the Northern Territory News (web address)
- DPIR homepage (web address)
- DPIR recreational fishing website (web address)
- AFANT homepage (web address).

Community inputs that were sought via the web portal included:

- Preferred locations for the deployment of five ARs and five FADs (within the study area)
- Which fish species they would target
- How often they would fish in the identified preferred location
- Why they have chosen the locations
- Other comments (free text field).

During Phase 2 of the project, data collected from the web portal was collated and used as an informative layer for the identification of potential AR and FAD deployment areas following the completion of the Round 2 MCA.

2.7 Monitoring Requirements

To assess the influence of AR and FAD deployment within the study area, DPIR and Cardno study team members identified a range of monitoring objectives and associated performance indicators (see

Section 7). This study identified monitoring program methods, sampling locations/designs and data analysis techniques to measure success criteria associated with AR and FAD deployment performance indicators.

2.8 Information Gaps and Further Investigations

Following the identification of potential AR and FAD deployment locations, an assessment was undertaken to identify further investigations and additional data that should be obtained prior to the deployment of this infrastructure. During this assessment consideration was given to:

- Resolution and extent of spatial data used in the MCA
- Structural requirements of ARs and FADs
- Legislative and permitting requirements.

3 Environmental Setting

3.1 Overview

This section defines the study area and summarises the physical, ecological, social and cultural values of the region, which may represent constraints to the deployment of ARs and or FADs.

3.2 Study Area

Shown in **Figure 1-2**, the study area encompasses the estuarine, coastal and marine waters of the Darwin region. Covering approximately 18,048 square kilometres, and straddling the Beagle and Van Dieman gulfs, it stretches from Cape Ford (south-west of Darwin), to Point Stuart in the East and north to the coastlines of Melville and Bathurst islands.

3.3 Physical Environment

3.3.1 Climate

The climate regime is monsoon tropical, with two distinct seasons: the Dry and the Wet. The Dry lasts between April and September, whereas the Wet lasts between October and March. A bulk of Darwin's annual; rainfall of 1,726 mm falls during the Wet.

Annual sea surface temperatures range between 23 - 34°C.

3.3.2 Metocean Conditions

Tidal forces have the greatest control over the water level and currents in the study area. Tidal currents flow in an east-west direction. The main direction changes northwest - southeast near the entrance to Darwin Harbour.

Winds are also influential, forcing water movements and wave activity, generally consisting of short-period waves generated within Beagle Gulf. During the dry season, easterly winds are the predominant force; generating waves, which are generally small, with a daily wave height typically below 0.5 m. During the wet season, waves arrive from a westerly direction. Typically, these waves are 0.8 to 0.9 m high - roughly twice that experienced during the dry season.

Larger waves are associated with tropical storms and cyclones that produce rough seas with very large, short period wind waves (up to approximately 3.5 m wave height and approximately 6 to 8 s periods). The maximum-recorded wave height (Hs) in the study area associated with cyclones is 6.32 m.

3.3.3 Geology and Geomorphology

The underlying lithology is dominated by Permian siltstones and sandstones of the Bonaparte Gulf Basin in the west, and in the east, by Proterozoic siltstones and sandstones of the Pine Creek Geosyncline. Areas in the north-east are overlain by Cretaceous sandstones and siltstones of the Bathurst Island Formation. Latitudinal position has strongly influenced the local geology, which is dominated by deeply weathered lateritic regolith formed on labile (unstable) Cretaceous marine sediments.

Modern surficial marine sediments have textures that suggest mixed composition and size ranges indicative of reworking (Geoscience Australia 2016). These sediments are dominated by coarse sands and gravels in the east grading to biogenic in the northeast. In the west of the study area, benthic sediments are dominated by biogenic sands and muds (offshore), with terrigenous sands and muds inshore, principally close to the mouths.

Major geomorphological features are the ria shorelines (drowned coastal features) in Darwin and Bynoe Harbours, the Vernon Islands reef complex on the eastern boundary and sandy beaches backed by chenier ridge systems and low (<10 m) cliffed headlands on the western coast. Numerous rocky reef and shoals are scattered throughout the area. The seabed is characterised by a complex network of geomorphic features including extensive areas of low-relief soft sediments, sand-waves and dunes. Patches of high-relief rocky outcrops provide support for abundant octocorals and sponges.

3.4 Biodiversity Values

3.4.1 Marine and Benthic Communities

Soft sediment habitats consist of predominantly bioturbated habitats (Siwabessy et al 2015 GA). Infaunal assemblages generally contain burrowing organisms such as polychaete worms, amphipod crustaceans, bivalve and gastropod molluscs and other worm-like phyla such as nemerteans and nematodes (which are often abundant).

Benthic epifauna generally consists of filter feeders from the subclass Octocorallia (sea whips, hydroids) and Tunicates (Stalked solitary ascidians), and Phylum Porifera (sponges).

Sponges and soft corals dominate reef benthos in the turbid waters of the study area and hard corals of the genus *Turbinaria*. In clearer waters at the Vernon Islands, hard corals such as *Acropora* and *Montipora* are predominate. Extensive coralline algal terraces are developed at Grose Island and Vernon Island reefs complex. The major coral areas in the Darwin are sparsely distributed across the intertidal reef flats, to a depth of 10 metres within Darwin Harbour, and to greater depths in subtidal regions outside the Harbour (Hooper 1987). A total of 125 scleractinian and non-scleractinian calcareous coral species belonging to 17 families and 47 genera are present, with the family Faviidae represented by the highest number of genera and species, while relatively high numbers of species from the families Acroporidae and Poritidae also occurred (Wolstenholme et al. 1997).

Several genera of seagrasses are present in the Darwin area, including *Cymodocea* sp. and *Syringodium* sp. However, seagrass communities are dominated by *Halodule* spp. (e.g. *Halodule uninervis*) and *Halophila* spp. (e.g. *Halophila decipiens*) and are generally not found below -10 m LAT.

Mangroves occur in many of the intertidal parts of the study area, particularly in bays or the mouths of rivers and creeks. The mangroves in Darwin harbour are amongst the most diverse in Australia with 36 of the approximately 50 species worldwide found there (Lee 2003).

3.4.2 Fish

Fish within the study area are associated with soft sediment, reef and pelagic habitats.

There is very little published information on offshore coral or rocky reef fish assemblages, their composition and structure is absent for the northern tropical Australian mainland. In a nearshore study, Gamelyuk (2009) found that although there are distinct assemblages at reef and soft habitats, ubiquitous species (fish with wide distribution and low selectivity in habitat preferences) comprise a significant part of fish assemblages, probably due to the high proportion of transitional species from the trevally (Carangidae) family.

A good understanding of the diversity of species available to fishers can be learned from the recreation catch. Barramundi (*Lates calcarifer*) was reported as the most commonly caught fish (21%), closely followed by Golden Snapper (*Lutjanus johnii*), smaller bait fish, catfish, Saddletail Snapper (*Lutjanus malabaricus*), Crimson Snapper (*Lutjanus erythropterus*) and mullet (Mugilidae) respectively (West et al. 2012). Many other lutjanids are also found on reefs as well as emperors (Lethrinidae), cods (Epinephelidae), Coral Trout (*Plectropomus leopardus*), tuskfish (*Choerodon* spp.) and Black Jewfish (*Protonibea diacanthus*).

Common fish associated with soft sediment habitat include Blue Threadfin (*Eleutheronema tetradactylum*), King Threadfin (*Polydactylus macrochir*), Northern Whiting (*Sillago sihama*) and Pikey Bream (*Acanthopagrus pacificus*).

There are many large predatory fish that live in the pelagic environment including mackerel (*Scomberomorus* spp.), trevally (Carangidae), Queenfish (*Scomberoides commersonnianus*) and Sailfish (*Istiophorus platypterus*). These species may be reef associated at times, depending on the location of suitable prey.

3.4.3 Threatened Species

A number of threatened species occur in the Study Area. These include six species of marine turtle (Green Turtle (*Chelonia mydas*), Hawksbill Turtle (*Eretmochelys imbricata*), Leatherback Turtle (*Dermochelys coriacea*), Olive Ridley (*Lepidochelys olivacea*), Flatback Turtle (*Natator depressus*) and Loggerhead Turtle (*Caretta caretta*)). Juvenile Green and Hawksbill Turtle feeding habitats are located around Grose Islands and feeding habitat for Olive Ridley and Loggerhead Turtle occur on shellfish beds in Fog Bay. Flatback turtle nesting habitat occurs on sandy beaches north of Native Point (Fog Bay) and on the Grose Islands.

Dugong (*Dugong dugon*) feed on seagrass beds in Bynoe Harbour, Shoal Bay and the Peron Islands. Various migratory marine mammals, including dolphins and whales are frequently sighted along with a diverse range of marine bird species.

The potential risks associated with potential interactions between threatened species and ARs / FADs are included in **Appendix C**.

3.5 Social Characteristics

3.5.1 Aboriginal Cultural Heritage

Aboriginal cultural heritage comprises a wide variety of sites. These may include:

- Dreaming sites
- Archaeological sites
- Burial sites
- Sites important for historical reasons
- Sites with culturally significant resources.

Locations of known cultural heritage are highly sensitive and are present herein with buffers to protect their values.

3.5.2 Historical Wrecks

A unique feature of the study area are a number of WWII shipwrecks sunk during the first Japanese air raid in Australia on 19 February 1942. These wrecks include:

- British Motorist
- Kelat
- Mauna Loa
- USS Meigs
- Neptuna
- USS Peary
- Zealandia.

Ironically, most of these wrecks were partially salvaged by a Japanese company in the late 1950s to early 1960s.

In addition to these shipwrecks, up to 35 planes are thought to have been lost in the region during WWII. Law protects all remaining components of these wrecks.

3.5.3 Existing Artificial Reefs

The Northern Territory has a number of existing artificial reefs deployed in the greater Darwin district, developed through acquisition and deployment of 'materials of opportunity' (such as old ship hulls, surplus road culverts, concrete pipes, decommissioned machines and plant equipment):

- Fenton Patches artificial reef complex comprised of 8 steel vessel, 6 wood vessel, 1 barge and a large concrete pipe, concrete bus shelters and truck tyres
- Lee Point comprised of three sites Rick Mills with plant equipment, sea container, culverts, Truck Tipper with 20 mining truck side tippers and two steel pontoons, Bottle Washer with decommissioned coke bottle washing machine, plant equipment and culverts
- Darwin Harbour has five steel vessels, sunk in various locations for the purpose of recreational fishing and diving. It is possible that some of the metal structures may have since disintegrated.

Stena Clyde is an unused oil rig stationed about 70 km off the coast of Darwin. It is located over sandy substratum and in a water depth of 31.5 m LAT (**12° 7'0.23"S 130°26'0.49"E)**. Anecdotal evidence indicates it is holding a variety of pelagic and demersal species and is now a very popular destination for anglers using medium to large-sized trailer boats.

3.5.4 Recreational Fishing

Coleman (2004) indicated that fishing 'households' in Darwin and coastal regions amount to 37% and 44% of the population. West et al. (2012) reports that between April 2009 and March 2010, 30,538 non-indigenous NT residents accounted for over 150,000 fisher days of effort, or approximately 5 days per fisher. Of these, it was noted that a significant proportion of these statistics were skewed by a small percentage of fishers accounting for approximately 60% of reported effort.

Scale fish, sharks and ray species comprised 90% of fishers' catch compositions. Angling surveys (Cardno 2013b) found that the most targeted species by fishers was Barramundi, while 17% of survey respondents offered reef fish, 16% Golden Snapper, 12% no targeted species and 7% Black Jewfish as the target species. In Cardno's (2013b) angling survey the targeting behaviour of anglers was, in part, dependent on seasonality (i.e. wet vs. dry season). Pelagic species and reef fish (e.g. Golden Snapper and Black Jewfish) were opportunistic targeted and mostly during the dry season (Cardno 2014).

There are 23 boat ramps in the Darwin region (NT Govt 2017a). Tidal constraints, size and characteristics of vessel, permit restrictions and accessibility are some constraints identified to influence popularity of boat ramps in the Northern Territory. Cardno (2013a) determined that artificial ramp utilisation outshone ramp use in Darwin Harbour. Utilisation was heightened on the weekends and Inner Darwin Harbour determined to be more favourable than ramps in Outer Darwin Harbour due to tidal conditions providing calm conditions.

Cardno (2013a) found that fishers using vessels generally frequented areas in inner Darwin Harbour, Outer Darwin Harbour and portions of nearshore Adelaide River and Bynoe Harbour. Inner Darwin Harbour was comparatively more frequented given access to inner river and estuary systems.

It is thought that offshore areas provide limited fishing opportunities and catch per unit effort given unsupportive infrastructure and unsuitable substrata conditions for targeted fish species. Notwithstanding this, existing artificial reefs in the Darwin region (see above) are popular amongst fishers, and there are 15 of these in the Darwin region (NT Govt 2017b).

3.5.5 Commercial Fishing

The Northern Territory (NT) commercial fishing industry has more than 200 commercial fishing licences, 190 registered fishing vessels and harvests on average 5,500 t of fish and other aquatic animals each year. There is commercial activity in 15 different wild harvest fisheries and some of these operate in the study area and would potentially conflict with AR or FAD placement or compete for target species (see **Appendix D** for a summary of the fisheries and their areas of operation).

There are also some Commonwealth fisheries that have access to the study area. These include the Northern Prawn Fishery and the Skipjack Tuna Fishery (not currently active).

3.6 Built Environment

Infrastructure within the study area includes:

- Shipping channels
- Dredged material management areas
- Submarine pipelines and cables
- Maritime facilities such as ports, jetties and landings.

4 Artificial Reefs - Results

4.1 Overview

This section presents a summary of results related to AR fit for purpose design and arrangement considerations, review and refinement of AR concept designs, identification of permitting (approval) requirements and Round 2 of the MCA to identify potential AR deployment areas.

4.2 Information Collation and Review Summary

4.2.1 Information Sources

Much of the information relating to the study area and ARs was sourced from Cardno's extensive library of books, technical reports, the internet and peer reviewed journal articles. **Appendix A** includes a review of this literature and key references.

4.2.2 Target Species

The scope for functional design of ARs considered the means for anglers to diversify their catches so there is may be less focus on vulnerable reef fish species. A list of reef species considered when designing the ARs provided to Cardno, together with habitat and structural preferences, is included in **Table 4-1.**

While many of these species can occur in estuaries or in coastal areas over mud, sand (with or without seagrass) or rubble, they can also occur, and in many instances prefer (particularly the adults), coastal reef habitat or wrecks. Kim et al. (2008) classified reef-associated species generally into three types:

- **Type I** - prefer very close contact with reef structures through physical contact (thigmotaxic) or visual excitation. These species are generally more sedentary around reefs. Examples of Type I species include Estuary Cod and Black Jewfish.
- **Type II** - prefer to remain adjacent, but in close proximity to, reef structures and respond to visual or stream excitation. These species include demersal or semi-demersal species such as most of the snappers (lutjanids)
- **Type III** - species are relatively indifferent to the reef structures but perceive stream or sound excitation caused by the structures and visit occasionally. These species include pelagic fish such as mackerel and tuna.

Table 4-1 includes the category of reef-association for each of the target species - a mixture of Type I (6 species) or Type II (4 species) categories. Notwithstanding this, there are variations within micro-habitats (niches) associated with reefs that are occupied by the various species. For example, although all Type I species live on the reef itself, they may occupy different structures within the reef (e.g. Coral Trout prefer smaller overhangs whereas Black Jewfish can school in the larger void spaces of reefs. This variation in structural preferences has led to the hypothesis that prefabricated reefs can be designed specifically to attract a particular species or suite of species and certain sizes of fishes (Sheehy 1982; Bell et al. 1989).

4.2.3 Specialist Consultation

Consultation with prominent manufacturers of ARs, managers of AR programs in New South Wales and scientists that had evaluated deployments was undertaken. Consultation involved general discussion around lessons learned from previous deployments and considerations for developing optimal ARs for the study area.

Organisations consulted include:

- Subcon Pty Ltd (AR manufacturer)
- Haejoo Pty Ltd (AR manufacturer)
- New South Wales Department of Primary Industries – Fisheries (AR program managers and researchers)
- Korea Fisheries Resources Agency (FIRA) - FIRA is the leading Korean agency responsible for the assessment of the efficacy of all new artificial reef designs and their approval for deployment in Korean coastal waters. FIRA has demonstrated a willingness to provide advice on artificial reef designs to third parties and agreed to examine the location characteristics and target species of the Northern Territory proposal and to provide general advice on suitable module designs and cluster layout arrays.

4.2.4 Fit-for-Purpose Design

Although the deployment of opportunistic structures remains the more common option in AR construction, there is a growing trend towards dedicated reef designs (Pickering and Whitmarsh 1997). Such 'design specific' structures are considered a more suitable alternative to using opportunistic materials as they have been demonstrated to be more effective in achieving specific fisheries management objectives (Sherman et al. 2002). While the use of opportunistic materials may be cheaper initially (mainly due to the lack of design and manufacture cost), a purpose built AR design is preferable over opportunistic materials for the following reasons:

- The proposed manufactured design facilitates long-term planning and budgeting as the project is not dependent on the availability of suitable secondary materials
- Purpose built designs can be engineered to suit the specific aims and objectives of the AR program targeting specific species, user groups and fishing gears
- Purpose built designs can also be manufactured to suit a chosen location in terms of depth, oceanography and substratum type
- A choice of suitable material can maximise the duration, durability and compatibility of the structure in the marine environment. Problems potentially associated with material toxicity or cleaning can be avoided
- The overall effectiveness and lifespan of the manufactured design is considered to yield comparatively greater cost-benefits than the use of secondary materials.

O'Leary et al. (2001) emphasized that "composition, arrangement and location" are the important factors to affect the success of ARs. When one of these factors is neglected, the probability of failure will increase.

Table 4-1 Benthic Target Species Habitat Preferences

Scientific Name	Common Name	Habitat Preferences	Structural Preferences	Classification
Lutjanus johnii 	Golden Snapper	Marine and brackish waters, oceanodromous. Juveniles found in brackish mangrove estuaries, adults frequent reef areas (Riede 2004).	Well light penetrated environments on outer shelf edge. Some can be found within inshore mangrove and estuarine waters, likely juveniles. Also found in inshore and middle reefs (Lythogoe 1993).	Type II
Lethrinus laticaudis 	Grass Emperor	Marine and brackish waters, reef-associated (Allen 2012). Juveniles associated with seagrass bed communities and mangroves. Adults schooling over reefs (Lieske 1994).	Shallow reef environments (Travers 2006).	Type II
Plectropomus leopardus 	Coral Trout	Marine, reef associated (Lieske 1994). Juvenile preferencing shallow water reef habitats, particularly with coral rubble (Brown 1991). Adults inhabit lagoon reefs and mid shelf reefs, with characteristic inactivity at night seeking refuge under ledges (Kailola 1993).	Brown (1991) reports juvenile preference for shallow reefs with coral rubble. Adults shelter under large living tubular corals, may facilitate hunting (Pratchett 2017).	Type I
Protonibea diacanthus 	Black Jewfish	Marine, brackish (Lal Mohan 1984). Juvenile prefer coastal estuaries and embayments (NT Govt 2016a). Adults prefer muddy bottomed coastal water, off the sea bed (Lal Mohan 1984). Also found in deep water harbours and around artificial reefs in the NT (Phelan 2002).	Known for preference for artificial reef structures and harbours (Phelan 2002).	Type I
Lutjanus sebae 	Red Emperor	Marine, brackish and reef-associated (Kailola 1993). Juveniles found in turbid waters and mangrove areas or among coastal and deeper water offshore reef (McB Williams 1992). Adults prefer coral and rocky reef environments, over adjacent sand and gravel flats and patches. Trawled along deeper, flat bottoms (Allen 1985).	Coral and rocky reef environments and offshore reefs (Allen 1985).	Type II
Lutjanus argentimaculatus 	Mangrove Jack	Marine, freshwater, brackish and reef associated species (Riede 2004). Juveniles frequent mangrove estuaries and the lower reaches of freshwater streams and tidal rivers (Sommer 1996). Adults school around coral reefs with eventual migration offshore (Lieske 1994).	Coral reefs in adulthood (Lieske 1994).	Type I
Choerodon cyanodus 	Blue Tuskfish	Marine associated, subtropical and reef associated (Randall 1990). Juvenile habitat preferences not determinable. Adults prefer sand and rubble flats, as well as, reef flats and outer reef slopes (Lieske 1994). Feeding habits see presence in very shallow water for mollusc feeding (Breder 1966).	Rocky shorelines (D.V. Fairclough 2008).	Type I

Scientific Name	Common Name	Habitat Preferences	Structural Preferences	Classification
Pomadasys kaakan 	Barred Javelinfish	Marine, brackish and reef associated (Smith 1986). Juvenile habitat preference is for shallow mangrove lined areas including mangrove creeks (Blaber et al. 1989). Adults inhabit turbid inshore waters with sandy to muddy bottoms with a depth up to 75 m and may tolerate low salinity conditions (van der Elst 1991).	Often associated with inshore wrecks (van der Elst 1991).	Type II
Epinephelus coioides 	Goldspotted Rockcod	Marine, brackish and reef associated (Smith 1986). Juveniles inhabit shallow waters of estuaries and mangroves over sand, mud and gravel (Kailola 1993). Adults inhabit turbid coastal reefs (Lieske 1994) and found over mud and rubble (Kailola 1993).	Coral reefs (Lieske 1994) and over mud and rubble (Kailola 1993).	Type I
Epinephelus malabaricus 	Blackspotted Rockcod	Marine, brackish and reef associated. Juveniles found in shallow water and in estuaries. Adults have diverse preferences, including coral, rocky reefs, tidal pools, estuaries, mangrove swamps and sandy or mud substrates from shore to depth of up to 150 m (Heemstra 1993).	Coral reefs, rocky reefs and sandy and mud substrates (Heemstra 1993).	Type I

4.2.4.2 Composition

The results of the information collation and review exercise suggested that:

- ARs can support fish assemblages that are similar to those found on natural reefs if they are constructed to match the physical characteristics of natural reefs, however, they can be made so that abundances and diversity of fishes (including recreationally important species) can exceed those on natural reefs if a variety of physical features (e.g. high relief and low relief areas) are incorporated into the design
- Modules with dimensions > 3 m are more effective than smaller modules. The height of modules should generally be around 1/10th water depth although a larger central module in an array can be taller
- Greater complexity in physical structures (at several spatial scales) increases the diversity of niches and hence the potential for diversity of fish
- The size of the effect (to abundance and diversity of fishes) generated by walls (vertical relief) is proportional to the size of the wall, with species richness and abundance generally increasing with wall height and length
- Complex ARs with vertical relief are preferable over low relief ARs to achieve rapid recruitment of settling or juvenile coral reef fish
- Importantly, complexity must include adequate shelter for species, or at worst, there must be adequate shelter nearby for ARs to enhance fisheries. The shelter can be in the form of voids. The available evidence indicates demersal reef associated species can travel as far as 1 km to forage away from their shelter. Given attraction from other reefs should be minimised to avoid draw-down from productive natural reefs it is preferable that the shelter is on AR modules themselves rather than nearby areas
- Whilst maximising void volume to total volume ratio is important to allow transparency to currents and stop the accumulation of silt, the shape of a void and its position on an AR is important for shelter. Tabular voids provide concealment or shade for large reef fishes, similar to the undercut edges of bommies that create overhangs. This is particularly important to roving fishes including Haemulidae and Lutjanidae, Serranidae and Mullidae which are popular to recreational fishers. Smaller fishes (Pomacentridae, Gobiidae, Blenniidae and Apogonidae) also use such shelters but prefer that the shelters do not visually obstruct their view
- Although there are some signs that deeper ARs have higher densities of species than on shallow ARs, it is likely that densities are driven mostly by individual species' depth preferences which can also include ontogenetic preferences.

4.2.4.3 Arrangement

Arrangement is important for the following reasons:

- Using more than one module maximises complexity of the AR and increases the potential for diversity of fish in the recreational catch
- Modules of various types should be arranged in clusters to maximise complexity at the scale of cluster. Further, the closer modules are placed together, the more they would function as a single unit. An optimal footprint for a cluster is ~ 400 m^2
- Optimal module spacing within a cluster should be 3-4 x base diameter of modules to encourage fishing around the cluster, not on top of it
- Clusters have scalability. However, the proximity between AR clusters is a key consideration for artificial reef research, and the low vagility of many reef-associated fish suggests clusters as close as 60 m will provide adequate foraging space for associated fish, as well as a necessary level of connectivity among clusters for foraging etc. and maximising the total footprint of the AR habitat. This distance also provides drift channels between the reefs for fishing.

- The optimal separation between reef clusters and natural reef can vary broadly depending on the relative sizes of nearby natural reef and the available evidence indicates some demersal reef associated species can travel as far as 1 km to forage away from their shelter. The optimal separation between reefs and natural reefs falls in the range of 500 m to 1000 m.

4.3 Recommended Design Specifications

With reference to the findings of the AR review, the different options for various design aspects of AR modules, including their arrangement, were assessed against the ‘fit for purpose’ criteria. **Table 4-2** presents the results of these assessments and justification for the preferred aspects of design. The full results of the decision analysis are given in **Appendix H**.

4.3.1 Modules

Cardno examined many of the commercially available AR modules, and although many include one or more of the desirable design features, few, if any, include all. Additionally, studies from Korea and Japan suggest that various (Type I) species prefer a range of shapes. Given the list of target species for this project is large, it is not necessarily desirable to use a single type of module. Rather, it is preferable to have a diversity of modules (of shapes and sizes) in configurations of ARs. This approach is consistent with recommendations by the Korea Fisheries Resources Agency (FIRA), which include the following cubes, pyramids and domes for inclusion in configurations:

- Concrete double pyramid - approximately 3.8 m x 3.3 m x 2.4 m, volume approximately 11.5 m^3, and weighing approximately 9 t with an internal dome frame within the structure to provide shelter for juvenile fish. An example of this form of module is FIRA module No. 51 (**Figure 4-1a**)
- Concrete cube - approximately 4 m x 4 m x 4 m, volume approximately 64 m^3 weighing approximately 17 t with internal cross members to promote turbulence and with a profile attractive to a range of snappers and related species (**Figure 4-1b**)
- Steel dome - approximately 11 m in diameter and 11 m high, 800 m^3 weighing approximately 30 t with an open and unobstructed internal void to provide for baitfish and pelagic and mesopelagic fish in the upper zones and to provide a measure of protection from line fishing within the void for shade loving species such as Black Jewfish. An example of this form of module is FIRA module No. 60 (**Figure 4-1c**).

Although all of these modules have features that would suit the requirements of juveniles or adults of the target species and the environmental conditions, Cardno considers further improvements are possible. Hence, these structure are a base case to which modifications, if made, are likely to increase diversity and abundance of fish. **Table 4-3** indicates where recommended modification of the external and internal features of the FIRA modules is required. This would include:

- Modification of internal structure of all modules with multiple voids that vary in size. Some of these need to be covered/shaded to accommodate the potential requirements of the different target species
- Increase in dimensions of the concrete pyramid to a more comparable weight and height to the concrete cube
- Vertical walls added to the pyramid. One or more narrow vertical walls included externally and/or above the pyramid structure
- The bases of all designs must have sufficient footprint to prevent sinking into the substratum or have scour protection skirts around the base.

Table 4-2 Preferred AR design aspects as determined using the decision support tool (see **Appendix H**).

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	1	**2**	**3**	**4**	**5**	
Material						
Concrete	N/A	N/A	✓	✓	✓	Structures made of concrete or steel have longevity >30 years and can be fabricated in modular form for scale-ability.
Steel	N/A	N/A	✓	N/A	✓	
Size						
Medium (10 – 100 m3)	✓	✓	✓	✓	✓	Medium sized reefs are a suitable compromise between maximising production and maximising total AR footprint for minimising congestion among fishers. A larger footprint provides a greater potential area for Type II species (the majority of target species)
Large (> 100 m3)	✓	✓	✓	✓	✓	Given the cost, the number of large reefs that could be built would be small and this could create potential risk to fishers in terms of safety and social conflict associated with congestion.
Depth						
11 m – 50 m	✓	N/A	N/A		N/A	Represents a suitable compromise between the potential for barotrauma, recruitment and maximising association of adult fish with ARs
Profile						
Width ≈ height	✓	✓	✓	✓	✓	Represents a suitable compromise for maximising opportunity for complexity for Type I species, including more vertical relief or walls, and reducing the risk of instability associated with tall profile modules
Voids						
Variable void spaces with diverse shapes	✓	✓	✓	N/A	N/A	Best potential for maximising diversity and abundance of fish given the variety of niches used by Type I species whilst also maximising void volume to total volume ratio
Number of modules						
Clusters of different modules	✓	✓	✓	✓	✓	Larger AR footprint potentially increases abundance of species, particularly Type II species, and reduces potential risks associated with congestion (i.e. safety and social conflict). In addition, different types of modules with varying structural complexity (in terms of void space and vertical relief would increase the types of niches available to Type I species and hence potentially increase diversity
Arrangement (for clusters)						
Spacing between modules is 3-4 x base diameter	✓	✓	✓		✓	Closely connected ARs are more likely to have a greater abundance of reef resident (Type 1) species

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	1	2	3	4	5	
Spacing > 60 m among clusters	✓	✓	✓	✓	✓	Avoids overlapping of feeding areas around clusters and potentially reduces competition for food. Also provides adequate fishing zones mong clusters for reducing fishing congestion

Criteria:

1. A focus on maximising the potential for aggregation of a diversity of reef (including juveniles) and/or pelagic species that are preferred by recreational fishers
2. Minimisation of attraction of fish from other reefs (for ARs), particularly vulnerable species, so that new aggregations are a result of new production
3. Scale and scale-ability of designs to provide for long-term network development
4. Siting (including configuration) that maximises the potential for recreational fisheries enhancement (including accessibility) and minimises the potential for compromising safety and social, economic or ecological risks
5. Construction, maintenance and deployment/ retrieval costs that are within the given budget and, for ARs, a design life of 30 yrs.

4.3.2 Arrangement

In Korea artificial reef arrays are described by the three categories of:

- Unit block (module)
- Reef set (cluster or array of modules)
- Reef group (complete array of reef sets).

The base reef group is to have:

- Six (6) clusters of four (4) modules
- Each cluster would consist of two (2) cubes and two (2) pyramids
- The separation distance between modules (in clusters) should be about 10 m to achieve the optimal footprint for a cluster of ~ 400 m^2
- Clusters would be separated by 60 m. Where budget allows, the reef group would include one (1) single steel dome as a centrepiece among the six clusters, and separated from them by 60 m (**Figure 4-3**)
- Reef groups have scalability, and to be independent, reef groups should be separated by at least ~ 1,500 m.

Table 4-3 Specifications for modules

Module	Material	Dimensions / weight	Stability	Large void space to volume ratio	Covered spaces for juvenile habitat	Facilitates Upwelling	Scour protection / skirt	Variable sizes of void spaces, including overhangs in lower sections	Vertical walls
Double-pyramid	Concrete	3.8 m x 3.3 m x 2.4 m; ~11.5 m^3; 9 t	✓	✓	✓	✓	Adequacy requires confirmation	Need to be added	Need to be added
Cube	Concrete	4 m x 4 m x 4 m; 64 m^3; 17 t	✓	✓	✓	✓	✓	Need to be added	✓
Dome	Steel	14 m x 12 m x 9 m; 800 m^3; 31 t	✓	✓	✓	N/A	Adequacy requires confirmation	✓	✓

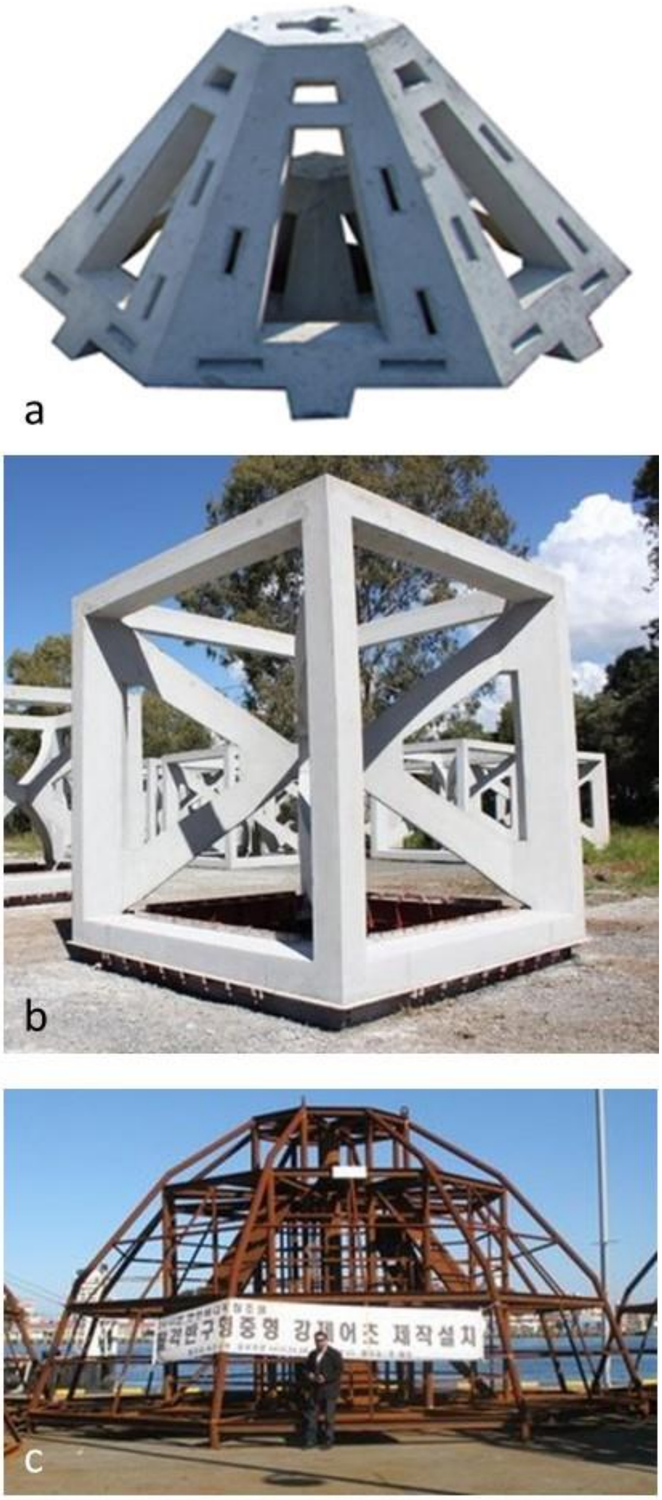

Figure 4-1 Recommended artificial reef module base design. (a) Concrete pyramid (e.g. FIRA module No. 51), (b) Concrete cube, and (c) Concrete pyramid (e.g. large steel dome (e.g. FIRA model no. 60).

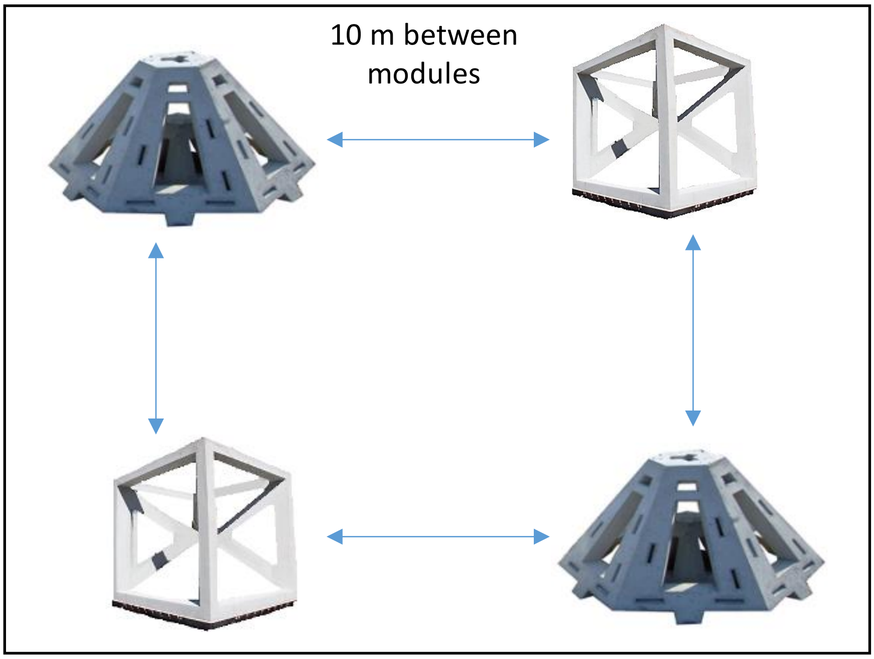

Figure 4-2 Base cluster of pyramids and cubes

4.3.3 Stability

The potential for the AR modules to slide or over-turn was investigated for three deployment depths (15, 25 and 40 m) within the least constrained parts of the study area. Stability was assessed with the aid of the following data and calculations:

- Available numerical modelling output for the Darwin area, specifically NNW of Darwin Harbour, provides the following information:
  - Peak H_s=6.1 m, T_p=11.1 s – leads to H_{max}=12 m
  - Maximum current speed 0.5m/s – depth averaged
  - We have assumed that peak wave conditions can occur at the same time as peak current speeds and be collinear.
- Estimation of the projected material cross-section projected on a vertical plane for each module. This required an estimate of the porosity of each module, as estimated visually
- Estimation of the 'submerged' mass of each structure, based on mass data provided and mass densities of concrete, steel and sea water (2.2, 8.1, 1.03 kg / m^3)
- Calculating the vertical profile of water particle speeds under a wave crest
- Estimation of the average water particle speed over each module's height and a moment arm above the seabed for three water depths – 15, 25 and 40 m – ignoring datum issues. Similar calculations were done for current speed
- Estimation of the drag force and applied moment on each module at all three depths
- Assuming a friction coefficient of 0.4 between the bases of the modules and the seabed, estimation of the frictional resistance for each module – coefficient x buoyant weight
- Estimation of the restoring moment available to resist overturning
- The bases of all designs must have sufficient footprint to prevent sinking into the substratum or have adequate scour protection skirts and slide protectors around the base.

The results of the stability analysis are included in **Table 4-4** and summarised as follows:

At 15 m, the concrete cube and large steel dome could potentially topple over when there were very large waves (i.e. during a severe cyclone) and the large steel dome could over-turn at 25 m. Further investigations are needed to determine a safe deployment depth for the steel dome between 25 – 40 m that also considers adequate clearance from shipping. None of the module types would be at risk of over-turning at 40 m.

All of the modules have potential to slide at 15 m, 25 m and 40 m deployment depths, apart from the concrete cube at 40 m.

Stabilising structures on the modules could prevent sliding and it is noted that all of the FIRA modules include pins and/or spikes that would penetrate the seafloor sediments upon installation. These structures at the bases of modules would improve stability with respect to sliding but further investigations to confirm this would be needed once engineered drawings of modules are developed. These investigations will also require detailed data of the composition of sediment on the seabed at the specific deployment sites.

Table 4-4 Potential for AR modules to slide or over-turn at three deployment depths

Module	Depth					
	15 m		25 m		40 m	
	Sliding	Over-turning	Sliding	Over-turning	Sliding	Over-turning
Concrete pyramid	Y	N	Y	N	Y	N
Concrete cube	Y	Y	Y	N	N	N
Large steel dome	Y	Y	Y	Y	Y	N

Y = likely, N = unlikely

4.4 Costs

There are three main components to the cost of an AR program:

1. Planning approvals Move approvals to a new section and include cross-reference – otherwise its out of context)
2. Module construction and deployment
3. Monitoring.

4.4.1 AR Planning Approvals

For an AR program there are statutory approvals under State and Commonwealth legislation that need to be considered (see **Section 6**). These requirements include an 'environmental assessment' of some form to justify the project on economic, social and environmental grounds. The exact nature of the planning approvals and planning considerations will be significantly influenced by the exact sites chosen for artificial reef deployment. It is difficult to be specific without a precise location and proposal, but Cardno understand that costs may vary between $50,000 and $300,000, depending upon the complexity of the process, the availability of existing baseline data and the number of locations considered.

4.4.2 AR Module Construction and Deployment

Construction and deployment costs include the cost of material, manufacturing and deployment vessel costs and these will vary according to the following:

- Whether concrete or steel is used and the amounts in each module (i.e. variance would exist among sizes, complexity or void to volume ratio
- The manufacturing process (i.e. according to different manufacturers)
- Whether modules are constructed locally (in Darwin) or further afield
- The size of the deployment vessel (or method) and efficiency (time involved).

All of these costs are likely to vary among AR builders, and given the cost estimates (below) are based on consultation with only two companies, they should be considered to be 'ball park' only. Further, for the purposes of this report, costs for each of the deployment options are directly related to the number of modules and have not considered efficiencies (or economies of scale) that may be realised with the Level 2 or Level 3 options. Costs also assume that modules would be constructed of concrete except for the large steel dome module recommended in some of the configurations for Level 2 or Level 3 (**Table 4-5**).

Table 4-5 Estimated cost breakdown of AR programs

Module	Dimensions	Material	Estimated Cost / module (construction and deployment)
Medium –sized concrete modules	Up to 20 t	Concrete	$10,000 - $50,000
Large –sized modules	Up to 31 t	Steel	$500,000 - $1Mil

4.4.3 AR Monitoring

A monitoring program is integral to verifying assumptions made about the positive and negative impacts of ARs. Cardno has developed a monitoring program (based on the agreed performance criteria) for determining its success (see **Section 5.7**). The monitoring program is scalable to the deployment option chosen (Level1, 2 or 3) and efficiencies of 50% have been included in the Level 2 or 3 cost estimates.

Base case cost estimates for monitoring are difficult to calculate given some aspects of the program could be incorporated into existing NT surveys (i.e. recreational fisher ramp surveys). It is likely however, that the program would have a minimum cost of $60,000/yr. Further, unlike many of the one-off costs components above, the cost of monitoring would be annual and for the purposes of costing the deployment options, we have estimated the base case cost of monitoring to be for five years and at ~$300,000. This is because it may be at least five years before the benefits of recruitment of juvenile fish onto the ARs are realised in recreational catch.

4.5 Deployment Options

4.5.1 Level 1 ($2 million)

The recommendation for the Level 1 deployment is one (1) location with six (6) clusters of four (4) modules (**Table 4-6**). Each cluster of six modules would consist of 2 x concrete cubes and 2 x concrete pyramids with modules spaced ~ 10 m apart and clusters spaced ~60 m apart (see **Figure 4-3**).

The large dome module was not considered in Level 1. Given the limited budget, and the high cost of constructing and deploying large dome modules, very few cubes or pyramids could also be constructed and deployed leading to a sub-optimal AR footprint and safety risks potentially associated with congestion of fishers.

Table 4-6 Estimated cost breakdown of Level 1 AR deployment and monitoring program

Level 1 ($2M)						
No. locations	**No. AR clusters**	**Type of modules**	**No. of modules per cluster**	**Total No. modules**	**Cost**	
1	6	Concrete cube 4 m x 4 m x 4 m; 64 m^3; 17 t	2	24	Planning Approvals	$500,000
		Concrete pyramid 3 m x 3.3 m x 2.4 m; 11.5 m^3; 9 t	2		Module Construction and Deployment	$1,200,000
					5 yrs. of Monitoring	$300,000
					Total	$2,000,000

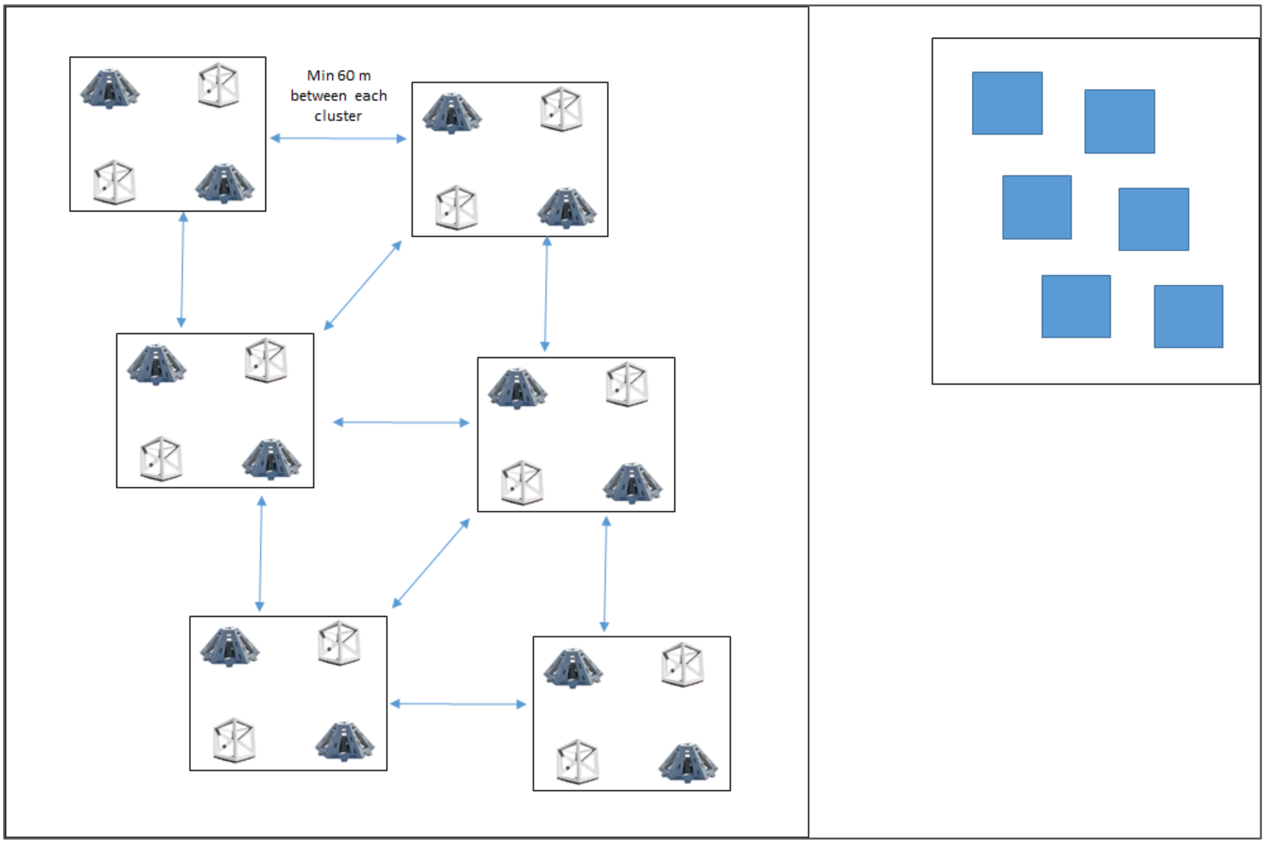

Figure 4-3 Level 1 reef group at one location. Reef group consist of clusters of cubes and pyramids

4.5.2 Level 2 ($2-5 million)

Potential options include:

- Option 1 - At three locations there would be six (6) clusters of four (4) modules (**Table 4-7**). Each cluster of four modules would consist of 2 x concrete cubes and 2 x concrete pyramids with modules spaced ~ 5 m apart and clusters spaced ~60 m apart (see **Figure 4-4**).
- Option 2 – At two locations there would be a large dome placed in the centre of (6) clusters of four (4) modules (**Table 4-7**). Each cluster would consist of the standard configuration of 2 x concrete cubes and 2 x concrete pyramids with modules spaced ~ 5 m apart and clusters spaced ~60 m apart (see **Figure 4-5**). This option would only be suitable if there were adequate water depth (for the large dome module).

Table 4-7 Estimated cost breakdown of Level 2 AR deployment and monitoring program

Level 2 ($2-5M)							
Option	No. locations	No. AR clusters	Type of modules	No. of modules per cluster	Total No. modules	Cost	
1	3	6 per location	Concrete cube 4 m x 4 m x 4 m; 64 m^3; 17 t	2	72	Planning Approvals	$900,000
						Module Construction and Deployment	$3,600,000
			Concrete pyramid 3.8 m x 3.3 m x 2.4 m; 11.5 m^3; 9 t	2		5 yrs. of Monitoring	$450,000
						Total	$4,950,000
Option	No. locations	No. AR clusters	Type of modules	No. of modules per cluster	Total No. modules	Cost	
2	2	6 per location	Concrete cube 4 m x 4 m x 4 m; 64 m^3; 17 t	2	48	Planning Approvals	$700,000
			Concrete pyramid 3.8 m x 3.3 m x 2.4 m; 11.5 m^3; 9 t	2		Module Construction and Deployment	$3,400,000
			Steel dome 14 m x 12 m x 9 m; 800 m^3; 31 t	1	2	5 yrs. Monitoring	$450,000
						Total	$4,550,000

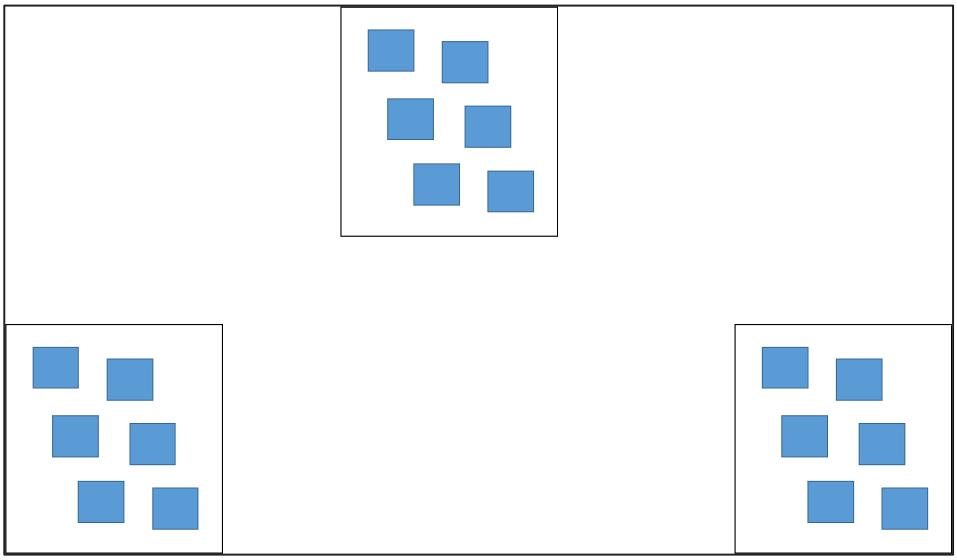

Figure 4-4 Level 2 Option 1

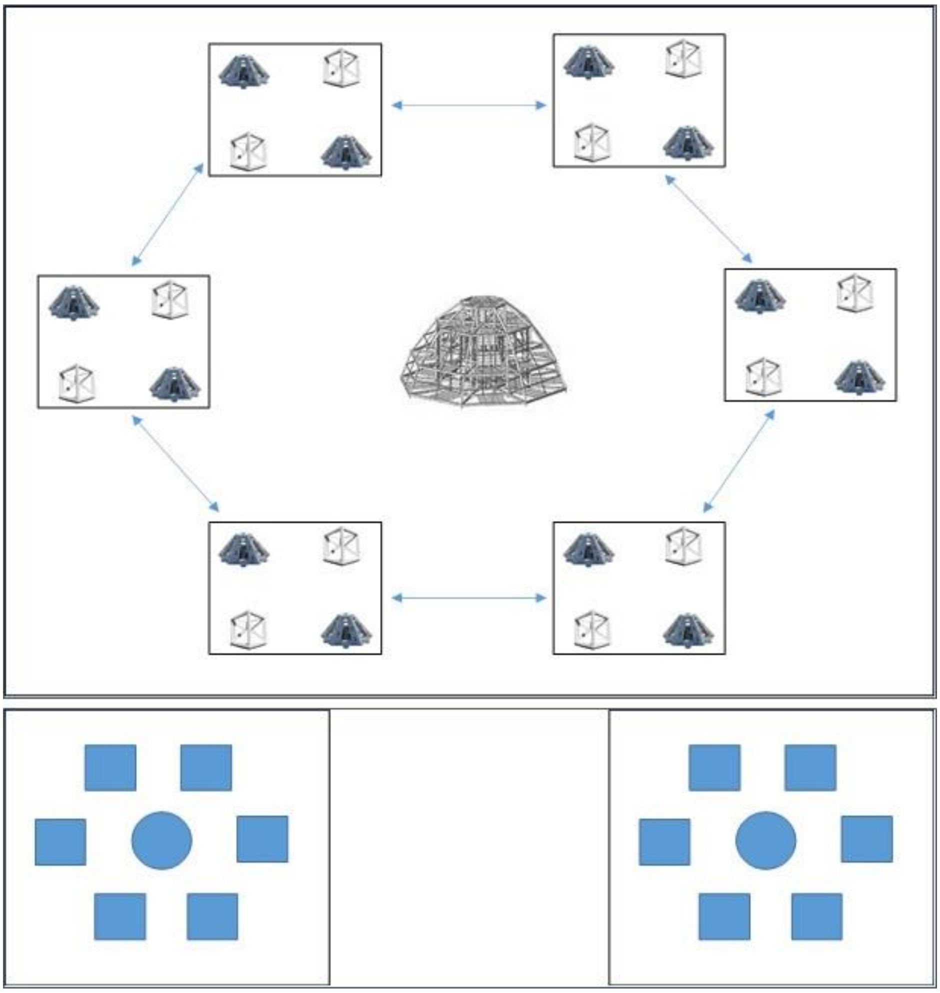

Figure 4-5 Level 2 Option 2

4.5.3 Level 3 ($10 million)

Potential options include:

- Option 1 – At six (6) locations (**Table 4-8**, **Figure 4-6**), there would be 6 clusters of AR's comprising 4 modules (2 concrete cubes, and 2 concrete pyramids).
- Option 2 – At five (5) locations (**Table 4-8**, **Figure 4-7**), there would be 6 clusters of AR's comprising 4 modules (2 concrete cubes, and 2 concrete pyramids).

Table 4-8 Estimated cost breakdown of Level 3 AR deployment and monitoring program

Level 3 ($10M)							
Option	No. locations	No. AR clusters	Type of modules	No. of modules per cluster	Total No. modules	Cost	
Option 1	6	6 per location	Concrete cube 4 m x 4 m x 4 m; 64 m^3; 17 t	2	144	Planning Approvals	$1,500,000
						Module Construction and Deployment	$7,200,000
			Concrete pyramid 3.8 m x 3.3 m x 2.4 m; 11.5 m^3; 9 t	2		5 yrs. Monitoring	$625,000
						Total	$9,375,000
Option	No. locations	No. AR clusters	Type of modules	No. of modules per cluster	Total No. modules	Cost	
Option 2	5	6 per location	Concrete cube 4 m x 4 m x 4 m; 64 m^3; 17 t	2	120	Planning Approvals	$1,100,000
			Concrete pyramid 3.8 m x 3.3 m x 2.4 m; 11.5 m^3; 9 t	2		Module Construction and Deployment	$8,000,000
						5 yrs. Monitoring	$625,000
			Steel dome 14 m x 12 m x 9 m; 800 m^3; 31 t	1	5	Total	$9,725,000

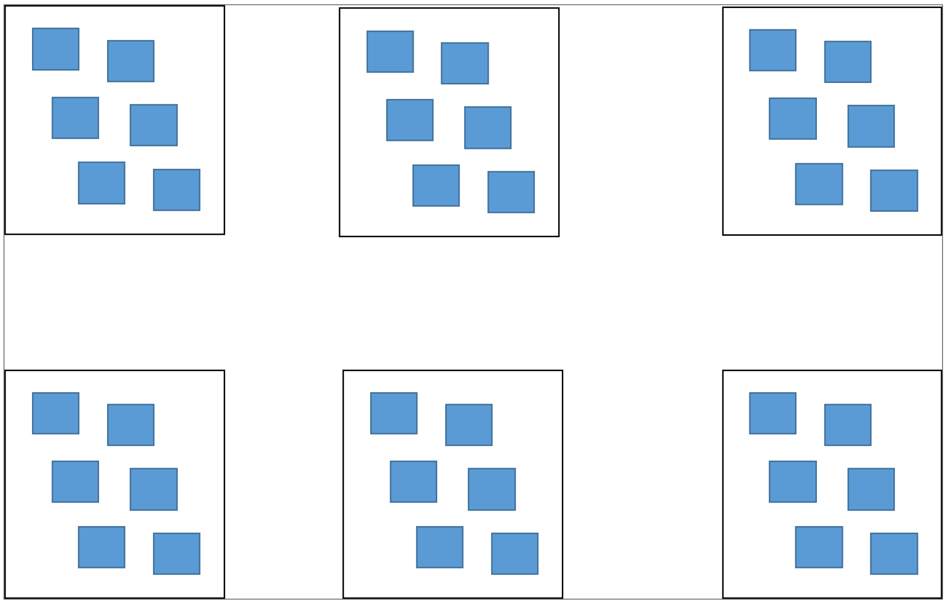

Figure 4-6 Level 3 Option 1

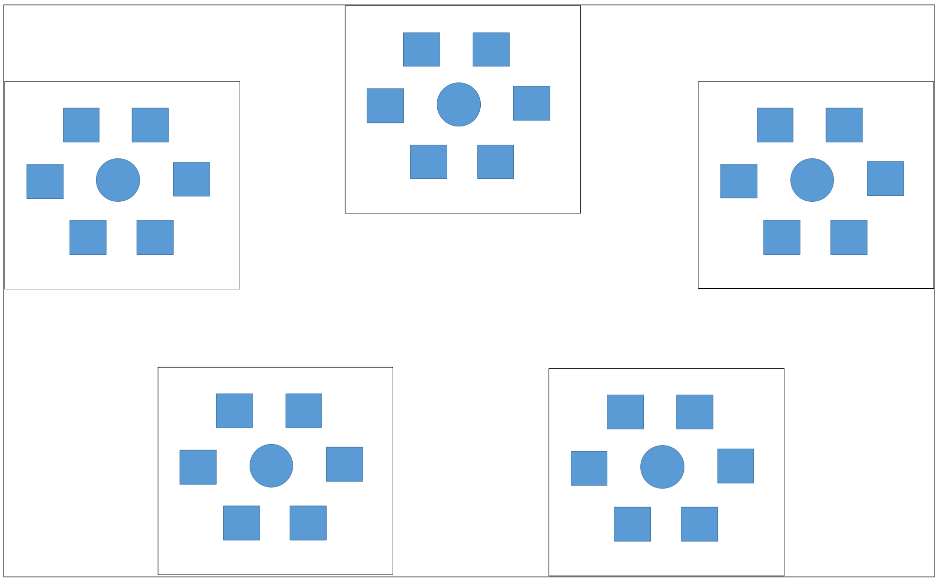

Figure 4-7 Level 3 Option 2

4.6 Potentially Suitable Deployment Areas - Artificial Reefs

The Round 2 MCA identified 43 areas within the study area that were considered least constrained for the potential deployment of ARs (**Figure 4-8**). These areas were distributed throughout the study area extending from Cape Ford to Point Stuart.

The identified areas of least constraint were characterised as those:

- Without high relief
- Not containing potential seagrass habitat (shallower than -10 m LAT)
- Not in an existing conservation area
- Not within 500 m of an existing fishing location
- Not within 1000 m of a wreck or war grave
- In excess of 500 m from a culturally sensitive area
- Not within an existing mineral or petroleum exploration area
- Within an area that primarily consists of a sandy substrata
- Less than 45 km from the nearest boat ramp or harbour entrance
- In water depths between -15 m and -40 m LAT
- In excess of 1000 m from existing infrastructure or shipping channel.
- Not within frequently used existing shipping channels
- Minimise interference with established shipping channels or high vessel traffic areas.

Areas considered lightly constrained were also present throughout the study area. Typically, these areas were located directly seaward of areas of least constraint **(Figure 4-8**) comprising:

- Gravel substratum
- Water depth between 40 m and 50 m
- Being between 45 km and 70 km from designated launch and retrieval sites or the harbour entrance.

Moderately constrained areas for the potential deployment of AR were widely distributed throughout the study area (**Figure 4-8**). Many areas identified as being moderately constrained areas were identified as such due to the additive effect of overlaying multiple lightly constrained weighted criteria. As such, consideration could be given to these areas for the deployment of ARs following examination of the characteristics of individual criterion weighting and further DPIR assessments beyond the scope of the present study.

A large portion of the study area was considered highly constrained for the deployment of ARs (**Figure 4-8**). In nearshore areas, limited water depth, conservations areas and shipping movements were substantial contributing criteria to the classification of highly constrained. Moreover, areas of high relief contributed to the distribution of highly constrained areas particularly in the vicinity of Cape Ford, Bynoe Harbour, Charles Point, Vernon Islands, nearshore to Bathurst Island and Melville and Van Dieman Gulf.

The criteria, criteria performance weighting and pairwise comparison results used in the MCA to identify potential AR deployment areas is in **Appendix E**. The pairwise assessment of the criteria completed by specialists from the DPIR project team identified the top four criterion deemed as being most important based in the standardised weighting when considering the identification of potential AR deployment areas for the Round 2 MCA were ‘conservation estate’ (16.67 %), ‘cultural heritage sites’ (15.15 %), ‘wrecks and war graves’ (13.64 %) and ‘mineral or petroleum exclusion areas’ (12.12%) **Appendix E**.

4.6.1 Size and Selective Attributes of Areas of Least Constraint for the deployment of ARs

Approximately 11.1 % (1993.1 square kilometres) of the study area (18,048.37 square kilometres) was identified in the Round 2 MCA as being least constrained for the potential deployment of ARs. The 43 discrete areas of least constraint ranged in size between 8 ha and 110,919 ha (**Table 4-9**). Sixteen areas were larger than 400 ha, and considered potentially suitable for further examination and consideration as AR deployment areas (**Table 4-9**). These larger areas were located throughout the study area and generally in the vicinity of

Dundee Beach, Bynoe Harbour, Darwin Harbour and in Van Dieman Gulf (**Figure 4-9**). The depth of least constrained areas ranged between -15 m and -30.5 m LAT and the distance to the closest access point ranged between 10.4 km to 45 km. The substrate of the 43 areas identified as being least constrained consisted exclusively of sand.

The minimum distance from 13 areas of least constraint for the potential deployment of ARs to the closest access point was less than 25 km (**Figure 4-9**).

Table 4-9 Area, depth, distance to access point and substrate type of the 43 areas identified during the Round 2 MCA as being least constrained for potential AR deployment

		Depth (m)	Distance to Access Point (km)	Substrate Type			Depth (m)	Distance to Access Point (km)	Substrate Type
Area ID	**Size (ha)**	**Mean (SE)**	**Mean (SE)**		**Area ID**	**Size (ha)**	**Mean (SE)**	**Mean (SE)**	
1	3630	19.6 (0.1)	19.4 (0.1)	Sand	**23**	159	20.3 (0.1)	43.8 (0.2)	Sand
2	2140	17.2 (0.1)	30.2 (0.1)	Sand	**24**	15	22.1 (0.1)	44.8 (0.1)	Sand
3	110919	23.4 (0)	36.2 (0)	Sand	**25**	19973	19.6 (0)	30.1 (0.2)	Sand
4	8	15 (0)	31.6 (0)	Sand	**26**	8	17.8 (0)	26.1 (0)	Sand
5	61	15 (0)	27.4 (0.1)	Sand	**27**	98	16.6 (0.3)	40.1 (0.1)	Sand
6	514	15.6 (0.1)	18.1 (0.1)	Sand	**28**	38	15.2 (0.1)	40.9 (0.1)	Sand
7	1097	20.2 (0)	36.6 (0.1)	Sand	**29**	30	17.3 (0.5)	42.6 (0.1)	Sand
8	3154	20.9 (0.1)	24.4 (0.1)	Sand	**30**	61	19.8 (0.3)	43.9 (0.1)	Sand
9	53	20.7 (0.4)	22.5 (0.1)	Sand	**31**	53	15.8 (0.3)	20.1 (0.1)	Sand
10	8	19.1 (0)	23.9 (0)	Sand	**32**	182	16.4 (0.3)	18.2 (0.1)	Sand
11	159	26.9 (0.3)	38.1 (0.3)	Sand	**33**	15	30.2 (0.2)	21.7 (0)	Sand
12	8	30.1 (0)	36.4 (0)	Sand	**34**	938	15.5 (0)	13.9 (0.1)	Sand
13	14679	30.5 (0)	39.8 (0.1)	Sand	**35**	15	15.5 (0)	10.4 (0.1)	Sand
14	8	28.4 (0)	33.2 (0)	Sand	**36**	8	20.7 (0)	27 (0)	Sand
15	151	30.1 (0.1)	32.2 (0.1)	Sand	**37**	666	27.3 (0.2)	28.4 (0.1)	Sand
16	832	29.5 (0.2)	38.2 (0.2)	Sand	**38**	16872	21 (0.1)	39.6 (0.1)	Sand
17	1634	30.4 (0.1)	42 (0.2)	Sand	**39**	8	18.7 (0)	45 (0)	Sand
18	650	30 (0)	43.8 (0.1)	Sand	**40**	45	18 (0.1)	44.8 (0.1)	Sand
19	13907	23.1 (0.1)	36.8 (0.1)	Sand	**41**	6027	20.1 (0.1)	38.8 (0.1)	Sand
20	91	27.3 (0.2)	25.1 (0.1)	Sand	**42**	265	17.4 (0.2)	44.1 (0.1)	Sand
21	61	18.2 (0.2)	29.8 (0.1)	Sand	**43**	45	15 (0)	36.2 (0.1)	Sand
22	30	25.9 (0.5)	41.3 (0.1)	Sand					

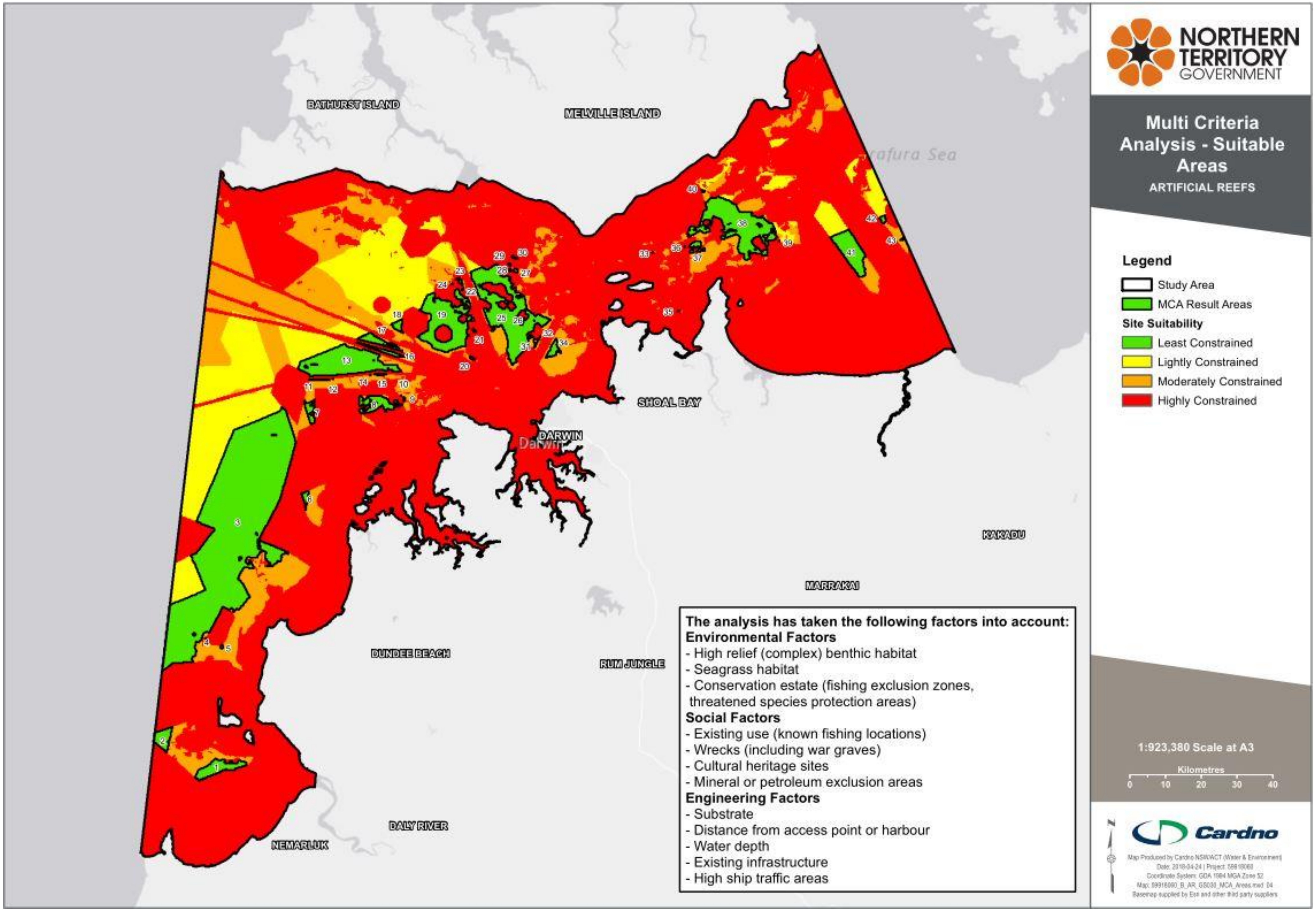

Figure 4-8 Round 2 Multi-criteria analysis identifying potential AR deployment areas

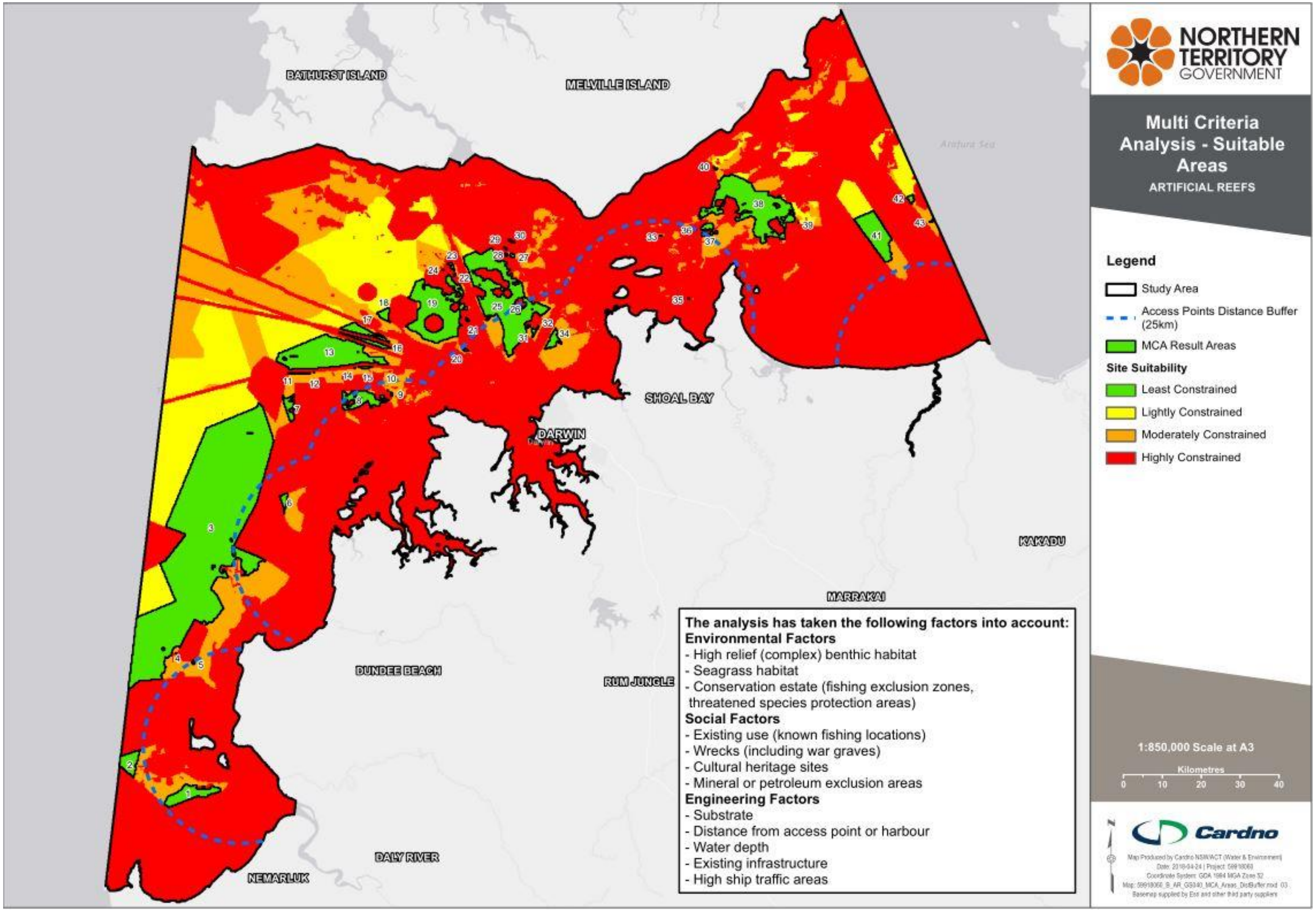

Figure 4-9 Round 2 Multi-criteria analysis identified 10 areas considered least constrained for the potential deployment of AR and within 25 km of an access point

4.7 AR Community Input – Web Portal

A total of 272 individual AR deployment locations were provided by the public via the web portal. The highest density of community identified AR deployment locations were recorded near Dundee Beach, within and seaward of Bynoe Harbour and Darwin Harbour and in the vicinity of the mouth of the Adelaide River (**Figure 4-10**). Kurnell density analysis revealed some overlap between areas of high density of community deployment location data and areas identified in the Round 2 MCA as being least constrained for the potential deployment of ARs. These overlapping areas are primarily in relatively close proximity to the shoreline in the vicinity of Dundee Beach and seaward of Bynoe Harbour and Darwin Harbour (**Figure 4-10**).

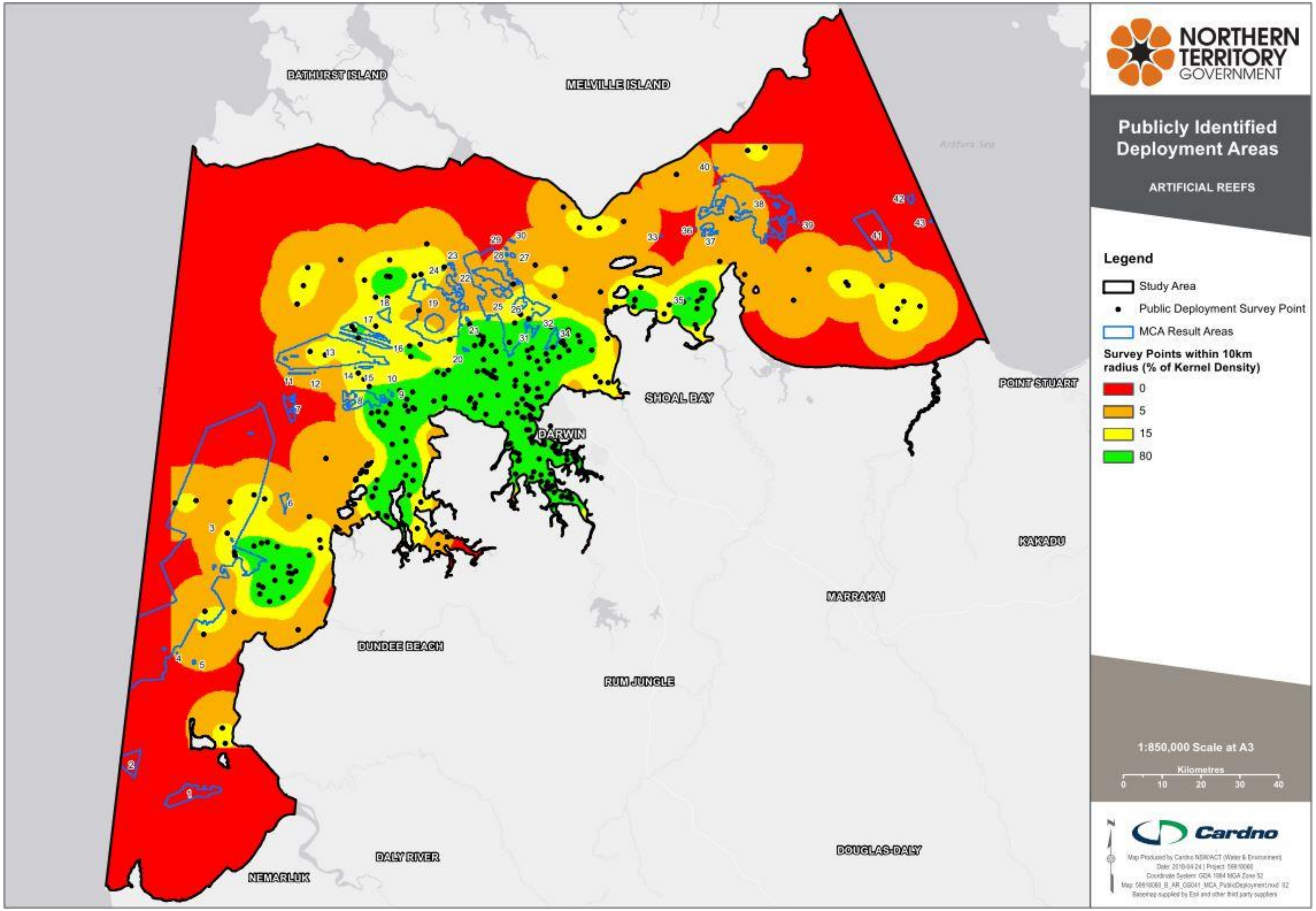

Figure 4-10 Community AR deployment locations collected via the public via the web portal with overlayed Round 2 MCA areas of least constraint for the deployment of AR within the study area.

5 Fish Attracting Devices – Results

5.1 Overview

This section presents a summary of results related to FAD fit for purpose design and arrangement considerations, review and refinement of FAD concept designs, identification of permitting (approval) requirements and Round 2 of the MCA to identify potential FAD deployment areas.

5.2 Information Collation and Review

5.2.1 Information Sources

Much of the information relating to the study area and ARs was sourced from Cardno's extensive library of books, technical reports, the internet and peer reviewed journal articles. **Appendix B** includes references cited during this task.

5.2.2 Target Species

FADs will play an important role diversifying the catches of anglers away from vulnerable demersal reef fish given they will attract only pelagic or semi-demersal species. A list of species considered when designing the FADs provided to Cardno, together with habitat preferences and seasonality of these species, is included in **Table 5-1**. According to the classification by Kim et al. (2008) (see **Section 4.1**), most of these species would be classified as Type III (perceive stream or sound excitation caused by reef structure and visit occasionally). The exceptions would be Giant Trevally (*Caranx ignobilis*), Golden Trevally (*Gnathanodon speciosus*) and Shortfin Batfish (*Zabidius novemaculeatus*), which are Type II (prefer to remain adjacent, but in close proximity to, reef structures and respond to visual or stream excitation). Type II and III species are therefore likely to be attracted to structure i.e. FADs.

5.2.3 Specialist Consultation

Consultation with prominent manufacturers of FADs, managers of FAD programs in New South Wales and scientists that had evaluated deployments or developed FADS was undertaken. Consultation involved general discussion around lessons learned from previous deployments and considerations for developing optimal FADs for the study area.

Organisations consulted include:

- New South Wales Department of Primary Industries – Fisheries (FAD program managers and researchers)
- Pacific Community – SPC (FAD program manufacturers, managers and researchers).

Table 5-1 Pelagic Target Species Habitat Preferences

Scientific Name	Common Name	Habitat Preferences	Structural Preferences	Classification	Seasonality (in NT)
Scomberoides commersonnianus 	Queenfish	Marine, brackish and reef associated (Sommer 1996). Early life stages in estuarine waters (Griffiths 2005) with amphidromous migration in adulthood to coastal waters, frequenting reefs and offshore islands (Sommer 1996).	Not determinable.	Type III	May - September
Scomberomorus semifasciatus 	Grey Mackerel	Marine, brackish, pelagic-neritic (Riede 2004). Juveniles often found in estuarine waters and coastal bays and nearshore areas, influenced by freshwater runoff and low salinity waters (GBRMPA 2011). Adults found in turbid tropical and subtropical waters and rarely occur at edge of the continental shelf to depths of 100 m (Riede 2004).	Congregate to close proximity to rocky headlands and reefs and on sand-mud and muddy-sand substrates (Riede 2004).	Type III	More common in May - September
Scomberomorus commerson 	Spanish Mackerel	Marine, pelagic-neritic (Riede 2004). Juveniles inhabit coastal-estuarine waters (Jenkins 1985). Adults inhabit waters near edge of continental shelf to shallow coastal waters, preferring low salinity and high turbidity conditions (McPherson 1985).	Drop offs and shallow, gently sloping reef and lagoon waters (Kailola 1991; Kuiter 2001).	Type III	Vast majority of catch from April - September
Scomberomorus munroi 	Spotted Mackerel	Marine, pelagic-neritic (Riede 2004). Limited information on habitat preferences of juveniles (Begg 1998; Robertson 2007). Adults schooling in offshore, open waters away from reefs and shoals (McPherson 1985).	Not determinable.	Type III	
Thunnus tonggol 	Longtail Tuna	Marine, pelagic-neritic (Riede 2004). Hypothesised that spawning in offshore international waters as juveniles less than 50 cm rarely encountered in Australian waters (Griffiths 2010). Adults are largely coastal, avoiding turbid waters and areas of reduced salinity (Collette 1983).	Not determinable.	Type III	May - September
Istiophorus platypterus 	Sailfish	Marine, pelagic-oceanic (Riede 2004). Juvenile stage rarely encountered thus little evidence to support preference (Idrisi 2003). Adults inhabit waters close to coasts and islands (Nakamura 1997).	Not determinable.	Type III	Dry season

Scientific Name	Common Name	Habitat Preferences	Structural Preferences	Classification	Seasonality (in NT)
Caranx ignobilis 	Giant Trevally	Marine, brackish and reef associated (Paxton 1989). Juveniles inhabit estuarine waters (Paxton 1989). Adults prefer sand and rock substrate (Mundy 2005). Adults inhabit clear lagoon and seaward reefs (Lieske 1994). Spawning occurs on shallow seaward reefs and offshore banks (Myers 1999).	Reef drop offs (McGrouther 2012).	Type II	May - September
Gnathanodon speciosus 	Golden Trevally	Marine, reef associated (Smith-Vaniz 1995). Smaller juveniles live among tentacles of jellyfish, whilst adults occur in deep lagoon and seaward reefs (Lieske 1994). Adults are diverse in their habitat preferences inhabiting deep offshore to inshore rocky reefs and sandy seabeds (Rome 2010).	Preferences for both reef and soft bottom habitats with preference toward clear water, thus rarely encountered in estuarine waters (Travers 2010).	Type II	May - September
Coryphaena hippurus 	Mahi Mahi (Dolphinfish)	Marine, epipelagic-oceanic. Juvenile and adults inhabit surface waters, rarely ventures inshore, and individuals often aggregate beneath floating debris or around structures (Bray 2018).	Not determinable.	Type III	Not seasonal
Coryphaena equiselis 	Pompano Dolphinfish	Marine, epipelagic-oceanic. Juvenile habitat preferences not determinable. A highly migratory pelagic species found mostly in the open ocean, although individuals may enter coastal waters (Bray 2018).	Not determinable.	Type III	Dry season
Istiompax indica 	Black Marlin	Marine, epipelagic- oceanic. Often found near shore in coastal waters, around islands and coral reefs. (Bray and Schultz 2017).	Not determinable.	Type III	Dry season

5.2.4 Fit-for-Purpose Designs

The success of FADs in aggregating fish make these devices important to the commercial, artisanal, recreational and sports fisheries (Pollard and Matthews 1985).

In their simplest form, FADs consist of a surface or subsurface buoy attached to an anchor. However, there can be variations on this design associated with the type and amount of floats used or whether rafts, netting or other appendages are attached to the top of the line or float.

There is growing effort towards tailoring FAD programs and designs to suit site-specific environmental conditions. Consequently, FAD programs must consider structural composition, siting and arrangement.

Tailored FAD programs are likely to have the following advantages:

- Reduced pressure on reef resources – Factors such as modern fishing gear and techniques, increasing population, exports, and tourism are placing pressure on inshore and coastal reef resources. In the study area, most pelagic species remain underexploited, and FADs provide a means for recreational fishers to diversify the way they fish, and to fish more sustainably. In particular, FADs allow fishermen to transfer some of their effort to more resilient species and away from sensitive stocks
- Improved safety at sea as fishermen are going to known locations to fish and there are likely to be other fishermen in the area
- Assist recreational fishing and charter operations with their fishing activities, which generally encourages more tourism.

In addition, tailored FAD programs can:

- Customise FAD designs to suit a chosen location in terms of depth and oceanography
- Select suitable material for construction of FADs to maximise the duration, durability and compatibility of the structure in the marine environment, helping to reduce problems potentially associated with entanglement of threatened species
- Optimise the effectiveness and lifespan of the FAD design to deliver a comparatively greater cost-benefit for the program.

Key findings in relation to 'composition and arrangement' are included below. **Section 5.6** addresses issues relating to identifying potential FAD deployment areas.

5.2.5 Composition

- Most of the FADs so far constructed have been generally successful in attracting a variety of pelagic fish species, including coastal pelagic species similar to those in the Northern Territory (e.g. Spanish Mackerel (*Scomberomorus commerson*))
- Some studies have shown that more species-rich assemblages occur around large FADs compared to small FADs although not all pelagic species show greater abundance around larger FADs
- There is evidence that fishes form larger assemblages around FADs possessing a fouling biota versus FADs without a fouling biota. Given it takes time for benthic organisms such as alga and sessile invertebrates to colonise objects in the ocean it is reasonable to assume that older FADs are more effective, although it is unclear at what age FADs become more affective or whether effectiveness continues to increase with age
- It is widely believed that appendages attached to or below a FAD buoy system increase the effectiveness of FADs in aggregating and holding fish. This has yet to be demonstrated by scientific research, but is supported by anecdotal accounts from throughout the Pacific
- Plastic strapping, of the type used to bind cartons, has proved to be an effective material when attached below the spar buoy system. Rafts or separate aggregators are recommended only in

areas of low current and there is potential risks of entanglement with threatened marine mammals, birds or marine reptiles

- Catches of pelagic fish around FADs can be similar to areas without FADs if they are over reef substratum. Hence, there are no advantages of using FADs in reefal environments. Notwithstanding this, an important consideration to siting FADs is the general abundance of pelagic fish in an area and their seasonality. Pelagic species can occur throughout the study area
- Many of the popular pelagic species in the Northern Territory are seasonal and are in greatest abundance between April and October
- The new SPC Indian Ocean FAD buoy system is specifically for deployment in areas where strong currents are common
- Catenary curve moorings are considered suitable for macro-tidal environments such as the study area as they minimise the potential for entanglement of mooring lines with boats or fishing gear. Catenary curve moorings are rigged from a combination of sinking and buoyant ropes. The properties of each rope perform specific functions or impart specific features to the mooring
- Consideration of the properties and performance characteristics of rope to be used is very important. For shallow water sites, it recommended to have the length of the polypropylene section of rope as equivalent to the water depth and the length of the nylon section equivalent to the 33% of the water depth
- In shallow sites such as the study area, it is impossible to use enough polypropylene rope to provide the buoyancy necessary to lift 3 m of chain/hardware clear of the seabed. For these sites, pressure-resistant floats are used to supplement the buoyancy of the polypropylene rope
- The holding power of concrete in seawater is 1:2. In other words, a 2000 kg concrete anchor has a holding power of 1000 kg in seawater. For shallow water FADs, an alternative is to use steel danforth anchors of a suitable weight.

5.2.6 Arrangement

- Common practice is to use more than one FAD (i.e., a cluster of FADs) at locations expected to be used commonly by fishers
- The most suitable distance between each FAD within a cluster depends on the abundance and type of species targeted but also on the potential for entanglement of FADs within the cluster. Typically, the distances between FADs within a cluster range from 500 m to 1000 m. The optimal distance between clusters of FADs is estimated to be 10 km.

5.3 Recommended Design Specifications

With reference to the findings of the FAD review above the different options for various design aspects of FAD units, including their arrangement, were assessed against the ‘fit for purpose’ criteria. **Table 5-2** presents the results of these assessments and justification for the preferred choices for design. The full results of the decision analysis are given in **Appendix H**.

Table 5-2 Preferred FAD design aspects as determined using the decision support tool (see **Appendix H**)

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	(1)	(2)	(3)	(4)	(5)	
FAD system						
Temporarily anchored FAD	✓	N/A	✓	✓	✓	Low maintenance and deployment costs, able to be moved to optimise siting and arrangement, can be deployed during peak pelagic season and then retrieved for annual maintenance
Head gear						
Strings of oval and purse seine floats with flagpole, light on marker buoy at the end with GPS locator	✓	N/A	N/A	✓	✓	Low buoyancy and low drag, does not require a heavy mooring, suitable for strong currents and broken FADs are able to be recovered given their whereabouts are known
Appendages						
Plastic strips on top chain	✓	N/A	N/A	✓	✓	Known to be effective fish aggregators, low risk of entanglement of marine turtles or marine mammals
Upper mooring line						
12 strand 16 mm nylon rope (25% of total mooring line)	N/A	N/A	N/A	✓	✓	No hardware connections (shackles, swivels etc.). Nylon rope sinks and is not a hazard to vessels, greater durability than 3 strand rope
Lower mooring line						
12 strand 16 mm polypropylene rope (66% of total mooring line and equal to site depth), swivel	N/A	N/A	N/A	✓	✓	Buoyant rope creates catenary curve, lifting ground chain (see below) and minimises potential for rope abrasion. A swivel placed between the polypropylene rope and the chain (see below) prevents twists in the chain and mooring rope. NB: Although 12 strand rope has greater durability than 3 strand rope and added buoyancy a supplementary float on lower mooring line maybe needed to lift chain by required distance (3 m) off bottom.

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	(1)	(2)	(3)	(4)	(5)	
Anchor system						
10 m x 16 mm long link chain	N/A	N/A	N/A	✓	✓	Ground chain rises and sinks in adequate response to surface and current forces. Adds necessary weight to anchor system total weight
Danforth anchor and clump weight (weight to be 3 x buoyancy of surface float)	N/A	N/A	N/A	✓	✓	Steel anchor has less bulk and weight than concrete, lower deployment and retrieval costs for temporary FADs.
Arrangement (for multiple FADs)						
Spacing > 500 m within clusters	✓	N/A	✓	✓	✓	No risk of tangling or conflict/incidents among fishing boats
Spacing > 10 km among clusters	✓	N/A	✓	✓	✓	Suitable distance for avoiding neighbouring clusters of FADs competing for coastal pelagic species

Criteria:

1. A focus on maximising the potential for aggregation of a diversity of reef (including juveniles) and/or pelagic species that are preferred by recreational fishers
2. Minimisation of attraction of fish from other reefs (for ARs), particularly vulnerable species, so that new aggregations are a result of new production
3. Scale and scale-ability of designs to provide for long-term network development
4. Siting (including configuration) that maximises the potential for recreational fisheries enhancement (including accessibility) and minimises the potential for compromising safety and social, economic or ecological risks
5. Construction, maintenance and deployment/ retrieval costs that are within the given budget and, for ARs, a design life of 30 yrs.

5.3.2 Modules

In summary, the optimal design for FAD modules would be as follows:

- FAD system: Temporarily anchored FAD
- Head gear: String of 3 x 30G-2 oval pressure float (200 m working depth; 20 kg buoyancy) and purse seine floats with flagpole on Sealite Aquafloat 600 buoy (and counterweight) at the end with GPS locator unit and Sealite 15 light (1-2 nm range, rated to IP68) attached.
- Appendages:
  - *Option 1*- 7 m long x 5 cm wide black plastic streamers or thin plastic hosing (spaced every 20 cm) attached to nylon rope from -4 m to – 11 m
  - *Option 2*- 7 m long x 5 cm wide weighted black plastic streamers or thin plastic hosing (spaced every 20 cm) hung under the top floats
- Upper mooring lines: 12 strand 16 mm (5300 kg breaking strain) nylon rope (25% of total mooring line)
- Lower mooring lines: 12 strand 16 mm (4875 kg breaking strain) polypropylene rope (66% of total mooring line and equal to site depth) with 1 x 25G-5 Oval pressure float, swivel
- Anchor system: 10 m x 16 mm long link chain and 25 kg 'Danforth' anchor with 350 kg metal weight in the middle of the chain length (weight equals 3 x floatation buoyancy). Floatation buoyancy calculated from buoys plus 100 kg drag force of streamers and assumes 1 nm of current
- The configuration of the module including shackles and swivels is included in **Figure 5-1**, **Figure 5-2** and **Figure 5-3**.

5.3.3 Arrangement

The arrangement (for multiple FADs):

- Spacing > 500 m within clusters
- Spacing > 10,000 m among clusters.

5.4 Costs

There are three main components to the cost of the FAD program: as with ARs

1. Planning approvals
2. Module construction, deployment and maintenance
3. Monitoring.

5.4.1 Approvals

There are statutory approval requirements under State and Commonwealth legislation that need to be considered (State and Commonwealth). These requirements include an 'environmental assessment' document of some form to justify the project on economic, social and environmental grounds. The environmental approval requirements are described in **Section 6**.

5.4.2 FAD Module Construction, Deployment and Maintenance

Construction and deployment costs include material, manufacturing and deployment vessel costs, which may vary according to the following variables:

- The supplier of material and the manufacturing process (i.e. according to different manufacturers)
- Whether modules are constructed locally (in Darwin) or further afield
- The water depth of deployments as deeper deployments will require more rope and potentially more anchor weight
- The size of the deployment vessel (or method) and efficiency (time involved).

In contrast to ARs, which have one-off construction and deployment costs, FADs will have a cost of maintenance. Given FADs will be temporary, there will annual costs associated with removal, cleaning and repairing components.

Additionally, with GPS locators there will be a cost associated with running the tracking system. Consultation with the FAD program manager in New South Wales indicates one-third of FADs are broken off every year. Although headgear is often recovered with the aid of the GPS tracker, there would be a cost of replacing the unrecoverable bottom gear.

5.4.3 Monitoring

A monitoring program is integral to verifying assumptions made about the positive and negative impacts of FADs. Cardno has developed a monitoring program (based on the agreed performance criteria) for determining success (see **Section 7.4.1**).

Base case costs for monitoring are difficult to estimate given some aspects of monitoring could be incorporated into existing NT programs (i.e. recreational fishing ramp surveys). It is likely however, that the program would have a cost of ~ $150,000/yr.

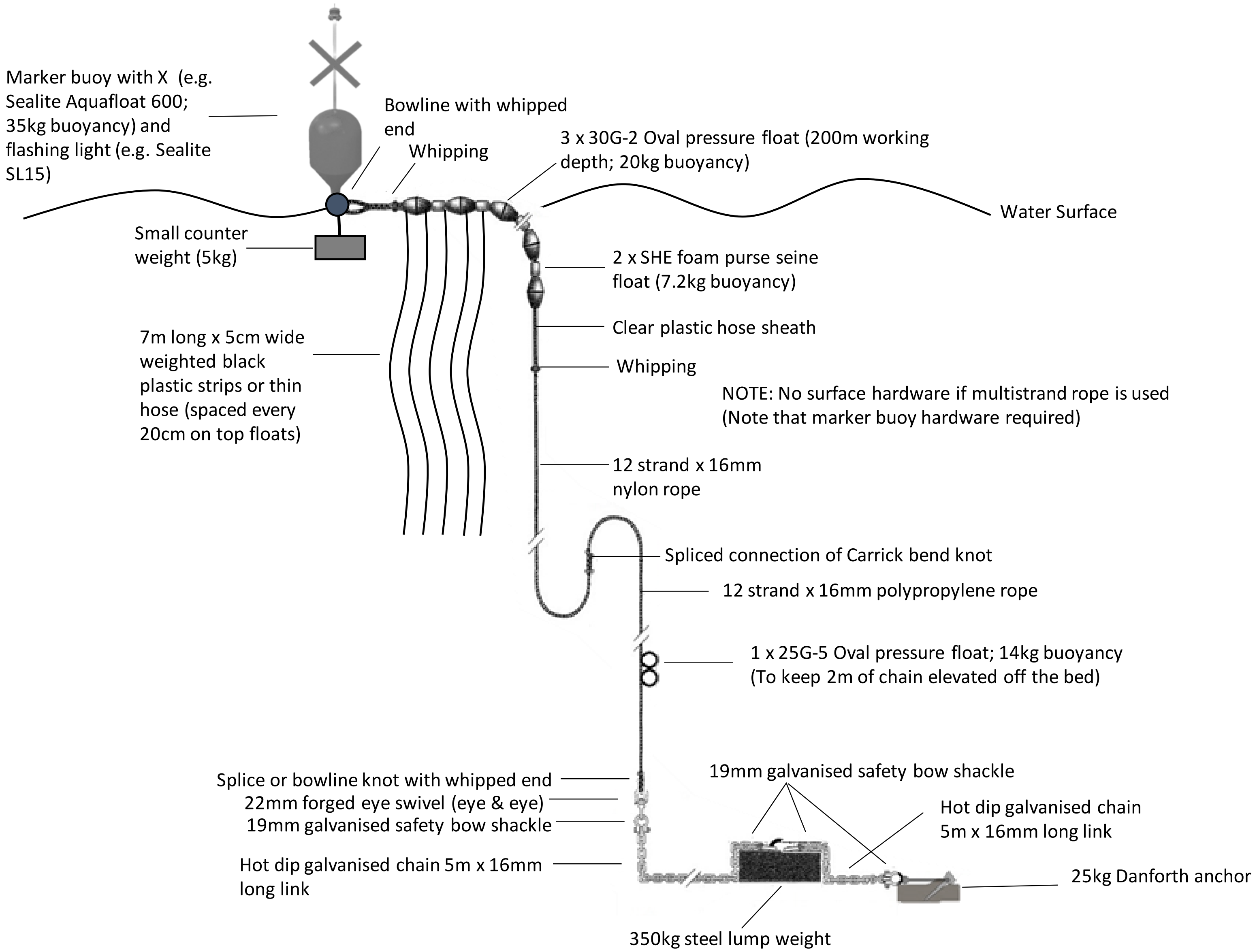

Figure 5-1 Configuration of FAD module with aggregator Option 1

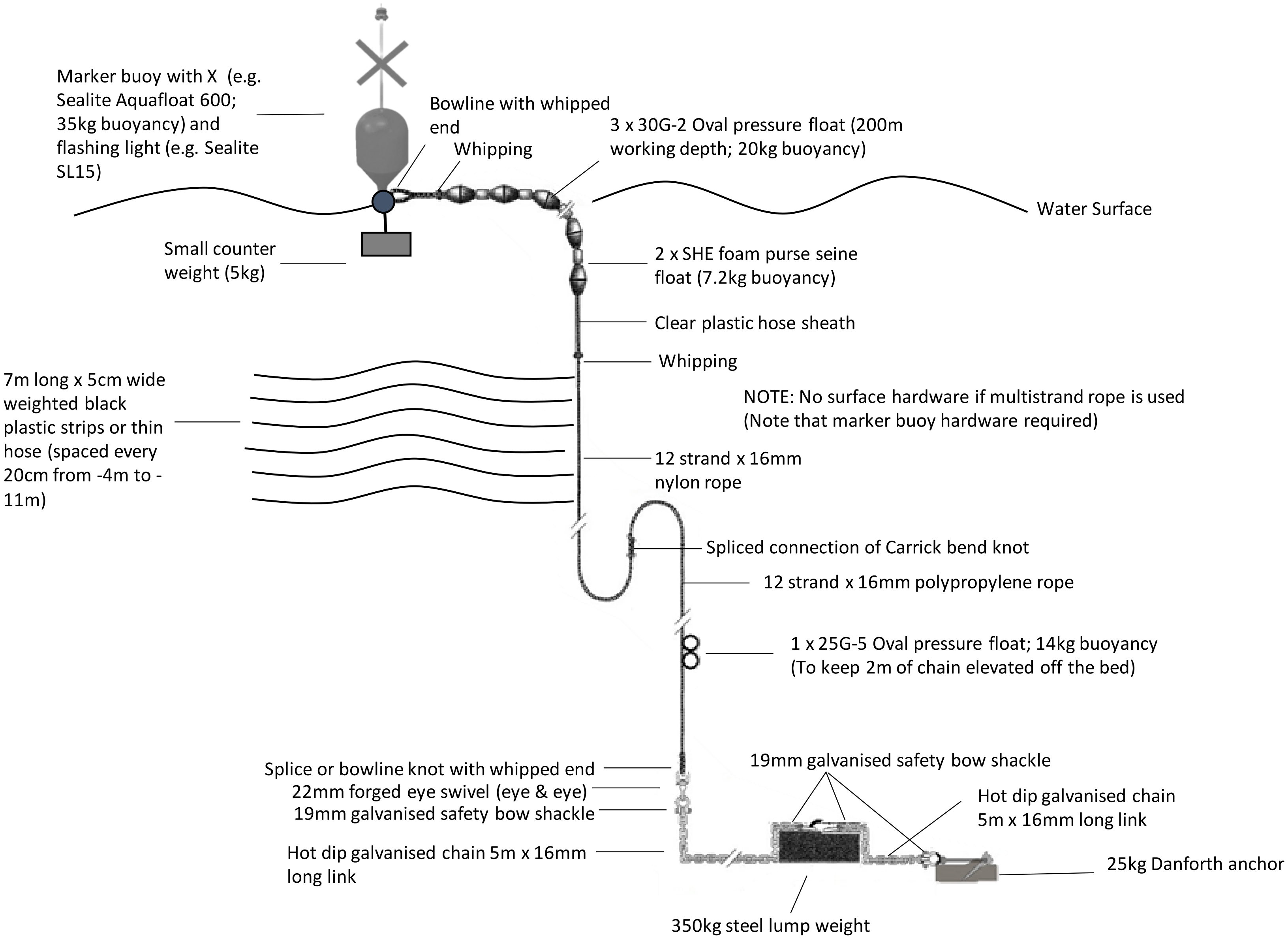

Figure 5-2 Configuration of FAD module with aggregator Option 2

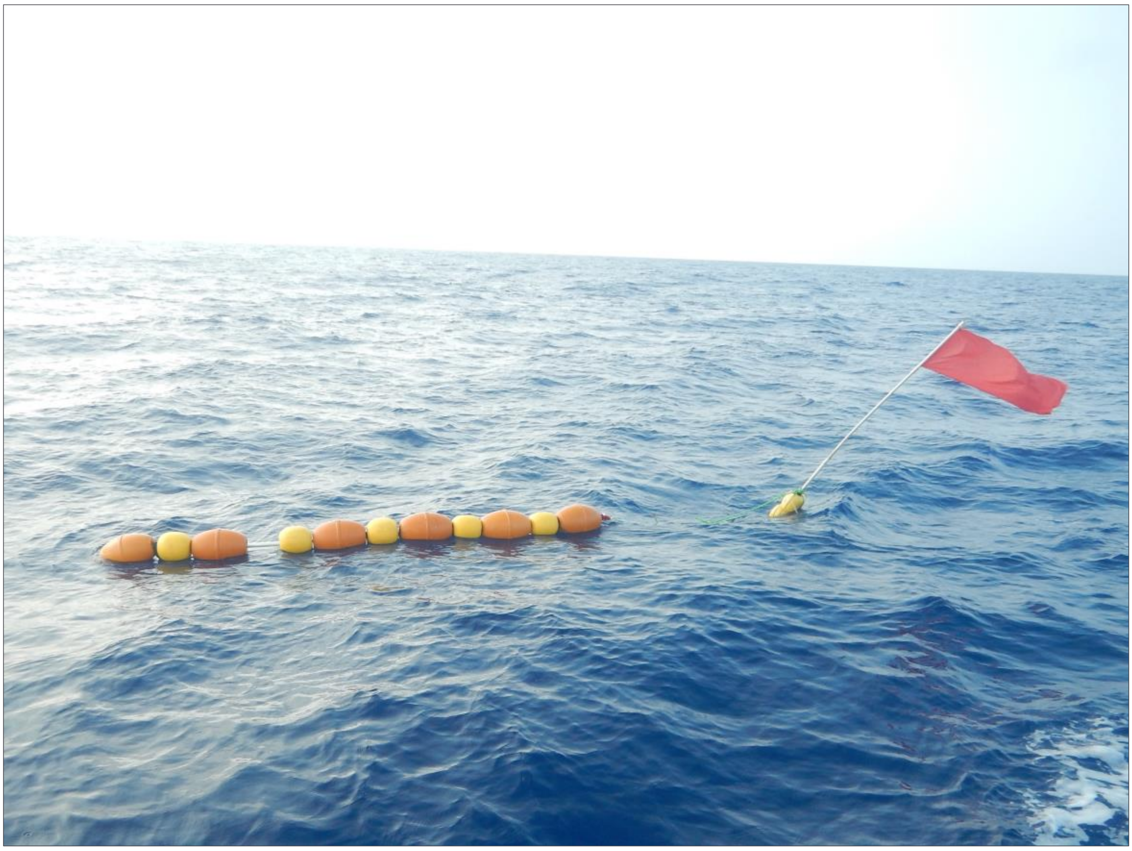

Figure 5-3 Example of surface buoys and markers on SPC Indian Ocean FAD buoy system

5.5 Deployment Options

The budget for FADs is $1,000,000 and the program is to consider deployment in at least five (5) sites. The recommendation is for a pilot study and three year program.

5.5.1 Pilot Study

The temporary FAD design allows an opportunity to test the integrity of the module design and components prior to deployment in the main program (below). This would involve two modules being deployed during an entire dry season at different sites, preferably where current speed is different.

Although the aim of the pilot study would be to determine how the gear stands up to deployment, opportunistic information could also be obtained on the fish attracting and aggregating ability of the modules. Lessons learned from the pilot study would be used to refine the design for the main program.

5.5.2 Three (3) Year Main Program

This program would involve dry season deployment of twelve (12) FAD modules spread across six (6) sites (**Table 5-3**). Each cluster (site) of modules would consist of one (1) or three (3) modules spaced 500 m apart and sites would be spaced ~10 km apart. This balanced design would allow testing for hotspots and would determine ideal numbers of modules in clusters (see **Section 7**).

Table 5-3 Estimated cost breakdown of FAD program

$1M Option				
No. Sites	No. FADS per Site	Total No. Modules	Cost	
2	1	2	Pilot Study	$50,000
6	1 to 3 (see Monitoring Design)	12	Planning Approvals	$200,000
			Year 1 Construction, Deployment and Retrieval x 9 modules	$85,000
			Year 2 Construction, Deployment and Retrieval x 9 Modules (includes replacement of lost modules	$60,000
			Year 3 Construction, Deployment and Retrieval x 9 Modules (includes replacement of lost modules	$60,000
			Tracertrak GPS Locator Hardware and System x 3 Years	$45,000
			3 years of Monitoring	$450,000
			Contingency	$50,000
			Total	$1,000,000

5.6 Potentially Suitable Fish Attracting Device Deployment Areas

The Round 2 MCA identified 52 areas considered least constrained for the potential deployment of FADs (**Figure 5-4**). These areas were primarily distributed seaward of Dundee Beach, north of Darwin Harbour and in Van Dieman Gulf.

The identified areas of least constraint for the potential deployment of FADs were characterised as those:

- Without high relief
- Not containing potential seagrass habitat (shallower than -10 m LAT)
- Not in an existing conservation area
- Not within 2000 m of an existing fishing location
- Not within 1000 m of a wreck or war grave
- In excess of 500 m from a culturally sensitive area
- Not within an existing mineral petroleum exploration area
- Within an area that does not consist of rock or coral substrate
- Less than 45 km from the nearest boat ramp or harbour entrance
- In water depths deeper than - 30 m LAT
- In excess of 2000 m from existing infrastructure or shipping channel.
- Does not interfere with established shipping channels or high vessel traffic areas.

Areas considered lightly constrained were also present throughout the study area (**Figure 5-4**). Lightly constrained areas were generally adjacent and seaward to or in relatively close proximity to areas of least constraint.

Moderately constrained areas for the potential deployment of FADs were widely distributed throughout the study area (**Figure 5-4**). Many areas identified as being moderately constrained areas were identified as such due to the additive effect of overlaying multiple lightly constrained weighted criteria. As such, consideration could be given to these areas for the deployment of FADs following examination of the characteristics of individual criterion weighting and further DPIR assessments beyond the scope of the present study.

A large portion of the study area was considered highly constrained for the deployment of FADs (**Figure 5-4**). In nearshore areas, limited water depth, conservations areas were substantial contributing criteria to the classification of highly constrained. Moreover the objective to avoid shipping vessel traffic areas (to reduce the potential of undesired interactions) substantially reduced the distribution of potential FAD deployment locations compared to results presented in the Round 1 MCA (Cardno 2017).

The criteria, criteria performance weighting and pairwise comparison results used in the MCA to identify potential AR deployment areas is in **Appendix E**. The pairwise assessment of the criteria completed by specialists from the DPIR project team identified the top four criterion deemed as being most important based in the standardised weighting when considering the identification of potential FAD deployment areas for the Round 2 MCA were 'conservation estate' (15.38 %), 'cultural heritage sites' (15.38 %), 'wrecks and war graves' (13.85 %) and 'interference with established shipping channels and 2017 vessel tracks' (10.77%) **Appendix E**.

5.6.1.1 Size and Selective Attributes of Areas of Least Constraint for the deployment of FADs

Approximately 7.6 % (1,368.9 square kilometres) of the study area (18,048.37 square kilometres) was identified in the Round 2 MCA as being least constrained for the potential deployment of FADs. The 52 discrete areas considered least constraint for the deployment of FADs ranged in size between 8 ha and 88,912 ha (**Table 5-4**). Seventeen areas were larger than 400 ha and are considered potentially suitable for further examination and consideration as FAD deployment areas (**Table 5-4**). These larger areas were located throughout the study area, including in the vicinity of Dundee Beach, north of Darwin Harbour and in Van Dieman Gulf (**Figure 5-5**). The mean depth of least constrained areas ranged between -20 m and -30.2 m LAT and the mean distance of an area of least constraint to the closest access point ranged between 7.9 km to 44.9 km (**Table 5-4**). Sand was identified as the dominant substrate type in 28 areas of least constraint consisted of sand while gravel, shells and pebbles dominated the substrate type for 12 areas and mud and clay was the dominated substrate in a further 12 areas (**Table 5-4**).

The minimum distance from 12 areas of least constraint for the potential deployment of FADs to the closest access point was less than 25 km (**Figure 5-5**).

Table 5-4 Area, depth, distance and substrate type of the 52 areas identified during the Round 2 MCA as being least constrained for potential FAD deployment based on the criteria examined.

		Depth (m)	Distance to Access Point (km)	Substrate Type	
Area ID	Size (ha)	Mean (SE)	Mean (SE)	Majority	Minority
1	7442	20.7 (0)	24.5 (0.1)	Mud & Clay	Gravel, Shells & Pebbles
2	6247	21 (0)	35.1 (0.1)	Mud & Clay	Sand
3	88912	24.7 (0)	36.4 (0.1)	Sand	Mud & Clay
4	98	22.2 (0.1)	44 (0.1)	Sand	Sand
5	38	20.7 (0)	34.4 (0)	Sand	Sand
6	1876	27.7 (0.2)	42.8 (0.1)	Sand	Sand
7	15	22.1 (0.1)	44.8 (0.1)	Sand	Sand
8	408	30.3 (0)	41.5 (0.1)	Sand	Sand
9	38	22.4 (0.3)	40.2 (0.1)	Sand	Sand
10	45	20.5 (0.2)	38.5 (0.1)	Sand	Sand
11	340	22.2 (0.4)	37.4 (0.1)	Sand	Sand
12	1195	20.9 (0.1)	33.9 (0.1)	Sand	Sand
13	15	20.2 (0)	34 (0.1)	Sand	Sand
14	45	25.6 (0.1)	30.9 (0.1)	Sand	Sand
15	15	22.7 (0.2)	28.3 (0.1)	Mud & Clay	Mud & Clay
16	144	20 (0)	41.3 (0.1)	Sand	Sand
17	2685	20.7 (0)	41.2 (0.1)	Sand	Mud & Clay
18	363	20.7 (0.1)	38 (0.1)	Sand	Sand
19	363	20.1 (0)	34 (0.2)	Sand	Sand
20	23	20 (0)	34.5 (0.1)	Sand	Sand
21	227	20.2 (0)	32.1 (0.1)	Sand	Sand
22	3486	21.6 (0.1)	29 (0.1)	Sand	Gravel, Shells & Pebbles
23	129	20 (0)	24.1 (0.1)	Sand	Sand
24	76	20 (0)	23.1 (0.1)	Sand	Sand
25	250	20.1 (0)	24.9 (0.1)	Sand	Sand
26	166	20.1 (0)	34.7 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
27	61	20 (0)	38.5 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
28	53	20.2 (0.1)	43.7 (0.1)	Sand	Mud & Clay
29	23	20 (0)	44.5 (0.1)	Mud & Clay	Mud & Clay
30	30	20.3 (0.1)	28.5 (0.2)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
31	159	30.1 (0.1)	28.8 (0.1)	Mud & Clay	Gravel, Shells & Pebbles
32	15	20 (0)	24.8 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
33	68	20.5 (0.1)	7.9 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
34	159	21.6 (0.3)	17.5 (0.1)	Mud & Clay	Mud & Clay

		Depth (m)	Distance to Access Point (km)	Substrate Type	
Area ID	Size (ha)	Mean (SE)	Mean (SE)	Majority	Minority
35	15	20 (0)	18.4 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
36	8	20 (0)	20.8 (0)	Mud & Clay	Mud & Clay
37	53	30.1 (0)	22.8 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
38	2322	29.8 (0)	26.9 (0.2)	Gravel, Shells & Pebbles	Sand
39	38	21.1 (0.2)	22.5 (0.1)	Mud & Clay	Mud & Clay
40	212	20 (0)	23.3 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
41	53	20.3 (0.1)	25.9 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
42	8	20.7 (0)	27 (0)	Sand	Sand
43	787	24.8 (0.2)	29.6 (0.1)	Sand	Gravel, Shells & Pebbles
44	91	20.2 (0.1)	33 (0.1)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
45	318	20 (0)	33.8 (0.1)	Mud & Clay	Sand
46	30	20 (0)	35.7 (0.1)	Mud & Clay	Mud & Clay
47	5127	20.7 (0.1)	41.1 (0.1)	Sand	Mud & Clay
48	522	30.1 (0)	29.2 (0.3)	Gravel, Shells & Pebbles	Gravel, Shells & Pebbles
49	4991	23.8 (0.1)	36.9 (0.1)	Sand	Gravel, Shells & Pebbles
50	484	20.1 (0)	43.6 (0.1)	Mud & Clay	Mud & Clay
51	1051	21.1 (0)	43.9 (0.1)	Mud & Clay	Mud & Clay
52	5581	22.1 (0.1)	41.5 (0.1)	Sand	Mud & Clay

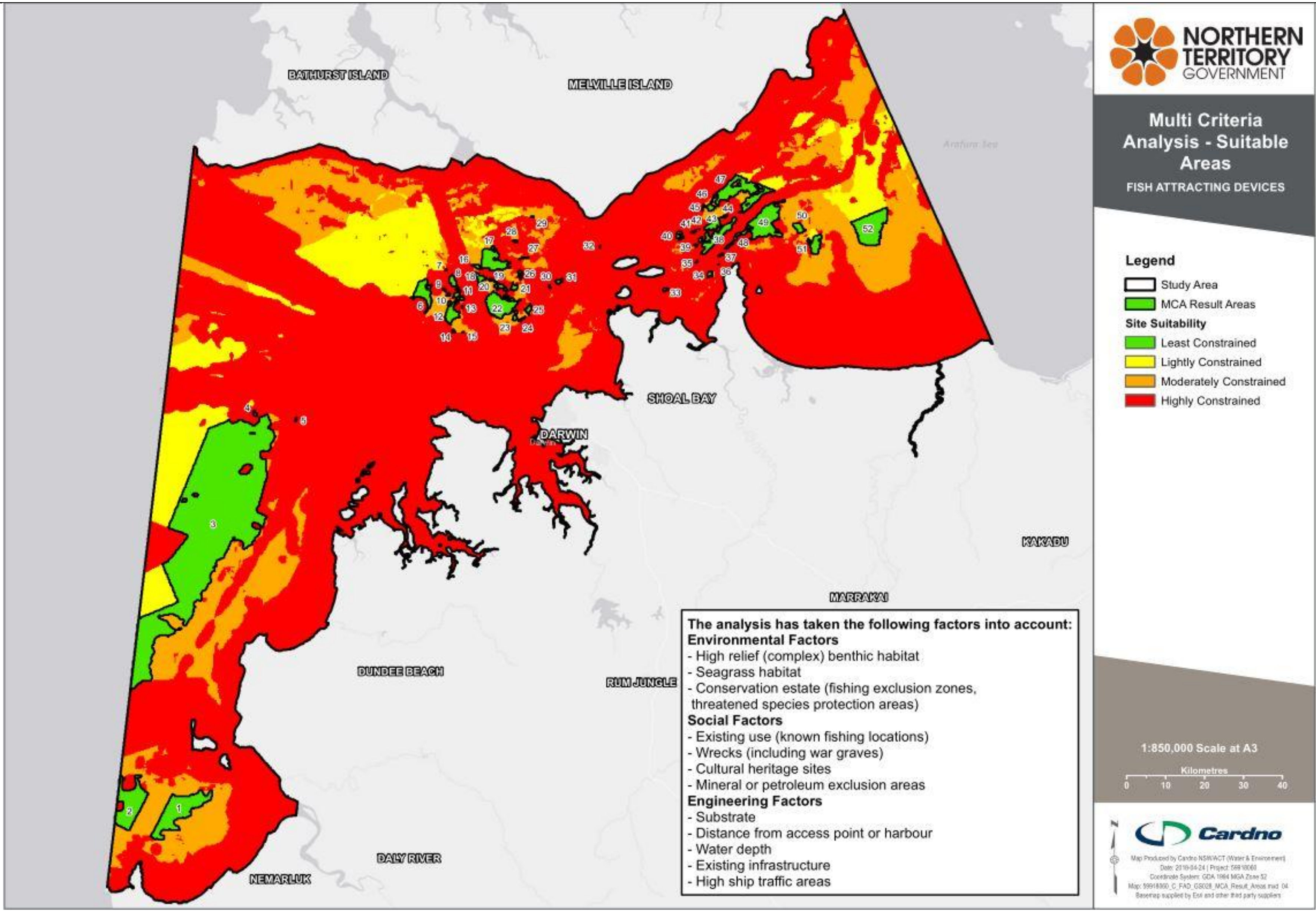

Figure 5-4 Multi-criteria analysis results to identify potential FAD deployment areas Round 1

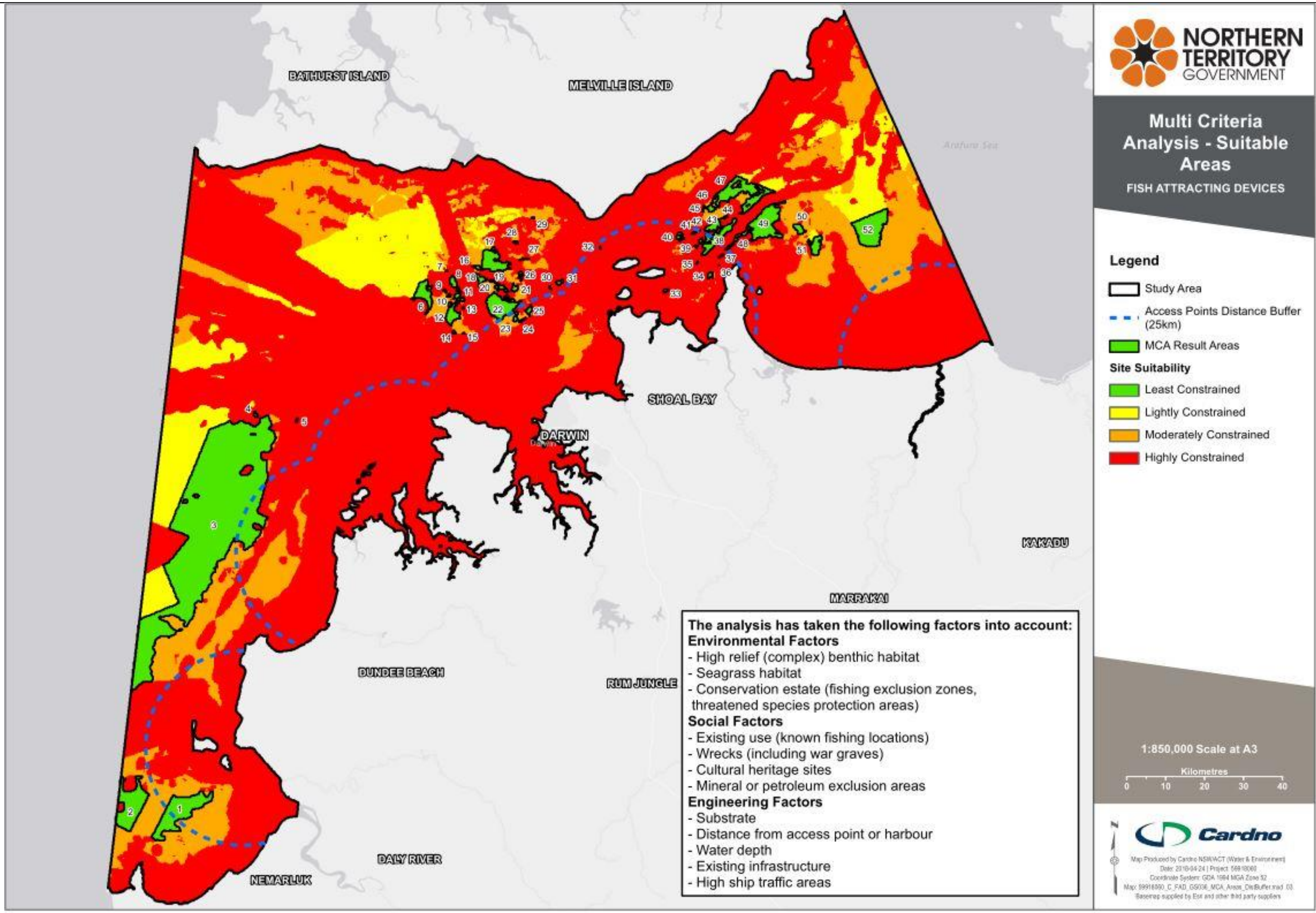

Figure 5-5 Round 2 MCA identified 10 areas considered least constrained for the deployment of FAD within 25 km of an access point

5.7 FAD Community Input – Web Portal

A total of 225 individual FAD deployment locations were provided by the public via the web portal. The highest density of community identified FAD deployment locations were recorded in the vicinity of Dundee Beach and both within and seaward of Bynoe Harbour and Darwin Harbour (**Figure 5-6**). Kurnell density analysis revealed some overlap between areas of high density of community deployment location data and areas identified in the Round 2 MCA as being least constrained for the potential deployment of FADs (**Figure 5-6**). These overlapping areas are primarily in relatively close proximity to the shoreline in the vicinity of Dundee Beach and seaward Darwin Harbour (**Figure 5-6**).

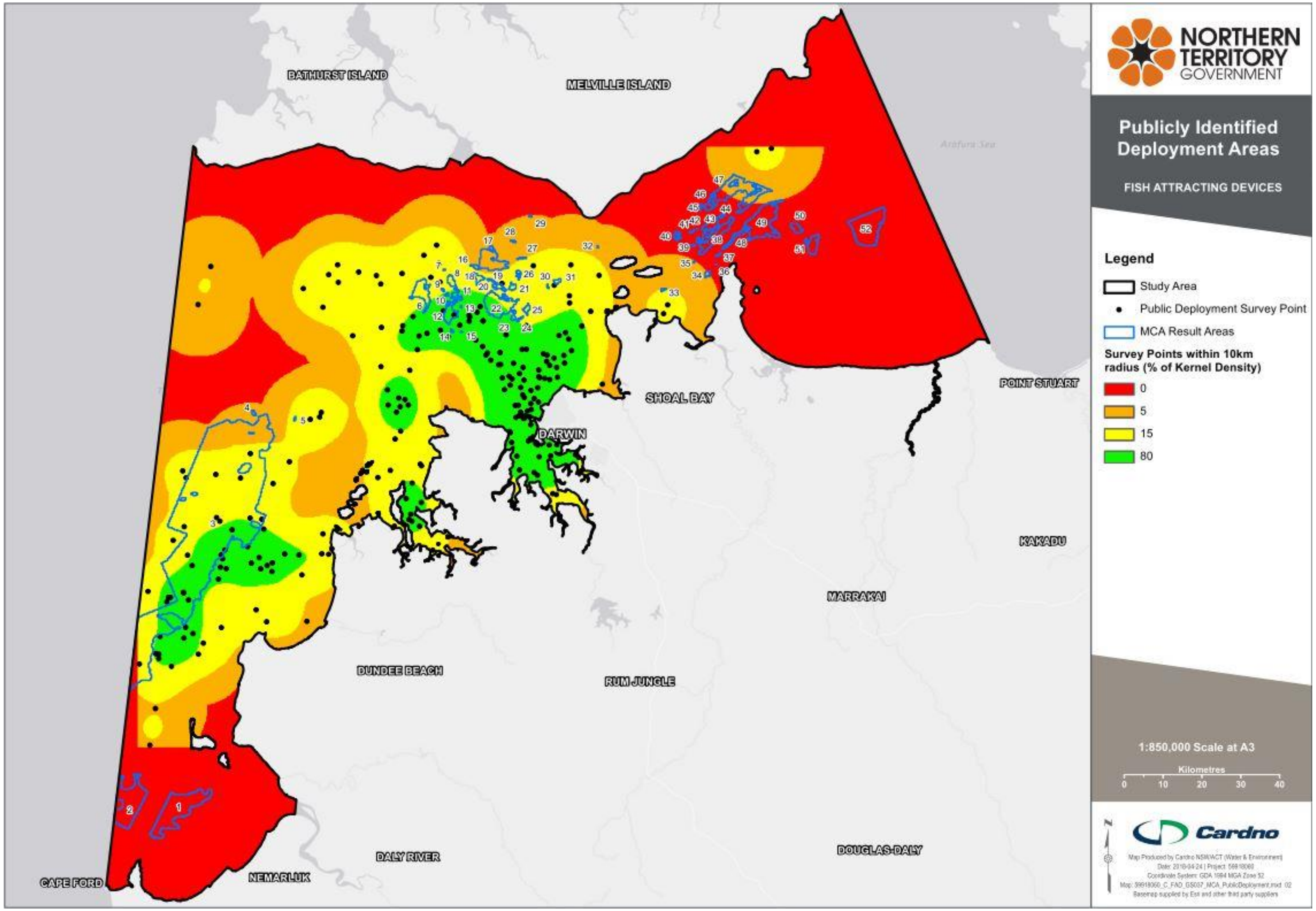

Figure 5-6 Community FAD deployment locations collected via the public via the web portal with overlayed Round 2 MCA areas of least constraint for the deployment of FAD within the study area

6 Approval Considerations

6.1 Overview

This section outlines the Commonwealth and Northern Territory environmental legislation requiring consideration during planning for the deployment of ARs and FADs within the study area.

6.1.1.1 Commonwealth Legislation

Under national environment law, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) includes process to protect nine matters of national environmental significance (MNES):

- World heritage properties
- National heritage places
- Wetlands of international importance (listed under the Ramsar Convention)
- Listed threatened species and ecological communities
- Migratory species protected under international agreements
- Commonwealth marine areas
- The Great Barrier Reef Marine Park
- Nuclear actions (including uranium mines)
- A water resource in relation to coal seam gas development and large scale coal mining development.

Other protected matters include the environment where a) the actions proposed are on or will affect Commonwealth land and the environment, and/or b) where the Commonwealth agencies are proposing to take the action.

Of these nine matters, national heritage places and listed threatened species and ecological communities are likely to be the most relevant for artificial reefs in the Northern Territory, although it will depend on the exact nature and location of a specific proposal.

Under the EPBC Act an action will require approval from the minister if the action has, will have, or is likely to have, a 'significant impact' on a MNES. Failure to refer the action for the approval of the Minister for the Environment (the Minister) could result in a number of outcomes including civil and criminal penalties should it be later identified that a referral was warranted.

The first step in determining this is a 'self-assessment' process to determine the significance of potential impacts. The Commonwealth of Australia (2013) provides guidance on the self-assessment process, including definition about what a significant impact would entail with respect to the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts. If the proponent (NT Government) determines, through self-assessment, that there is no potential for significant impact, then there is no Commonwealth approval required. The 'self-assessment' process can be done in parallel with preparation of the NOI above. If an impact is expected to an MNES, the first next step is to prepare a Referral[4]. 'Referral' of an action involves filling out a referral form and sending it to the Department of the Environment and Energy (DoEE). A Referral includes a brief description of the proposal, the project location, the nature and extent of any potential impacts, and any proposed mitigation

[4] Examples of referrals in Northern Territory can be found here: http://epbcnotices.environment.gov.au/referralslist/

measures. The Referral provides the information upon which the (DoEE) can make a determination as to whether a proposed activity is deemed a controlled action that is likely to significantly impact MNES. It should be noted that the likely presence at a specific location of, for example a listed species such as dugong, is by itself not grounds for a decision that an activity is a controlled action. Rather it is whether there is a likelihood of a significant impact on a MNES, not just its presence.

If the DoEE determines an activity is not a controlled action, then there is no Commonwealth approval required if the activity is undertaken in accordance with the referral. If significant impacts are considered likely, and the action is deemed to be a controlled action, then the referral will proceed to the next stages of the process - environmental assessment and approval. The proponent may be asked to provide further information about the proposal. The EPBC Act provides for five different levels of assessment:

- assessment on referral information (no further information required)
- assessment on preliminary documentation
- assessment by Environmental Impact Statement (EIS)
- assessment by Public Environment Report (PER)
- assessment by public inquiry

6.1.1.2 Northern Territory Legislation

In terms of Northern Territory legislation and processes, the Northern Territory Environment Protection Authority (EPA) is responsible for the implementation of the environmental assessment process in the Northern Territory under the *Environmental Assessment Act 2012* (EA Act 2012). The NT EPA provides notices on the decision on the level of assessment and the assessment report for specific proposals to the Minister.

The initial notification of a proposed action to the NT EPA is known as a Notice of Intent (NOI). The NOI provides essential details of the proposed action to assist in determining whether assessment under the EA Act 2012 is required. Under the EA Act the NT EPA has the power to request a NOI for a project if it is deemed to be of a scope and scale, and/or has the potential to result in a significant environmental impact, which requires further assessment. Once a NOI is received by the NT EPA, a decision is required in the first instance on whether the proposed action could have a significant effect on the environment. The NOI is examined in relation to:

- potentially significant environmental impacts, particularly the type, magnitude, duration, frequency and extent of impacts
- the significance and sensitivity of the surrounding biophysical environment
- processes inherent in the proposed action and related inputs and outputs/discharges, potential for on-site or off-site effects on the environment
- issues such as statutory planning, heritage, public health, water resources, water quality and resource management.

If the proposed action is considered to not involve a significant impact on the environment, the NT EPA will notify the proponent and Minister that assessment is at an end. If it is determined that a significant impact is likely then either the preparation of a Public Environment Report (PER) or an Environmental Impact Statement (EIS) is required. A PER is required if there is only a single or limited number of environmental issues; and impacts are limited in magnitude, duration, frequency and extent. An EIS is called for to assist in assessing environmental impacts which are considered significant either in terms of site specific issues, off-site issues and conservation values and / or the nature of the proposed action.

7 Monitoring Considerations

7.1 Overview

This section provides a description of performance indicators and likely monitoring programs for both ARs and FADs.

7.2 Performance Indicators

DPIR and the Cardno project team identified a range of performance indicators to measure program success. These performance indicators fall into three broad categories, biological, social and engineering as shown in **Table 7-1**.

Table 7-1 Performance indicators - deployment of ARs and FADs

Category	Performance Indicator Objective	Measure of Success
A. Biological		
A1. Fish	A1.1 Assess fish species assemblage, size and numbers at AR deployment location(s)	Fish species assemblage, size structure and numbers at AR deployment location(s) similar to natural reefs
	A1.2 Investigate larval and juvenile fish presence at AR deployment location(s)	Presence of larval and juvenile fish at AR deployment location(s)
	A1.3 Assess species assemblage, size and numbers at FAD deployment location(s)	Fish species assemblage, size structure and numbers at FAD deployment location(s) is enhanced compared to other open pelagic areas
	A1.4 Assess fish residency at AR deployment locations	Fish residency times at AR deployment locations are similar to those reported in the Darwin region.
A2. Macroinvertebrates	A2.1 – Assess colonisation of the AR structure by macroinvertebrates and pest species	Diversity and abundance of macroinvertebrates and pest species recorded at AR deployment locations is similar to that recorded throughout the greater Darwin region and natural reefs
	A2.2 – Assess colonisation of the FAD structures by macroinvertebrates and pest species	Diversity and abundance of macroinvertebrates and pest species is similar to that recorded throughout the greater Darwin region
B1. Social		
B1. Recreational Fishers	B1.1 Assess number and frequency recreational fishers utilise AR and FAD deployment locations	Significant increase in the number and frequency recreational fishers access AR and FAD deployment sites compared to pre-deployment periods
	B1.2 Assess recreational angler catch composition at AR and FAD deployment sites	Recreational angler catch composition is similar between AR and FAD deployment sites to similar habitats within the study area
	B1.3 Assess issues of conflict or overcrowding at AR or FAD deployment locations	Conflict or overcrowding at AR and FAD deployment locations is not identified by recreational fishers as a major issue
C. Engineering		
C1. Sediments	C1.1 Assess sediment scour in the vicinity of AR deployments	Sediment scour in the vicinity of deployed ARs sufficient to impact stability is not detected.
C2. FAD	C2.1 FAD maintains integrity and position at deployment location(s)	Integrity of FAD headgear and subsurface infrastructure is maintained and FAD does not substantially move from deployment location.

7.3 Monitoring Programs

Standardisation and consistency in monitoring methods used to investigate performance indicators is essential to enable the formulation of meaningful conclusions from any data collected to support subsequent DPIR management and research decisions.

Table 7-2 provides a description of the methods, sampling location(s), sample timing and data analysis techniques proposed to assess the identified performance indicators (**Table 7-1**).

Table 7-2 Monitoring program methods and locations. (Sampling Timing: PD – Pre-deployment, AD – After deployment).

Category	Performance Indicator Objective	Measure of Success	Method(s)	Sampling Location(s)/Design	Sampling Timing	Data Collected/ Derived	Data Analysis
A. Biological							
A1. Fish	A1.1 Assess fish species assemblage, size and numbers at AR deployment location(s)	Fish species assemblage, size structure and numbers at AR deployment location(s) similar to natural reefs	1. Fisheries Independent Sampling – Standardised fishing activities using a variety of hook sizes, baits and angling procedures. 2. BRUV deployments (if possible – based on visibility)	Asymmetric sampling design with a single AR location (if only one AR deployment) and multiple (minimum of three) natural 'reference' reef habitats. Avoid non-independence of samples: Ensure AR reference locations are space far enough apart so that fish are unlikely to commonly travel amongst them	PD: No sampling except to determine the location of natural 'reference' reefs. AD: Minimum of two sampling events in wet and dry season annually Duration: 3-5 years	1. Species present 2. Length of catch 3. Catch rates 4. nMax (BRUVS)	Multi-variate and univariate permutational analysis of variance (e.g. PERMANOVA) on various parameters including catch rates, assemblage composition and nMax. Size class comparisons (KS Tests)
	A1.2 Investigate presence of larval and juvenile fish at AR deployment location(s)	Presence of larval and juvenile fish at AR deployment location(s)	1. Deployment of baited fish traps at AR deployment location(s) 2. Deploy light traps at AR deployment location(s)	At AR deployment location(s).	PD: No sampling AD: Minimum of two sampling events in wet and dry season annually (or known spawning and recruitment times for fish within Darwin region) Duration: 3-5 years	1. Species present 2. Length of retained specimens 3. Catch rates	Multi-variate and univariate permutational analysis of variance (e.g. PERMANOVA) on various parameters including catch rates, community composition. Size class comparisons (KS Tests)
	A1.3 Assess species assemblage, size and numbers at FAD deployment location(s)	Fish species assemblage, size structure and numbers at FAD deployment location(s) is optimised for recreational fishers compared to other open water pelagic areas	Fisheries Independent Sampling – Standardised fishing activities at FAD deployment location(s) and non-FAD deployment locations.	Asymmetric sampling design with a single FAD location (if only one FAD deployment) else multiple FAD locations and multiple (minimum of three) 'reference' open water habitats. Avoid non-independence of samples: Ensure FAD clusters and reference locations are space far enough apart so that fish are unlikely to commonly travel amongst them within the sampling period	PD: Minimum of two sampling events in dry season prior to FAD deployment AD: Minimum of two sampling events in dry season annually Duration: 3-5 years	1. Species present 2. Length of catch 3. Catch rates	Multi-variate and univariate permutational analysis of variance (e.g. PERMANOVA) on various parameters including catch rates and assemblage composition Size class comparisons (KS Tests)
	A1.4 Assess fish movement patterns/residency times at AR deployment locations	Fish movement patterns/residency times at AR deployment location(s) are similar to those reported in the Darwin region.	Use fish tagging techniques to examine fish movement patterns/residency times at AR deployment location(s)	At AR deployment location(s).	PD: No sampling AD: As per ongoing DPIR fish tagging activities Duration: Ongoing - based on DPIR funding availability	1. Fish movement/residency pattern 2. Fish growth (based on days at large)	von-Bertalanffy growth function analysis Spatial distribution analysis
A2. Macroinvertebrates	A2.1 – Assess colonisation of the AR structure by macroinvertebrates and pest species	Diversity and abundance of macroinvertebrates and pest species recorded at AR deployment locations is similar to that recorded throughout the greater Darwin region, natural reefs and other artificial reef structures	Examination of removable settlement plates installed at AR deployment location(s). Use of settlement plates that facilitates short and long term colonisation and succession investigations If no data available on in relation to macroinvertebrate assemblages at natural reefs and other artificial reef structures data to be collected from these alternate locations BRUV/Camera deployments (if possible – based on visibility)	At AR deployment location(s) and potentially at natural reefs and other artificial reef structures	PD: No sampling AD: Annually Duration: 3-5 years	1. Species assemblage present 2. Diversity index 3. Presence of pest species 4. Temporal changes in the composition of species present at AR deployment location(s)	Multi-variate and univariate permutational analysis of variance (e.g. PERMANOVA).
	A2.2 – Assess colonisation of the FAD structures by macroinvertebrates and pest species	Diversity and abundance of macroinvertebrates and pest species is similar to that recorded throughout the greater Darwin region.	Examine and describe macroinvertebrate assemblages that colonise FAD headgear and associated in water infrastructure	At FAD deployment location(s)	PD: No sampling AD: Annually Duration: Ongoing with FAD deployment program	1. Species assemblage present 2. Diversity index 3. Presence of pest species	Descriptive – percentage cover Multi-variate and univariate permutational analysis of variance (e.g. PERMANOVA) between FAD deployment locations and successive seasons.
B. Social							

Category	Performance Indicator Objective	Measure of Success	Method(s)	Sampling Location(s)/Design	Sampling Timing	Data Collected/ Derived	Data Analysis
B1. Recreational Fishers	B1.1 Assess number and frequency recreational fishers utilise AR and FAD deployment locations.	Significant increase in the number and frequency recreational fishers access AR and FAD deployment sites compared to pre-deployment periods.	Recreational fishing surveys/ access point surveys with specific reference to selecting fishing areas visited (grid references).	1. Various boat ramps (access points) within the greater Darwin region with particular emphasis on those ramps in relatively close proximity to AR and FAD deployment location(s). 2. Telephone interviews	PD: Minimum of two sampling events in dry and wet season prior to AR and FAD deployment AD: Minimum of two sampling events in dry and wet season annually or as per existing ongoing recreational survey sampling design Duration: 3-5 years	1. Spatial and temporal recreational fisher distribution 2. Spatial and temporal distribution of recreational fishers at boat ramps 3. Number of fishing trips being conducted to AR and FAD locations (locals and tourists)	Univariate permutational analysis of variance (e.g. PERMANOVA) examining spatial distribution of fishing effort and number of fishing trips conducted
	B1.2 Assess recreational angler catch composition at AR and FAD deployment sites.	Recreational angler catch composition and catch rates at AR and FAD deployment location(s) are comparable or considered better than natural reefs or existing artificial reefs and open pelagic areas respectively.	1. Recreational fishing surveys/ questionnaires that specifically reference activities and catch at AR and FAD deployment location(s) and other fishing sites. 2. Angler log book program	1. Various boat ramps within the greater Darwin region with particular emphasis on those ramps in relatively close proximity to AR and FAD deployment location(s). 2. Telephone interviews 3. Dissemination of log books to identified stakeholders and volunteers	PD: Minimum of two sampling events in dry and wet season prior to FAD deployment AD: Minimum of two sampling events in dry and wet season annually or as per existing ongoing recreational survey sampling design. Log books as per participation rates Duration: Ongoing	1. Recreational catch composition at AR and FAD deployment location(s) 2. Catch rates at AR at AR and FAD deployment location(s) 3. Recreational catch composition at comparable non AR and FAD deployment location(s) 4. Catch rates at non AR and FAD deployment location(s)	Univariate permutational analysis of variance (e.g. PERMANOVA) examining catch rates between AR and FAD deployment location(s) and other fishing sites.
	B1.3 Assess issues of conflict or overcrowding at AR or FAD deployment locations	Conflict or overcrowding at AR and FAD deployment locations is not identified by recreational fishers as a major issue	1. Recreational fishing surveys/ questionnaires that specifically reference conflict or overcrowding at AR and FAD deployment location(s) 2. Monitor fishing forum(s) and social media posts making reference to conflict or overcrowding at AR and FAD deployment location(s)	1. Various boat ramps within the greater Darwin region with particular emphasis on those ramps in relatively close proximity to AR and FAD deployment location(s). 2. Telephone interviews 3. Identified popular fishing forum(s) within the greater Darwin region (e.g. Northern Australian Fish Finder Forum, https://fishingterritory.com/) 4. Liaise with local police 5. Take note of any conflict during sampling described in A1.1, A1.3, A1.4 and A2.1.	PD: No sampling AD: Minimum of two sampling events in dry and wet season annually or as per existing ongoing recreational survey sampling design. Monitoring forum(s) monthly Duration: Ongoing	Anecdotal and records of conflict and overcrowding at AR and FAD deployment location(s)	Spatial and temporal distribution of conflict and overcrowding reports.
C. Engineering							
C1. Sediments	C1.1 Assess sediment scour in the vicinity of AR deployments	Sediment scour in the vicinity of deployed ARs sufficient to impact stability is not detected.	Use multi-beam survey techniques to conduct high resolution surveys of AR deployment location(s)	At AR deployment location(s)	PD: No sampling AD: After 1st year and prior to 3rd year after deployment	Multi-beam point source data	Multi-beam point topographic and contour for interpretation of sediment scour
C2. FAD	C2.1 FAD maintains integrity and position at deployment location(s)	Integrity of FAD headgear and subsurface infrastructure is maintained and FAD does not substantially move from deployment location.	1. Visually and where possible use a camera to examine integrity of FAD headgear and subsurface infrastructure 2. Inspect and record position of FAD using GPS.	At FAD deployment location(s)	PD: No sampling AD: Weekly in the first month following deployment, and monthly during the first deployment season	1. Photographs/field notes of FAD headgear and underwater infrastructure 2. GPS coordinates of deployed FAD	Examination of photographs and field noted in relation to FAD headgear and subsurface infrastructure integrity Temporal examination of the GPS coordinates for each FAD

7.4 Sampling Design Considerations

7.4.1 FADs

Kingsford (1999) considered issues related to the design of experiments associated with FADs, focusing on how data should be collected, rather than what data should be collected. He argued that good experimental design has not been applied in many studies, which limits the way that findings can be interpreted. Other key points for consideration included:

- Use of MBACI (Multiple-Before-After-Control-Impact) sampling designs, which requires sampling at multiple locations when FADs are to be deployed, multiple control locations (areas of the sea where no FADs are deployed), multiple time of sampling before FADs deployment and multiple times of sampling after deployment. Kingsford (1999) argued that FADs can be seen as an environmental "impact" (albeit beneficial for fishers) and adapted the approaches developed for environmental impact assessment (EIA) to measure unambiguously the effects of FADs (see Keough and Mapstone 1985, Underwood 1994, 1997 for further details). This type of approach has been utilised in others fisheries projects (see Lincoln Smith et al. 2006 for use in a study of a marine protected area).
- Avoidance of non-independence of samples. This occurs where one sample in space or time influences another. For example, if FADs are deployed very close together the fish may swim between them. If fish are sampled by net or line fishing at a FAD on one day, sampling the next day may be non-independent if many of the fish have removed on the previous day.
- Use of sample replication and avoidance of pseudoreplication. For every type of FAD deployed and monitored there should be replicate FADs to provide a measure of variability among units. Pseudoreplication applies to confounding of effects due to sampling replicates at a single site or time;
- Confounding by "demonic intrusions". Kingsford (1999) argued that floating objects drifting past FADs could confound estimates of diversity or abundance if such objects (e.g. drifting logs) bring fish to the FADs or attract them away. This may be significant in the Territory Study Area where there are big tides, strong currents and runoff.

Recently, Bell et al. (2015) presented a sampling design using an MBACI approach to monitor nearshore FADs at Pacific Islands Countries and Territories (PICT). They argued that long-term sampling around replicate FADs at multiple sites is needed to provide robust estimates of average catches.

Bell et al. (2015) presented a multifactorial study design for studying FADs simultaneously at three PICT including five factors, which conforms to the MBACI approach recommended by Kingsford (1999):

1. Before v After deployment of FADs
2. Random Periods sampled before and after deployment
3. Treatment (FADs v no- FADs)
4. Country
5. Comparisons of replicate FADs (or no-FADs) deployed in each of two Locally-Managed Marine Areas (LMMA) within each PICT.

This design requires a minimum of 48 FADs (i.e. two replicates) to be deployed and studied across the three PICT. Though the above design is only an example, DPIR should ensure that any FAD monitoring program incorporates MBACI design principles. Moreover, DPIR should consider the sampling design of future monitoring program requirements prior to committing to particular FAD deployment configurations.

7.4.2 Artificial Reefs

As per FAD monitoring (see **Section 7.4.1**), where possible a MBACI sampling design should be incorporated into any AR monitoring program. In reality, given the cost of AR construction and deployment it is likely that a limited number of AR deployments are conceivable. As such, AR monitoring will inherently need to incorporate an asymmetrical sampling design (i.e. a single AR sampling location and multiple control or reference locations). Such an asymmetrical design allows for comparison of variability of indicators within and among reference locations compared with the variability associated with the AR. DPIR should consider the sampling design of future monitoring program requirements prior to committing to particular AR deployment configurations.

8 Further Investigations

8.1 Overview

This section provides a description of the limitations associated with the data used to identify potential AR and FAD deployment areas as well as identifying further investigations that are recommended to further inform the identification and prioritisation of deployment locations.

Further data collection and investigations should be undertaken once DPIR have identified and prioritised potential AR and FAD deployment areas.

8.2 Data Limitations and Opportunities

MCA analyses were undertaken using spatial data from a variety of sources with extensive efforts were made to use the highest quality data during the study. It is acknowledged however that due to the nature and size of the study area as well as the limited coverage of some data sources, there is scope to further refine the resolution of the data used in the MCA. A summary of the potential limitations associated with the spatial data for criteria used in the MCAs that have existing potential opportunities to increase the resolution of data available for the identification potential AR and FAD deployment areas are provided in **Table 8-1**. Details relating to the source and data processing steps undertaken for each MCA criteria used as part of this study are in **Appendix E**.

8.3 Further Investigations Required

As identified in **Section 8.2**, data with a variety of limitations was used to identify potential AR and FAD deployment areas. Once DPIR have identified priority AR and FAD deployment areas it is recommended that some further investigations are undertaken to ensure the suitability of these areas and identify specific sites within the larger areas. **Table 8-2** outlines the further investigations that are recommended to be undertaken prior to the selection of a specific location to deploy ARs or FADs.

Table 8-1 Summary of MCA criteria data sources, spatial coverage and existing known opportunities to increase the resolution of dataset

Criterion	Data Source Used	Spatial Coverage	Existing known opportunities to increase resolution and applicability of data
Loss of existing high relief benthic habitat is avoided	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017	AusENC data covered the whole study area and were interpolated from bathymetric vector contours	**Data Set:** Geoscience Australia high resolution multi-beam bathymetric data. **Limitation:** The high quality grid data currently only covered areas within Darwin and Bynoe Harbours and the inshore area from Lorna Shoal through to Gunn Point
Loss of existing seagrass habitat is minimised	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017. Seagrass assumed to potentially inhabit all waters between 0 and -10 LAT	AusENC data covered the whole study area and were interpolated from bathymetric vector contours	**Data Set:** Limited seagrass distribution known for Darwin Harbour and Bynoe Harbour. **Limitations:** Limited knowledge of seagrass distribution throughout the study area
Artificial Reefs and Fish Attracting Devices are Stable	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017.	AusENC substrate point data covered the whole study area but were more densely distributed in and around Bynoe Harbour and the Vernon Islands. They were sparsely distributed around Chambers Bay in the Van Diemen Gulf area, and around Anson Bay and Fog Bay in the South West.	**Data Set:** Sediment particle size map derived substrates INPEX Ichthys Gas Field Development Project 2011, survey by Geo Oceans. **Limitations:** The INPEX substrates type map was limited to the inshore coastal area between Cape Ford in the South West Charles Point

Table 8-2 Recommended further investigations to be undertaken to identify potential AR and FAD deployment areas

Criteria	Existing Information	Further Investigation
Loss of existing high relief benthic habitat is avoided	AusENC data covered the whole study area and were interpolated from bathymetric vector contours	Complete drop camera and collate high resolution multi-beam bathymetric data to determine the local bathymetric profile at proposed deployment location
Loss of existing seagrass habitat is minimised	Seagrass assumed to potentially inhabit all waters between 0 and -10 LAT	Complete drop camera survey at proposed deployment location to ensure no seagrass is present
Artificial Reefs and Fish Attracting Devices are Stable	AusENC substrate point data covered the whole study area but were more densely distributed in and around Bynoe Harbour and the Vernon Islands. They were sparsely distributed around Chambers Bay in the Van Diemen Gulf area, and around Anson Bay and Fog Bay in the South West.	Complete sediment grab sampling at proposed AR and FAD deployment areas to ensure the particle size distribution and sediment characteristics are suitable to ensure the stability of deployed infrastructure.
Interference with marine infrastructure is avoided	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017. Dredge spoil grounds - Ichthys Gas Field Development Project - Appendix 13 - Dredging and Spoil Disposal Modelling	Liaison with Harbour Master and other stakeholders (e.g. Defence, INPEX, Connex) to ensure AR and FAD deployment locations will not interfere with future infrastructure.
Cultural Heritage sites are avoided	AAPA_NT_Coastal_Sacred_Sites.kmz supplied by NT Government List of sacred sites are considered comprehensive throughout the study area in terms of protection status.	Liaise with aboriginal stakeholders in relation to the appropriateness of potential AR and FAD deployment areas.

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APPENDIX

A

AR LITERATURE SUMMARY

Artificial Reefs

Overview

Artificial Reefs (ARs) are deployed in many countries to enhance artisanal, commercial and recreational fisheries as well as for spearfishing (Baine 2001). More recently, ARs have also been deployed for aquaculture, recreational diving, habitat restoration, environmental mitigation or purely for experimental research (Seaman 2002). The two principle goals of AR deployment are for economic/community development and, more recently, for environmental resource conservation (Seaman 2002). In many countries ARs have now become important elements of integrated fishery or coastal management plans (Leitão et al. 2007, Becker et al. 2017, Fabi et al. 2002, Leitão et al. 2007, Tessier et al. 2015). A recent trend for deployment has been to use specifically designed structures as opposed to using opportunistic waste materials (see below). Given the objectives for this project are focused on enhancing recreational fishing opportunities, the review below focuses on artificial reefs for fishing.

History of Artificial Reefs for Fishing

General

A demand for more recreational fishing opportunity or improved habitat has driven an increase in deployment of ARs (Bohnsack et al. 1997). Patented 'reef ball' technology (using purpose built, moulded concrete modules) is used in almost all coastal states of the United States (US). In Florida, there are approximately 29 projects and in South Carolina, there are permits for the continued development of 38 AR and inshore or offshore sites, located at depths between 3 m to 37 m. The US National Oceanic and Atmospheric Administration (NOAA) has since developed a National Artificial Reef Plan including practical guidelines for the siting, development and construction of artificial reefs to assist in managing the escalating number of projects.

In Europe, the construction of ARs began in the late 1960's and they have since been deployed in Norway, Poland, Finland, UK, France, Germany, Greece, Turkey, Spain, Italy, Netherlands, Israel, Russia and Portugal. The AR complex of the Algarve (Southern Portugal) for example, deployed for the purpose of restoring and enhancing fisheries resources, is currently the largest structure of its kind in Europe, extending over 43.5 km^2 (Ramos et al. 2007), and consists of seven AR systems (Moura et al. 2006).

As an alternative to their disposal, investigation of decommissioned gas and oil rigs as ARs has also been undertaken in the North and Adriatic seas (Sayer and Baine 2002, Fabi et al. 2004, Løkkeborg et al. 2002) as well as in Australia (Fowler et al. 2014). Although results have shown some increases in total catch and species diversity in and around the platforms there is divided opinion about using decommissioned oil rigs as ARs for fishing.

In South-East Asia, overexploitation of fisheries and degradation of coastal and marine habitats has prompted development of large-scale AR projects (Pauly and Chua 1988). Artificial reefs have been developed in Malaysia, Thailand, the Philippines, Taiwan, Singapore, Brunei, Indonesia, Hong Kong, Korea and Japan. Recently, Japan and Korea have become leaders in research and development of purpose built, large-scale ARs for fisheries enhancement. Results of long-term monitoring studies show that ARs yielded catch volumes 2 – 13 times greater than those of natural reefs (Kim et al. 2008). In 2001, Korea invested over $2 billion (US), over a 6-year period, in AR projects for enhancing coastal fisheries. Many of the world's largest ARs have been deployed in Japan as part of the national fisheries program for enhancement of commercial fish stocks. They consist of both shallow water ARs targeting shellfish and deeper water ARs for finfish.

There have been at least four detailed reviews of artificial reefs in Australia (Pollard and Mathews 1985; Kerr 1992; Branden et al. 1994 and Coutin 2001). Collectively these reviews detail the development between 1965 to 2001 of Australian AR design, construction, deployment and monitoring. The first AR was created from concrete pipes laid in Port Phillip Bay (Kerr 1992). Within a few years there were ARs constructed of various materials (tyres, concrete rubble and or car bodies) in New South Wales, South Australia, Western Australia and Queensland. The main purpose of ARs in Australia has been for recreational fishing and diving (Branden et al. 1994) and historically, materials of opportunity (waste material) have been the main materials used in their construction, including objects such as car bodies, tyres and decommissioned ships (Pollard 1989; Kerr 1992).

Given it is now known that different species of fish may respond to hard objects in different ways (Kim et al. 2008), recent emphasis has been on designing ARs (for fisheries enhancement) to the requirements of the target species. In Korea, for example, the differing ecological needs (in terms of shelter) of the target species, have guided the design of box reefs for marine ranching. The effect of tailored designs on catch rates are generally considered positive (Seaman 2007)

Previous Artificial Reef Deployments in the Northern Territory

There are a number of ARs already deployed in the greater Darwin district. The existing ARs have been developed through acquisition and deployment of 'materials of opportunity' (such as old ship hulls, surplus road culverts, concrete pipes, decommissioned machines and plant equipment). A summary of deployments is given below and in Table A-1, noting that some of the metal structures may have since disintegrated.

In 1988, the Northern Territory Government constructed the Fenton Patches artificial reef complex. Seven reefs were deployed that include a two nautical mile wide zone exclusively for recreational use by anglers and divers.

In 1996, three artificial sites were created closer to Darwin at Lee Point. The three sites at Lee Point (Rick Mills, Truck Tipper and Bottle Washer) are approximately 3 nm offshore and are easily accessible from boat ramps in Darwin's northern suburbs. Between 2006 and 2013, various additional structures have been added to the sites opportunistically.

Within the confines of Darwin Harbour, five steel vessels were sunk in various locations for the purpose of recreational fishing and diving.

Additionally, for the past two years there has been an unused oil rig (Stena Clyde) stationed about 70 km off the coast of Darwin. Anecdotal evidence indicates it holds various pelagic and demersal species and it is a very popular destination for anglers using medium to large-sized trailer boats.

Design

In a review of AR projects, Baine (2001) indicated that only 50% of cases had met their objectives, the remainder having no, little or limited success, hence raising questions about their value. Baine (2001) concluded that although ARs do have the potential to fulfil the many objectives for which they are promoted, their success ultimately reflects the quality of prior planning and ongoing management that is afforded them. In terms of the important design features, 36 papers (14%) noted the importance of complexity, the configuration of the AR, its size, volume and area. The provision of shelter through refuges and crevices was highlighted as important in 6% of studies, particularly in relation to juveniles or for shellfish. Other factors considered important to their success included structural integrity and stability and the type of material used for construction. Aspects for important consideration in the design of ARs for specific species included the amount of void space, bottom relief, height and shading.

Very much integrated with the AR and its design is the site where it is to be placed and local environmental conditions. Forty papers (16%) cited local habitat and sediment type to be important as well as the ecological aspects of recruitment/ colonisation by target species, behaviour of adults and targets for biodiversity. Other factors often cited as important included currents or wave action, and other hydrographic parameters such as temperature, depth and water quality.

Table A-1 Description of existing artificial reefs in the study area.

Fenton Patches Sites	Description	Size (m3)
Amanda Lee	20 m steel vessel	500
Antares and steel barge	20 m steel vessel & 10x10 m steel barge	500
Amelia C and Merindah Pearl	2 x 20 m steel vessels	1000
Marchart	32 m steel vessel	700
Albatross/ Grevillea	2 x 20 m steel vessels	No data
Bus Stop	6 x steel shipping pontoons, 45 x truck tyres, 3 x concrete bus shelters, 1 x 10 m steel boat cut in 2 sections, approximate total- 200 tonnes of materials	500
Galah/Heron	2 x 20 m timber vessels	No data
Pipeline	200 tonnes of large concrete pipe	500
Cockatoo / Mudlark	2 x 20 m timber vessels	No data
Brolga/Eagle	2 x 20 m timber vessels	No data
Lee Point Sites	**Description**	**Size (m^3)**
Rick Mills	Assorted plant equipment	300
Rick Mills Containers	Modified sea container	100
Rick Mills culverts	culverts	300
Bottle washer	Decommissioned coke bottle washing machine and various plant equipment	500
Bottle washer culverts	culverts	300
Assorted pipes and concrete culverts	assorted concrete items	700
Truck tippers	Twenty mining truck side tippers and two steel pontoons	500
Kay Lee	Steel vessel 15 m	300
Cullen Bay Pontoon	Pontoon Walkway	600
Darwin Harbour Sites	**Description**	**Size (m^3)**
Medkhanun	27 m steel vessel	700
Ham Luong	15 m steel vessel	500
Song Saigon	20 m steel vessel	500
John Holland Barge	18 m x 12 m steel barge	500
DSAC Barge	20 m steel barge	500

Size

Several companies are now patenting AR modules of various sizes. In general, smaller, low relief ARs (e.g. 'reef balls') are often deployed in sheltered estuaries or bays (Folpp et al. 2011) whereas larger modules are generally deployed in offshore waters (Reeds 2017).

The largest ARs for fishing are decommissioned oil rigs. As of 2012, 420 platforms in the Gulf of Mexico have been decommissioned, re-purposed and permitted as ARs through state-run 'Rigs-to-Reefs' programs (Ajemian et al. 2015) and as more platforms reach the end of their operational lifespans, the potential for more of these types of ARs is increasing (Ajemian et al. 2015). In terms of purpose build ARs, some of the largest consist of high relief, complex steel structures deployed in deep water, such as those used to augment fish populations in Japan and Korea (Seaman 2002, Ito 2011). The first 'designed' large steel AR in Australia was deployed off the coast of Sydney, NSW, in 2011, with the aim of providing habitat for target recreational fish species such as snapper and yellowtail kingfish. The success and popularity of this Sydney 'Offshore Artificial Reef' (OAR) (Keller et al. 2016, 2017), has paved the way for numerous multi-component reefs throughout Australia. These are predominantly funded through recreational fishing licence fees and seen as a positive and tangible return to the fishing community (NSW DPI, Pers. comm.).

The size of an AR may be relevant to the accumulation properties of ARs given size imposes physical limits on the abundance of fishes that can be accommodated. Notwithstanding this, large, simple structures are poor fish attractants without some complexity of microhabitat (Kerry and Bellwood 2012).

Shape (including complexity, vertical relief, void space, shelter and shading)

In addition to the varied sizes of AR modules, companies are manufacturing and patenting modules of various shapes (e.g. cubes, cylinders, domes and pyramids) (Reeds 2017).

General Complexity

Bohnsack and Sutherland (1985) suggest that complexity is an important consideration in the design of ARs because greater complexity can increase diversity of species and biomass. There are many studies of fish on natural and artificial reefs that confirm this hypothesis.

In the Southern Californian Bight, Granneman and Steele (2015) investigated fish communities on ARs of a varying complexity. The findings were consistent with the intuitive prediction that fish assemblages on ARs would be similar to those on natural reefs if their physical attributes were similar. ARs made from smaller boulders and that had relatively low vertical relief and rugosities, were structurally similar, and had similar fish assemblages, to low relief natural reefs in the region. The more complex artificial reefs (i.e. that had greater rugosities and relief because they were built of larger boulders that were piled higher than for natural reefs) supported fish assemblages that were approximately two- to five-fold more dense and had two- to three-fold more biomass than those on nearby natural low relief reefs. The difference in biomass was somewhat less exaggerated than density due to the abundance of small fish on ARs. This difference in the size of fish was considered possibly due to enhanced recruitment of small, young fish to the higher relief and structurally more complex ARs, coupled with the presence of older, bigger fish on natural reefs.

In another study in Brazil, reef blocks with greater area and number of holes possessed greater species richness and abundance than those of blocks with less complexity (Hackradt et al. 2011). Reef blocks with greater complexity had higher abundance of almost 30% of fish types present. In this study, natural reef and ARs were different in their species composition, trophic structure and categories of water column occupancy by fish (spatial categories), probably because the ARs were less complex than the natural reefs. Although natural reef was more diverse and harboured more trophic levels, ARs presented the greater abundances and the presence of distinct species.

Importantly, to have high abundances and/or diversities of fish, ARs need to include shelter for species, or at worst, there must be shelter nearby. In an acoustic tagging study of white sea bream (*Diplodus sargus*) in Portugal, fish were found to only use the ARs for foraging during the day, preferring to take shelter at night on natural reefs ~ 1 km away (Abecasis et al. 2013). Hence, if ARs do not include structures that provide refuge, or are not close to refuge areas, their potential for enhancement of populations of some species may be limited. This is discussed further in sections below.

Vertical Relief

Natural reefs that offer vertical relief are often characterized by great taxonomic diversity relative to their surroundings (Fagerstrom 1987) and there is ample evidence to suggest that if ARs have vertical relief then they too can have great taxonomic diversity (Bohnsack et al. 1994; Ogawa 1967; Molles 1978; Beets 1989).

Boswell et al. (2010) observed the great aggregations of fish underneath a decommissioned oil and gas platform to be closely associated with the vertical slopes in the structure. Similar association of great diversity and abundance with vertical relief has also demonstrated in other studies of ARs (e.g. Thorne et al. 1989, and Nakamura and Hamano 2009). Davis and Smith (2017) assessed proximity effects of small natural and artificial vertical walls on patterns of fish assemblages, testing whether wall size affected assemblages, and whether assemblages differed between wall types. Fish assemblages were found to change in the immediate vicinity of both natural and artificial walls, with significantly greater species richness and abundance occurring at reef walls than in surrounding, flatter reef areas. The size of the effect generated by walls was found to be proportional to the size of the wall, with species richness and abundance generally increasing with wall height and length. Differences between natural and artificial walls were detected, but these were confounded by differences in size between wall types. The study builds on previous work by showing that, within reefs, local areas of great species richness and abundance can occur in the vicinity of small but important reef features such as vertical walls, suggesting that walls appear to act as localised biodiversity 'hotspots'.

Vertical relief also plays an important role in recruitment, at least for coral reef fish. The construction of complex vertical ARs is preferable over low relief ones to achieve rapid recruitment of coral reef fish. Rilov and Yehuda Benayahu (2002) tested the hypothesis that high relief artificial reefs had more recruitment of coral reef fishes, mainly planktivores, than near-bottom low relief artificial reefs. Indeed, recruitment was about two orders of magnitude more in the experimental vertical installations than to the near-bottom ones. Most of the initial recruitment occurred at the upper sections of the vertical installations, which may indicate near surface movement of fish larvae as they approach the structure. Alternatively, it may result from preference by planktivorous species for areas with greatest water/ plankton flux.

Void Space, Shelter and Shade

Determining the optimal amount of void space is complicated. Void space is simply another term for shelter size, and the optimum appears to be highly species dependent (Bohnsack et al. 1991; Spieler et al. 2001). Several studies have noted the importance of hole size relative to body size of reef fishes as a means of predator exclusion (e.g. Hixon and Beets 1993; Almany 2004a, Almany 2004b).

Kellison and Sedberry (1998) found significantly more benthic fishes aggregated to ARs with holes present than for ARs with holes absent, supporting the hypothesis that the addition of holes (or voids) to an AR can increase the mean numbers of species and individuals present on an AR. They considered that the smaller numbers of species and individuals on ARs without holes may have been because there was less juvenile and adult recruitment to those units.

It is apparent from the many studies that some void space is important for biomass and diversity but very large voids may be less desirable than smaller voids because they offer less shelter and less niches. For example, Sherman et al. (2002) considered that ARs with less void space and more structural complexity had greater fish abundance, species richness, and biomass than hollow reefs. These results support Eklund's (1996) observations that adding concrete block rubble to the void space of ARs increased the numbers of fishes, species, and biomass compared to hollow reefs, noting that ARs with the concrete blocks added had smaller voids. Shulman (1984) also found that the number and size of refuges significantly affected the number, size, and species richness of fishes. Likewise, Hixon and Beets (1989) found a positive correlation between the number and size of refuges with the number and size of the associated fishes. It is noteworthy that these researchers indicated that their results may not be applicable to all reef types, environments, and fish assemblages.

In addition to size, the shape of the void and its position on an AR can also be very important. In a study of large reef fishes at Lizard Island on the Great Barrier Reef, Kerry and Bellwood (2012) found tabular corals were utilised significantly more often by large reef fishes than branching or massive corals with no undercuts, with more than triple the abundance, biomass and resident times of large fishes compared to the other morphologies. The association with tabular corals of all but one of the 11 families of large reef fishes observed (including Haemulidae and Lutjanidae, along with lower counts of the Serranidae and Mullidae), underlines the importance of this result and provides quantitative evidence in support of previous studies that point to a relationship between fishes and tabular corals (Shibuno et al. 2008). Kerry and Bellwood's (2012) study suggested that it is the species composition of corals or specific structural attributes that shape habitat usage by large reef fishes. Given their canopy, it is intuitive that tabular corals should outperform both branching and massive corals in providing concealment or shade for large reef fishes. Branching corals provide highly complex microhabitat, which is often utilised by smaller reef fishes for shelter. Tabular corals may be more important to large fishes, while branching corals support smaller species and the early ontogenetic stages of larger species. The authors also note that large massive corals (i.e. bommies) may also provide similar functional characteristics as tabular corals if their undercut edges create overhangs, producing a similar canopy effect to that offered by tabular corals.

Importantly, Kerry and Bellwood (2012) found artificial shelter units and tabular corals were functionally equivalent, supporting fish communities that were not significantly different, and had comparable occupancy rates for large reef fishes. Notably, large reef fishes preferred opaque rather than translucent canopies. It appeared that large fishes cued to tabular corals because of the concealment and/or shade provided. A 20-cm gap between base and canopy was considered necessary to maximise artificial shelter units used by fishes. Colony size of tabular corals had a positive effect on the abundance of large reef fishes but showed no clear relationship with biomass or residence times, suggesting that larger shelters can accommodate greater numbers of fishes but are otherwise no more useful to large fishes than moderately sized colonies (40 cm mean diameter). The families recorded using tabular corals in the observational study were predominantly roving fishes. It may be that these fishes utilise refuge stations such as tabular corals to reduce predation risk when resting in between feeding and other activities. In this case, the same principles apply but in reverse, so the ambush predator is both better able to see oncoming prey (Helfman 1981) and at the same time less easy to detect (Mazur and Beauchamp 2003). Larger reef fishes are less likely to be subjects of ambush predation, are more at risk from roving apex predators and are also more likely to be ambush predators (Almany 2004b), hence the attraction of concealment and shade. In contrast, smaller fishes Pomacentridae, Gobiidae, Blenniidae and Apogonidae) were associated mainly with artificial shelter units that did not visually obstruct their view. The authors suggested that this is because smaller bodied species are more likely to be subjects of ambush predation (Almany 2004a, 2004b) and benefit from being able to see in every direction, thereby reducing opportunities for ambush predators. It is also possible that in Kerry and Bellwood's (2012) study smaller reef fishes did not generally associate with shaded treatments because they were displaced by larger fishes (Shulman 1985a, 1985b).

Water Depth

Few studies that have been designed to determine if water depth is a factor affecting diversity and abundance of fish on ARs. In Portugal, Santos et al (2013) showed there were slightly higher densities of species recorded on deeper reefs relative to shallow reefs but other investigations focusing on particular species are confounded by potential ontogenetic shifts in habitat. For example, in a study of red snapper (*Lutjanus campechanus*) in the Gulf of Mexico, there were significantly more small fish (<33 cm TL) at shallower depths (<35 m) and on small artificial reefs than at deep sites (>35 m) (Jaxion-Harm and Szedlmayer (2015).

Location (including configuration, distance apart and distance from other reefs)

Siting

Choosing optimal locations for ARs and the configuration of modules is one of the main challenges to managers. For example, it would not be prudent to put them in areas that fish are known to avoid (e.g. areas where bottom water is anoxic or where there are other deterrents to fish) or, in the case of ARs designed for fishing, where fishing is limited because for example, currents, near the seabed, are too strong to hold fishing gear.

Distances between ARs and from Natural Reefs

Ideally, the diversity and abundance of fish on an AR would be additional production to the regional natural reefs and there would be minimal attraction of fish from the closest natural reefs (see **Appendix C**). To minimise the potential for attraction, ARs should be positioned beyond the home ranges of fish on natural reefs. Home ranges are not known for the target species for this project but studies of demersal reef fish in other countries associated with ARs and/or natural reefs give an indication of suitable separation distances.

The optimal separation between an AR system and natural reef can vary broadly depending on the relative sizes of nearby natural reef (Kim et al. 2008), but falls in the range of 500 m to 1000 m. A distance of 500 m is generally regarded as the maximum range over which two groups of fish resident in a natural/artificial reef are likely to interact. Topping and Szedlmayer (2011) manually tracked red snapper (*Lutjanus campechanus*) (550–745 mm TL) at ARs in the in the Gulf of Mexico over 24-hr periods. Fish stayed near ARs (<100 m, with 75% of locations within 30 m of the structure), but were significantly further from the reefs at night (mean = 27.5 m) than day (mean = 19.1 m). Based on manual tracking, home range and mean distance from the reef increased with fish size. These fish also showed long-term residence of 332–958 days based on passive acoustic monitoring.

In another acoustic tagging study by Abecasis et al. (2013), already discussed above, White Sea bream (*Diplodus sargus*) in Portugal were found to make regular use of ARs. However, utilisation had a strong diel pattern with detections occurring almost exclusively during daytime. This use, on a regular basis, was considered most likely related to feeding and may also suggest that those AR structures were not particularly adequate for providing shelter during the night or are not preferred when other types of habitats (i.e. natural reefs) are available nearby (~1 km away).

Configuration of Modules

Individual AR modules can be arranged within clusters to form multi-component reef 'complexes' or patch reefs that increase the effective footprint of the AR system. The spatial complexity plays a prominent role in the ecological effectiveness of ARs but the spatial configuration is seldom discussed. Complicating the problem is that decision makers often have the challenge of a limited budget for deploying ARs and want to maximise 'bang for their buck' (Lan et al. 2004). Determining the appropriate distances between ARs and the number of modules requires primarily an understanding of how far fish move away from modules to forage (see previous section). Some researchers have tried sophisticated approaches to determining spatial configurations and numbers of ARs. Lan et al (2004), for example, developed a model that can optimise an arrangement by considering the costs, the budget and the deploying distance.

Properly spaced ARs would ideally take advantage of small-scale movements of fish while also limiting potential foraging overlap. Consequences of resource depletion caused by the overlap of foraging haloes are a reason why the deployment of artificial reefs should include consideration of reef spacing to minimize halo overlap, or foraging area. The resource mosaic hypothesis predicts (in part) that as reef spacing decreases, access to prey that inhabit the soft-bottom area around the reefs also decreases (Frazer and Lindberg 1994). Given some species feed on non-reef associated demersal prey they can create areas of intense prey depletion ('foraging haloes') around the reef structures, and prey depletion increases as reef spacing decreases because of the greater overlap of foraging activity (Lindberg et al. 1990; Frazer and Lindberg 1994; Campbell et al. 2011). The feeding haloes may have negative effects on abundance, growth, and residence time of fish on ARs if the fish are forced to forage outside of the halo area, making them more susceptible to predation (Lindberg et al. 1990). Frazer and Lindberg (1994) believed that more widely spaced reefs should result in decreased halo overlap, leading to an increased density of potential prey species in soft-bottom habitat and increased foraging opportunities for species.

Scott et al. (2015) showed that a fish assemblage associated with an AR is unlikely to be detected 30 m away from the AR, even for associated pelagic species (e.g. yellowtail kingfish, *Seriola lalandi*) (Figure A-1). This distance is likely to depend on numerous factors, such as the size of the AR, the species-specific composition of the assemblage, the willingness of fish to travel far from an AR possibly related to their ability to find their way back to those structures (i.e. their homing ability) and, perhaps most importantly, the proximity of an AR to other structures. It is thought that more isolated ARs will have a greater species diversity and be used by a larger abundance of pelagic fish (Walsh 1985; Jordan et al. 2005; Vega Ferna´ndez et al. 2008), whereas highly connected ARs will have a greater abundance of reef resident species (Vega Ferna´ndez et al. 2008).

Lowry et al. (2017) in a study of the yellowfin bream (*Acanthopagrus australis*) in a south-east Australian estuary found a large number of fish moved within a network of ARs but remained resident within the network. This study provides further evidence that large-scale reef complexes provide benefit in terms of habitat use. Lowry et al. (2017) also suggested that a network of ARs possibly reduces the risk of fishing-related mortality.

The proximity between artificial reef units within reef clusters is a key consideration for artificial reef research (Campbell et al. 2011), and the low vagility of reef-associated fish inferred from Scott's et al. (2015) study suggests reef units as close as 60 m will avoid overlapping distributions of associated fish, while still promoting a necessary level of connectivity.

The Korea Fisheries Resources Agency (FIRA) has been studying spacing options for many years. They suggest that the optimal module spacing within a cluster should be 3-4 x base diameter of modules to encourage fishing around the cluster, not on top of it. They suggest that modules of various types should be arranged in clusters to maximise complexity at the scale of cluster. Further, the closer modules are placed together, the more they would function as a single unit. An optimal footprint for a cluster is ~400 m^2.

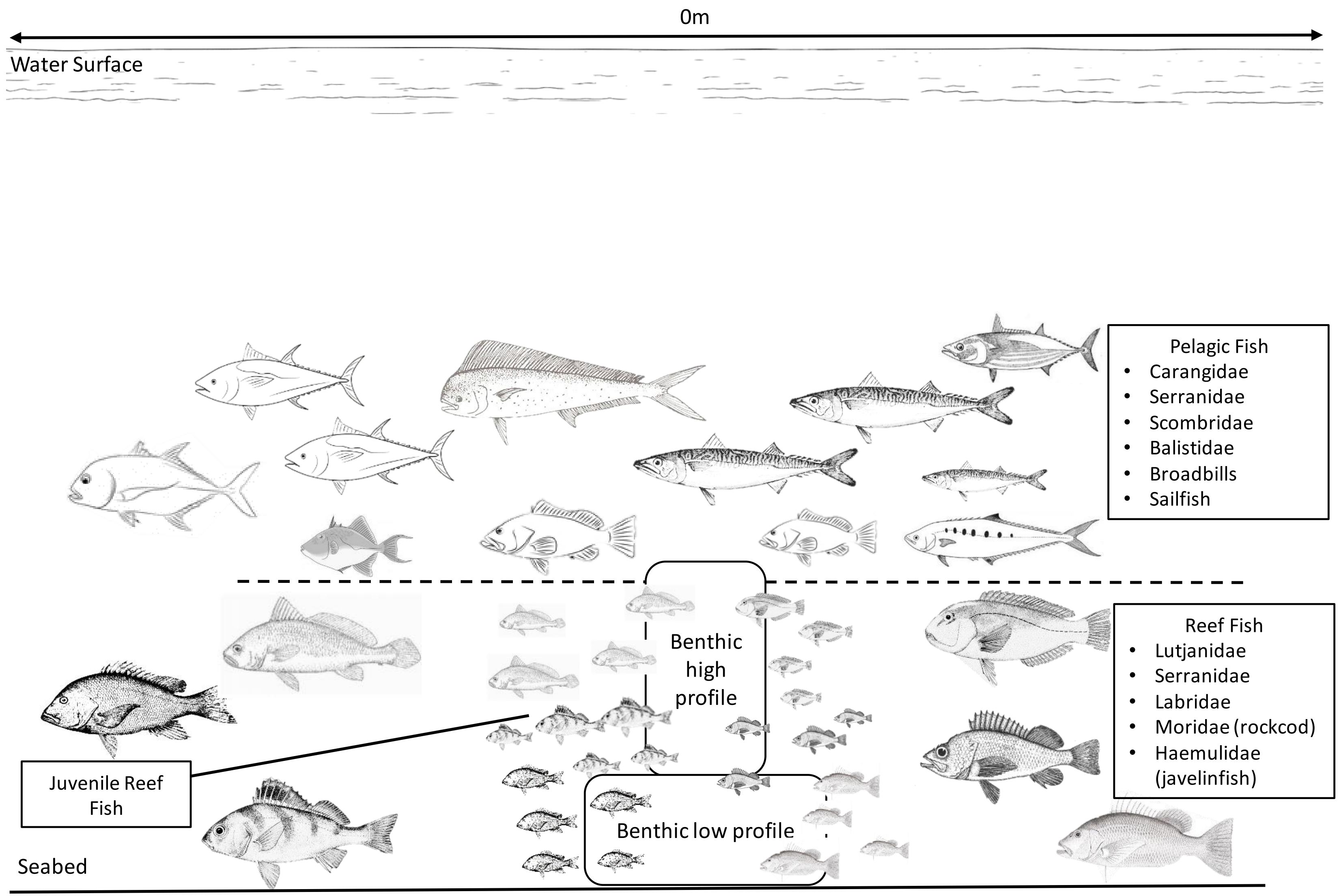

Figure A-1: Potential fish assemblage associated with an AR

Materials

A variety of alternative materials have been developed for manufactured ARs that are designed to enhance fisheries. These include concrete, iron and steel, reinforced concrete (concrete and steel), ceramic, plastic, plastic concrete (concrete mixed with polyethylene, polypropylene sand and iron) and fibre reinforced plastic amongst others (O'Leary et al. 2001). Concrete and steel modules have longevity of greater than 30 years.

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APPENDIX

B

FAD LITERATURE SUMMARY

Fish Attracting Devices

Fish attracting devices (FADs), sometimes referred to as fish aggregating devices, are anchored or drifting objects that are placed in the ocean to attract fish. They may be a permanent, semi-permanent or temporary structures made from any material and are used to concentrate pelagic fish is areas and in ways where they can be caught more easily. FADs have been used for many years in various forms since people discovered that, after a short period, objects in the water attracted and aggregated fish. Fish aggregate in considerable numbers around objects such as drifting logs, flotsam, rafts, jellyfish, and floating seaweed and even whale sharks. The earliest surface/ midwater FADs were constructed using natural materials, such as driftwood and trees (Rohit 2013). Fishermen from Indonesia and Philippines began building floating rafts of bamboo and other materials to attract fish as early as 1900.

The success of FADs in aggregating fish have made these devices important to the commercial, artisanal, recreational and sports fisheries in many tropical and subtropical countries (Pollard and Matthews 1985). Although studies of catch per unit effort (CPUE) at FADs show no significant difference between FADs and known offshore productive fishing spots, CPUEs around FADs have been reported as being higher than from other open-water areas (Buckley et al. 1989, Sharp, 2011a, 2011b)

The objectives for this project are focused on enhancing recreational fishing opportunities, but useful knowledge about FADs was gained from their various applications.

History of FADs for Fishing

General

The first commercial use of FADs was in the Philippines in the 1960s-70s to attract yellowfin tuna (*Thunnus albacares*) (Greenblatt 1979; Matsumoto et al. 1981; Kihara 1981). Before the use of FADs, the commercial purse seine fleets located surface-visible aggregations of birds and dolphins, which were a reliable sign of the presence of tuna schools below. The use of FADs is now common practice in tropical, industrial tuna fisheries. Although some anchored FADs are used, the majority of FADs used by purse-seine fleets are drifting FADs. Thousands of drifting FADs are now used by purse-seine fleets and more than 50% of the world catch of tropical tuna is caught with the assistance of this technology (Sempo et al. 2013). Although this has been beneficial to industrial tuna fisheries there is concern that drifting FADs could act as an 'ecological trap', by taking fish to areas where they would not normally go or retaining them in places that they would otherwise leave (Dagorn et al. 2010).

Artisanal FADs are smaller and used by subsistence, artisanal fishers (Albert et al. 2014). Artisinal FADs have the potential to divert fishing effort away from reef systems by making pelagic fish more accessible to village fishers. Research has found a notable increase in the catch and weight of fish from artisanal FADs suggesting that they may in fact increase the quantity of fish that coastal reef dwelling communities catch and consume, thereby contributing to increased protein intake and community health (Prange et al. 2009).

FADs for sport or recreational fishing are becoming more common. In the Hawaiian Islands for example, schools of tunas and other important recreational or sport pelagic fishes such as dolphin fish (*Mahi mahi*), wahoo (ono) and billfishes are induced by the presence of FADs (Higashi 1994). In New South Wales in 2002, a fish aggregating device (FAD) program was established to provide additional fishing opportunities for sport fishing and game fishers. Anchored FADs provide a fixed location where fast-growing pelagic fish species can be targeted by recreational fishers. This project has developed into a long running recreational fisheries enhancement program, with 25 FADs deployed from October to June over 100's of kilometres of coastline.

Previous FAD Deployments in the Northern Territory

The Northern Territory has recently trialled subsurface FADs. Two sub surface trial FADs were deployed in 20 m water depth at Fenton Patches (an AR site) in October 2012 at the sites of the 20 m steel vessels Amelia C and Merindah Pearl.

The sub surface FADs sit approximately 9 m below the surface at MLW and are attached to 2 tonne mooring blocks fore and aft of the two vessels. They were rigged with 10 m of 15 mm stainless cable threaded through eight polypropylene buoys with 50 mm blue line PVC pipe inserted through each buoy (see Figure B-1).

One FAD came adrift in 2014 and was found washed ashore. The other may still be secured.

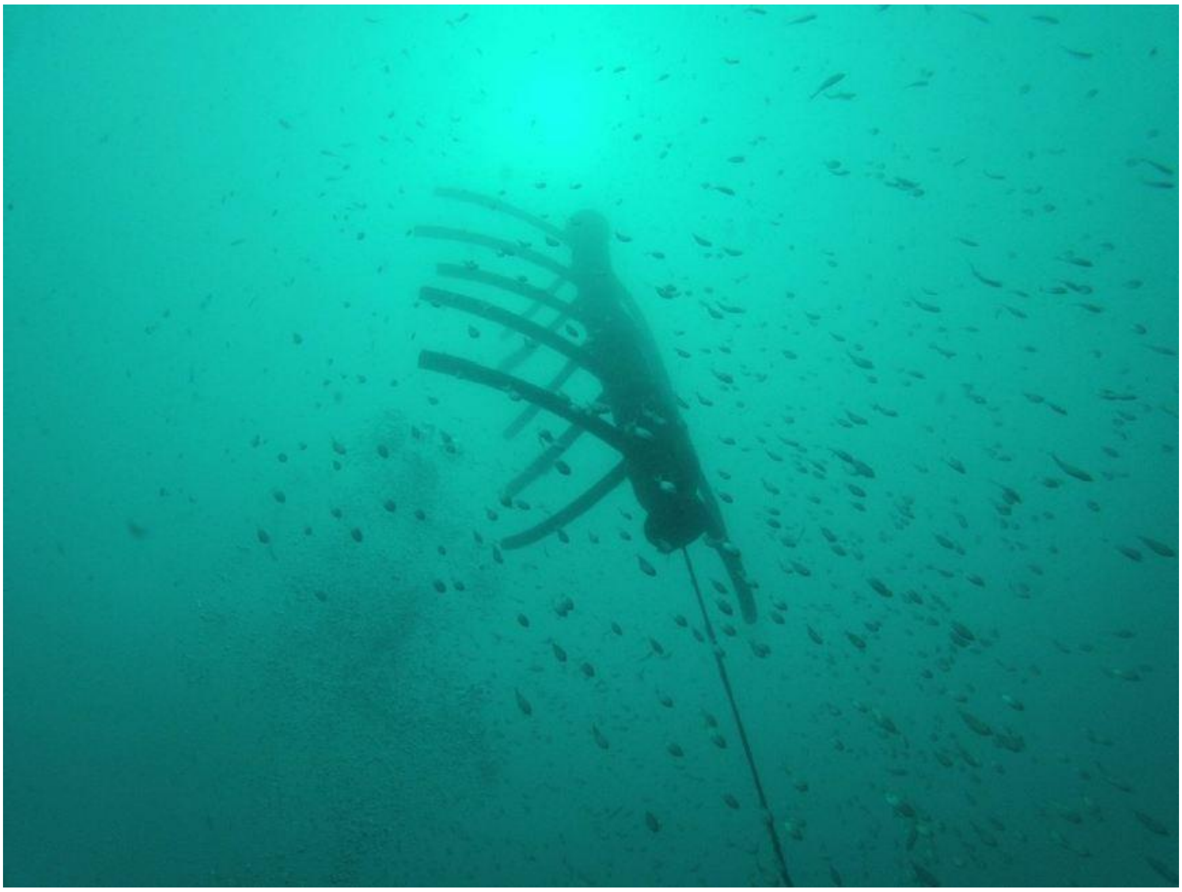


Figure B-1. FAD deployed in the study area in 2012.

Species

Most of the FADs so far constructed have been generally successful in attracting a variety of pelagic fish species. The fauna associated with the FADs can be very similar to published reports of fauna associated with floating *Sargassum* spp. and jellyfish blooms, suggesting similar origins and causes of these associations (Rountree 1989). Castro et al. (2002) reported over 333 fish species belonging to 96 families, at both adult or juvenile and larval stages, that habitually aggregated or associated to floating structures (algae, jellied zooplankton, whales, flotsam) or man-made FADs. The trophic range of fish species present typically included planktivores, piscivores, omnivores and herbivores/planktivores), both in equatorial and tropical regions, however, piscivorous fishes dominated communities associated with FADs in all areas (Taquet et al. 2007).

Baitfish probably play a role in aggregating some of the larger recreationally popular piscivores at FADs. The round scad, *Decapterus punctatus*, for example, accounted for 97.6% of the individuals around FADs in South Carolina (Rountree 1990). In oceanic waters, tuna species make up most of the piscivorous fishes but for FADs anchored in coastal waters, the piscivorous fishes are logically comprised of more coastal species. In a study in the Caribbean by Friedlander et al. (1994), FADs placed in 14 m water depth attracted more coastal pelagic species such as barracuda (*Sphyraena barracuda*), various jacks/trevallas (Carangidae) and king mackerel (*Scomberomorous cavala*), a species similar to Spanish mackerel (*Scomberomorus commerson*).

Designs

The high probability of finding fish around FADs may be the result of an 'attraction' process (high flow of fish through FADs) as well as an 'aggregation' process (high density of fish because fish stay for several days around FADs) (Girard et al 2004). In order to understand the role of various aspects of FADs to attraction or aggregation, it is necessary to first understand how FADs operate.

'Attraction': Olfactory or Acoustic Cues?

The first part of the process is for a FAD to 'attract' the fish. There is strong evidence that pelagic fish can find floating objects in the sea. Dempster and Kingsford (2004) found more juvenile mahi mahi, colonising FADs with odours than unscented controls, indicating small fish may use chemical cues to locate drifting structures. Returns from down- and across-current release sites were similar at all distances for mahi mahi and yellowtail kingfish, *Seriola lalandi*, providing no evidence to suggest that these species used only chemical cues to home to FADs. As fish returned from up to 275 m away, Dempster and Kingsford (2004) suggested sensory processes other than vision and olfaction must operate, possibly sound or vibrations from associated fish and the FAD. Girard et al (2007) estimated that mahi mahi are able to orientate towards a FAD site from distances of at least 820 m.

Ghazali et al. (2013) also showed that the underwater noise signal of FADs showed a distinct rise in sound energy between 500 and 2000 Hz across three octave bands. The spectral characteristics of this signal suggested that the source was animals inhabiting the FAD. The daily sound pattern showed that the signal was loudest during dusk, followed by night, dawn and significantly lowest during the day (14–20 dB lower than dusk). In comparison to the estimated background noise of the prevailing sea state, the FAD signal was detectable up to 400 m away during the day and up to 1000 m during dusk. The bio-acoustically rich signal overlaps the frequency range of the hearing of many fishes, indicating that the acoustic signal emanating from FADs has the potential to attract fish and provide a long-range orientation cue.

'Aggregation': The 'Meeting Point' Hypothesis

The second part of the process, after fish have been attracted, is for a FAD to 'aggregate' the fish. Numerous studies have explained this phenomenon as a consequence of several possible behavioural mechanisms including shelter from predators and food supply, as well as schooling and substrata for juveniles undergoing a change of life-style from pelagic to benthic (Gooding and Magnuson 1967; Hunter and Mitchell 1968). Fréon and Dagorn (2000) formulated a theory of "meeting points" according to which "fish make use of floating devices to increase the frequency of encounters between isolated individuals and other schools in order to form larger groups and thereby potentially improve the survival of the species". Castro et al. (2002) proposed that this evolutionary phenomenon has evolved to safeguard the survival of eggs, larvae and juvenile stages, during dispersion to other areas. Soria et al. (2009) tested the theory in Reunion Island by confirming the following predictions for tagged and released big eye scad (*Selar crumenophthalmus*): (1) fish spend more time at FADs than at any other random points and therefore aggregate around FADs; and (2) fish arrive at FADs as isolated individuals or in small groups and leave them in larger groups. In another experiment using an echo sounder to monitor the aggregated biomass of tuna under FADs it was clear that the aggregated biomass of tuna was distributed asymmetrically (indicative of social behaviour playing a role in the dynamics). These results suggest that social interactions underlie aggregation processes (Robert et al. 2013).

Size

Some studies have shown more species-rich assemblages around large FADs compared to small ones (Nelson 2003). In a study of shallow water FADs in the Atlantic Ocean off South Carolina, the round scad, *Decapterus punctatus*, exhibited a significant linear FAD size effect, although other pelagic species did not show such an effect (Rountree 1989).

Biological Attractants

There is evidence that fishes form larger assemblages around FADs possessing a fouling biota versus FADs without a fouling biota, although this effect was also closely tied to temporal factors (Nelson 2003). Given that it takes time for benthic organisms such as algae and sessile invertebrates to colonise objects in the ocean it is reasonable to assume that older FADs are more effective, although anecdotal evidence is that FADs can be fished effectively one month after deployment.

Further, Nelson (2003) also found that FADs with associated fish communities, accumulated additional recruits faster than FADs with fewer fish and therefore the presence of prior recruits had a strong, positive effect on subsequent recruitment.

Appendages

The simplest FAD design for attracting and aggregating fish is a single surface float but recent emphasis has been to design FADs with the inclusion of appendages. It is widely believed that appendages attached to or below the FAD buoy system increase the effectiveness of the FAD in aggregating and holding fish. This has yet to be demonstrated by research, but is supported by anecdotal accounts from throughout the Pacific (Chapman et al. 2005).

A wide variety of materials and configurations have been used to rig appendages. Coconut fronds, rubber tyres, plastic strapping, old rope and netting have all been used. Plastic strapping, of the type used to bind cartons, has proved to be an effective material when attached below the spar buoy system. It is durable, inexpensive, presents minimal drag on the FAD system and is simple to attach to the mooring. Attaching a separate raft or aggregator to the buoy system has also proven to be effective (Chapman et al. 2005).

Appendages can be attached to the upper mooring chain of FADs. Lengths of strapping which are longer than 4 m tend to break off and 2 m lengths appear preferable (Chapman et al. 2005).

A raft can be made out of bamboo with purse seine or polystyrene floats attached to provide additional flotation (Chapman et al. 2005). In some Pacific Island nations, coconut fronds are used to cover the raft to provide shade, while other materials including coconut fronds or ropes with plastic strapping can be hung under the raft. Wire mesh covered in coconut fronds hung vertically in the water with floats on the top is another form of aggregator that seems to work well. Attaching a raft or separate aggregator to a buoy system is generally done by using a rope bridal arrangement with shackles and a swivel. Rafts or separate aggregators are recommended only in areas of low current (Chapman et al. 2005) and there is potential risks of entanglement with threatened marine mammals, birds or marine reptiles

In the Indian Ocean, weighted ropes can be hung under a FAD with coconut fronds or plastic strapping attached. However, where these are used, they need to be clear of the swivel at the buoy and mooring line connection to avoid tangling and causing the swivel to stop functioning (Chapman et al. 2005).

Currents

Abundances of mahi mahi, and unicorn leatherjacket *Alutera monoceros* (Monacanthidae) were correlated with current speed, with greatest abundances observed when currents were strong and weak, respectively (Dempster 2005). Dempster and Kingsford (2004) suggested that the strong relationship between abundance of mahi mahi around FADs and current speeds was possibly due to a behavioural shift towards closer association with FADs during strong currents.

Location (including configuration, distance apart).

Proximity to Natural Reefs

Friedlander et al. (1994), showed that for coastal FADs, pelagic species abundance and diversity of catch is significantly greater compared to soft bottom areas without FADs. However, catches of pelagics can be similar to areas without FADs over reef substratum. Hence, careful selection of FAD siting must be considered to avoid areas which already concentrate pelagic fishes.

Known Fishing Areas and Seasonality

Chapman et al. (2005) indicated that an important consideration for siting FADs is the abundance of pelagics in an area and their seasonality.

In the Atlantic and Pacific Oceans, time and spatial variations in pelagic fish under FADs reflect physical changes in the environment, which in turn influence the fish fauna, in particular its lateral movement, reproduction and recruitment (Rountree 1989, Kingsford 1992, Kingsford 1999). In a study of pelagic fishes around FADs moored between 3 and 10 km offshore on the continental shelf off Sydney, Australia, assemblages of fishes at FADs followed a seasonal pattern, however, biological and physical variables influenced the seasonal composition of fish greatly (Dempster 2005). Abundances of fish were greatest in spring due to the appearance of large schools (100s to 1000s) of juveniles of the baitfish *Trachurus* sp. In contrast, diversity was far greater in summer and autumn, principally due to the appearance of schools (10s to 100s) of juvenile mahi mahi and other warm water species from January to May when water temperatures were >20^0 C.

The Recreational Fishing Survey data indicates that the Northern Territory's pelagic fish are caught from the Western Australia to the Queensland border and can turn up anywhere from near shore to well offshore. Hence, there is no specific region or area that has higher concentrations of pelagic species, although the highest catch rates were generally associated with some form of hard bottom structure. Further, the majority of pelagic species are caught in the dry season, either because of migratory patterns or because of general seasonal differences in catchability.

Number of FADs

One previous study concluded that "under the hypothesis that the local biomass of tuna in the area cannot be increased by immigration of new fishes, if too many FADs are moored in the same place they will enhance the dispersion of the fish and decrease the concentration on any single FAD". This hypothesis is likely to also apply to the coastal pelagic species of the study area.

The diversity of target species makes it difficult to determine the optimal number and density of FADs for any given area. In addition, very few studies have been done on redistribution of species around anchored FADs (Beverly et al. 2012). In a study of acoustically tagged bigeye scads (*Selar crumenophthalmus*) in an array of shallow water FADs, there was a 'leading' FAD that recorded the majority of visits and retained the fish for a longer period of time. There was also diel variability in the residence times, with fish associated at daytime and exploring the array of FADs at night-time (Capello et al. 2012).

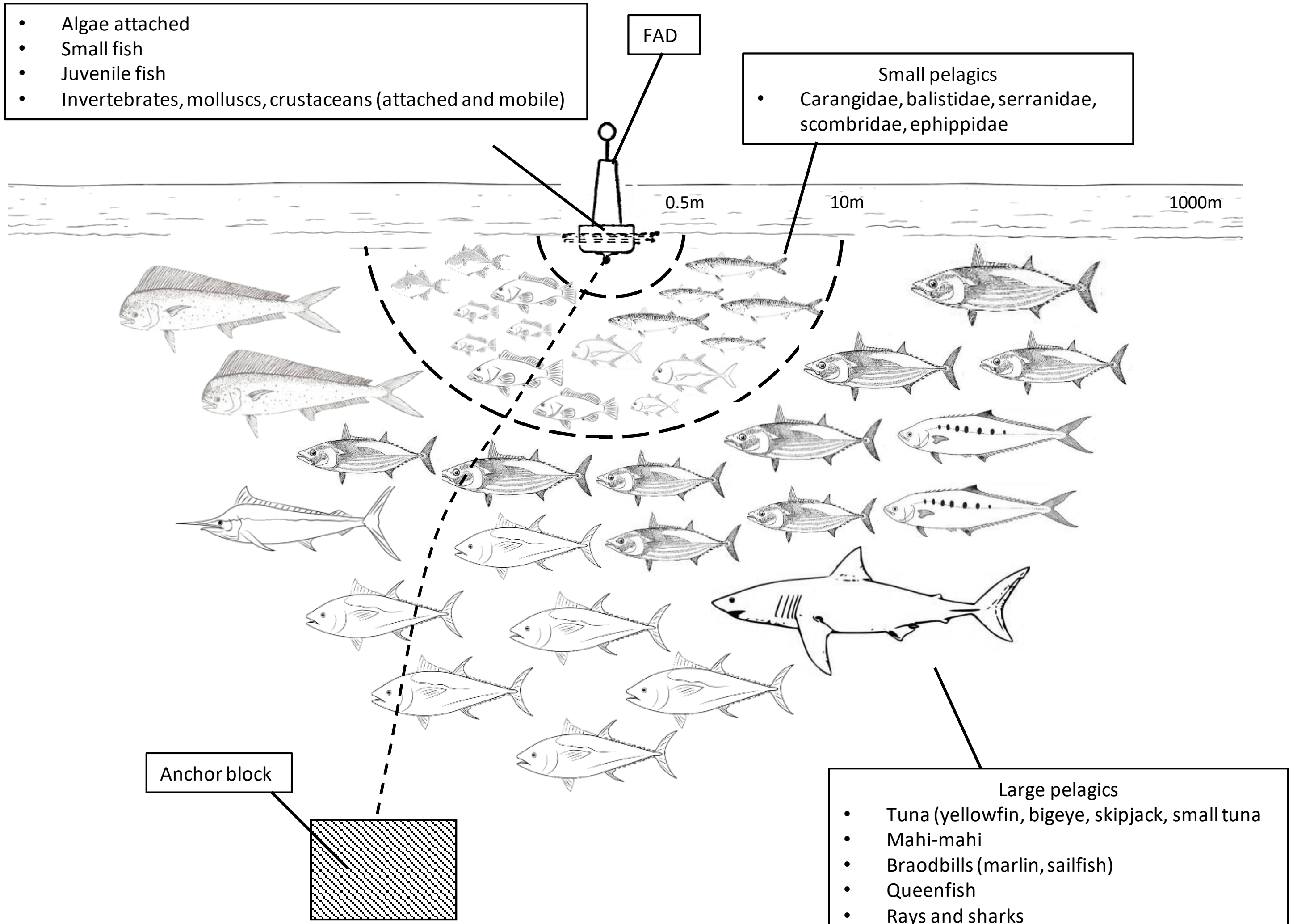
Modelling also predicts that, depending on the species' level of sociality, fish will be scattered among FADs or aggregated around a single FAD based on the number of FADs deployed in a homogeneous oceanic region (Sempo et al. 2013). For a small number of FADs, the majority of individuals are predicted to be aggregated around only one FAD. However, for a critical number of FADs the modelling predicts that the aggregation disappears and individuals scatter among FADs in identical small groups. It is noteworthy that for social fish species, like many of those in the coastal areas of Darwin, the largest total number of individuals associated with FADs can be reached in two different situations, depending on the size of the population and the number of FADs. When fewer FADs are present, there is selection, and a large proportion of the population is aggregated around one FAD. When there are many FADs, there is an equal distribution of fish among all of the FADs, each of them being occupied by a small number of individuals. The modelling shows that for small or intermediate numbers of FADs, the population around a FADs is higher for social species, in comparison with non-social ones, or social situations with a scattered population among a large number of FADs. Another important result is that for each size of population of fish (for social species), there are a number of FADs that maximize the total population of associated fish. Those theoretical results are close to experimental and theoretical dynamics previously reported for social species, such as the tunas. In other studies (e.g. Auger et al. 2010), a very large number of FADs in comparison with the local abundance of the fish population resulted in a small number of fish aggregated under each FAD.

Distances between FADs

There are not necessarily more benefits when FADs were anchored close to each other. Actually, concentrations of FADs can lead to tangling and aggregation interaction or competition between neighbouring FADs (Beverly et al. 2012). Over-concentration of FADs in an area thus is not cost-effective and can potentially lead to loss of overall productivity.

Not all the species of fish recorded as aggregated or associated with FADs maintain the same distance from the float or behave in the same way near it (Castro et al. 2002). Kingsford (1999) suggested that the sphere of influence of a FAD is dependent upon the species of the fish and its stage of development. Thus, for juvenile fish (e.g. *Seriola* spp.) the sphere of influence may be on a scale of a few centimetres to meters, while for adults of the same species the distance may be up to a hundred meters. The distance of association of the pilot fish, *Naucrates doctor*, is from a few centimetres to a few meters, while for the yellowfin tuna it may range up to hundreds of meters. Hence, aggregated fish tend to move around FADs in varying orbits, rather than remaining stationary below the buoys. In terms of the tunas, shoals of juvenile bigeye tuna and yellowfin tuna aggregate closest to the devices, 10 to 50 m. Further out, 50 to 150 m, there can be a less dense group of larger yellowfin and albacore tuna. Yet further out, to 500 m, there can be a dispersed group of various large adult tuna (Figure B-2). The distribution and density of these groups can be variable and overlapping. Generally the aggregations disperse at night (Rohit 2013).

The optimal distance between clusters of FADs is estimated to be 10 kilometres (Sokini pers. comm.) but it is not clear what the distance between individual FADs in a cluster should be (but when FADs are placed in deep water, it should be at least 500 m to avoid tangling).



Modified from Rohit (2013)

Figure B-2. FAD fish assemblages.

Materials

The construction of FADs should take the following design criteria into consideration: wave and current forces related to the FADs, deployment depth, mooring hardware and ropes (Özgül et al 2011).

Traditional FADs in the Pacific Islands, are made on-the-spot with local materials and used in shallow coastal waters by artisanal fishers to catch small pelagic fish and bait. Modern FADs, the result of imported technology and materials, are more steadfast and can be anchored in water depths of over 1,000 m. Moored FADs, which occupy a fixed location and attach to the sea bottom using a weight such as a concrete block. A rope made of floating synthetics such as polypropylene for the lower portion to avoid snagging on the substratum and a sinking rope for the upper portion to reduce the risk of entanglement with boats etc., attaches to the mooring and in turn attaches to a buoy (see section on Catenary curve moorings below). The buoy can float at the surface or lie subsurface (mid water FAD) to avoid detection and surface hazards such as weather and ship traffic. Subsurface FADs – where the only surface component is a small marker buoy are less subject to stress from wind and waves and the risk of damage by ships. Subsurface FADs last longer (5–6 years) than surface FADs (2-3 years) due to less wear and tear, but can be harder to locate. FADs can also include appendages that assist with the aggregation of fish. Smart FADs include sonar and GPS capabilities so that the operator can remotely contact it through satellite to determine its location (if broken) and the population of fish under the FAD.

Much of the following information about components of FADs was taken from the Secretariat of the Pacific Community (SPC) Manual on Fish Aggregating Devices (FADs): Lower Cost Moorings and Programme Management (Chapman et al. 2005).

Surface Buoy Systems

The SPC steel spar buoy is a robust, long-lasting buoy, capable of carrying both a navigation light and a radar reflector. It is a non-directional, wave-riding buoy made from steel. The buoyancy provided by the size of the hull is sufficient to support the weight of the buoy itself and the upper mooring, which includes 15 m of chain (which stabilises the buoy) and a section of nylon rope. In addition, sufficient reserve buoyancy is provided to ensure that the buoy is not submerged when the mooring is fully extended under the effect of currents, winds or high seas. It is considered a suitable design buoy system for offshore FADs.

The new SPC Indian Ocean FAD buoy system is specifically for deployment in areas where strong currents are common, and is rigged by stringing 15 hard plastic pressure floats and 14 soft purse-seine floats alternately on an 18 m length of 28 mm nylon 3- strand rope. Less floats can be used depending on the current. The buoyancy and low drag of this type of buoy system places less strain on the mooring under the effect of strong surface currents. In extreme currents, the buoy system submerges without damage and resurfaces when currents ease. A flagpole arrangement is attached to the end of the buoy system to aid in locating this low profile buoy design.

There are many ways to make up a flagpole arrangement, using three or four purse-seine floats, or a teardrop-shaped plastic pole buoy, on a 3 m length of galvanised or aluminium pipe, or even bamboo.

The Catenary Curve Mooring System

Catenary curve moorings can be considered to consist of three separate sections: the upper mooring, the catenary curve, and the lower mooring. The upper mooring section consists of a chain or rope, sinking nylon rope or lead-core polypropylene rope and connecting hardware. Chain forms the link between the buoy system and the mooring line and acts as a counterweight for the top float. The nylon rope or lead-core polypropylene rope stretches and recoils in response to forces produced by waves. A swivel, placed between the chain or rope and the sinking nylon rope or lead-core polypropylene rope, responds to the motion of the buoy and prevents twisting of the chain, or rope, and mooring line. The catenary curve section forms around the point where the nylon rope or lead-core polypropylene rope and polypropylene rope are spliced together end to end. The offsetting sinking and buoyant properties of the two ropes cause the curve to form, although this is only in times of calm weather and very little current. Wind, wave action and current will stretch the mooring line out and remove the catenary curve. The sinking property of the nylon or lead-core polypropylene rope is used to maintain the catenary curve at a safe depth away from vessels on the surface. The lower mooring section consists of buoyant polypropylene rope, chain, and connecting hardware. The buoyancy of the rope must be sufficient to lift at least 3 m of the connecting lower hardware, thus preventing the rope from abrading on the sea floor. Forces exerted on the buoy system and mooring by wind, waves and currents near the surface are transferred down the mooring to the chain, which rises and sinks in response. A swivel placed between the polypropylene rope and the chain prevents twists in the chain and mooring rope.

Hardware and Hardware Connections

Anchor-type safety shackles are used to make all connections. The large bow on this type of shackle makes it easy to connect different-sized hardware, and allows the components to move without binding.

The SPC steel spar buoy FAD system requires chain in the upper mooring to link the buoy and the upper mooring rope. Both systems require bottom chain to link the lower mooring rope to the anchor. Hot-dip galvanized, low-carbon steel chain is recommended. Long-link or open-link type chain is most suitable because the larger link openings allow easier fitting of other hardware. However, this type of chain is harder to come by so regular-link chain may need to be used.

Hot-dip galvanized, forged eye-and-eye large-bow swivels made from low-carbon steel are recommended.

Rope connectors are used to connect rope to other mooring components. Rope connectors ensure that the eyesplices formed at the rope ends are secured against working loose. The best connector designs also prevent contact between the hardware and the rope, safeguarding the rope from abrasion. Modified Samson Nylite rope connectors are recommended. Samson connectors are easy to fit and provide maximum protection for the rope.

Mooring Ropes

Catenary curve moorings are rigged from a combination of sinking and buoyant ropes. The properties of each rope perform specific functions or impart specific features to the mooring. Consideration of the properties and performance characteristics of rope to be used is very important.

One of the recommended materials for the upper mooring rope is nylon, as it sinks in seawater. Nylon is one of the strongest, most widely available, synthetic fibre ropes. Nylon is elastic. It will stretch up to 17 per cent of its length under a working load equal to 20 per cent of its ultimate breaking strength. Nylon rope can withstand both the routine cyclic loading (stretch and recoil) caused by ocean swells, and the shock loading (strong, sudden jerks) which will affect a FAD mooring during rough seas and stormy weather. Nylon is also durable. It resists surface wear and internal abrasion caused by flexing and stretching. Nylon also withstands ageing and deteriorates only slightly from exposure to sunlight. Nylon does tend to stiffen somewhat with prolonged immersion in seawater.

The recommended material for the lower mooring rope is polypropylene, as it floats. Its buoyant property can be used to lift weight. Polypropylene has moderate breaking strength, which actually increases slightly in seawater. It has good elastic properties and can be stretched by about nine percent of its length and still return to its original length. Polypropylene has excellent shock loading capabilities. Polypropylene is fairly durable. The single most important exception to its durability is that it does deteriorate with exposure to sunlight.

SPC, therefore, recommends that when using a steel spar buoy where there is a chance of the buoy spinning, 8- or 12-strand plaited ropes be used in preference to 3-strand twisted ropes, although the latter can still work effectively. For the new Indian Ocean FAD system, 3-strand twisted rope is recommended in preference to 8- and 12-strand plated rope, as the profile of the buoy system basically eliminates the chance of it spinning in the water.

The length of buoyant polypropylene rope and sinking nylon or lead-core polypropylene rope required to rig an inverse catenary curve mooring for any FAD depends on the site depth, the length of the catenary curve, the weight of the nylon rope, and the buoyancy of the polypropylene rope. Determining what rope lengths must be used to ensure that the mooring maintains the catenary curve at a set depth below the surface and buoys up a section of bottom hardware to keep the lower rope away from the seabed, requires careful calculation. For shallow, it recommended to have the length of the polypropylene section of rope as equivalent to the water depth and the length of the nylon section equivalent to the 33% of the water depth (Sokimi, pers.comm.).

Supplementary Buoyancy

In shallow sites such as the study area, it is impossible to use enough polypropylene rope to provide the buoyancy necessary to lift three m of chain/hardware clear of the seabed. For these sites, pressure-resistant floats are used to supplement the buoyancy of the polypropylene rope. Floats come in a variety of sizes and depth ratings. Both of these variables are important for mooring adjustments. The size, and therefore the buoyancy, of an individual float will determine the number of floats required. A one litre float can lift one kg. The floats should also be placed below the lowest point of the catenary curve to avoid any possibility of them entangling this part of the mooring as it moves in changing currents.

Anchor System

There are established methods for calculating anchor weight that adequately compensates for buoyancy and drag. Well-constructed massive anchors are essential for holding FADs on station. Commercial anchors are generally too expensive for FAD moorings. Suitable anchors can be made up from surplus steel or concrete. Concrete anchors are recommended for FAD moorings. They are especially well suited for the rocky bottoms which characterise FAD sites in island countries. Cement is widely available and relatively inexpensive. Anchors constructed with care will outlast the life of most FAD moorings. The holding power of concrete in seawater is 1:2. In other words, a 2000 kg concrete anchor has a holding power of 1000 kg in seawater. For shallow water FADs, an alternative is to use steel danforth anchors of a suitable weight.

Costs

The materials for an anchored spar buoy or Indian Ocean FAD, the running costs for a survey vessel and deployment vessel, and monitoring and maintenance costs can range from US$2,000 to US$4,000 per FAD. Of course, a FAD made from natural materials, such as a bamboo payao, will be less expensive than a spar buoy or Indian Ocean FAD, but the difference may not be so significant because the most expensive component of an anchored FAD is the mooring line, not the raft. Therefore the deeper the water depth, the greater the anchored FAD cost. Other factors that can significantly affect costs are the type of buoy, type of rope or cable used in the mooring, and type and size of anchor.

Other important considerations are the cost of purchasing materials to build the FADs and their installation and maintenance costs. If and when FADs are lost, there needs to be a stockpile of spare FAD materials so that lost FADs can be replaced quickly.

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APPENDIX

C

AR AND FAD RISKS

Risks

The Attraction versus Production Debate

Fish will utilise ARs and FADs, however there is the question of where these fish will come from and whether they will be those that are desirable to recreational fishers. There has long been debate in the scientific community about whether artificial reefs increase overall production of a defined area (as they provide new habitat in an otherwise saturated environment) or whether they merely attract and aggregate existing fish to a new location (i.e. an AR attracts fishes, which would have settled, survived and grown on natural habitats in its absence (Brickhill et al. 2005)). This has become known as the 'attraction versus production' issue.

Attraction is defined as the net movement of individuals from natural to artificial habitats whereas a simplified definition of production is accumulation of biomass over time (Carr and Hixon 1997). For ARs, attraction, without production, is a major concern given that they could potentially make recreationally and commercially important species more easily harvestable by aggregating them in one place, thereby facilitating increased fishing mortality. When ARs are located close to boat ramps and their positions mapped, they can increase access, and potentially fishing effort to hard-bottom surfaces in an area (McGlennon and Branden 1994). The problem is exacerbated if new reefs attract fishers who previously did not fish hard-bottom areas due to a prior lack of availability, thus increasing overall fishing effort within a management area.

Another potentially adverse effect of ARs is increased predation on fish associated with them that leads to an overall increase in natural mortality to some species (Leitao et al. 2008). It is feasible that this could potentially decrease recruitment to populations if predators and prey are attracted to ARs when the latter may be more vulnerable. It is possible however, that the opposite can occur (i.e. where predators are fewer on artificial reefs compared to natural reefs) as a result the isolated nature of ARs.

In assessing the effects of ARs on production, it is essential to define explicitly the region or management area in question (Carr and Hixon 1997) as well as the loss of production to habitat that ARs replace. The size of a management area and the spatial distribution of reefs within that area can influence interpretation of the effects of an AR. For example, if no natural reef occurs in a management area containing an AR, then any obligate reef organism on the AR has necessarily enhanced production on reefs within that management area. Clearly, the smaller the management area, then the greater the contribution of the AR to that area will be. However, there may also be a loss of production from the habitat replaced by the AR (usually soft sediment) and this is seldom taken into account.

To increase overall reef productivity, ARs must provide additional habitat which increases carrying capacity. This could be done by:

- Providing new substrata for benthic fauna and flora (food sources of fishes)
- Providing shelter from predation; recruitment habitat; spawning habitat
- Reducing harvesting pressure on natural reefs (Pickering and Whitmarsh 1997).

In support of the production hypothesis, one theory states that concentrating food resources and/or increasing feeding efficiency by deployment of ARs could increase localised fish productivity in the long-term, through trophic linkages (Leitao et al. 2007, 2008). Brickhill et al. (2005) reported that production is more likely to occur with the addition of more reefs, or more complex reefs and that ARs could possibly act as nursery areas for economically important species. Until recently, there were very few studies that indicated ARs increase the local biomass of benthic invertebrates and fishes (but see Pickering and Whitmarsh 1997).

It has only been in recent years that the weight of evidence for increased production has become great. Studies of the ages of fishes inhabiting ARs supports the contention that ARs in the northern Gulf of Mexico enhance production of red snapper (Lutjanus campechanus). The mean age of red snapper differed significantly across reefs of different ages, wiith older reefs having older fish (Syc and Szedlnayer 2012). In another study of fish ages on ARs, all life-history stages of resident Pseudanthias rubrizonatus, a small protogynous serranid, included recently settled juveniles, females and terminal males, indicating the structures sustained full populations of this species (Fowler and Booth 2012).

Quantitative models are now being used to test production on reefs but distinguishing new production and redistributed production is notoriously difficult (Smith et al. 2015) and requires knowledge of surrounding habitats and fish movements at a range of spatial and temporal scales. Distinguishing between new and redistributed fish production can be done by estimating the duration of an association between fish and the modified habitat, which indicates the value of the habitat to the individual rather than simply the average standing population. Recent research has shown that oil platforms, per unit area of seafloor, are likely to be among the most productive marine habitats—exceeding all surveyed natural habitats (Claisse et al. 2014). This high level of production is intuitive given their size and vertical extent, and identifies them as valuable fish habitats (Claisse et al. 2015). However, it has also been shown that a designed AR can be extremely productive and comparable to oil platforms as some of the most productive marine fish habitats (Smith et al 2016). This result could be expected given that these reefs have features (i.e. shape, complexity, location) specifically designed to promote fish production (as opposed to 'opportunistic' habitats such as oil rigs). Only 4–5 %, however, of the local fish production was likely to be new.

If productive on a deployed AR were to be increase, it does not however, indicate unequivocally that biomass increases at a regional scale as it is difficult to discern whether:

- Fishes that settle or are attracted to ARs would have found suitable habitat if these reefs were not present
- Fishes would have better survival, growth or recruitment on ARs than on natural habitats
- Foraging success and food web efficiencies have improved
- Habitat is vacated by fishes moving from natural habitats to ARs (Bohnsack et al. 1994).

Wilson et al. (2001) suggest that both attraction and production are likely to interact in driving artificial-natural reef complexes and that much of the question relates to the role of larval supply and density-dependence driving fish dynamics in general (Hixon 1998, Tupper and Hunte 1998). Osenburg et al. (2002) also considers that attraction and production are not mutually exclusive and can be considered as extremes along a gradient. Furthermore, while ARs may simply attract and aggregate some species, they may promote the production of others and the situation is likely to lie between the two extremes. (Bohnsack 1989 in Leitao et al. 2008).

Overall, and ignoring the concept of which is the dominant factor, there is a body evidence that properly designed and managed ARs, particularly when deployed in less complex or reef-limited habitats, can increase the abundance and in many cases diversity of fish assemblages (in comparison to control locations), making them useful management tools in fisheries enhancement and habitat rehabilitation (e.g. Pollard and Matthews 1985, Rilov and Benayahu 2000). Smith et al (2016) consider that reefs with a more resident fish assemblage are most likely to encourage sustainable fishing due to the comparative ease of linking fishing landings with local fish production. Hence, in this project, AR designs would best focus on reef limited, demersal, philopatric (i.e. those that return to their place of origin to breed), territorial and obligatory reef species.

The question of attraction versus production at FADs is less complicated but still a potential issue. FADs, by their nature are designed to attract and aggregate fish. Although they still have potential to increase the quantity of fish in a broad area, they too concentrate fish in one localised area, making them easier to catch by both fishers using industrial drifting FADs or by artisanal or recreational fishers using anchored FADs. This has led to concern amongst fisheries biologists, fisheries managers and environmentalists that pelagic species that aggregate at FADs can be too easily over-exploited. It has been hypothesized that FADs enhance catch per boat when total fishing pressure is low, but can exacerbate fishery collapse when fishing effort is high (Cabral et al 2014). Notwithstanding this, if fished FADs are well managed and fishing harvest rates across a broader area are sustainable, then FADs with more transient fish assemblages can still be successful as highly productive yet sustainable marine habitats (Smith et al 2016). In this project, FAD designs would best focus on transient pelagic species with few issues concerning their local or regional sustainability.

Marine Debris

ARs and FADs can be a source of pollution. ARs made of hazardous material that leaches into the environment are a potential issue. Similarly, ARs that no longer serve a purpose for fishing, either because they have collapsed to a low profile of rubble and no longer attract fish, or because their original design was inadequate, are no more than marine debris. Car tyre reefs are a good example of ARs with less than optimal potential to attract or produce fish, but a high likelihood of contributing to marine debris (Pollard 1989, Kerr 1992).

Anchored FADs that break from their moorings and particularly those with plastic components are a form of marine debris that can pollute beaches and reefs and the open seas. FADs have also been identified as one source of abandoned, lost or otherwise discarded fishing gear. The negative impacts of this type of marine debris can be ghost fishing (including species of conservation significance such as sea turtles), alteration of the benthic environment, creating a hazard to navigation, creation of beach litter, introduction of synthetic materials into the marine food web, transporting alien species, and additional clean-up costs. Anchored FADs with global positioning system (GPS) homing devices, though more expensive, can be tracked and recovered if they break loose from their mooring. However, this has to be done in a timely manner before the transmitters stop functioning.

Anchored FADs also have a limited lifespan relative to ARs (Pollard and Matthews 1985), which if made of suitable material, can last decades or even longer. In the 1980s, the average lifespan of an anchored FAD was nine months. Since then several initiatives have been conducted to promote cheaper and longer lasting FADs. The average lifespan of FADs in the Western Indian Ocean had increased to two years by the 1990s, and from 2001 to 2008 anchored FADs were lasting four to eight years in Niue, but longevity is still a recurring problem for anchored FADs. Premature loss of anchored FADs in the Maldives has been attributed to mooring rope failure caused by environmental forces, and design flaws like inadequate buoyancy of the FAD raft, inadequate anchor holding capacity, wear and tear or failure of the FAD hardware, accidental propeller entanglement with the mooring line or vandalism. The lifespan of an anchored FAD can be significantly increased by using proven designs made with recommended materials, and by carrying out regular monitoring and maintenance. One recommendation from the Tahiti FAD conference in 2011 was that reducing the number of components (shackles and swivels) in the mooring system was likely to increase anchored FAD longevity. Recently, Franco et al. (2009) proposed different designs of ecologically friendly FADs that used only biodegradable materials. Moving from traditional to environmentally safe (and, if possible, biodegradable), FADs appear to be a necessary and appropriate step for reducing the ecological impact of FADs. Some focus on FAD materials that are environmentally friendly are currently being undertaken in the Indian and Atlantic oceans by the French and Spanish fleets

Developing a public awareness programme and a code of conduct for responsible fishing practices around FADs will also likely increase anchored FAD longevity. For example, some FAD programmes do not allow boats to tie up to anchored FADs as this can result in dislodging of the anchor, and fishing may be restricted within a certain minimum radius adjacent to a FAD to avoid damage caused by fishing gear. FAD users should be made aware of such regulations. One solution to theft and vandalism is the sub-surface anchored FAD – the buoy of a sub-surface FAD usually lies 25–50 m below the water surface and so is out of reach.

Entanglement of Marine Mammals, Turtles or Sharks

This risk is generally only applicable to FADs given ARs are rarely designed with free-floating equipment attached that could potentially entangle marine biota.

Purse seiners deploy thousands of Drifting Fish Attracting Devices (DFADs) in all tropical oceans to catch tropical tunas. Although different designs of DFADs exist, fishers all over the world mainly use bamboo rafts with black netting hanging underneath. This type of FAD is responsible for incidental mortality of sea turtles and sharks through entanglement. Whales have also been shown to be occasionally found near FADs and this makes them vulnerable to entanglement.

Some attempts have been made to test FAD designs with built-in measures to reduce marine mammal, shark and turtle entanglement in the FAD structures themselves (Delgado de Molina et al. 2007), but no conclusive results were found because of the small number of tests.

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APPENDIX

D

COMMERCIAL FISHING IN THE STUDY AREA

COMMERCIAL FISHING IN THE STUDY AREA

Commercial Fishing

The Northern Territory (NT) commercial fishing industry has more than 200 commercial fishing licences, 190 registered fishing vessels and harvests on average 5,500 t of fish and aquatic life each year. There is commercial activity in 15 different wild harvest fisheries. Fisheries operating in the study area and that would potentially interact with AR or FAD placement or compete for target species are described below and in Table D-1.

Inshore

Bait Net Fishery

The fishery is restricted to two licences and is allowed from the high water mark to 3 nm seaward of the low water mark but does not include Darwin Harbour and Shoal Bay. Given these restrictions there would potentially be little overlap with potential AR or FAD deployment areas in the study area apart from nearshore areas in the western part of the study area near Dundee Beach, the eastern part near the Vernon islands and the northern part near the Tiwi and Bathurst islands.

Barramundi Fishery

Commercial fishing for barramundi is allowed from the high water mark to 3 nm seaward of the low water mark. The fishing area is restricted to waters seaward from the coast, river mouths and legislated closed lines. Commercial fishers must not fish within any of the following areas:

- Between the Little Finnis River and the Wildman River, including Bynoe Harbour, Darwin Harbour and Shoal Bay
- Kakadu National Park.

Given these restrictions there would potentially be little overlap with potential deployment areas in the study area apart from nearshore areas in the western part of the study area near Dundee Beach, the eastern part near the Vernon islands and the northern part near the Tiwi and Bathurst islands.

Coastal Line Fishery

Fishers can operate along the NT coast between the high water mark and 15 nm out from the low water mark. The following fishing methods or equipment can be used:

- Vertical lines, cast nets, scoop nets or gaffs can be used from the high water mark out to 15 nautical miles from the low water mark
- Drop lines and up to five fish traps can be used from two to 15 nautical miles out from the low water mark
- Up to five hooks per vertical line and up to 40 hooks per drop line.

Black jewfish and golden snapper are the main species taken and byproduct species include emperors, cods and other snappers. Given these species are generally associated with hard rather than soft bottom there would be little overlap with ARs and FADs if they were located on soft substratum. Notwithstanding this, given the suite of species caught in the fishery are similar to the target species in the AR program (see below) there could potentially be conflict for the newly created resource and fishing grounds.

Coastal Net Fishery

The fishery extends from the high water mark to 3 nm out from the low water mark. The fishery is divided into regions and fishers can only fish in the region or regions nominated on their licence. Fishers use various types of nets. Mullet is the primary species taken in the coastal net fishery but a number of byproduct species are also taken including blue threadfin, sharks, queenfish, garfish, snapper and whiting.

There would potentially be conflict with this fishery and or FADs if they were located on soft substratum close to shore.

Offshore

Demersal Fishery

Demersal fishing is allowed from 15 nautical miles from the low water mark to the outer boundary of the Australian fishing zone (AFZ) 200 nautical miles offshore, excluding the area of the Timor Reef fishery, using the following fishing method:

- Vertical lines
- Drop lines
- Finfish long-lines
- Baited fish traps
- Semi-demersal trawl nets in two multi-gear areas.

Trawl operators must use a bycatch reduction device and square mesh funnel or cod end to reduce the amount of bycatch and increase the value of the landed product

Trap catch is mainly goldband snapper and red snapper. Byproduct species include red emperor and cods. Trawl catch is mainly saddletail snapper and crimson snapper. Byproduct species include painted sweetlip, redspot emperor and goldband snapper.

Given that species targeted by the trap fishery are generally associated with hard rather than soft bottom there would be little overlap of the trap fishery with ARs and FADs if they were located on substratum. Notwithstanding this, given the suite of species caught in the fishery are similar to the target species in the AR program (see below) there could potentially be conflict for the resources on the ARs and FADs and fishing grounds.

Net and Line Fishery

This fishery operates in all NT waters from the high water mark to the boundary of the AFZ. Most fishing is done in the coastal zone within 12 nautical miles of the coast, and immediately offshore in the Gulf of Carpentaria. Gear used includes demersal or pelagic long lines or pelagic nets. Bottom-set gillnets are prohibited. Black-tip sharks and grey mackerel are the primary species taken in off-shore net and line fishing. Other shark species caught are hammerhead, bull, tiger, pigeye, lemon and winghead sharks and dusky whalers. Other byproduct catch includes Spanish mackerel, longtail tuna, black pomfret and other finfish.

There would potentially be conflict with this fishery with AR or FAD locations. Given the suite of species caught in the fishery are similar to the target species in the FAD program (see below) there could potentially be conflict for the newly created resource and fishing grounds.

Spanish Mackerel Fishery

Commercial fishing for Spanish mackerel is allowed from the high water mark to the outer boundary of the AFZ. Most Spanish mackerel are caught off the western and eastern mainland coasts and near islands including Bathurst Island, Groote Eylandt and the Wessel Islands. Fishing generally takes place around reefs, headlands and shoals.

The following methods to catch Spanish mackerel:

- Troll lines
- Floating hand lines
- Rods.

Commercial fishers operate using a mothership and up to two dories. It is common for fishers to troll two to four lines behind a dory and up to eight lines from a mothership. Most commercial fishers purchase bait for fishing but can use small mesh nets to catch bait. The nets must be set in the open sea within and the fisher must always stay with the net.

There may be some overlap with ARs and FADs if they were to be located near Bathurst Island Further, given Spanish mackerel are a target species in the FAD program (see below) there could potentially be conflict if these structures are placed too close to existing habitat for Spanish mackerel.

Table D-1. Potential overlap with commercial fishing areas and AR and FAD placement and with target species, assuming ARs and FADs would be placed on soft bottom.

Fishery	Overlap with fishing ground			Competition for target species	
	< 3 nm from coast	< 15 nm from coast	> 15 nm from coast	ARs	FADs
INSHORE					
Bait Net Fishery	✓1				
Barramundi Fishery	✓1				
Coastal Line Fishery	✓2	✓2		✓	
Coastal Net Fishery	✓			✓3	✓4
OFFSHORE					
Demersal Fishery			✓2	✓	
Net and Line Fishery	✓5	✓5	✓5		✓
Spanish Mackerel Fishery	✓6	✓6	✓6		✓7

[1] excluding nearshore areas within Darwin Harbour and Shoal Bay

[2] no overlap if ARs or FADs deployed on soft bottom

[3] snappers only

[4] queenfish only

[5] most fishing is done within 12 nm of coast

[6] most fishing is done off the western and eastern mainland coasts and near islands including Bathurst Island

[7] Spanish mackerel only

APPENDIX

E

MCA METHODS TO IDENTIFY POTENTIAL AR AND FAD SITING LOCATIONS

Multi-Criteria Analysis Methods

Cardno used a multi-criteria analysis (MCA) for identifying potential sites for artificial reef (AR) and fish attracting device (FAD) deployment within the study area. The sections below detail the MCA methods and criterion used in this study.

Step 1 - Desktop Review

In order to define the overall environmental and social characteristics of the region of interest, a review of publicly available data and reports was completed.

Step 2 – Identify Evaluation Criteria

Evaluation criteria for identifying potential deployment sites for ARs and FADs identified by Cardno and DPIR teams comprise the following categories.

Environmental

- High relief (complex) benthic habitat
- Seagrass habitat
- Conservation estate
- Threatened species

Social

- Existing use
- Wrecks (including War graves)
- Cultural heritage sites
- Exclusion areas

Engineering

- Substrate type
- Distance from
- Water depth
- Oceanographic conditions
- Sediment transport regime
- Interference with infrastructure.

Step 3 – Data Review

The next step was to identify available data to represent the evaluation criteria identified in Step 2. For each data set, the accuracy and currency of the data were evaluated. A bibliography of GIS datasets is included in in the criterion table (see Table E-1 through Table E-11).

Evaluation criteria not accurately represented (in the Geographic Information System (GIS) model) were rejected. Wherever possible, these criteria will be included in the Round 2 investigations.

Step 4 – Assign Performance Weightings

The project team (Cardno and DPIR), developed performance ratings for each criterion:

- Highly Constrained (Fatal Flaw (No Data)) – Highly constrained and unsuitable for further consideration (for example, in the proximity of an existing pipeline, at a wreck site)
- Moderately Constrained (1)

- Slightly Constrained (5)
- Least Constrained (9).

Values in brackets indicate performance weightings assigned to GIS attributes. In determining performance ratings, project team considered:

- Legislative requirements, for example, requirements to avoid areas of cultural sensitivity.
- Environmental values and sensitivities, and the need to protect ecosystems and species.

Step 5 – Pairwise Weighting of Criteria

Multi-criteria analysis requires consideration of the relative importance of each criterion compared to other criteria. Paired comparisons between criterion were undertaken, using the method for weighting of criteria described by Stevens (1997). This approach requires each criterion to-be compared to each other criteria to determine which of the two (paired) criteria is considered more important. By considering the number of times any particular criterion is rated as more important than any other, the criteria can then be ranked as a set in terms of importance.

For this project, criteria were compared in the categories of environmental, social and engineering considerations. The paired comparison completed involved DPIR representatives and specialists selected from the project team. Weightings were normalised so that weightings were a percentage for each criterion. Results of the paired comparison for each set of criteria for AR and FAD are presented in Section 4 of the main report.

Step 6 - GIS Analysis

GIS analysis required data for each evaluation criterion to be compiled and analysed according to the performance ratings on a series of 275 m by 275 m grids across the study area. Following this, the weightings applied to each criterion and the overall score for each evaluation criterion in each grid calculated (0). The GIS model then compiled scores across all the evaluation criteria for each grid and identified areas that range from least constrained to highly constrained (unsuitable) for the deployment of ARs and FADs (**Error! Reference source not found.**).

Multi criteria analysis performed by Cardno personnel using the data sourced in Step 1. Files reprojected into GDA 94 (Zone 50) and an attribute field added in which a performance rating assigned. Some datasets required more processing such as buffering and merging. The result is an overall sensitivity map. The lower the score, the more attractive the location is for the potential deployment of an AR or FAD (**Error! Reference source not found.**).

0	5	5
999	5	0
999	5	0

Constraint # 1. e.g. coral reefs

+

3	0	3
3	0	3
0	3	0

Constraint # 2 e.g. marine park

=

3	5	8
1002	5	3
999	8	0

Scores for the two constraints are added together. The result represents the overall level of constraint

Figure E- 1 MCA methodology for construction of the weighted overlay

Criteria Performance Weighting

Cardno project team members assessed and developed performance weightings for each criterion used during the Round 2 MCA to identify potential FAD deployment locations. Weightings based on four constraint levels (least, slightly, moderately and highly constrained) were assigned. Criteria weighting results used in the AR and FAD MCA are in **Table E-1** and **Table E-2** respectively.

Table E-1. Criteria performance weighting for the identification of potential AR deployment areas

Constraint	Criteria	Least Constrained	Slightly Constrained	Moderately Constrained	Highly Constrained
Environmental	High relief (complex) benthic habitat	>250 m from high relief benthic habitat	None	None	Within 250 m of high relief benthic habitat
	Seagrass habitat	Outside of indicative seagrass habitat (deeper than -10 m LAT)	None	Inside of indicative seagrass habitat (shallower than -10 m LAT)	None
	Conservation estate	Outside Conservation Estate area	None	None	Within Conservation Estate area
Social	Existing use	> 2000 m of existing fishing location	None	Within 2000 m of existing fishing location	None
	Wrecks (including war graves)	> 1000 m of wreck	None	None	Within 1000 m of wreck
	Cultural heritage sites	> 500 m of site	None	None	Within 500 m of site
	Mineral or petroleum exploration area	Outside mineral or petroleum exploration area	Within mineral or petroleum exploration area	None	None
Engineering	Substrate type	Sand	Gravel	None	Mud, rock, coral
	Distance from access point or harbour	< 45 km from designated launch and retrieval site or harbour entrance	Between 45 and 70 km from designated launch and retrieval site or harbour entrance	> 45 km from designated launch and retrieval site or harbour entrance	None
	Water depth	Between -15 and -40 m LAT	Between -40 and -50 m LAT	Deeper than - 50 m LAT	Shallower than -15 m LAT
	Interference with existing infrastructure	> 1000 m of marine infrastructure	None	None	Within 1000 m of marine infrastructure
	Interference with established shipping channels and vessel tracking	Vessel track density ≤ 5	Vessel track density 5-10	None	Vessel track density > 10

Table E-2. Criteria performance weighting for the identification of potential AR deployment areas

Constraint	Criteria	Least Constrained	Slightly Constrained	Moderately Constrained	Highly Constrained
Environmental	High relief (complex) benthic habitat	>250 m from high relief benthic habitat	None	None	Within 250 m of high relief benthic habitat
	Seagrass habitat	Outside of indicative seagrass habitat (shallower than -10 m LAT)	None	Inside of indicative seagrass habitat (deeper than -10 m LAT)	None
	Conservation estate	Outside Conservation Estate area	None	None	Within Conservation Estate area
Social	Existing use	> 2000 m of existing fishing location	None	Within 2000 m of existing fishing location	None
	Wrecks (including war graves)	> 1000 m of wreck	None	None	Within 1000 m of wreck
	Cultural heritage sites	> 500 m of site	None	None	Within 500 m of site
	Mineral or petroleum exploration area	Outside mineral or petroleum exploration area	Within mineral or petroleum exploration area	None	None
Engineering	Substrate type	Sand, mud, gravel	None	None	Rock, coral
	Distance from access point or harbour	< 45 km from designated launch and retrieval site or harbour entrance	Between 45 and 70 km from designated launch and retrieval site or harbour entrance	> 45 km from designated launch and retrieval site or harbour entrance	None
	Water depth	Deeper than -30 m LAT	None	Between -15 and -30 m LAT	Shallower than -15 m LAT
	Interference with existing infrastructure	> 2000 m of marine infrastructure	None	None	Within 2000 m of marine infrastructure
	Interference with established shipping channels and 2017 vessel tracking	Outside identified established shipping channels	None	None	Within identified established shipping channels

Pairwise Criteria Weighting

The paired comparison for AR and FAD criteria was undertaken by specialists from the DPIR project team. Pairwise criteria weighting results used in the AR and FAD MCA are in **Table E-1** and **Table E-2** respectively.

Table E-3. Results of the Round 2 pairwise comparison weighting for Environmental (E), Social (S) and Engineering (C) criteria to identify potential AR deployment areas

			High relief (complex) benthic habitat	Seagrass habitat to	Conservation estate	Existing use	Wrecks (including War graves)	Cultural heritage sites	Mineral or petroleum exclusion areas	Substrate type	Distance from access point or harbour	Water depth	Interference with existing infrastructure	Interference with established shipping channels	Count	Standardised Weighting
Constraint	**Criteria**	**Criterion ID**	**E1**	**E2**	**E3**	**S1**	**S2**	**S3**	**S4**	**C1**	**C2**	**C3**	**C4**	**C5**		
Environment	High relief (complex) benthic habitat	**E1**		e1	E3	E1	S2	S3	S4	E1	E1	E1	C4	C5	5	7.58
	Seagrass habitat	**E2**	E1		E3	S1	S2	S3	S4	E2	E2	E2	C4	C5	3	4.55
	Conservation estate	**E3**	E3	E3		E3	E3	E3	E3	E3	E3	E3	E3	E3	11	16.67
Social	Existing use	**S1**	E1	E2	E3		S2	S3	S4	C1	C2	C3	C4	C5	0	0.00
	Wrecks (including war graves)	**S2**	S2	S2	E3	S2		S3	S2	S2	S2	S2	S2	S2	9	13.64
	Cultural heritage sites	**S3**	S3	S3	E3	S3	S3		S3	S3	S3	S3	S3	S3	10	15.15
	Mineral or petroleum exclusion areas	**S4**	S4	S4	E3	S4	S2	S3		S4	S4	S4	S4	S4	8	12.12
Engineering	Substrate type	**C1**	E1	C1	E3	C1	S2	S3	S4		C1	C1	C4	C5	4	6.06
	Distance from access point or harbour	**C2**	E1	E2	E3	C2	S2	S3	S4	C1		C1	C4	C5	1	1.52
	Water depth	**C3**	E1	C3	E3	C3	S2	S3	S4	C1	C3		C4	C5	3	4.55
	Interference with existing infrastructure	**C4**	E4	C4	E3	C4	S2	S3	S4	C4	C4	C4		C5	6	9.09
	Interference with established shipping channels	**C5**	E1	C5	E3	C5	S2	S3	S4	C5	C5	C5	C5		6	9.09
													Total		**66**	**100**

Table E-4. Results of the Round 2 pairwise comparison weighting for Environmental (E), Social (S) and Engineering (C) criteria to identify potential FAD deployment areas

			High relief (complex) benthic habitat	Seagrass habitat to	Conservation estate	Existing use	Wrecks (including War graves)	Cultural heritage sites	Mineral or petroleum exclusion areas	Substrate type	Distance from access point or harbour	Water depth	Interference with existing infrastructure		Count	Standardised Weighting (%)
Constraint	**Criteria**	**Criterion ID**	**E1**	**E2**	**E3**	**S1**	**S2**	**S3**	**S4**	**C1**	**C2**	**C3**	**C4**	**C5**		
Environment	High relief (complex) benthic habitat	**E1**		E1	E3	S1	S2	S3	S4	E1	E1	E1	C4	C5	4	6.15
	Seagrass habitat	**E2**	E1		E3	E2	S2	S3	S4	E2	E2	E1	C4	C5	3	4.62
	Conservation estate	**E3**	E3	E3		E3	S2	E3	E3	E3	E3	E3	E3	E3	10	15.38
Social	Existing use	**S1**	E1	E2	E3		S2	S3	S4	C1	S1	S1	S1	C5	3	4.62
	Wrecks (including war graves)	**S2**	S2	S2	E3	S2		S3	S2	S2	S2	S2	S2	S2	9	13.85
	Cultural heritage sites	**S3**	S3	S3	E3	S3	S3		S3	S3	S3	S3	S3	S3	10	15.38
	Mineral or petroleum exclusion areas	**S4**	E1	E2	E3	S4	S2	S3		S4	S4	S4	S4	S4	6	9.23
Engineering	Substrate type	**C1**	C1	C1	E3	C1	S2	S3	S4		C1	C3	C4	C5	4	6.15
	Distance from access point or harbour	**C2**	E1	E2	E3	C2	S2	S3	S4	C1		C3	C4	C5	1	1.54
	Water depth	**C3**	E1	E2	E3	C3	S2	S3	S4	C1	C3		C4	C5	2	3.08
	Interference with existing infrastructure	**C4**	C4	C4	E3	C4	S2	S3	S4	C4	C4	C4		C4	7	10.77
	Interference with established shipping channels	**C5**	C5	C5	E3	C5	S2	S3	S4	C5	C5	C5	C4		6	9.23
														Total	**65**	**100**

Evaluation Criteria Data Tables

Below are the evaluation criteria data tables used to weight the performance of individual criterion to identify potentially suitable AR and FAD deployment sites. The criteria used are broken into groupings based on being Environmental, Social or Engineering constraints.

Evaluation criteria identified as being Environmental, Social or Engineering constraints are provided below:

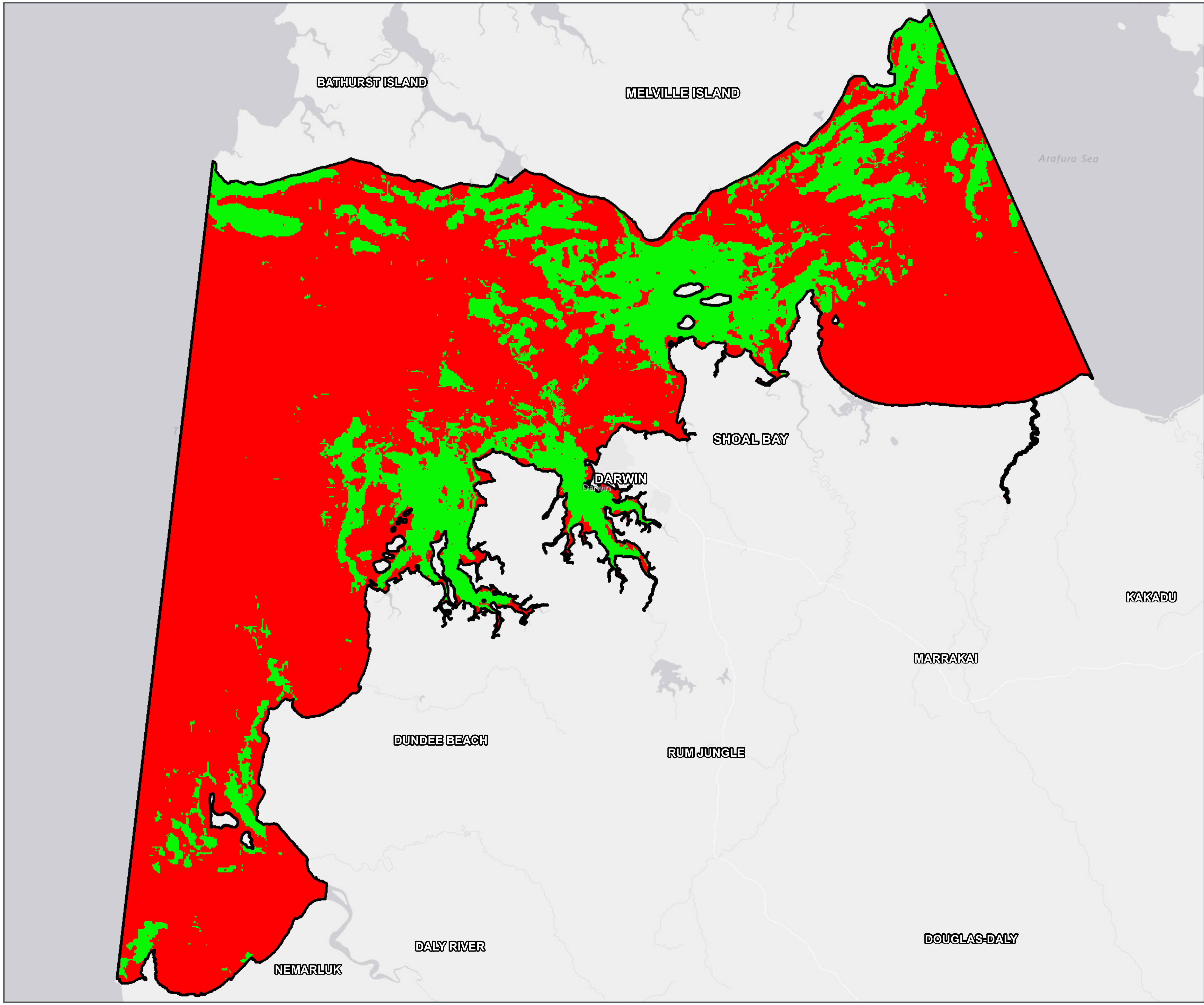
Environmental

High Relief (complex) Benthic Habitat

High relief (complex) benthic habitat (coral reefs, shoals, rocky outcrops and existing artificial reefs) are important habitats for fish and other marine biota and maintaining ecosystem health. Avoid loss (physical damage) of existing high relief habitat.

Table E-1. High Relief Benthic Habitat

Objective	Loss of existing high relief benthic habitat is avoided
How measured	Distance from high relief benthic habitat
Ratings	AR and FAD
Highly Constraned (No Data)	Within 250 m of high relief benthic habitat
Moderately Constrained (1)	None
Lightly Constrained (5)	None
Least Constrained (9)	>250 m from high relief benthic habitat
Data Source	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017. Multi-beam Survey, 1m Bathymetric Grid of Darwin Harbour (inner and outer) and Outer Bynoe Harbour, Geoscience Australia (GA).
Data Coverage / Quality	AusENC data covered the whole study area and were interpolated from bathymetric vector contours (relative to LAT) into a 50m grid from tiles AU412130, AU412131, AU413129, AU413130, AU413131, AU414129, AU414130. GA multi-beam bathymetric data. The high quality grid data only covered areas within Darwin and Bynoe Harbours and the inshore area from Lorna Shoal through to Gunn Point.
Data Processing	High relief benthic areas were mapped using an interpretive threshold analysis on a combination of slope and curvature analysis on the two separate bathymetric grid models that were then amalgamated into one layer post classification. The AusENC vector bathymetric contours were first interpolated into a bathymetric grid using ArcMAPs topo-to-raster tool. Percent Slope, Curvature, Curvature Profile and Curvature Plan were each calculated and then an arithmetic threshold was interpretively applied to each derived layer to isolate areas that were interpreted as high relief from a hillshade model (which was derived from the same source data). The was aggregated to a 25m grid as a suitable scale for slope and curvature analysis. Percent Slope, Curvature, Curvature Profile and Curvature Plan were each calculated and then an arithmetic threshold was interpretively applied to each derived layer to isolate areas that were interpreted as high relief from a hillshade model (which was derived from the same source data). The course scale of the input data did not allow for a precise measurement basis for a 250m setback from high relief habitat. Rather this was considered in the interpretive threshold which was applied substantially.



NORTHERN TERRITORY GOVERNMENT

Raw Constraints - High Relief (complex) Benthic Habitat

ARTIFICIAL REEFS

Legend

Study Area

Proximity to High Relief (complex) Benthic Habitat

Outside 250m

Within 250m

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

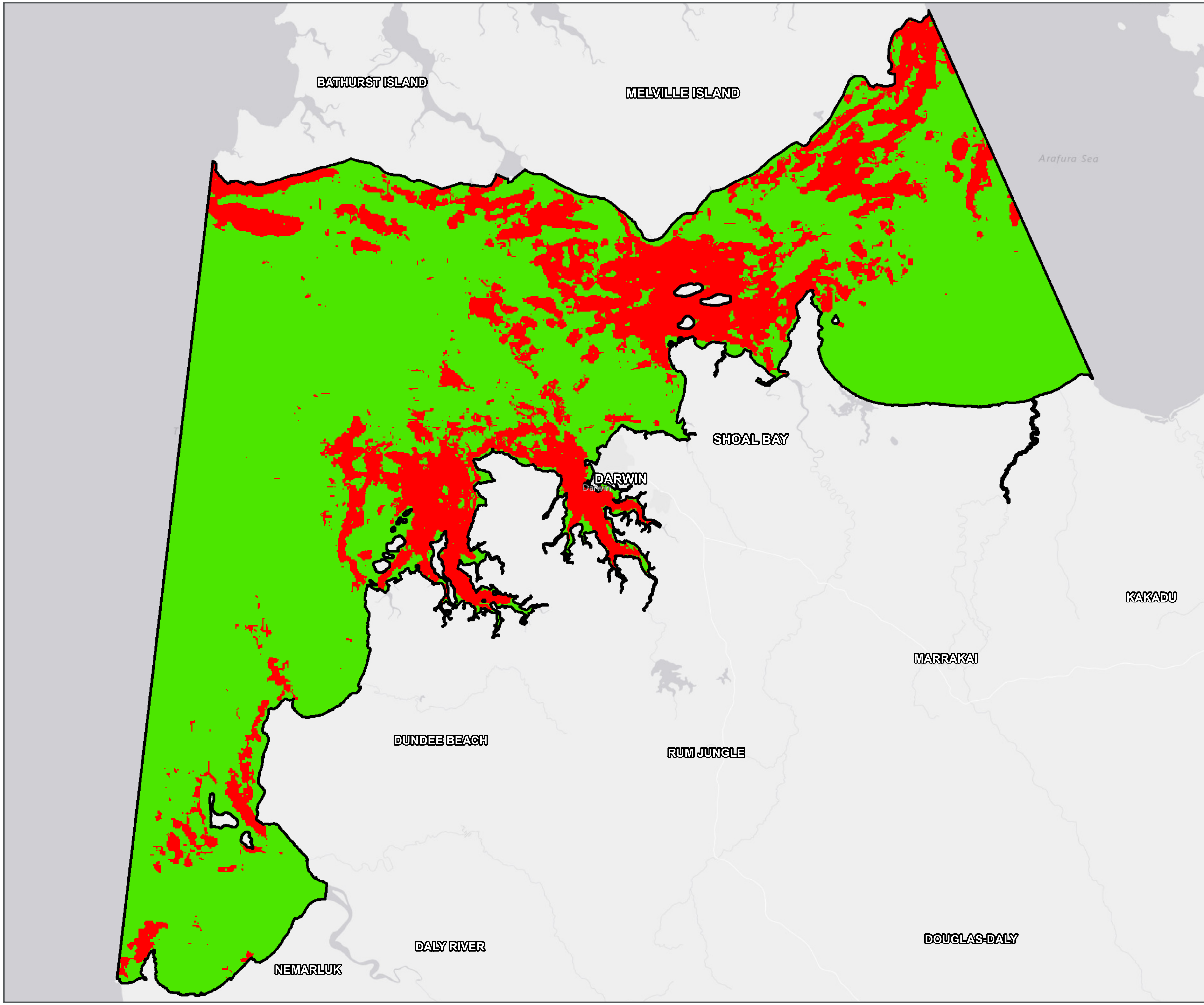
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-26 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS043_ConstraintsBenthicHabitat.mxd 05
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Classified Constraints - High Relief (complex) Benthic Habitat

ARTIFICIAL REEFS



Legend

Study Area

Proximity to High Relief (complex) Benthic Habitat

Least Constrained

Highly Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

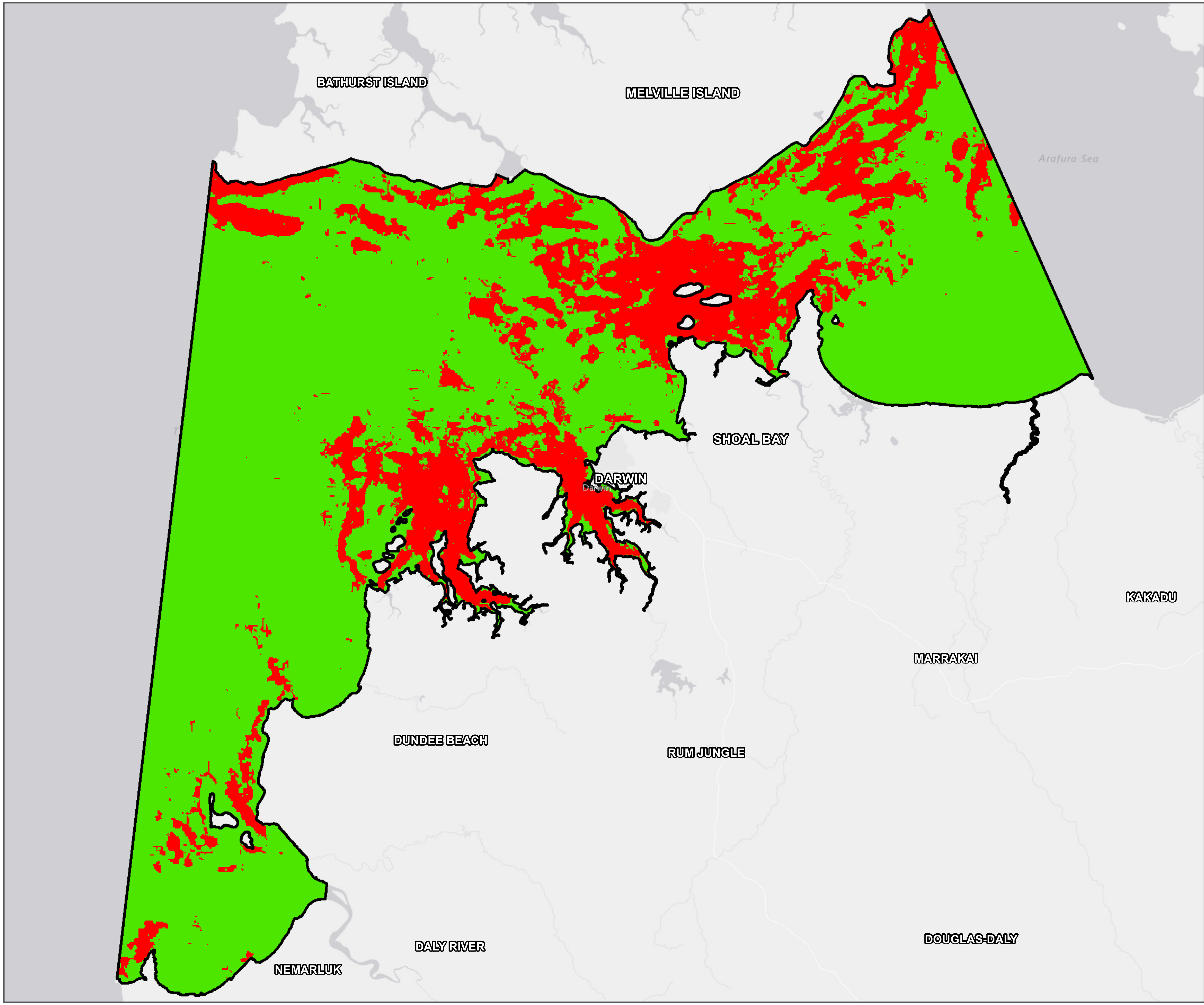
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-26 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS044_MCA_ConstraintsBenthicHabitat.mxd 05
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Classified Constraints - High Relief (complex) Benthic Habitat

FISH ATTRACTING DEVICES



Legend

Study Area

Proximity to High Relief (complex) Benthic Habitat

Least Constrained

Highly Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-26 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS041_MCA_ConstraintsBenthicHabitat.mxd 05
Basemap supplied by Esri and other third party suppliers

Seagrass Habitat

Seagrass are important primary producers providing food for the local dugong and turtle population and habitat for juvenile fish and other marine biota. Seagrass is essential for maintaining ecosystem health. Loss of existing seagrass habitat should be minimised.

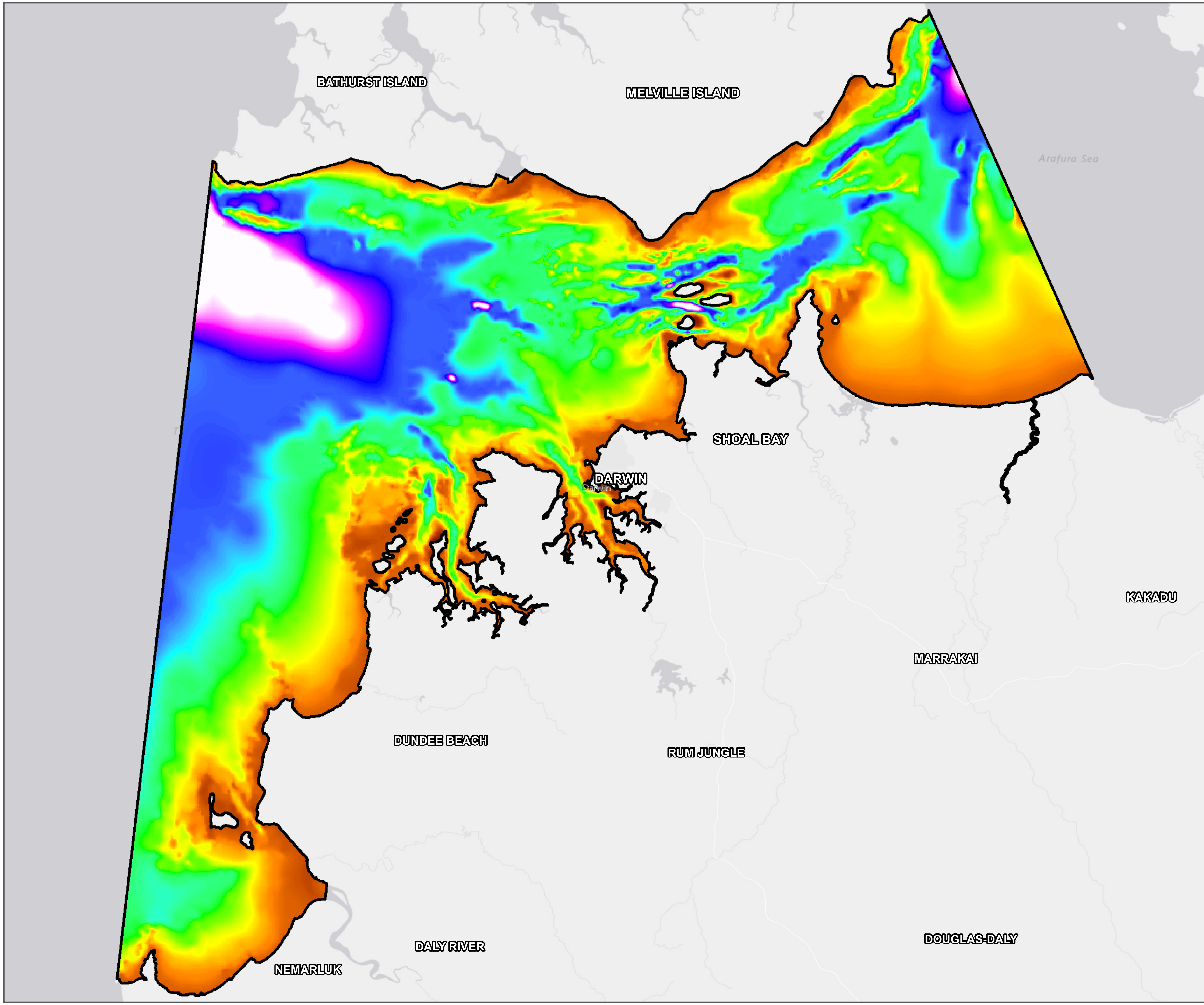
Table E-2. Seagrass habitat

Objective	Loss of existing seagrass habitat is minimised
How measured	Indicative seagrass habitat areas (considered to be less than – 10 m LAT)
Ratings	AR and FAD
Highly Constrained (No Data)	None
Moderately Constrained (1)	Within seagrass polygon
Lightly Constrained (5)	None
Least Constrained (9)	Outside of seagrass polygon
Data Source	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017.
Data Coverage / Quality	AusENC data covered the whole study area and were interpolated from bathymetric contours (relative to LAT) into a 50m grid from tiles AU412130, AU412131, AU413129, AU413130, AU413131, AU414129, AU414130.
Data Processing	The AusENC bathymetric vector contours were first interpolated into a bathymetric grid using ArcMAPs topo-to-raster tool. An arithmetic threshold was interpretively applied to define areas higher (greater than) -10 LAT.

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Potential Seagrass

ARTIFICIAL REEFS



Legend

Study Area

Bathymetry (LAT) (m)

5.74208

-23.8763

-53.4947

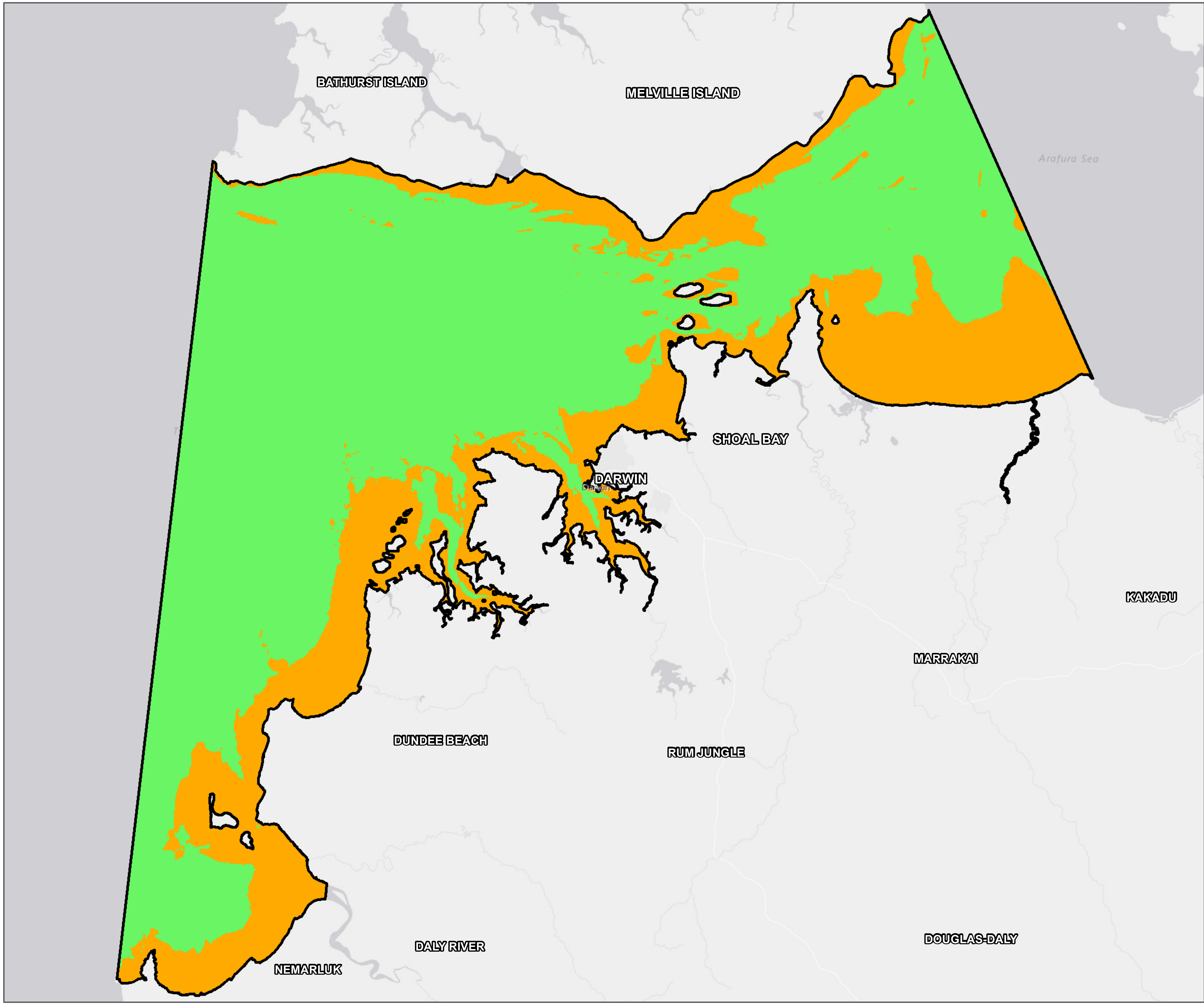
1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS003_ConstraintsPotentialSeagrass.mxd 02
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Potential Seagrass

ARTIFICIAL REEFS

Legend

Study Area

Potential Seagrass Habitat

Moderately Constrained

Least Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS015_ClassConPotentialSeagrass.mxd 01
Basemap supplied by Esri and other third party suppliers

Conservation Estate

Conservation areas (Reef Fish Protection Areas – e.g. Charles Point Patches, Marine Parks) have high biological diversity, often supporting rare and threatened species and are in pristine or largely undisturbed condition. Additionally, these areas usually have high recreational and aesthetic value to the community. Impacts on sites with legal conservation status are avoided.

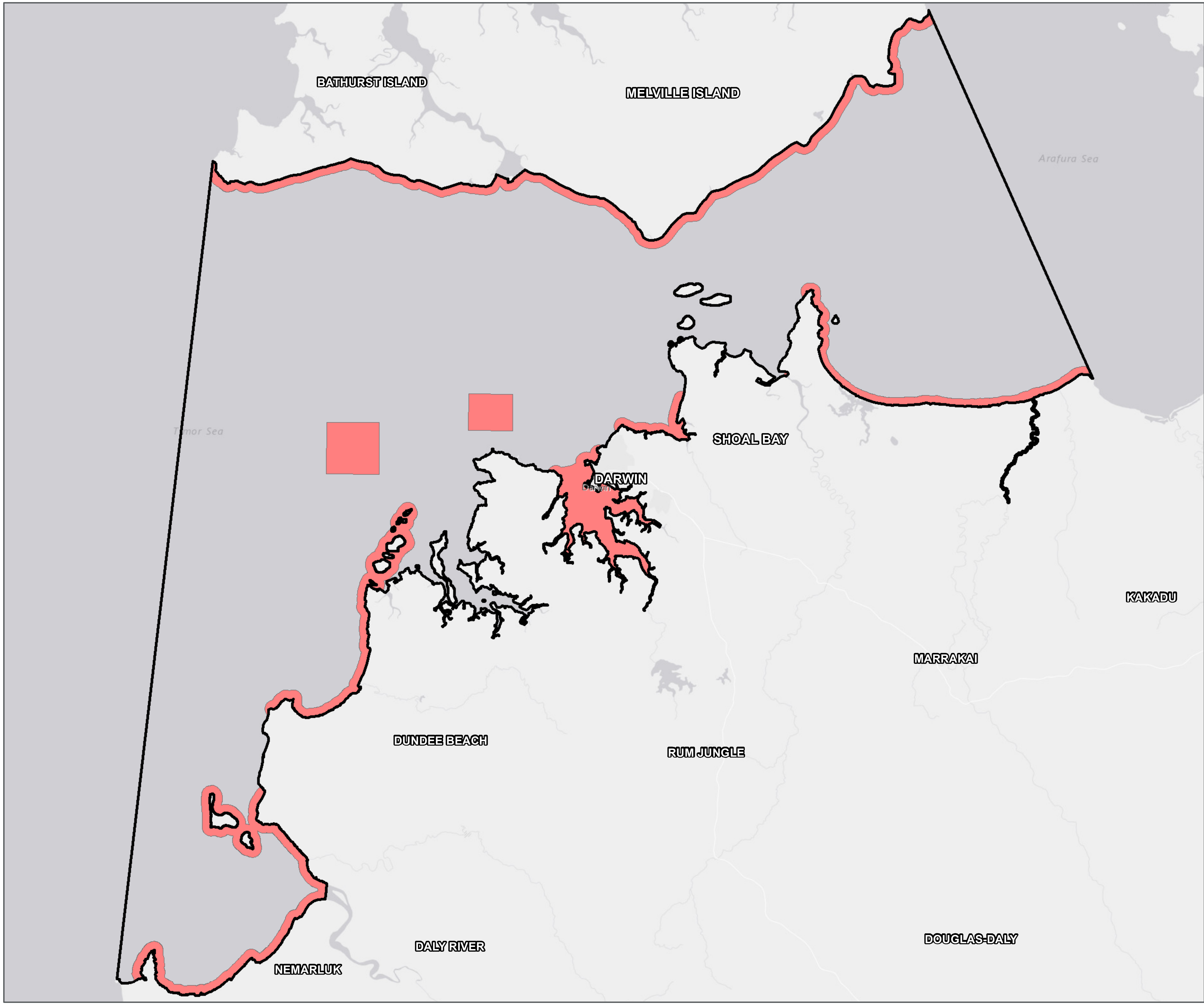
Table E-3. Conservation Estate

Objective	Impacts on sites with legal conservation status are avoided (or minimised)
How measured	Conservation estate polygon
Ratings	AR and FAD
Highly Constrained (No Data)	Within Conservation Estate polygon
Moderately Constrained (1)	None
Lightly Constrained (5)	None
Least Constrained (9)	Outside Conservation estate polygon
Data Source	Reef Fish Protection Area, Charles Point Wide & Lorna Shoal (https://nt.gov.au/marine/recreational-fishing/reef-fish-protection-areas) Sites of conservation significance (https://nt.gov.au/environment/environment-data-maps/important-biodiversity-conservation-sites/conservation-significance-list)
Data Coverage / Quality	Both data sets depicted discrete areas within the study area beyond which are not conservation areas, so that the whole of the study area is considered.
Data Processing	The Reef Fish Protection Areas were digitised into shapefile using the coordinates provided on the NT Government website before being rasterised. The Sites of Conservation Significance were provided in shapefile format. The Anson Bay and Tiwi Islands areas were amended to be limited to areas within 2km of the coastline. All areas relevant to the study area were then rasterised.

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Conservation Estate

ARTIFICIAL REEFS



Legend

- Study Area
- Conservation Estate

1:850,000 Scale at A3

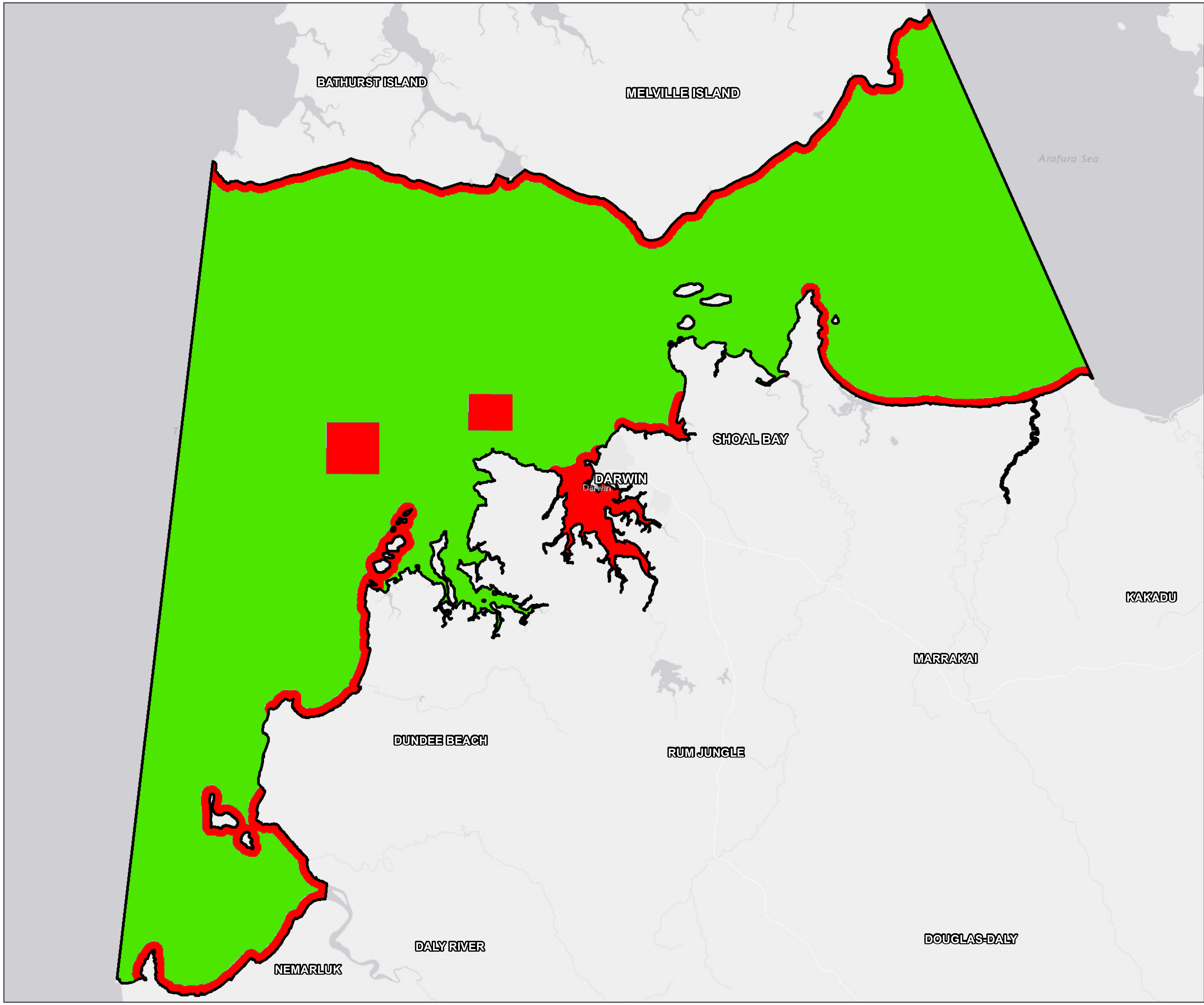
Kilometres
0 10 20 30 40

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-07 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS004_ConstraintsConservation.mxd 02
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Conservation Estate

ARTIFICIAL REEFS



Legend

- Study Area

Conservation Estate

- Least Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres: 0, 10, 20, 30, 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS017_ClassConConservation.mxd 01
Basemap supplied by Esri and other third party suppliers

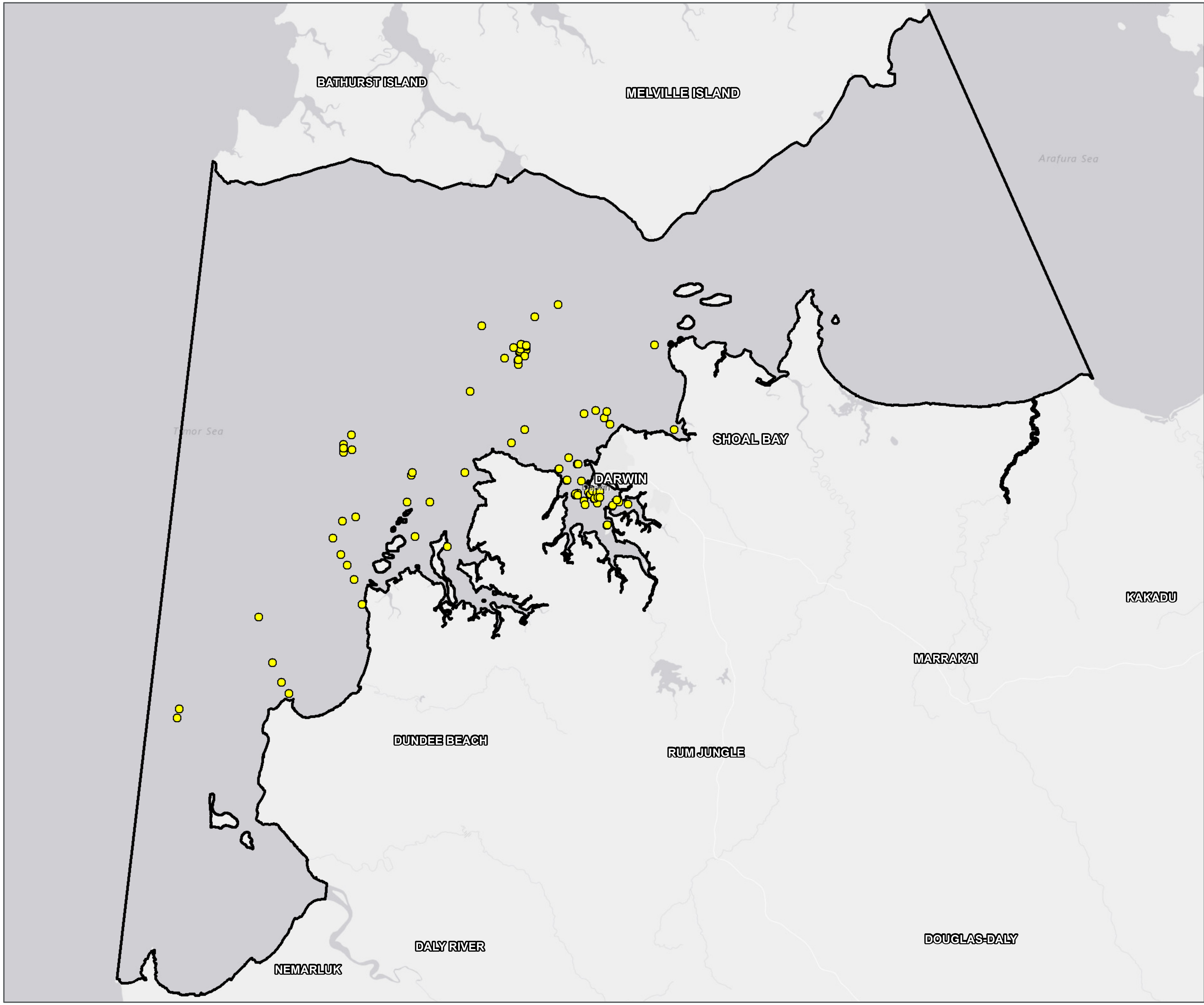
Social

Existing Use – Fishing spots

Existing or established uses (e.g. recreational fishing, commercial fishing, marine based tourism) are important to both industry and community. Creation of artificial reefs may give rise to conflicts over use and resource allocation. Conflicts over artificial reefs can arise over 1) common stock; and/or 2) user congestion; and 3) resource allocation. For example, if artificial reefs are allocated to enhance recreational fishing, to the exclusion of commercial fishing, this may have real or perceived costs to commercial fishers, especially if reduction in overall common stocks results; alternatively, if artificial reefs are open to both sectors, overall fishing pressure and associated risks may be significantly higher. Similarly, conflicting interests may arise between fishing and tourism sectors, or conservation and pro-development groups. Diving and fishing may be incompatible uses of the same artificial reef areas as each interferes with the goals of other large fish are amongst the first to be depleted by fishing, but are of considerable economic value to dive tourism.

Table E-4. Fishing spots

Objective	Value of existing fishing spots are maintained
How measured	Fishing spot (point) with a buffer (2000 m)
Ratings	AR and FAD
Highly Constraned (No Data)	None
Moderately Constrained (1)	Within buffer (2000 m)
Lightly Constrained (5)	None
Least Constrained (9)	Outside buffer
Data Source	A compilation of point locations was derived from a variety of coordinate and map sources: NT Government Artificial Reefs and FAD coordinate list (https://nt.gov.au/marine/recreational-fishing/artificial-reefs-and-fish-aggregating-devices) Coordinates from public online maps: http://fishingspots.scentblazer.com/?p=1 http://www.ozpolitic.com/fish/map-gps-marks-fishing/Darwin-Harbour-Northern-Territory-map-gps-marks-fishing.html NT Fish Finder magazine
Data Coverage / Quality	There is a great number of fishing locational information available from a variety of sources. The value and reliability of all sources and the level of duplication of information was considered against local knowledge. The layer created will have limitation in that it will only depict well known locations and may omit some popular areas that are not well publicised. Further, all locations were depicted as point or coordinate information which does not reflect the variable size of some locations (such as Lorna Shoal) compared to others which are smaller. This was catered to by using a significant 2000m buffer.
Data Processing	Coordinates plotted into vector point locations before being buffered by 2000m and rasterised. Coordinates plotted into vector point locations before being buffered by 2000m and rasterised. Positions that could be determined from coordinates were preferred over georeferencing. For those locations without provided coordinates, magazine pages were scanned and georeferenced for accurate plotting of locations to points. All locations were then buffered by 2000m and rasterised.



NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Existing Fishing Locations

ARTIFICIAL REEFS

Legend

- Study Area
- Existing Fishing Locations

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

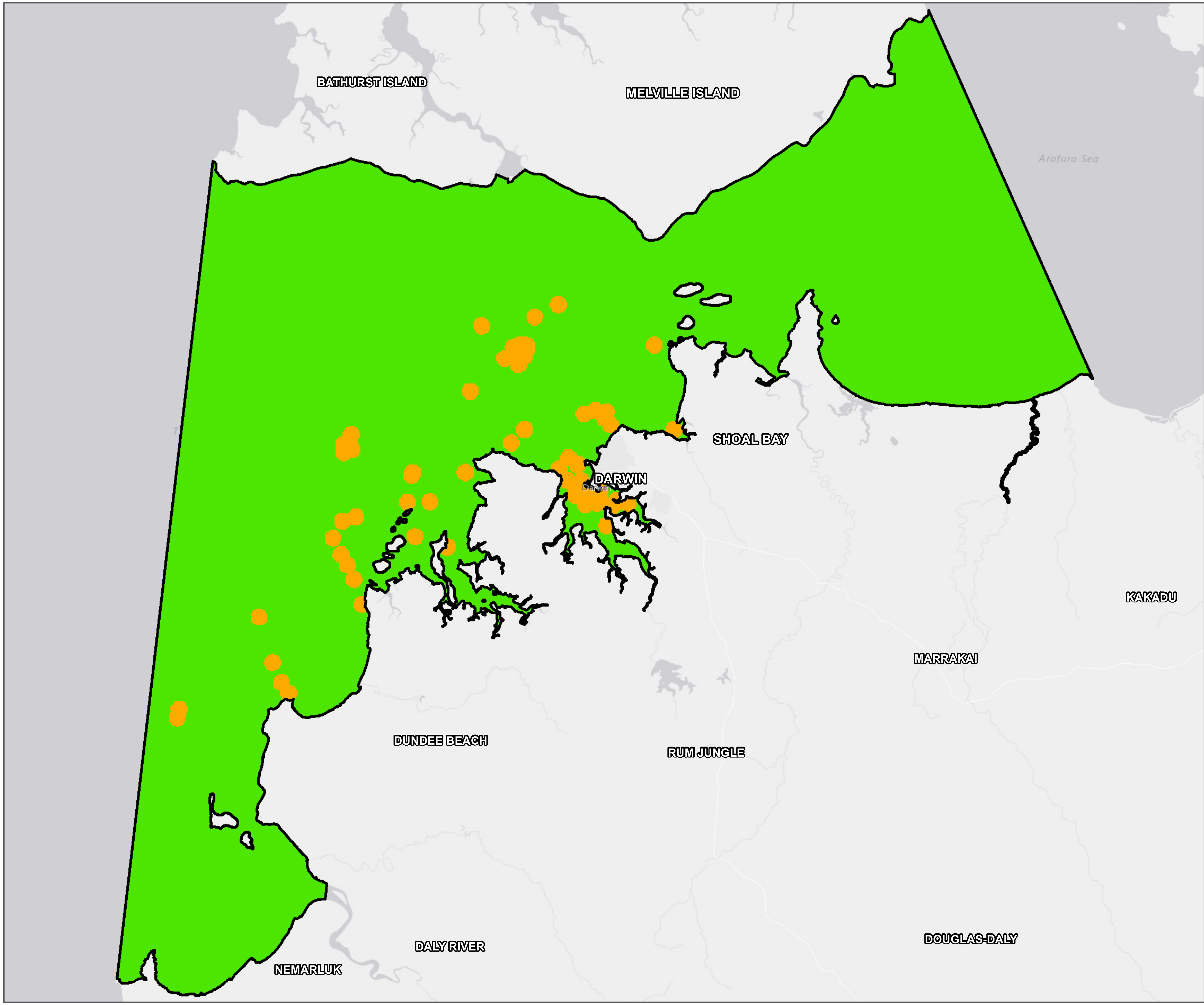
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-07 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS006_ConstraintsFishingLocations.mxd 02
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Existing Fishing Locations

ARTIFICIAL REEFS



Legend

- Study Area

Existing Fishing Locations

- Moderately Constrained
- Least Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

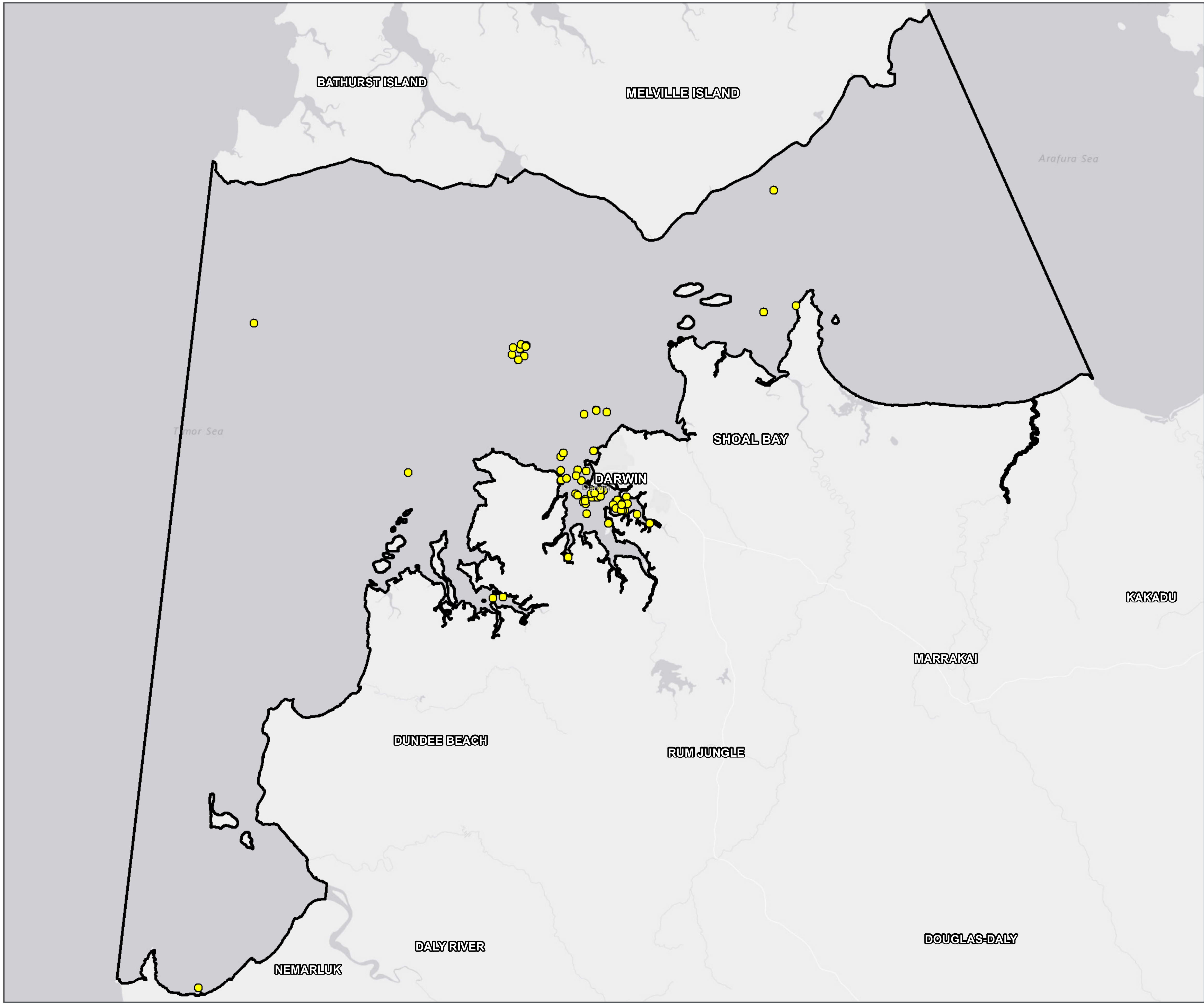
Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS014_ClassConFishingLocations.mxd 01
Basemap supplied by Esri and other third party suppliers

Wrecks, including War graves

Wrecks, including those with human remains (e.g. WW2 aircraft wreck) are protected by law, and have high social and historical heritage value. These areas are to be avoided.

Table E-9. Wrecks and War graves

Objective	Wrecks, including known war graves are avoided
How measured	Buffer around wreck – 1000 m
Ratings	AR and FAD
Highly Constraned (No Data)	Within 1000 m of wreck
Moderately Constrained (1)	None
Lightly Constrained (5)	None
Least Constrained (9)	Outside buffer
Data Source	INPEX
Data Coverage / Quality	List of wrecks and war graves are considered comprehensive throughout the study area in terms of protection status. The accuracy of the location is considered more precise in Darwin Harbour than other areas. They were reviewed against their apparent location in multi-beam bathymetry for positional accuracy.
Data Processing	Each point location was buffered by 1000m and rasterised.



NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Wrecks

ARTIFICIAL REEFS

Legend

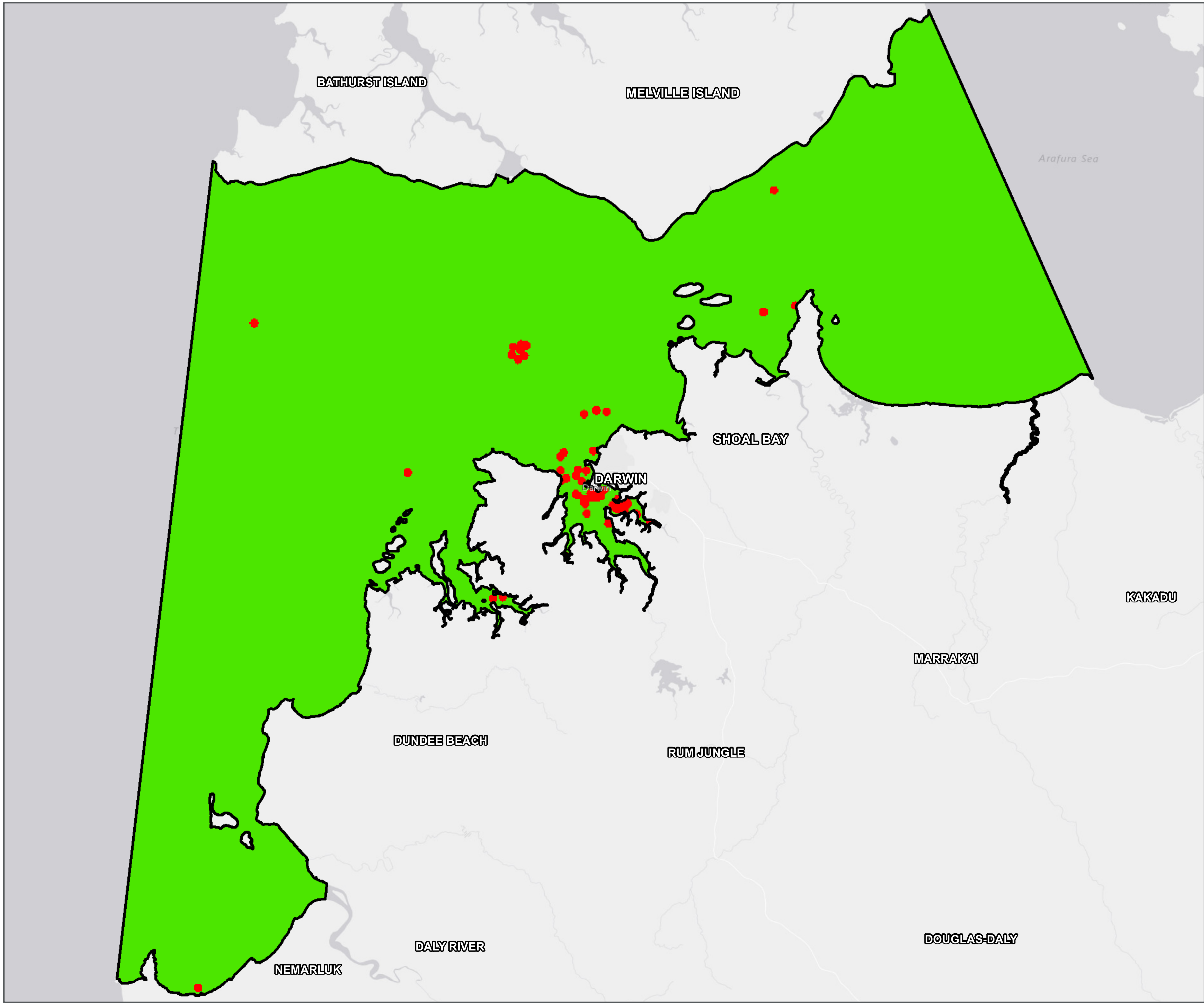
- Study Area
- Wrecks

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-07 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS007_ConstraintsWrecks.mxd 02
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Wrecks

ARTIFICIAL REEFS

Legend

Study Area

Wrecks

Least Constrained

Highly Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

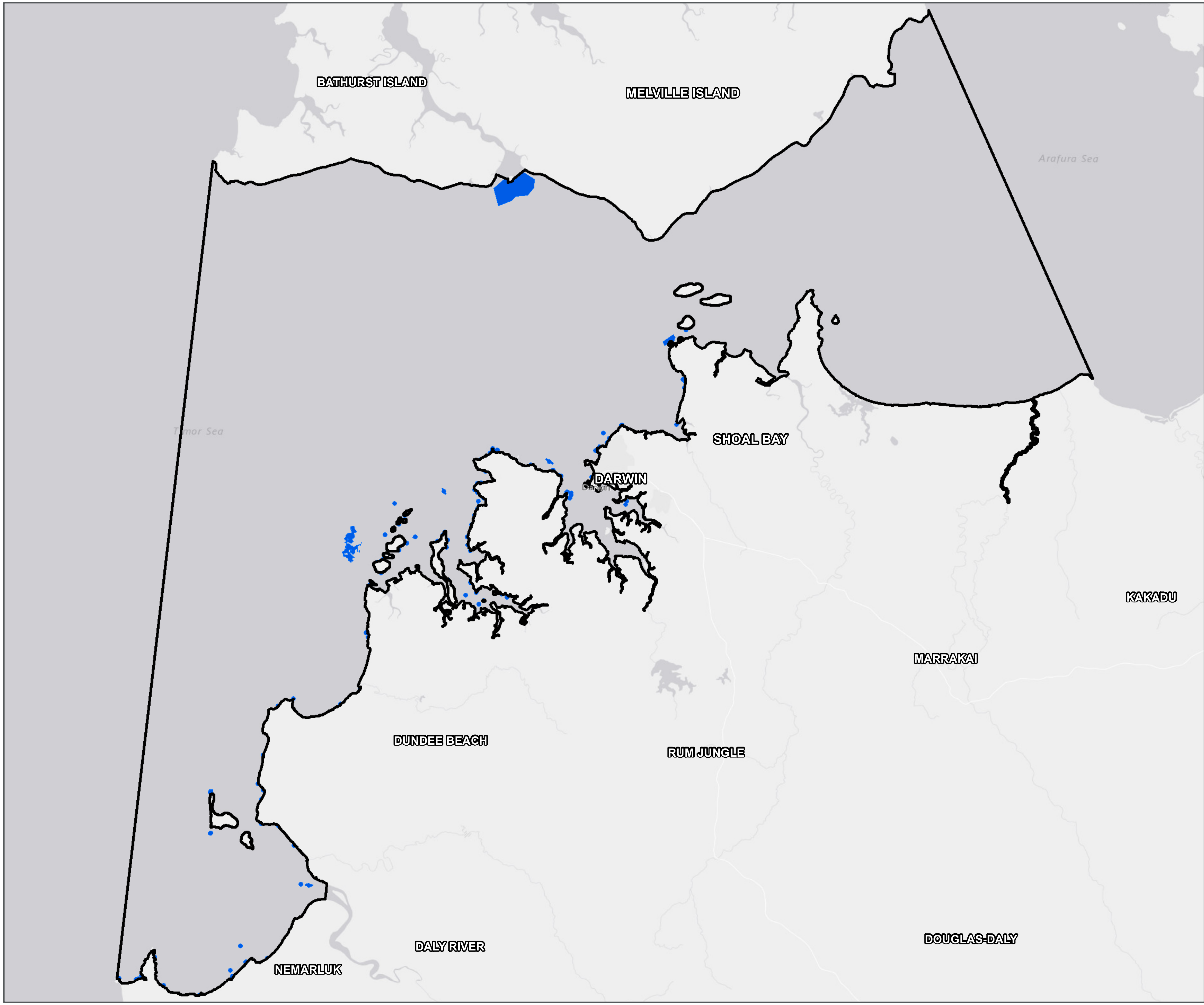
Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS016_ClassConWrecks.mxd 01
Basemap supplied by Esri and other third party suppliers

Cultural Heritage Sites

Cultural heritage sites (middens, artefact scatters, fish traps) are of significant value to Traditional Owners. These areas are to be avoided.

Table E-6. Cultural Heritage

Objective	Cultural Heritage sites are avoided
How measured	Location with 500m buffer
Ratings	AR and FAD
Highly Constraned (No Data)	Within buffer
Moderately Constrained (1)	None
Lightly Constrained (5)	None
Least Constrained (9)	Outside buffer
Data Source	AAPA_NT_Coastal_Sacred_Sites.kmz supplied by NT Government
Data Coverage / Quality	List of sacred sites are considered comprehensive throughout the study area in terms of protection status. Only the marine and not the terrestrial coastal sites were considered.
Data Processing	Sacred sites provided in point form were buffered by 500m and merged with sacred sites that were provided in polygon form before being rasterised.



NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Cultural Heritage

ARTIFICIAL REEFS

Legend

- Study Area
- Cultural Heritage

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

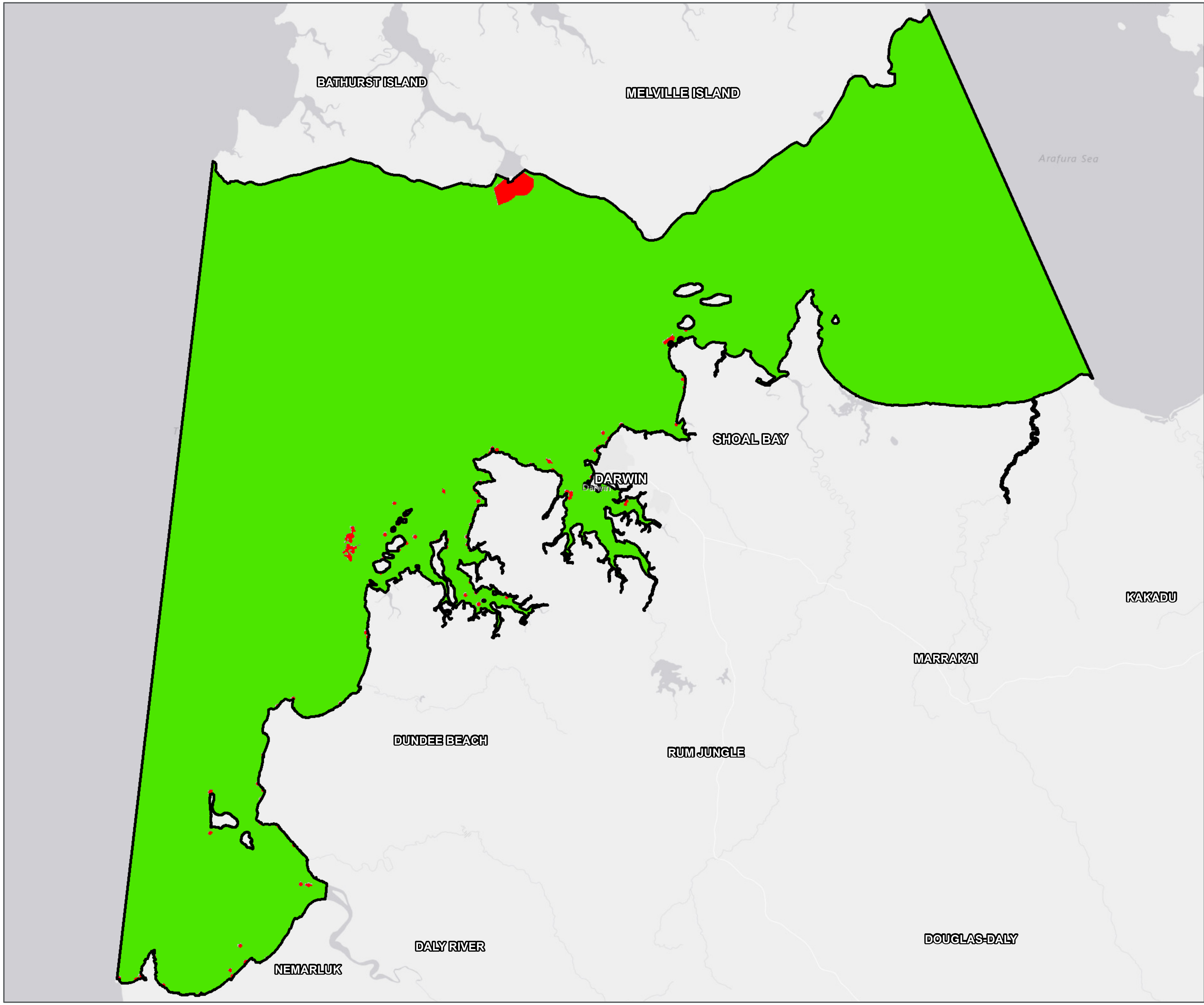
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-07 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS010_ConstraintsHeritage.mxd 02
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Cultural Heritage

ARTIFICIAL REEFS



Legend

Study Area

Cultural Heritage

Least Constrained

Highly Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS018_ClassConHeritage.mxd 02
Basemap supplied by Esri and other third party suppliers

Mineral or Petroleum Exploration Areas

Exclusion areas around pipelines or other infrastructure may preclude installing and using artificial reefs (boundary constraints not infrastructure per sae.).

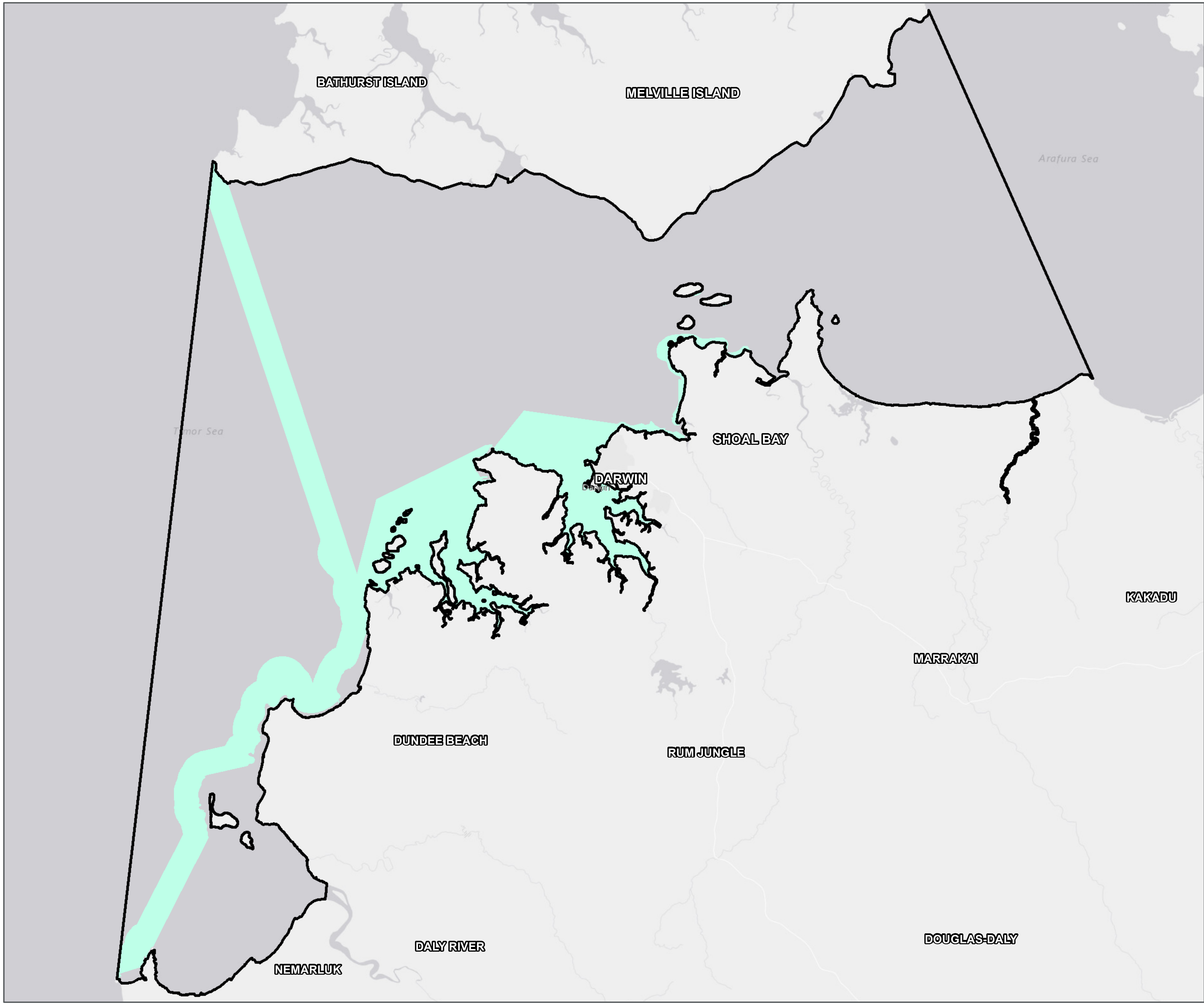
Table E-7. Mineral or Petroleum Exclusion Areas

Objective	Impact on mineral or petroleum exploration activities are minimised
How measured	Petroleum exploration polygon
Ratings	AR and FAD
Highly Constraned (No Data)	None
Moderately Constrained (1)	None
Lightly Constrained (5)	Within polygon
Least Constrained (9)	Outside polygon
Data Source	Northern Territory Mineral Tenure from Department of Primary Industry and Resources (https://dpir.nt.gov.au/mining-and-energy/STRIKE/accessing-nt-datasets/nt-wide-titles-datasets)
Data Coverage / Quality	Considered comprehensive for the study area.
Data Processing	Polygons that depicted mineral and petroleum reserves (rather than exploration licences) were rasterised.

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Mining Lease

ARTIFICIAL REEFS



Legend

- Study Area
- Mineral/ Petroleum Reserve

1:850,000 Scale at A3

Kilometres: 0, 10, 20, 30, 40

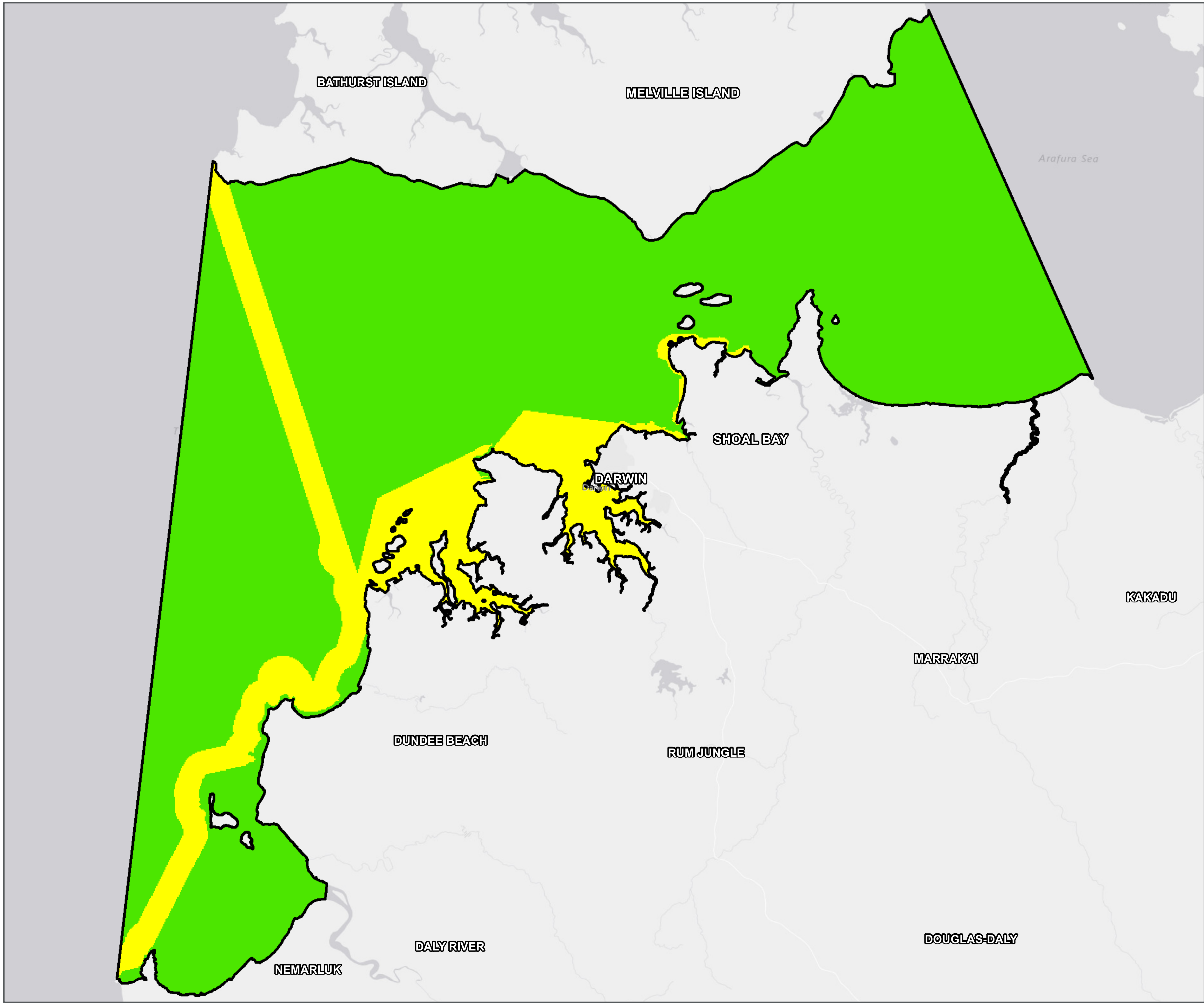
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-07 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS008_ConstraintsMiningLease.mxd 02
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Mining Lease

ARTIFICIAL REEFS



Legend

- Study Area
- **Mineral/ Petroleum Reserve**
- Lightly Constrained
- Least Constrained

1:850,000 Scale at A3

Kilometres
0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-11 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS019_ClassConMiningLease.mxd 01
Basemap supplied by Esri and other third party suppliers

Engineering Constraints

Substrate type

Artificial reefs are installed / located on stable substrate. Substrate that may result in instability are to be avoided.

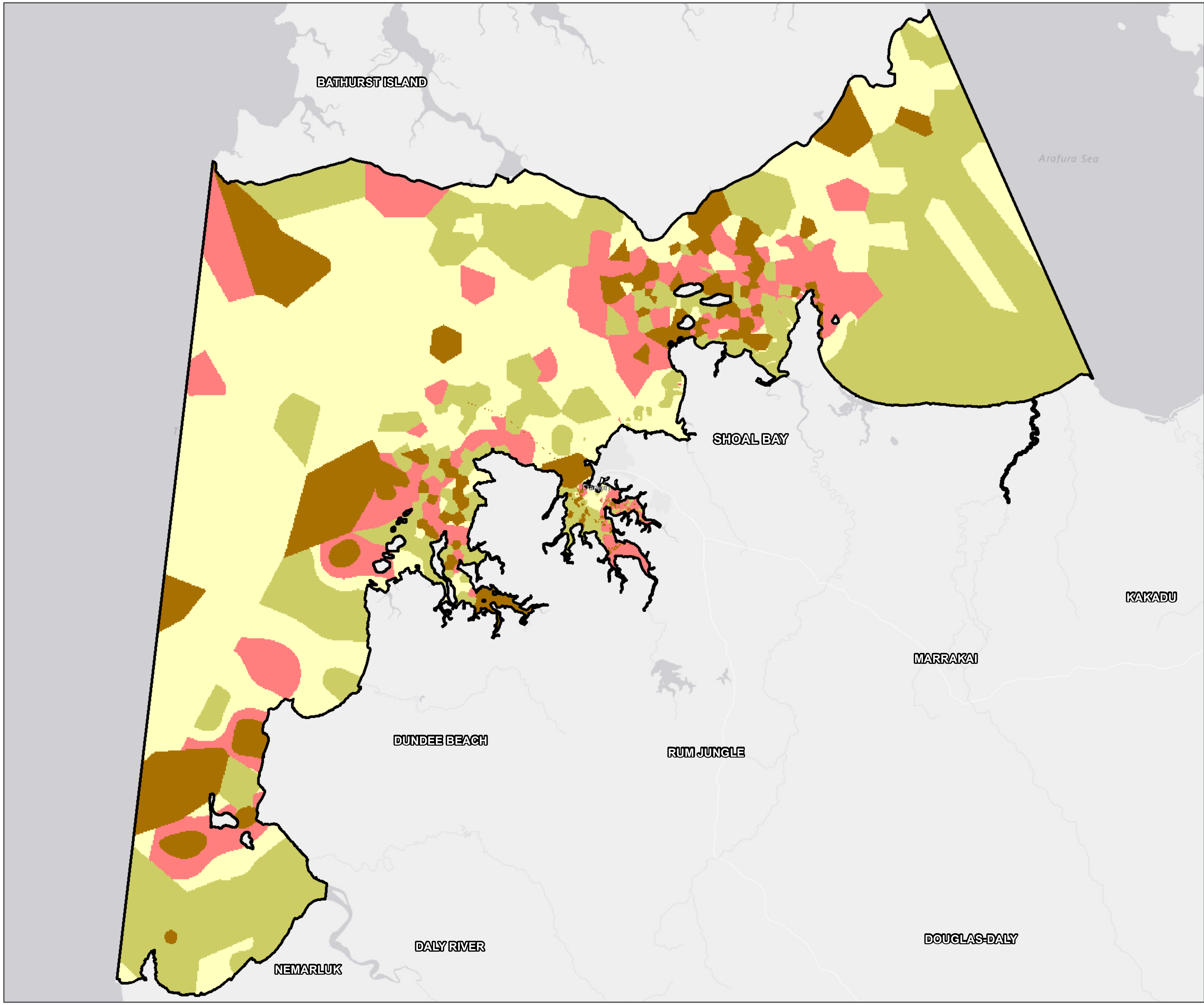
Table E-8. Substrate Type

Objective	Artificial reefs are stable	
How measured	Substrate type polygon	
Ratings	AR	FAD
Highly Constraned (No Data)	mud, rock, coral	rock, coral
Moderately Constrained (1)	none	none
Lightly Constrained (5)	gravel	none
Least Constrained (9)	sand	mud, sand, gravel
Data Source	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017. Sediment particle size map derived substrates INPEX Ichthys Gas Field Development Project 2011, survey by Geo Oceans.	
Data Coverage / Quality	AusENC substrate point data covered the whole study area but were more densely distributed in and around Bynoe Harbour and the Vernon Islands. They were sparsely distributed around Chambers Bay in the Van Diemen Gulf area, and around Anson Bay and Fog Bay in the South West. AusENC Substrate points were interpolated to Theissen polygons using the ET Geowizards add on to ArcMap, from tiles AU412130, AU412131, AU413129, AU413130, AU413131, AU414129, AU414130. The INPEX substrates type map was limited to an inshore coastal area between Cape Ford in the South West and	
Data Processing	Polygons derived from the two separate sources were not locally consistent with regards to their substrate classification. As both sources were coarsely interpolated, neither classification was considered more reliable than the other. In order to use the most important information from both data sets the classifications were merged in a hierarchy based upon a worst case of classification in the following order: Rock from Inpex over Rock and Coral from AusENC Mud from Inpex over Mud/Clay from AusENC Gravel from Inpex over Gravel/Pebbles/Shells from AusENC Sand from Inpex over Sand from AusENC The codified NATSUR attribute was translated to substrate classes by referring to the corresponding location in the AusGeoTIFF raster charts in which they are labelled. Each location was tagged with multiple substrate types, presumably in order of cover abundance, which were simplified according to the first tag and grouped into clay/mud; coral; gravel/pebbles/shells; rock; and sand. Classified Theissen polygons were then rasterised INPEX Substrate polygons and their tagged substrate classes of Gravel; Mud; Rock; and Sand were adopted and rasterised.	

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Substrate

ARTIFICIAL REEFS



Legend

Study Area

Substrate

1 - rock & coral
2 - mud & clay
3 - gravel, shells, pebbles
4 - sand

1:850,000 Scale at A3

Kilometres
0 10 20 30 40

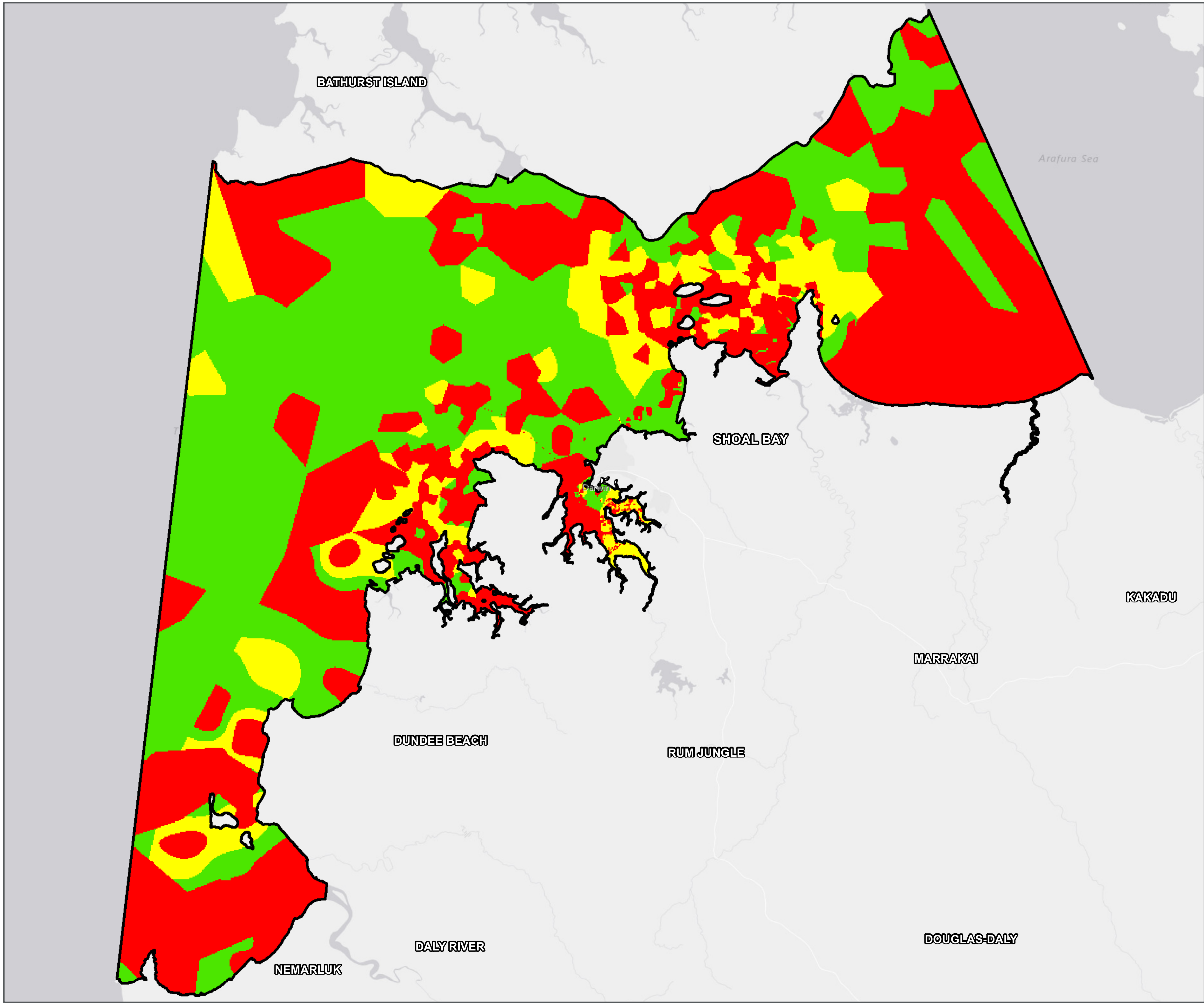
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-07 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS020_ConstraintsSubstrate.mxd 01
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Substrate

ARTIFICIAL REEFS



Legend

Study Area

Substrate

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

N

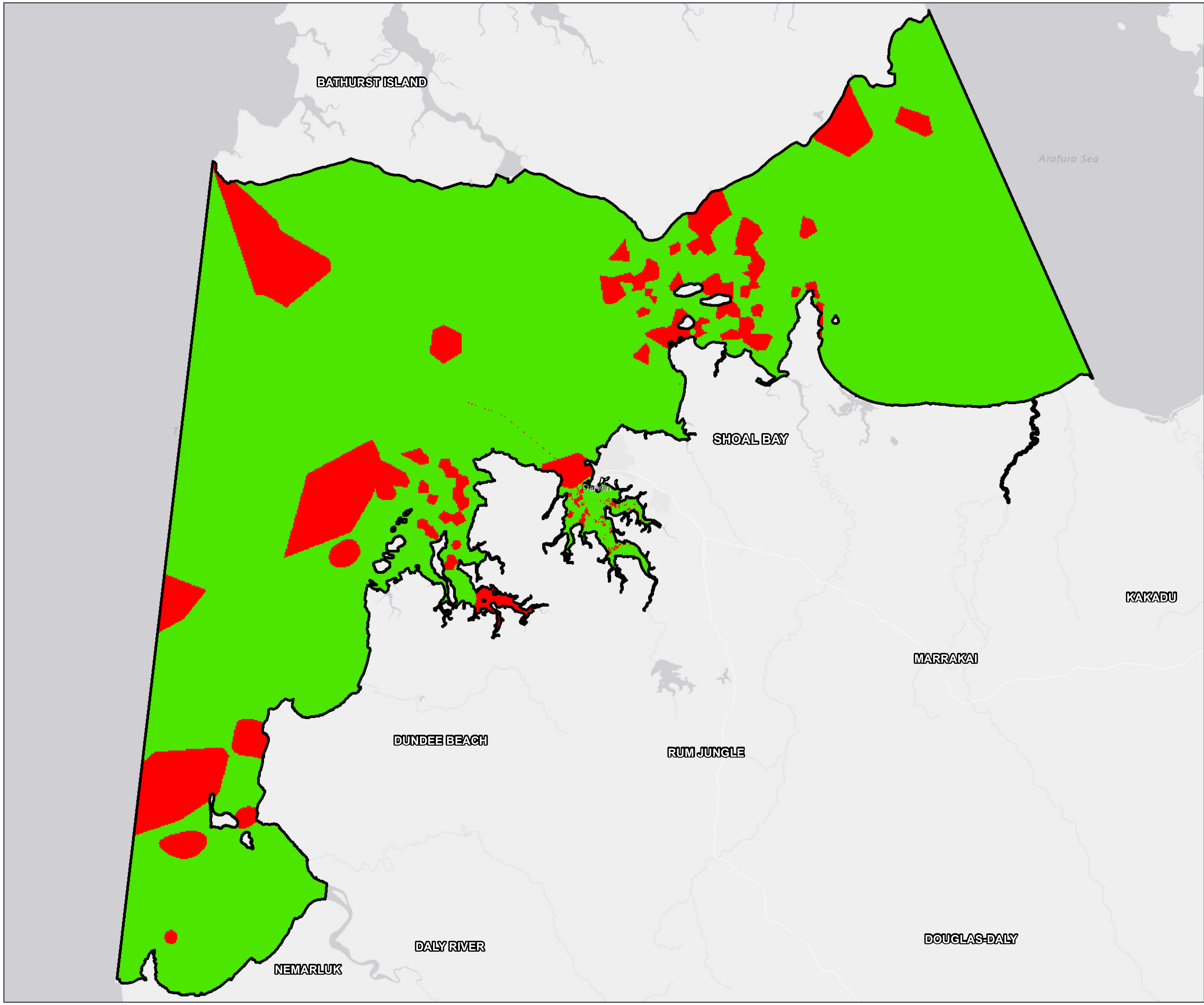
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS021_ClassConSubstrate.mxd 01
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Substrate

FISH ATTRACTING DEVICES (FADS)



Legend

Study Area

Substrate

Least Constrained

Highly Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-11 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS022_ClassConSubstrate.mxd 01
Basemap supplied by Esri and other third party suppliers

Distance to launch site (boat ramp)

Further offshore the greater the travel time, rougher the seas, requiring larger vessels and potentially reduces the safety of recreational fishing parties.

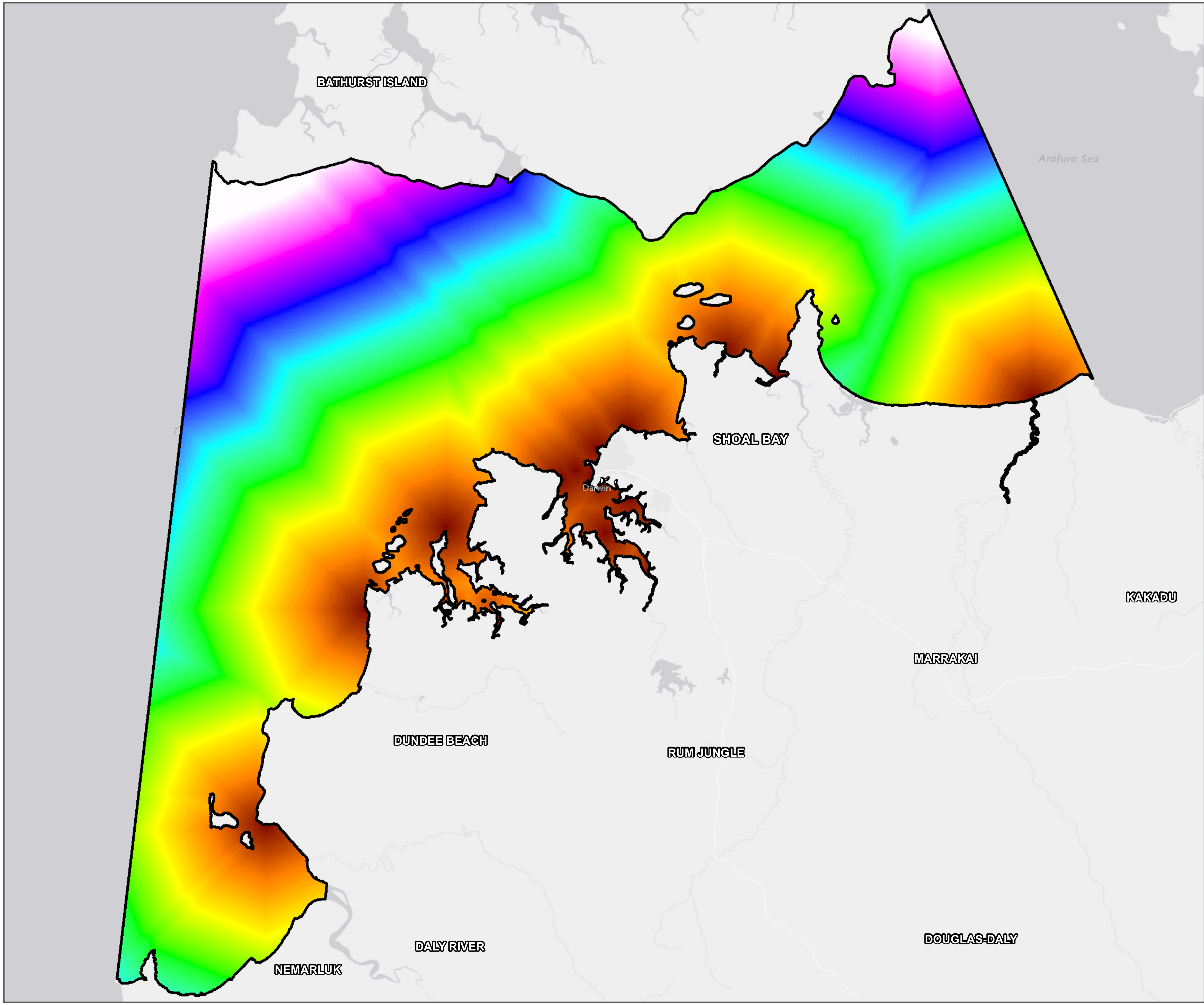
Table E-9. Distance to launch site

Objective	Artificial reefs are accessible
How measured	Distance km from vessel launching facilities or entrance to Bynoe Harbour, Darwin Harbour or mouth of Mary River
Ratings	AR and FAD
Highly Constraned (No Data)	None
Moderately Constrained (1)	Greater than 70 km from designated launch and retrieval site
Lightly Constrained (5)	45 – 70 km from designated launch and retrieval site
Least Constrained (9)	Less than 45 km from designated launch and retrieval site
Data Source	BoatRampsCoastal_20171025 Supplied by NT Government (https://nt.gov.au/marine/for-all-harbour-and-boat-users/find-a-boat-ramp)
Data Coverage / Quality	Comprehensive for public formal ramps throughout the study area
Data Processing	Ramp point locations were supplemented with additional 'dummy' locations at the mouths of Bynoe Harbour, Darwin Harbour, Leaders Creek, Adelaide and Mary Rivers to depict a source point for measuring distance of open water travel from access points rather than of total travel. This is to account for the safety/discomfort of open water travel as a greater concern than travel in enclosed waters. Enclosed waters without ramps were not considered. Ramps that met directly with coastal waters were considered as they were. The Cost Distance tool in ArcMap was run with an even friction value of 1 in order to measure the true travel distance around obstructions.

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Distance To Boat Ramps

ARTIFICIAL REEFS



Legend

Study Area

Distance To boat ramp (km)

107415

53707

0

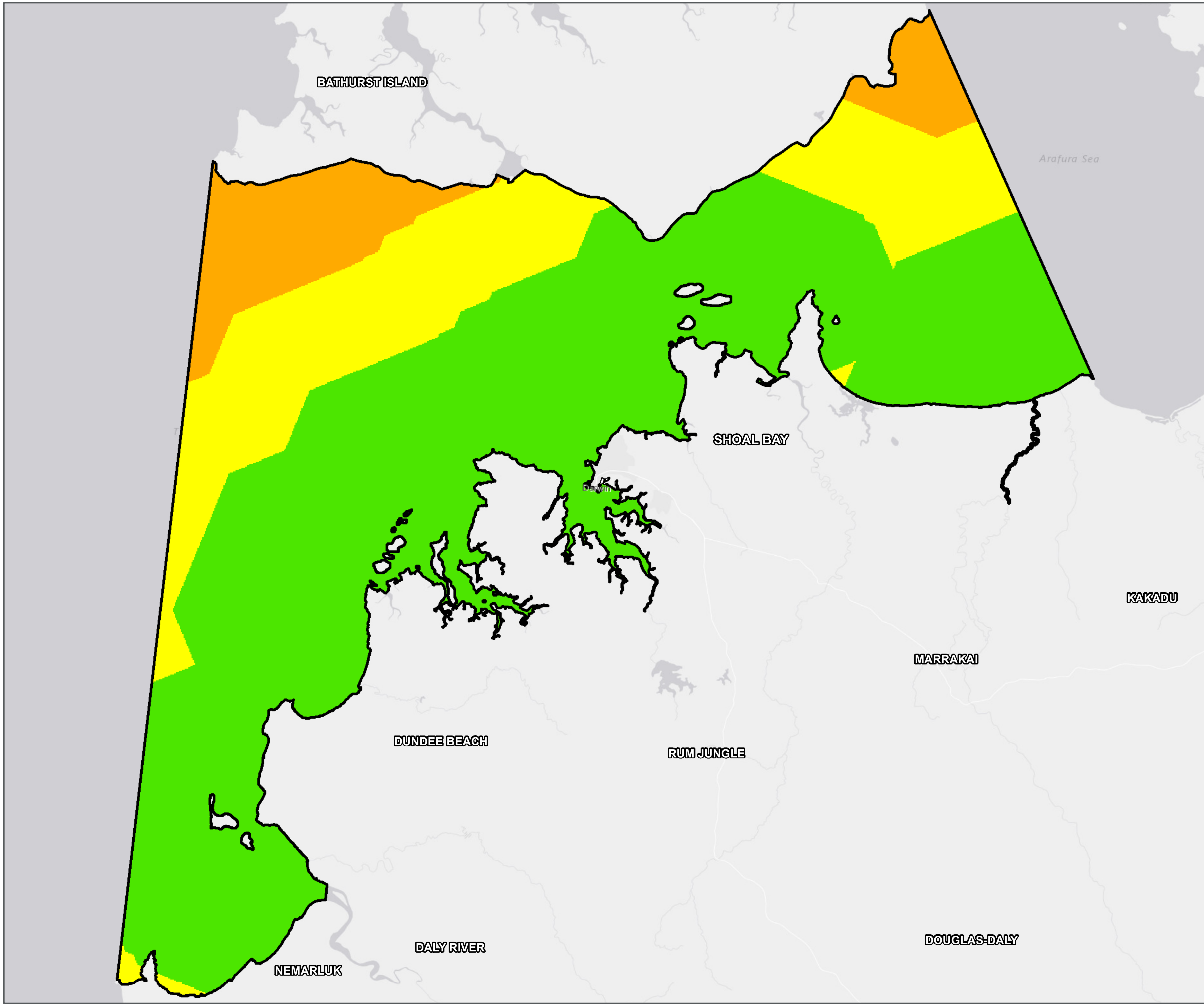
1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-11 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS022_ConstraintsAccess.mxd 01
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Distance To Boat Ramps

ARTIFICIAL REEFS

Legend

Study Area

Distance To Boat Ramp (km)

- Moderately Constrained
- Lightly Constrained
- Least Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

N

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS023_ClassConAccess.mxd 01
Basemap supplied by Esri and other third party suppliers

Water depth

Avoid creating navigational hazards and exposing infrastructure at low tide.

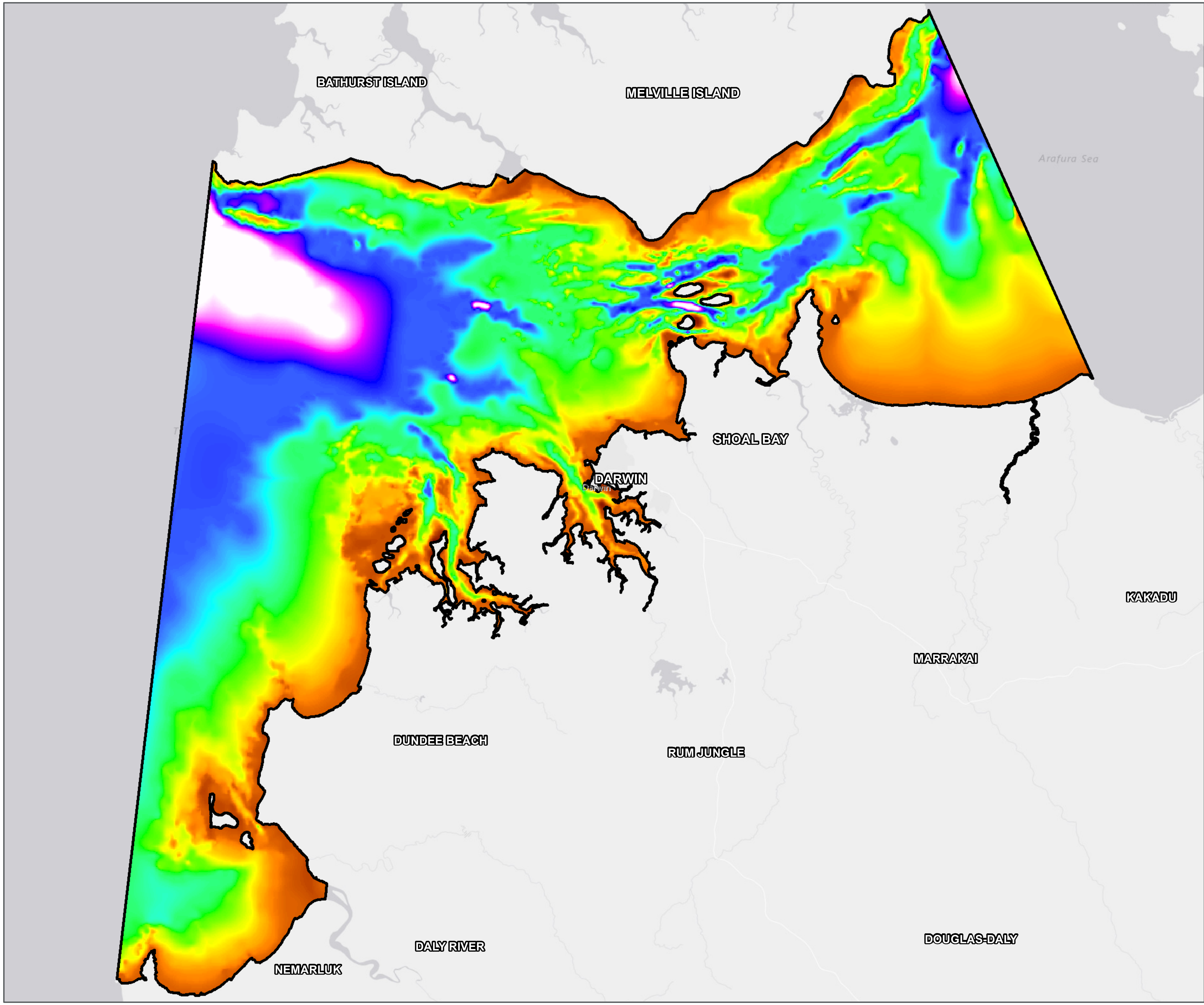
Table E-10. Water Depth

Objective	Artificial reefs and FADs are not exposed at LAT	
How measured	Depth below LAT	
Ratings	AR	FAD
Highly Constraned (No Data)	< 15 m	< 15 m
Moderately Constrained (1)	> 50 m	15 – 30 m
Lightly Constrained (5)	40 – 50 m	None
Least Constrained (9)	15 – 40 m	> 30 m
Data Source	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017.	
Data Coverage / Quality	AusENC data covered the whole study area and were interpolated from bathymetric contours (relative to LAT) into a 50m grid from tiles AU412130, AU412131, AU413129, AU413130, AU413131, AU414129, AU414130.	
Data Processing	The AusENC bathymetric vector contours were first interpolated into a bathymetric grid using ArcMAPs topo-to-raster tool. Arithmetic thresholds were applied using the Reclassify tool to define classes with different depth intervals.	

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Bathymetry

ARTIFICIAL REEFS



Legend

Study Area

Bathymetry (LAT) (m)

5.74208

-23.8763

-53.4947

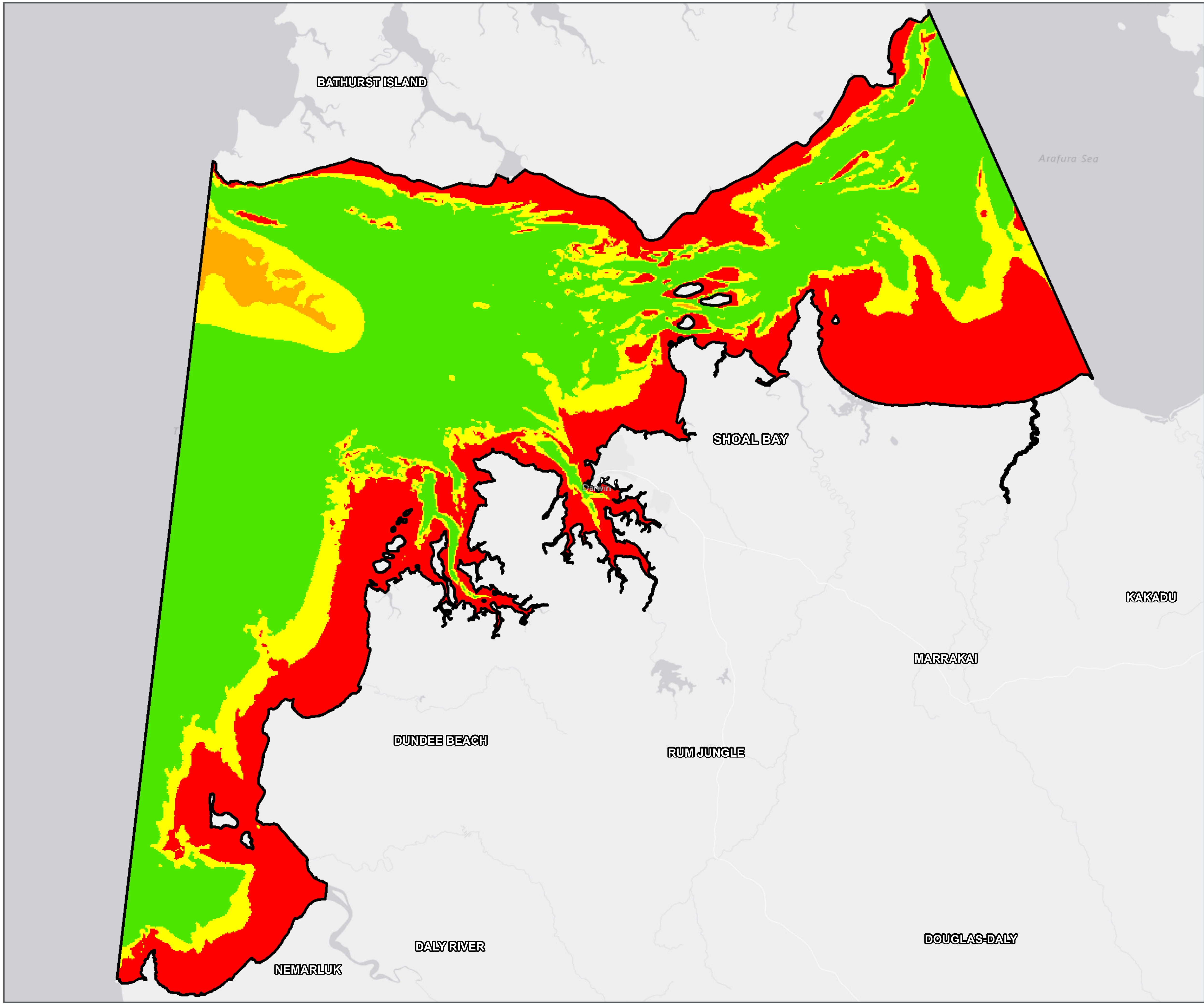
1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS024_ConstraintsBathymetry.mxd 01
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Bathymetry

ARTIFICIAL REEFS

Legend

Study Area

Bathymetry (LAT) (m)

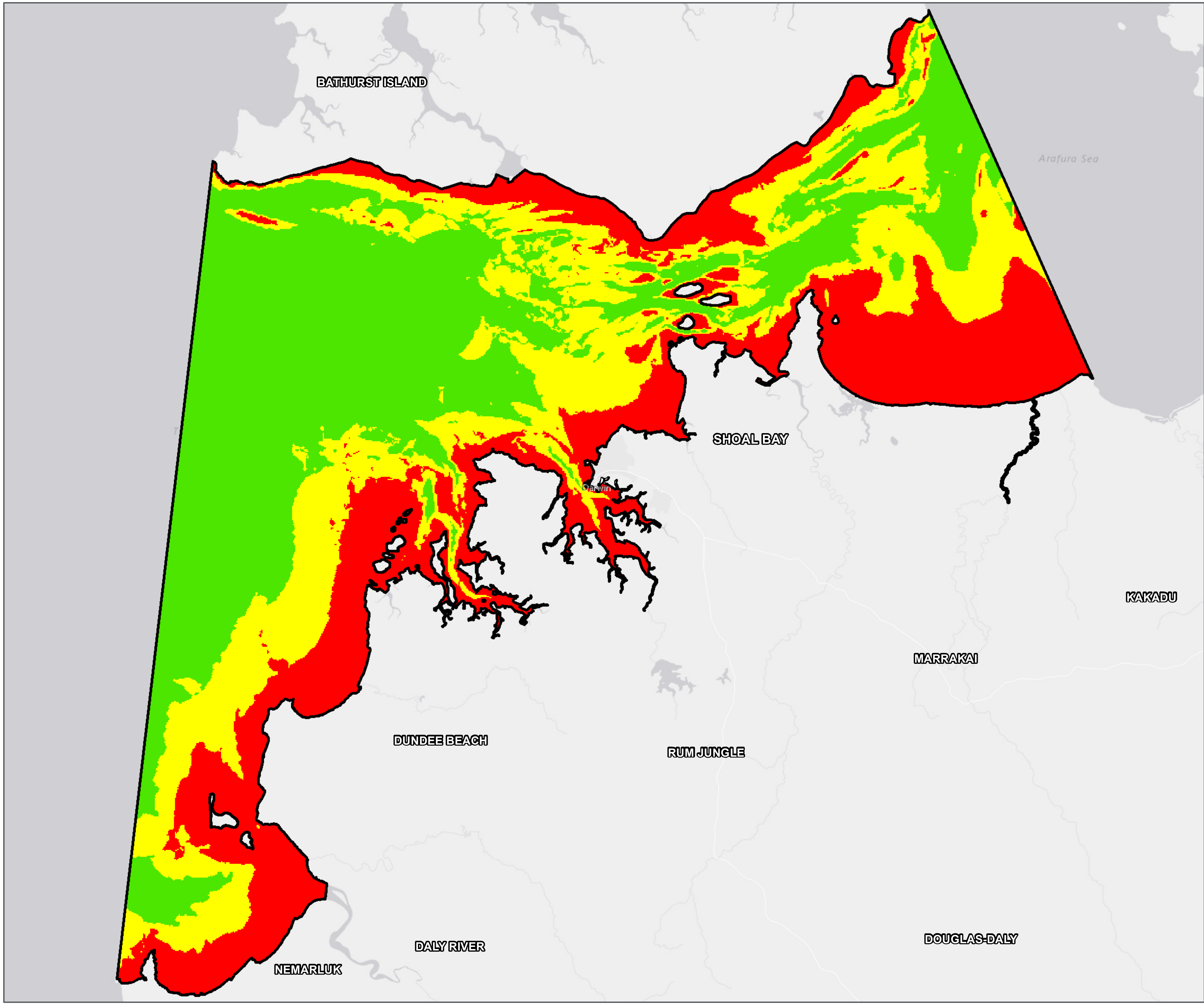
- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres
0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS025_ClassConBathymetry.mxd 01
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Bathymetry

FISH ATTRACTING DEVICES (FADS)

Legend

- Study Area

Bathymetry (LAT) (m)

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres 0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-11 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS024_ClassConBathymetry.mxd 01
Basemap supplied by Esri and other third party suppliers

Interference with infrastructure

Artificial reefs should not affect the use of existing marine infrastructure (dredge channels, gas pipelines, navigation aids) or increase risk to operators and or fishers Hazards to navigation. Existing marine infrastructure is avoided.

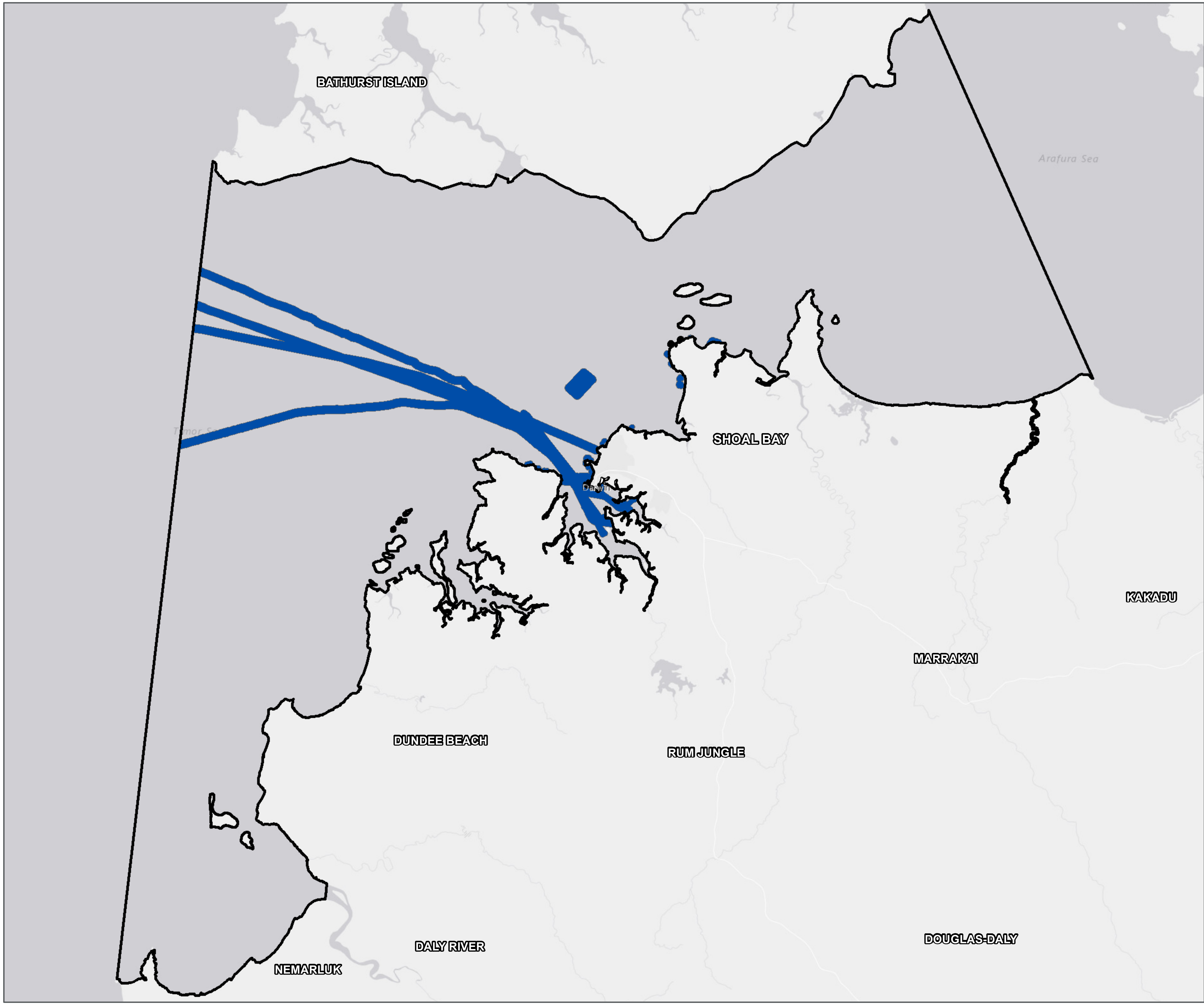
Table E-11. Interference with Infrastructure

Objective	Interference with marine infrastructure is avoided	
How measured	Distance from existing marine infrastructure	
Ratings	AR	FAD
Highly Constrained (No Data)	Within 1000 m of marine infrastructure	Within 2000 m of marine infrastructure
Moderately Constrained (1)	None	None
Lightly Constrained (5)	None	None
Least Constrained (9)	> 1000 m from marine infrastructure	> 2000 m from marine infrastructure
Data Source	AusENC (Electronic Navigation Charts) in S.57 format supplied by The Australian Hydrographic Service, November 2017. Spoil disposal site - INPEX job Dredge spoil grounds - Ichthys Gas Field Development Project - Appendix 13 - Dredging and Spoil Disposal Modelling	
Data Coverage / Quality	AusENC data covered the whole study area from tiles AU412130, AU412131, AU413129, AU413130, AU413131, AU414129, AU414130.	
Data Processing	The polyline layers sourced from AusENC, as well as the polygon layers indicating the spoil grounds had a buffer applied to them (2000, 500m). These polygon layers were combined using the merge tool, once merged the layer was converted to a raster using the polygon to raster tool. Arithmetic thresholds were applied using the reclassify tool to define areas outside as well as inside the infrastructure buffer.	

NORTHERN TERRITORY GOVERNMENT

Raw Constraints - Infrastructure

ARTIFICIAL REEFS



Legend

- Study Area
- Infrastructure

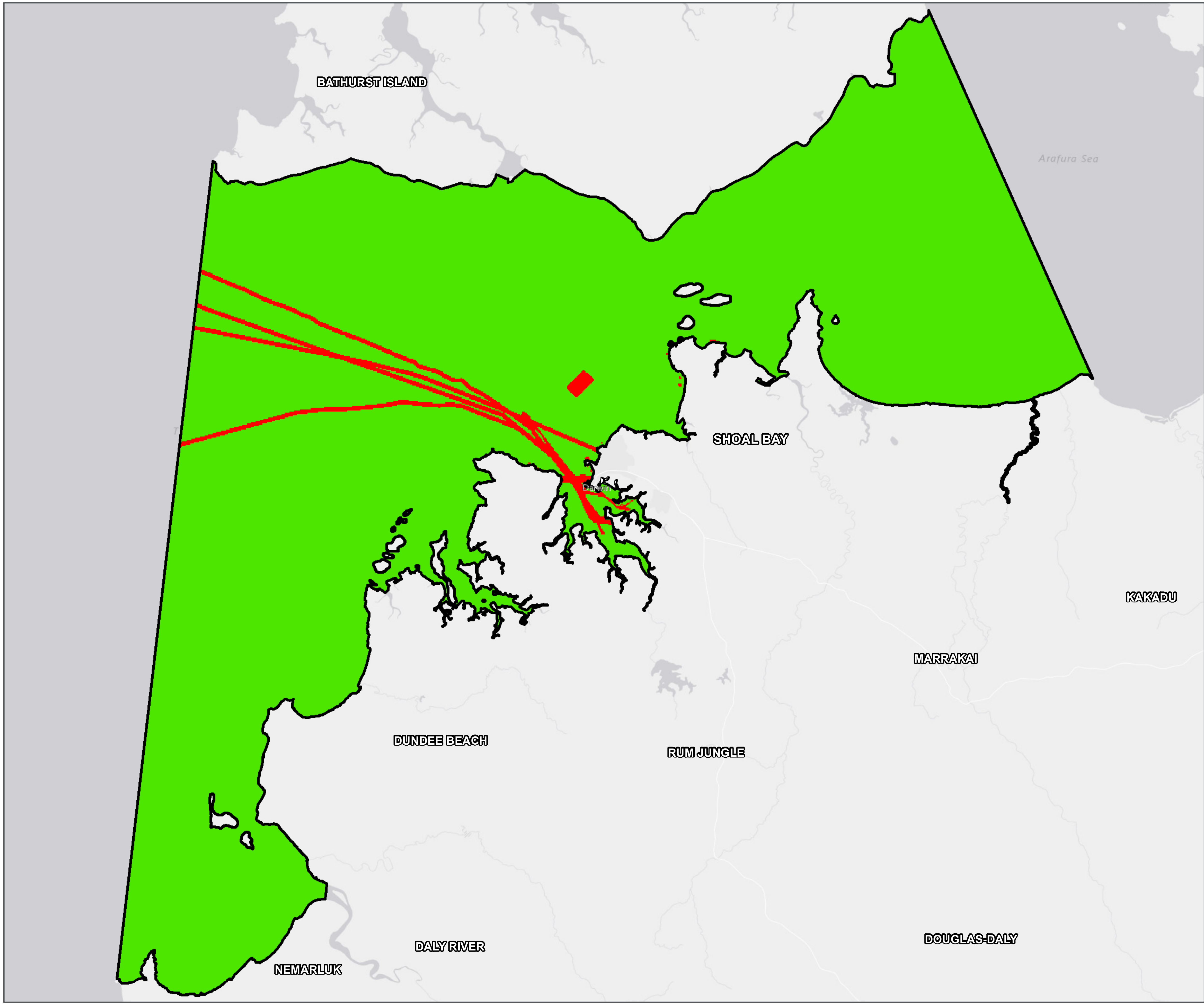
1:850,000 Scale at A3

Kilometres 0 10 20 30 40

N

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-07 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS009_ConstraintsInfrastructure.mxd 02
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Bathymetry

ARTIFICIAL REEFS

Legend

Study Area

Infrastructure

Least Constrained

Highly Constrained

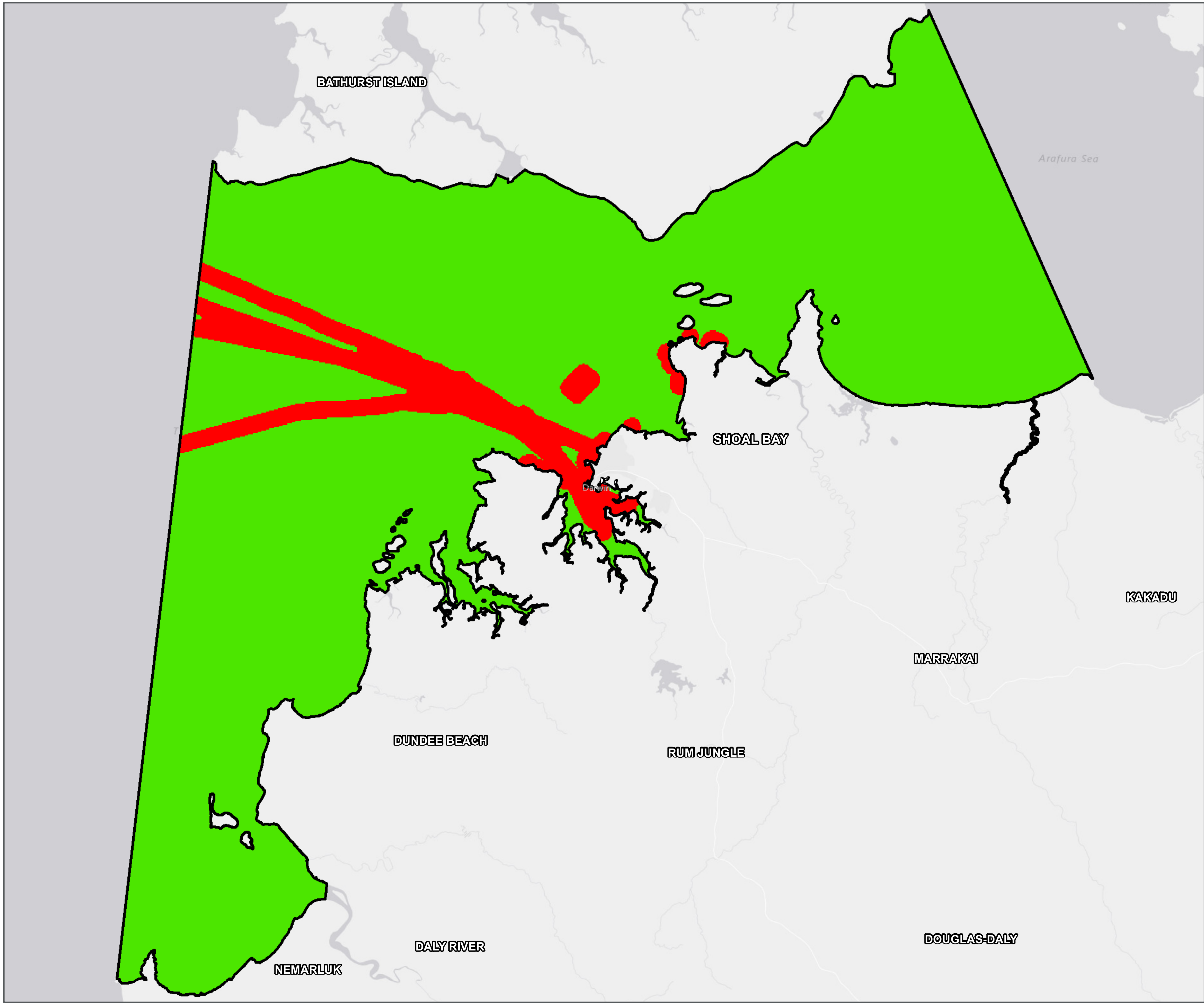
1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-08 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS026_ClassConInfrastructure.mxd 01
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Bathymetry

FISH ATTRACTING DEVICES (FADS)

Legend

Study Area

Infrastructure

Least Constrained

Highly Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-11 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS023_ClassConInfrastructure.mxd 01
Basemap supplied by Esri and other third party suppliers

Round Two Constraints

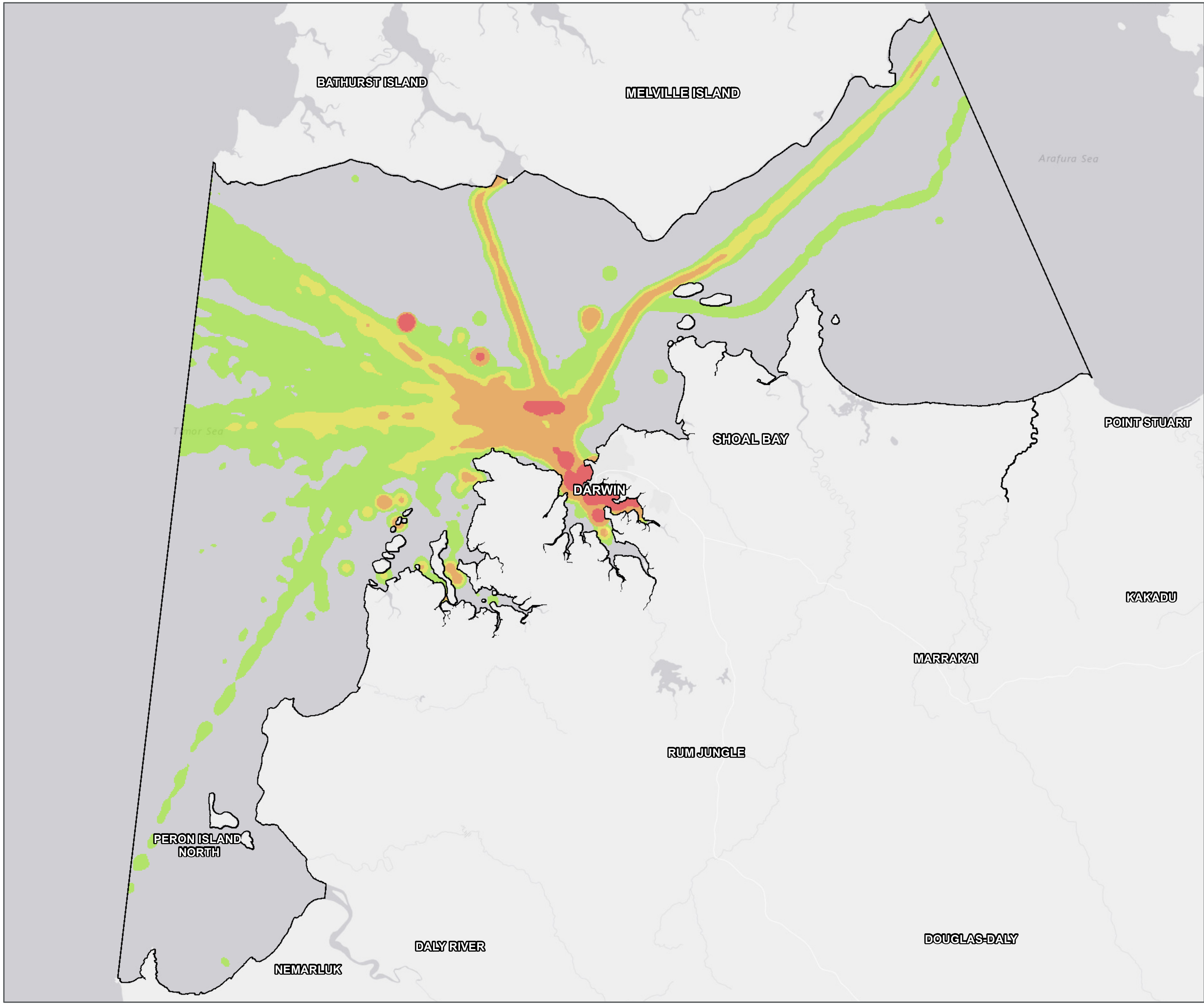
Engineering

Interaction with High Ship Traffic Areas

The waters surrounding Darwin support a diverse range of shipping related activities and movements. Many shipping movements follow specific routes (e.g. ferry between Tiwi Island and Darwin) as well as others that have a more diffuse routing based on the destination/origin of the journey. Australian Maritime Safety Authority (AMSA) records vessel movements within the Darwin region (though tracking information is not exhaustive). To reduce potential conflict with recreational fishers and interactions with infrastructure, high-density shipping movement areas are to be avoided.

Table E-16. Interaction with High Ship Traffic Areas

Objective	Interaction with High Ship Traffic Areas	
How measured	Density of 2017 AMSA ship tracking data	
Ratings	AR	FAD
Highly Constrained (No Data)	Shipping Density > 10	Shipping Density > 1
Moderately Constrained (1)	None	None
Lightly Constrained (5)	Shipping Density 5-10	None
Least Constrained (9)	Shipping Density <= 5	Shipping Density < 1
Data Source	(https://www.operations.amsa.gov.au/Spatial/DataServices/DigitalData) AMSA Vessel Tracking Data, 2017	
Data Coverage / Quality	Comprhensive for entire study area, 2017	
Data Processing	Data was compiled from monthly datasets for the whole of 2017 into a single file. Data was then clipped to the study area. Point data was analysed using a 2.5km density kurnel to derive a continuous density raster dataset. The density raster was then interpreted to define five density rankings according to spatial coverage. The lower the density, the larger the spatial coverage. The rank classes are roughly proportional to the volume of points. The density pattern of points was used as a visual check for class breaks.	



NORTHERN TERRITORY GOVERNMENT

Vessel Traffic Density

ARTIFICIAL REEFS AND FISH ATTRACTING DEVICES (FADS)

Legend

Study Area

Tracking Points within 2.5km radius (20km^2)

- <1
- 1 - 5
- 5 - 10
- 10 - 150
- >150

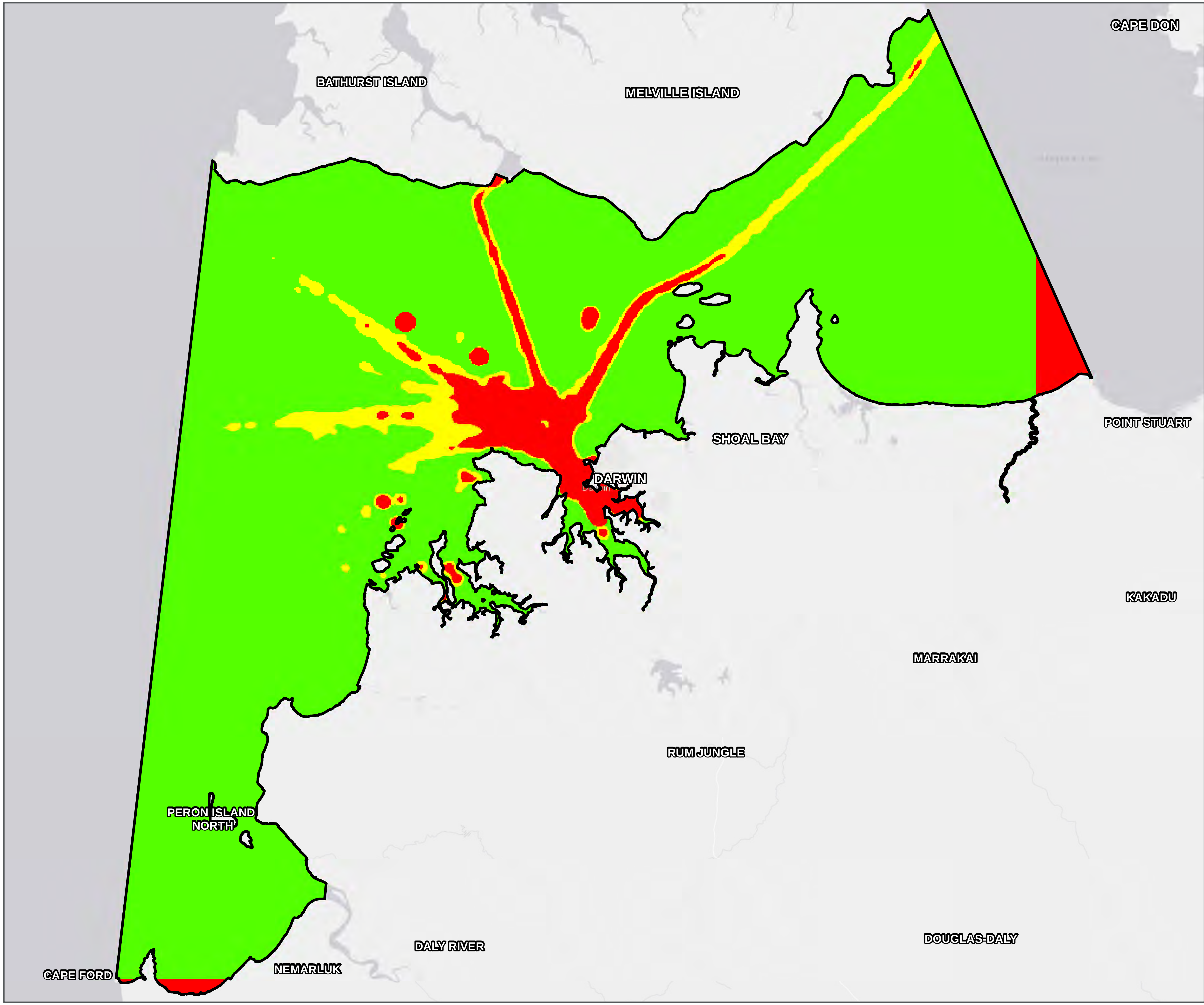
1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-03-21 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS035_VesselTrafficDensity.mxd 01
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Vessel Traffic Density

ARTIFICIAL REEFS

Legend

Study Area

Vessel Tracking Density

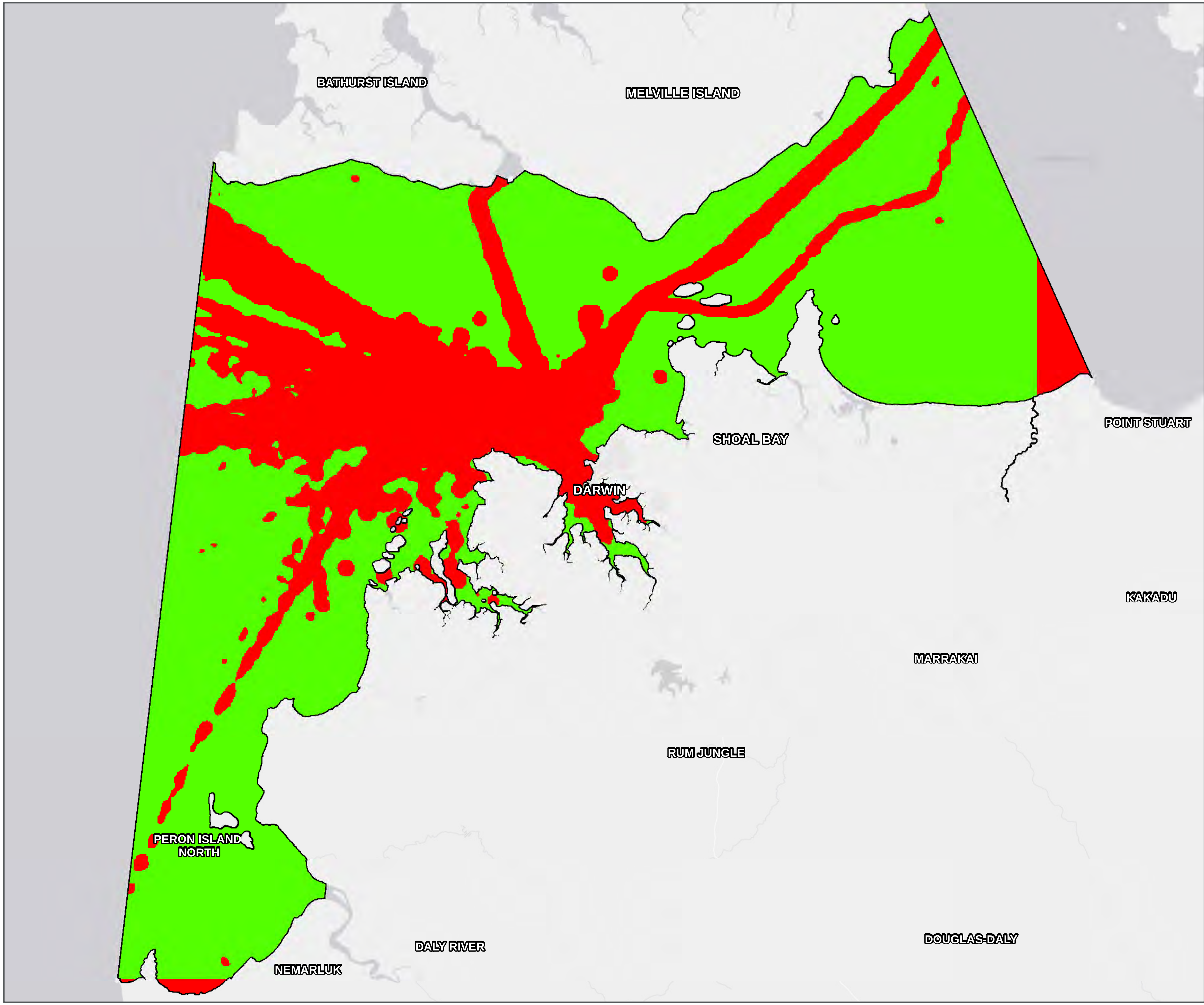
- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres
0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-10 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS039_ClassConVesselTrafficDensity.mxd 01
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Classified Constraints - Vessel Traffic Density

FISH ATTRACTING DEVICES (FADS)

Legend

Study Area

Vessel Traffic Density

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

N

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-10 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS035_ClassConVesselTrafficDensity.mxd 01
Basemap supplied by Esri and other third party suppliers

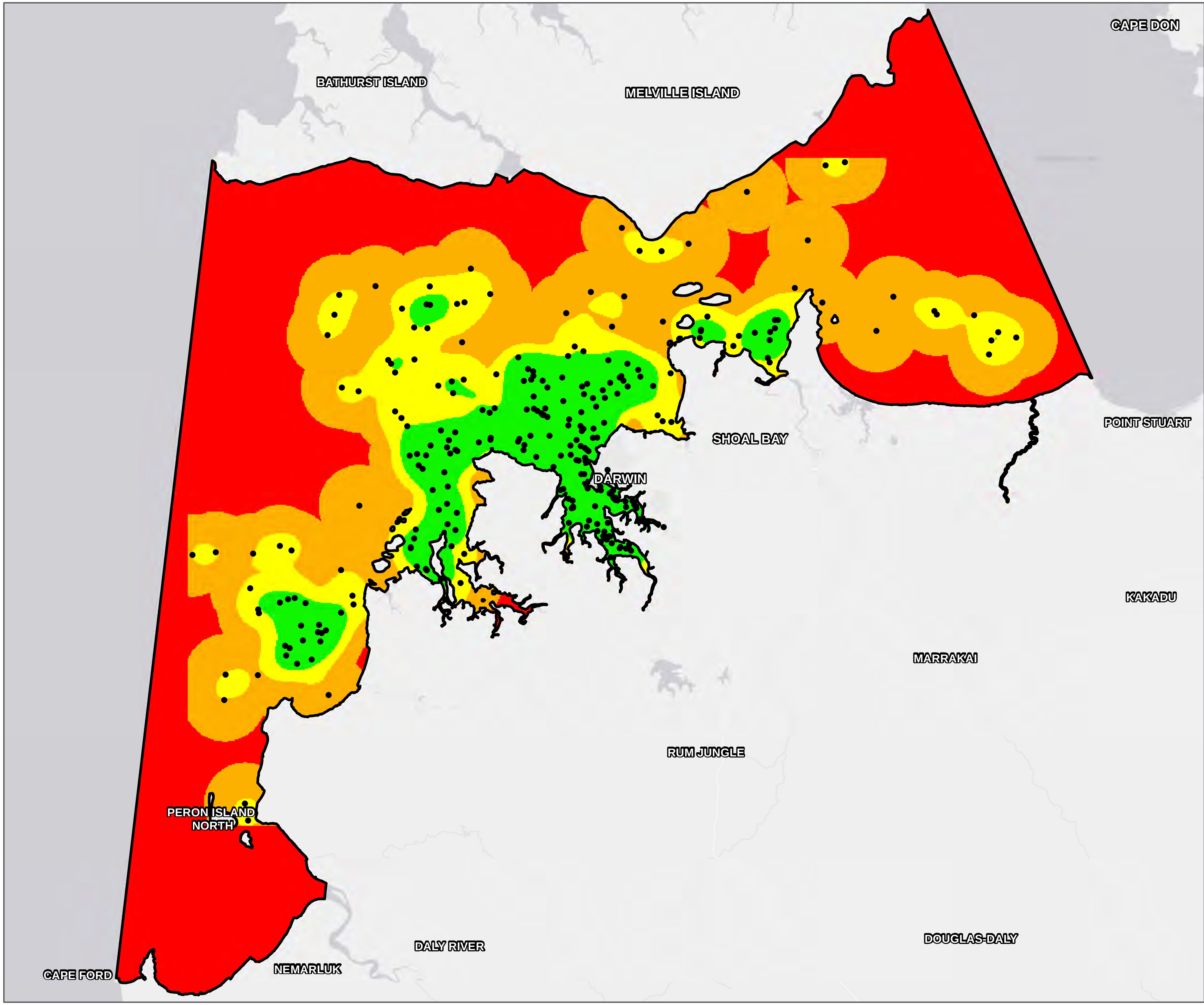
Web Portal

Publically Identified Deployment Locations

Artificial reefs and FADs are installed / located where the public have identified as preferable (if possible). Areas identified as being preferred by the public are considered to be priority deployment areas.

Table E-17. Publically Identified Deployment Locations

Objective	Publically Identified Deployment Locations
How measured	Density of publically identified AR and FAD deployment locations
Ratings	AR and FAD
Highly Constraned (No Data)	None
Moderately Constrained (1)	Low density (0-50%)
Lightly Constrained (5)	Medium Density (50-75%)
Least Constrained (9)	High Density (>75%)
Data Source	Public input collected via a web portal that was publically accessible from XXXX to 19 January 2018.
Data Coverage / Quality	Comprehensive public was able to place desired AR and FAD deployment locations throughout the entire study area
Data Processing	Raw data collected from the web portal was examined and erroneous data screened out based on instructions provided by NT Fisheries. Density kernels were calculated using the kernel density tool in ArcMap. The Kernel density tool applied a 10km search distance between survey points. The output generated is a continuous raster dataset that visualizes the areas in which the public believe are the best deployment locations.



Publicly Identified Deployment Areas

ARTIFICIAL REEFS

Legend

- Study Area
- Public Deployment Survey Point

Public Deployment Survey - Density (% of Kernel Density)

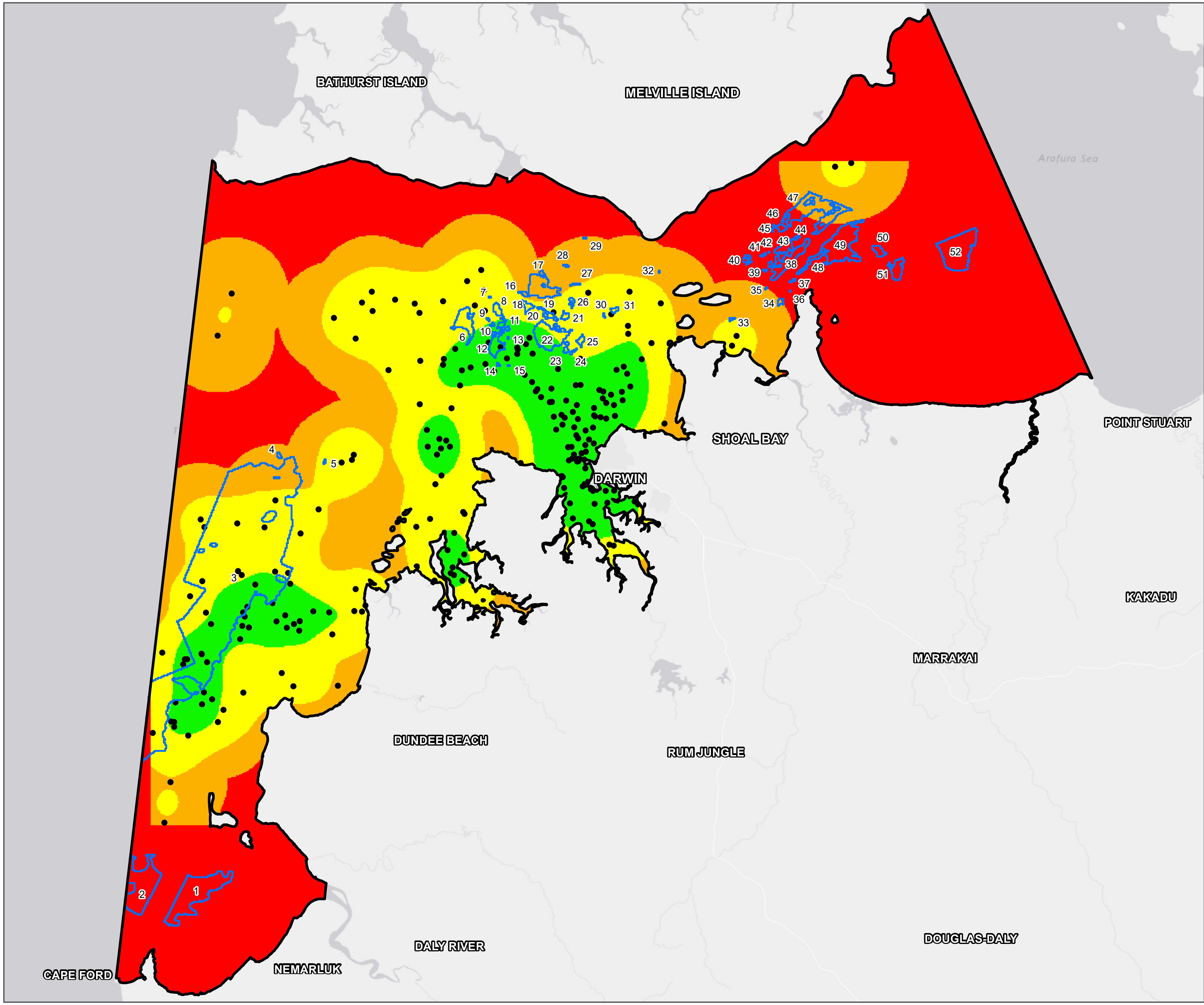
- 0
- 5
- 15
- 80

1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-10 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS037_ConstraintsPublicDeployment.mxd 01
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Publicly Identified Deployment Areas

FISH ATTRACTING DEVICES

Legend

- Study Area
- Public Deployment Survey Point
- MCA Result Areas

Survey Points within 10km radius (% of Kernel Density)

- 0
- 5
- 15
- 80

1:850,000 Scale at A3

Kilometres
0 10 20 30 40

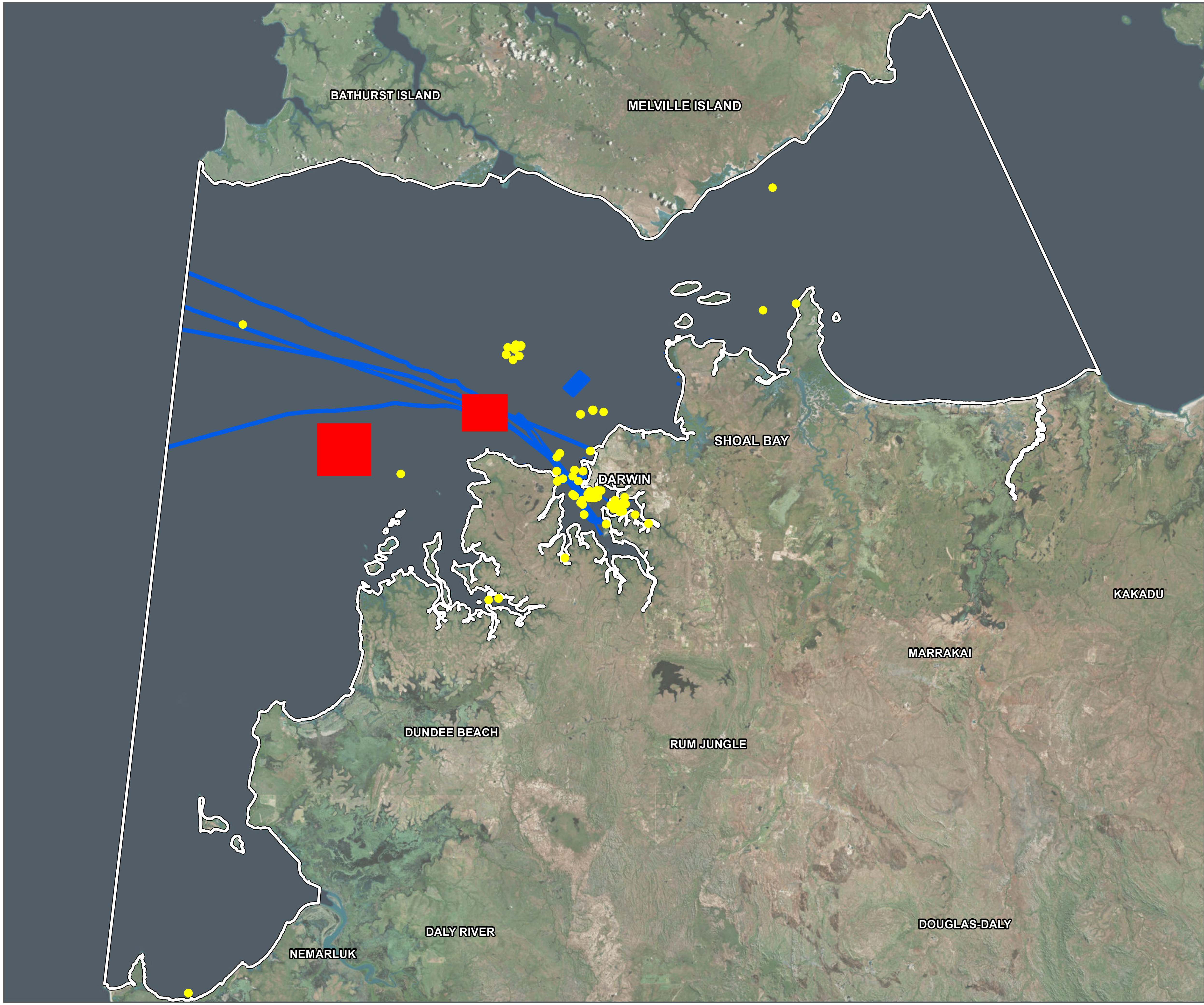
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-24 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS037_MCA_PublicDeployment.mxd 02
Basemap supplied by Esri and other third party suppliers

APPENDIX

F

WEB PORTAL BASE LAYER



Combined Constraints

ARTIFICAL REEFS AND FISH ATTRACTING DEVICES (FADS)

Legend

- Study Area
- Conservation Estate
- Wrecks
- Infrastructure

1:850,000 Scale at A3

Kilometers

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd (WOL)
Date: 2017-12-06 | Project: 59918060
Coordinate System: GCS GDA 1994
Map: 59918060_B_AR_GS002_ConstraintsCombined.mxd 03
Basemap supplied by Esri and other third party suppliers

APPENDIX

G

MCA RESULTS

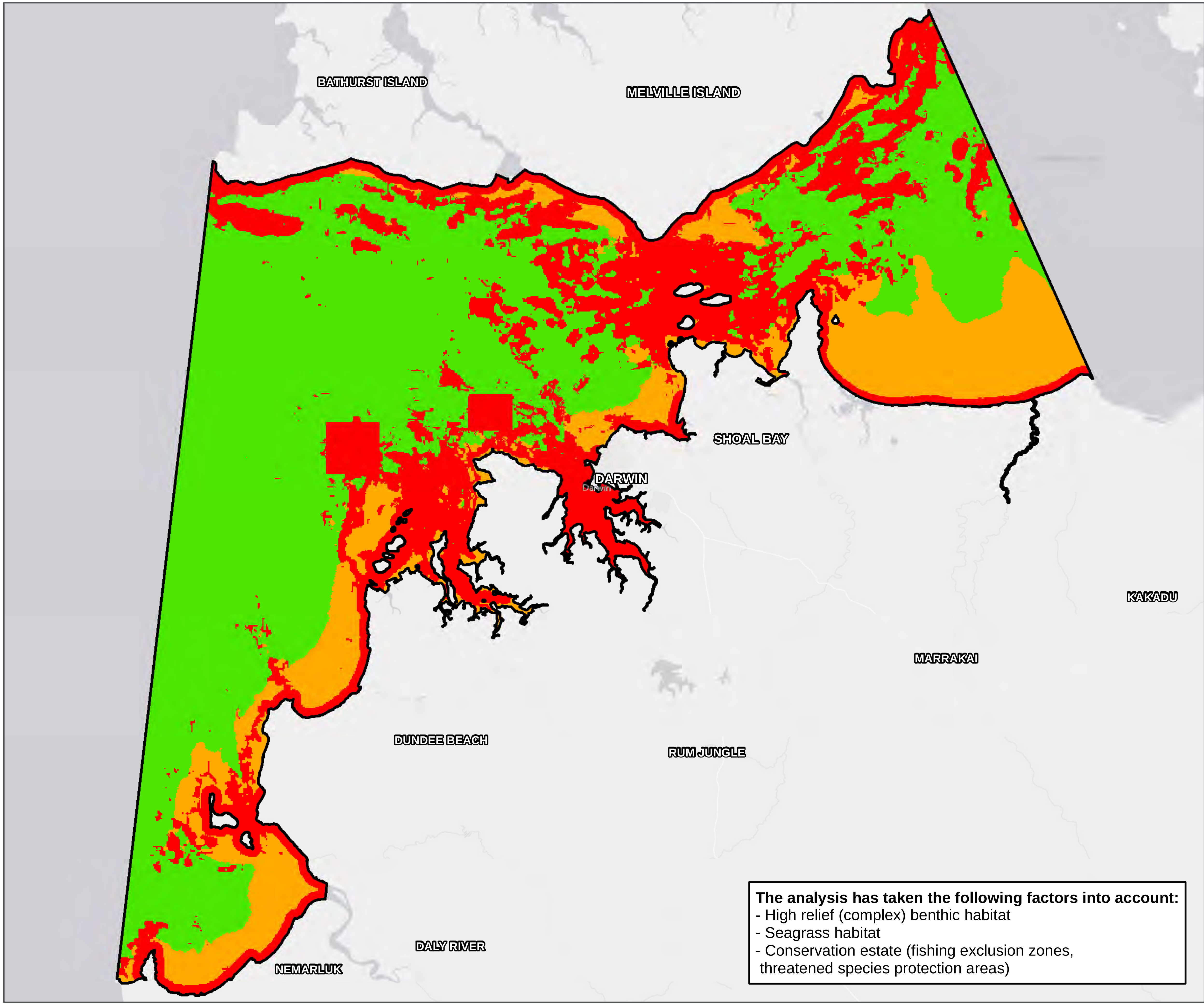
Multi-Criteria Analysis Results: AR and FAD Deployment Areas

Cardno used a multi-criteria analysis (MCA) approach to identify potential artificial reef (AR) and fish attracting device (FAD) deployment areas. The results of the Environmental, Social and Engineering constraints MCA for the identification of potential AR (**Figure G-1 to Figure G-3**) and FAD (**Figure G-4 to Figure G-6**) deployment areas are included below.

Figure Index

Multi Criteria Analysis - Environmental Factors

ARTIFICIAL REEFS



Legend

Study Area

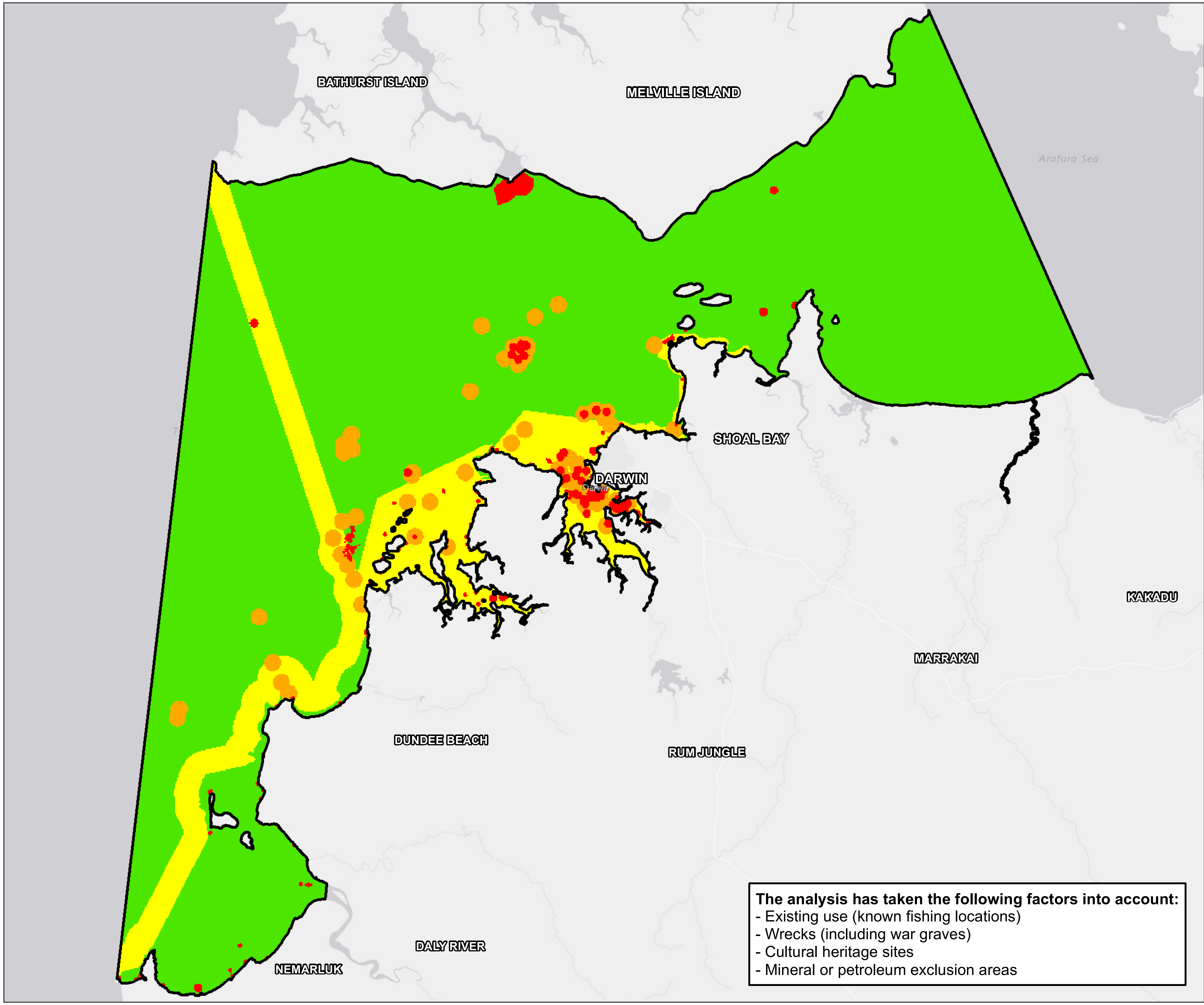
Site Suitability

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres 0 10 20 30 40

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-06 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS011_MCA_EnviroFactors.mxd 02
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Multi Criteria Analysis - Social Factors

ARTIFICIAL REEFS

Legend

Study Area

Site Suitability

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

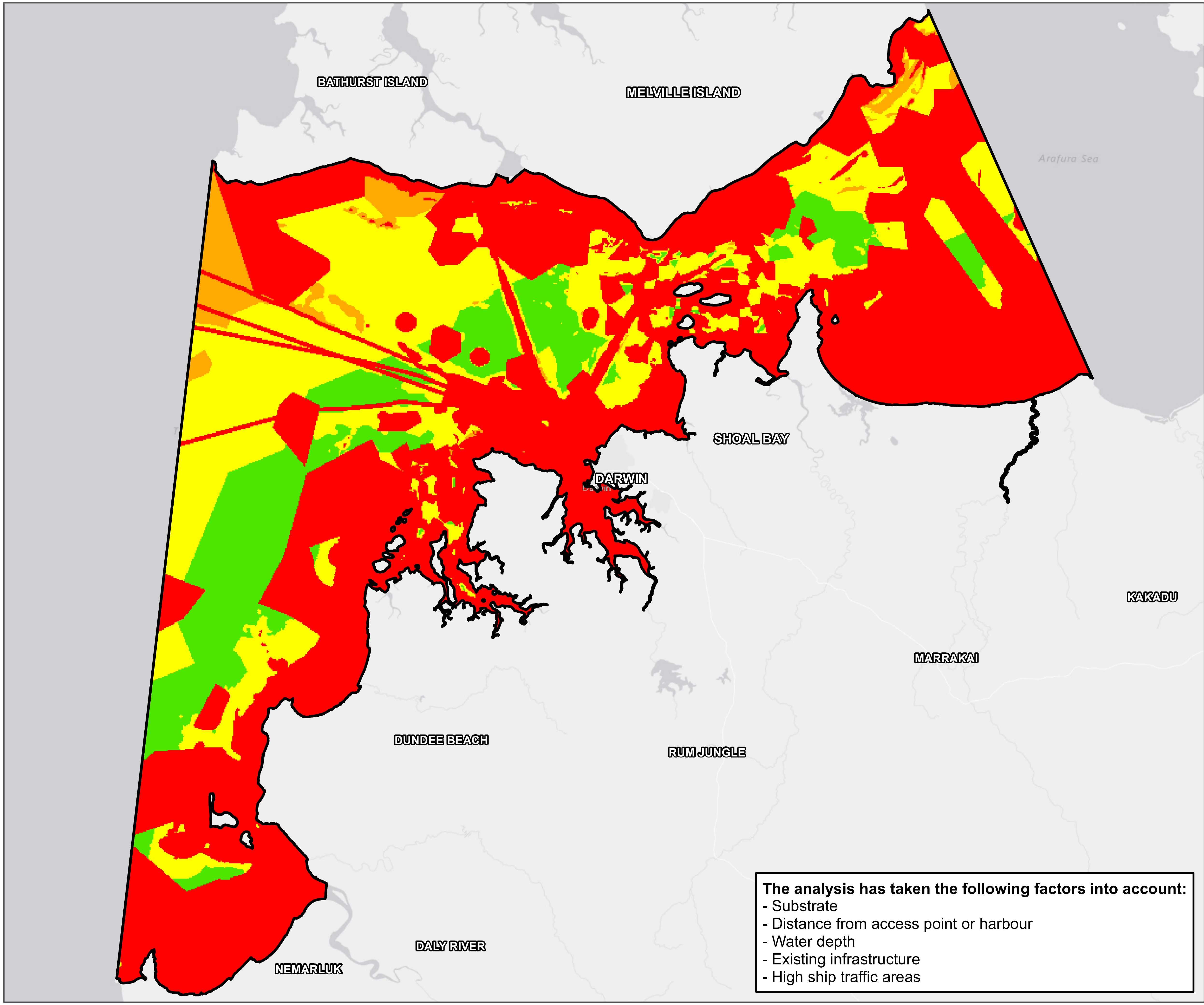
1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-11 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS012_MCA_SocialFactors.mxd 02
Basemap supplied by Esri and other third party suppliers



The analysis has taken the following factors into account:
- Substrate
- Distance from access point or harbour
- Water depth
- Existing infrastructure
- High ship traffic areas

NORTHERN TERRITORY GOVERNMENT

Multi Criteria Analysis - Engineering Factors

ARTIFICIAL REEFS

Legend

Study Area

Site Suitability

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

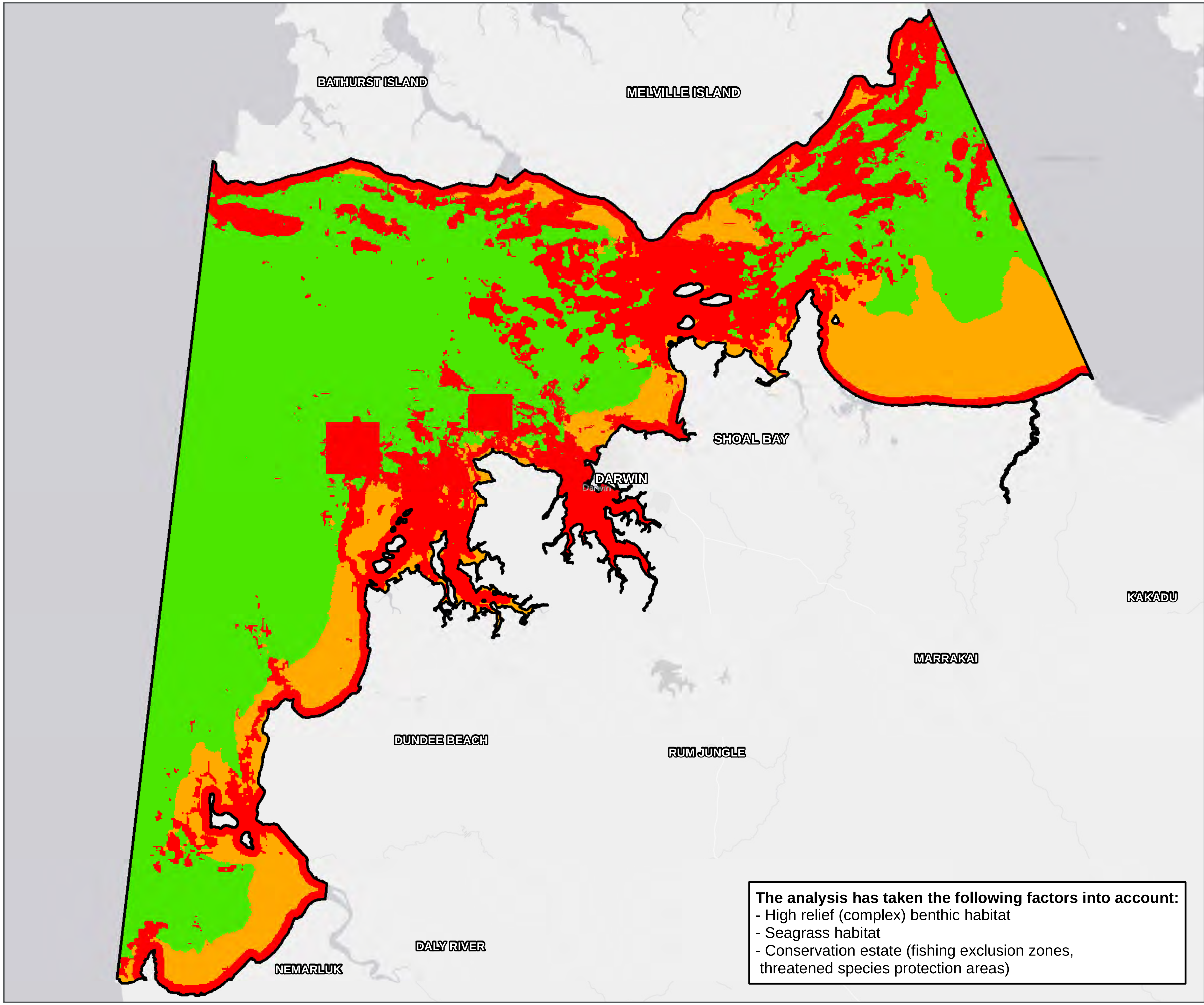
1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-12 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_B_AR_GS013_MCA_EngineeringFactors.mxd 03
Basemap supplied by Esri and other third party suppliers



NORTHERN TERRITORY GOVERNMENT

Multi Criteria Analysis - Environmental Factors

FISH ATTRACTING DEVICES

Legend

Study Area

Site Suitability

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres
0 10 20 30 40

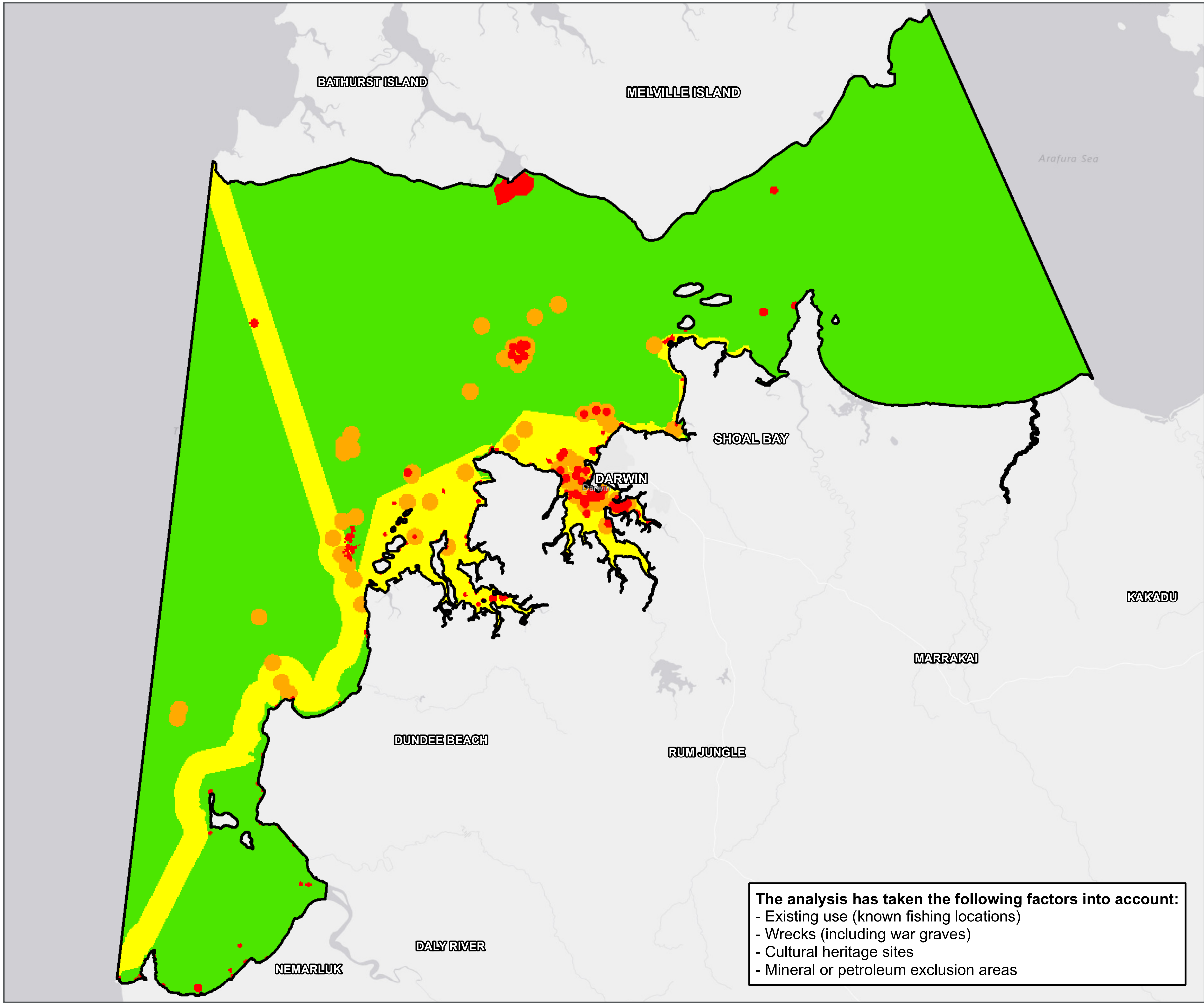
Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-07 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS001_MCA_EnviroFactors.mxd 02
Basemap supplied by Esri and other third party suppliers

NORTHERN TERRITORY GOVERNMENT

Multi Criteria Analysis - Social Factors

FISH ATTRACTING DEVICES



Legend

Study Area

Site Suitability

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

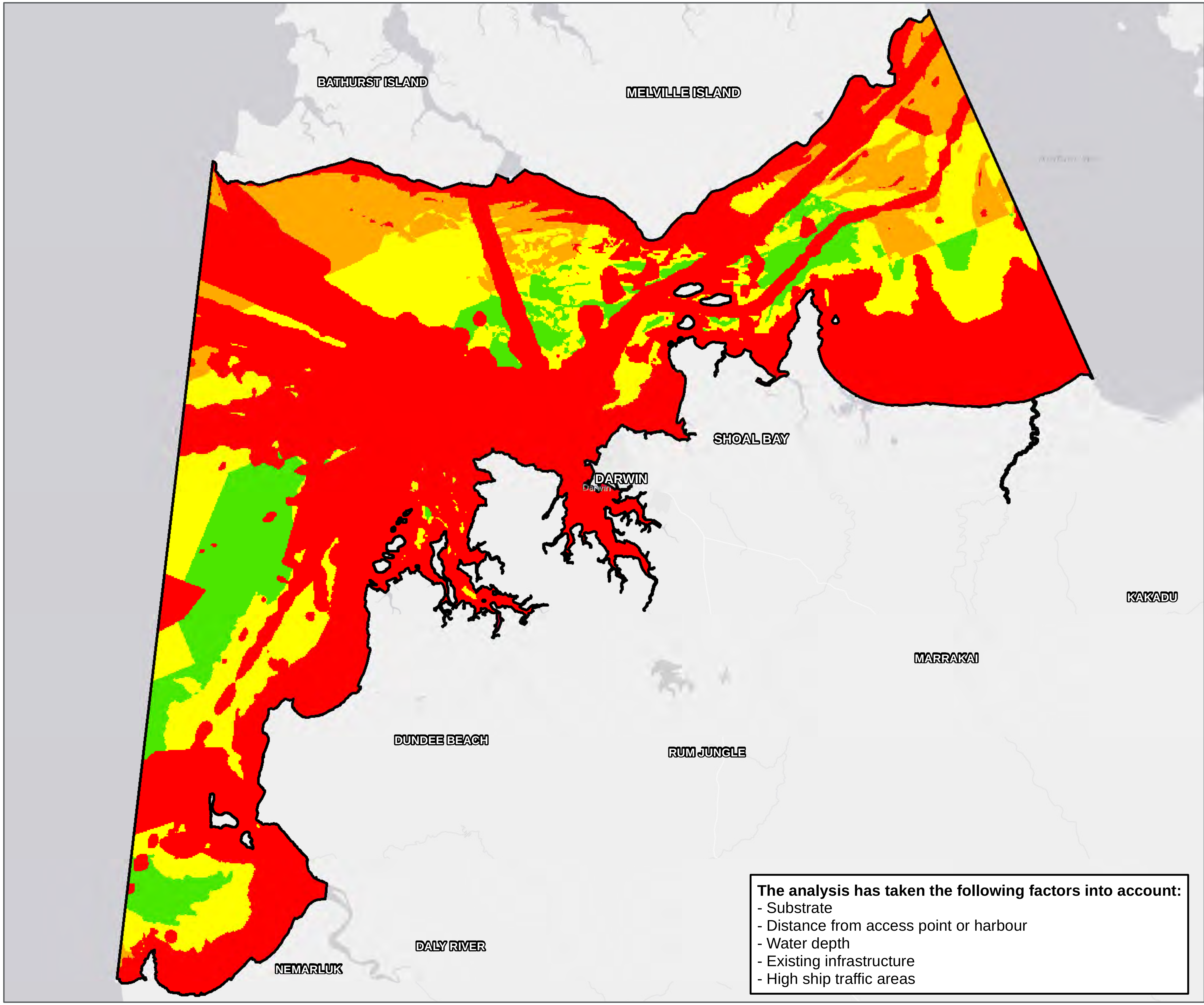
1:850,000 Scale at A3

Kilometres

0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2017-12-11 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS002_MCA_SocialFactors.mxd 02
Basemap supplied by Esri and other third party suppliers



The analysis has taken the following factors into account:
- Substrate
- Distance from access point or harbour
- Water depth
- Existing infrastructure
- High ship traffic areas

NORTHERN TERRITORY GOVERNMENT

Multi Criteria Analysis - Engineering Factors

FISH ATTRACTING DEVICES

Legend

Study Area

Site Suitability

- Least Constrained
- Lightly Constrained
- Moderately Constrained
- Highly Constrained

1:850,000 Scale at A3

Kilometres
0 10 20 30 40

Cardno

Map Produced by Cardno NSW/ACT (Water & Environment)
Date: 2018-04-12 | Project: 59918060
Coordinate System: GDA 1994 MGA Zone 52
Map: 59918060_C_FAD_GS003_MCA_EngineeringFactors.mxd 03
Basemap supplied by Esri and other third party suppliers

APPENDIX

H

DECISION TOOL FOR ARS AND FADS

Artificial Reefs

Decision support tool for determining preferred AR design. Preferred options in green.

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	1	**2**	**3**	**4**	**5**	
Material						
Concrete	N/A	N/A	✓	✓	✓	Structures made of concrete or steel have longevity >30 years and can be fabricated in modular form for scale-ability.
Steel	N/A	N/A	✓	N/A	✓	
Other	N/A	N/A		N/A		These include old tyres, plastic, wood or unconsolidated material whose properties would not allow structures to meet criteria (3) or (5)
Size						
Small (<20 m3)		✓	✓	✓	✓	Small reefs impose physical limits on the abundance and size of fishes that can be accommodated
Medium (20 – 100 m3)	✓	✓	✓	✓	✓	Medium sized reefs are a suitable compromise between maximising production and maximising total AR footprint for minimising congestion among fishers. A larger footprint provides a greater potential area for Type II species (the majority of target species)
Large (> 100 m3)	✓	✓	✓	✓	✓	Given the cost, the number of large reefs that could be built would be small and this could create potential risk to fishers in terms of safety and social conflict associated with congestion.
Depth						
< 10 m		N/A	N/A	✓	N/A	No barotrauma of discards and potentially greater recruitment of juveniles of some species.
11 m – 50 m	✓	N/A	N/A		N/A	Represents a suitable compromise between the potential for barotrauma, recruitment and maximising association of adult fish with ARs
> 50 m		N/A	N/A		N/A	Barotrauma of discards or returned fish likely to cause mortality
Profile						
Width > height (low profile)			✓		✓	Limited potential for complexity, including vertical relief, and hence limited diversity and abundance of fish

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	1	2	3	4	5	
Width ≈ height	✓	✓	✓	✓	✓	Represents a suitable compromise for maximising opportunity for complexity for Type I species, including more vertical relief or walls, and reducing the risk of instability associated with tall profile modules
Width < height (tall profile)	✓	✓	✓		✓	Risk of instability in strong current and during large swell
Voids						
No voids		✓	✓	N/A	N/A	Less diversity and abundance of fish than ARs with voids (shelter)
Variable void spaces with diverse shapes	✓	✓	✓	N/A	N/A	Best potential for maximising diversity and abundance of fish given the variety of niches used by Type I species whilst also maximising void volume to total volume ratio
Large voids		✓	✓	N/A	N/A	Less diversity and abundance of fish than ARs with small, diverse voids
Number of modules						
Single module			✓	✓	✓	Potential risk to fishers in terms of safety and social conflict associated with congestion
Clusters of the same modules		✓	✓	✓	✓	Larger AR footprint potentially increases abundance of species, particularly Type II species, and reduces potential risks (above) associated with congestion
Clusters of different modules	✓	✓	✓	✓	✓	As above. In addition, different types of modules with varying structural complexity (in terms of void space and vertical relief would increase the types of niches available to Type I species and hence potentially increase diversity
Arrangement (for clusters)						
Spacing between modules is 3-4 x base diameter	✓	✓	✓		✓	Closely connected ARs are more likely to have a greater abundance of reef resident (Type 1) species
Spacing between modules >3-4 x base diameter			✓	✓	✓	Potentially less connectivity among modules and less abundance of reef fish
Spacing < 60 m among clusters			✓		✓	Potential for overlapping of feeding areas around clusters and competition for food resources
Spacing > 60 m among clusters	✓	✓	✓	✓	✓	Avoids overlapping of feeding areas around clusters and potentially reduces competition for food. Also provides adequate fishing zones mong clusters for reducing fishing congestion

Criteria:

1. A focus on maximising the potential for aggregation of a diversity of reef (including juveniles) and/or pelagic species that are preferred by recreational fishers
2. Minimisation of attraction of fish from other reefs (for ARs), particularly vulnerable species, so that new aggregations are a result of new production

3. Scale and scale-ability of designs to provide for long-term network development
4. Siting (including configuration) that maximises the potential for recreational fisheries enhancement (including accessibility) and minimises the potential for compromising safety and social, economic or ecological risks
5. Construction, maintenance and deployment/ retrieval costs that are within the given budget and, for ARs, a design life of 30 yrs.

FADs

Decision support tool for determining preferred FAD design. Preferred options in green.

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	(1)	(2)	(3)	(4)	(5)	
FAD system						
Drifting FAD		N/A				Suitable only for oceanic tuna fisheries
Permanently anchored FAD	✓	N/A	✓			High maintenance and deployment costs, risk that site is unproductive and FAD cannot be moved
Temporarily anchored FAD	✓	N/A	✓	✓	✓	Low maintenance and deployment costs, able to be moved to optimise siting and arrangement, can be deployed during peak pelagic season and then retrieved for annual maintenance
Subsurface FAD	✓	N/A	✓			High maintenance costs, not visible to recreational fishers, breakage would not be known, has the advantage of protection from vandalism
Head gear						
Single spar buoy <u>without</u> GPS locator	✓	N/A	N/A			Wave rider buoy with high buoyancy-to-drag ratio, requires a heavy mooring which adds to construction and deployment/retrieval expense, suitable for oceanic FADs
Single spar buoy <u>with</u> GPS locator	✓	N/A	N/A	✓		As above <u>and</u> Broken FADs are able to be recovered given their whereabouts are known
Strings of oval and purse seine floats with flagpole at the end <u>without</u> GPS locator	✓	N/A	N/A		✓	Low buoyancy and low drag, does not require a heavy mooring, suitable for strong currents
Strings of oval and purse seine floats with flagpole at the end <u>with</u> GPS locator	✓	N/A	N/A	✓	✓	As above <u>and</u> Broken FADs are able to be recovered given their whereabouts are known

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	(1)	(2)	(3)	(4)	(5)	
Appendages						
None		N/A	N/A			FADs <u>without</u> appendages attached to or below the surface buoy are considered less effective
Plastic strips on top chain	✓	N/A	N/A	✓	✓	Known to be effective fish aggregators, low risk of entanglement of marine turtles or marine mammals
Rafts	✓	N/A	N/A		✓	High risk of entangling marine turtles or marine mammals
Netting on top chain	✓	N/A	N/A		✓	High risk of entangling marine turtles or marine mammals
Weighted ropes below top floats	✓	N/A	N/A		✓	High risk of entangling marine turtles or marine mammals
Upper mooring line						
10 m x 10 mm ballast chain + nylon rope (25% of total mooring line)	N/A	N/A	N/A		✓	Requires hardware connections (shackles, swivels etc.). Nylon rope sinks and is not a hazard to vessels
3 strand 16 mm nylon rope (25% of total mooring line)	N/A	N/A	N/A		✓	No hardware connections (shackles, swivels etc.). Nylon rope sinks and is not a hazard to vessels
12 strand 16 mm nylon rope (25% of total mooring line)	N/A	N/A	N/A	✓	✓	No hardware connections (shackles, swivels etc.). Nylon rope sinks and is not a hazard to vessels, greater durability than 3 strand rope
Lower mooring line						
3 strand 16 mm polypropylene rope (66% of total mooring	N/A	N/A	N/A		✓	Buoyant rope creates catenary curve, lifting ground chain (see below) and minimises potential for rope abrasion. A swivel placed between the polypropylene rope and the chain (see below) prevents twists in the chain and mooring rope. NB: supplementary float on lower mooring line maybe needed to lift chain by required distance (3 m) off bottom

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	(1)	(2)	(3)	(4)	(5)	
line and equal to site depth), swivel						
12 strand 16 mm polypropylene rope (66% of total mooring line and equal to site depth), swivel	N/A	N/A	N/A	✓	✓	As above, but greater durability and added buoyancy may not require supplementary float
Anchor system						
7 m x 16 mm long link chain	N/A	N/A	N/A		✓	Maybe too short to rise and sink adequately in response to surface and current forces.
10 m x 16 mm long link chain	N/A	N/A	N/A	✓	✓	Ground chain rises and sinks in adequate response to surface and current forces. Adds necessary additional weight (than above) to anchor system total weight
Concrete block (weight to be 3 x buoyancy of surface float)	N/A	N/A	N/A			Requires bulky and heavy mooring block given holding power of concrete in seawater is 1:2 (i.e. 200 kg concrete anchor has a holding power of 100 kg in seawater), high deployment and retrieval costs for temporary FADs
Danforth anchor and clump weight (weight to be 3 x buoyancy of surface float)	N/A	N/A	N/A	✓	✓	Steel anchor has less bulk and weight than concrete, lower deployment and retrieval costs for temporary FADs.
Arrangement (for multiple FADs)						
Spacing < 500 m <u>within</u> clusters	✓	N/A	✓		✓	High concentrations of FADs can lead to tangling and aggregation interaction or competition between neighbouring FADs, conflict/incidents among fishing boats
Spacing > 500 m <u>within</u> clusters	✓	N/A	✓	✓	✓	No risk of tangling or conflict/incidents among fishing boats
Spacing < 10 km <u>among</u> clusters		N/A				Possibility that clusters of FADs would compete for coastal pelagic species

FEATURE	'FIT-FOR-PURPOSE' CRITERIA					JUSTIFICATION
	(1)	(2)	(3)	(4)	(5)	
Spacing > 10 km <u>among</u> clusters	✓	N/A	✓	✓	✓	Suitable distance for avoiding neighbouring clusters of FADs competing for coastal pelagic species