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Final Report

Assessment of Key Dugong and Turtle Seagrass Resources in North-west Torres Strait

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JAMES COOK UNIVERSITY AUSTRALIA

Assessment of Key Dugong and Turtle Seagrass Resources in North-west Torres Strait

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Cover photographs: TropWATER, James Cook University.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

BMI	Benthic macro-invertebrate
DFT	Dugong feeding trail
GPS	Global Positioning System
IDW	Inverse Distance Weighted
IUCN	International Union for Conservation of Nature
JCU	James Cook University
LSMU	Land and Sea Management Unit
MSL	Mean sea level
NESP	National Environmental Science Programme
PZJA	Protected Zone Joint Authority
RRRC	Reef and Rainforest Research Centre Limited
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research
TSRA	Torres Strait Regional Authority
TWQ	Tropical Water Quality

ABBREVIATIONS

dbMSL	depth below mean sea level (m)
gdw m^{-2}	grams dry weight per metre square
ha	hectare
km	kilometre
m	metre
R	reliability estimate
s.e.	standard error of mean

ACKNOWLEDGEMENTS

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The subtidal seagrass assessment team with TSRA ranger vessel on Boigu Island

EXECUTIVE SUMMARY

Seagrasses are one of the most productive marine habitats on earth that provide food for herbivores like dugongs (*Dugong dugon*) and green sea turtles (*Chelonia mydas*). Torres Strait contains extensive seagrass meadows, the largest dugong population in the world, and a globally significant population of green turtles. Assessing and managing seagrass resources in Torres Strait requires adequate baseline information. North-west Torres Strait was identified in a 2014 review as an important hunting and fishing ground for Torres Strait Islanders with large dugong and turtle populations, but where seagrass data was lacking.

The project aim was to provide information on intertidal and subtidal seagrass in north-west Torres Strait detailing seagrass distribution, biomass, species composition, and other benthic characteristics (algae, macro-invertebrates).

Boat and helicopter surveys were conducted November 2015 to January 2016. Seagrass information recorded included presence/absence, percent cover, above ground biomass, species composition and diversity. Other benthic information included percent cover of algae (by functional group) and macro-invertebrates. Boat-based surveys were conducted in collaboration with TSRA LSMU Rangers from Boigu Island and Saibai Island.

North-west Torres Strait contains extensive seagrass habitat. Seagrass was present at 43% of the 853 sites surveyed. Seagrass area mapped was 60 263 ha across 34 meadows. Ten seagrass species from three families were identified. The most dominant species in terms of contribution to mean biomass was *T. hemprichii* (35%); *H. uninervis* was the most commonly occurring species. Extensive dugong feeding trails (DFTs) were present in intertidal meadows along the Papua New Guinea shoreline and around Boigu Island. Coral communities were the dominant form of benthic macro-invertebrates. Extensive algae habitat was throughout the region.

Subtidal seagrass meadows were extensive in the area bounded by Deliverance, Turnagain and Boigu Islands, but sparse elsewhere, likely due to strong currents south of Deliverance Island and poor underwater visibility from suspended sediments close to Papua New Guinea. The presence of dugong feeding trails in intertidal meadows and frequent turtle and dugong sightings during the surveys identifies the region as ideal foraging habitat. Subtidal meadow distribution mapped in this study overlaps spatially with very high dugong and turtle density distributions recorded during aerial surveys.

Effective management and planning requires current, spatially relevant seagrass information at the scale of individual communities' sea country to inform community-based Turtle and Dugong Management Plans and will require cooperation with adjacent Papua New Guinea coastal communities. Recommendations include: (1) Establish baseline seagrass information in high-very high dugong density areas between Turnagain and Gabba Islands, Orman Reefs and the eastern boundary of the Dugong Sanctuary; (2) Establish a seagrass long-term monitoring program in regions of high-very high dugong density; (3) Continue collaboration with TSRA LSMU Rangers for seagrass surveys and monitoring.

1. INTRODUCTION

Seagrasses are one of the most productive marine habitats on earth and provide a variety of important ecosystem services with substantial economic value (Costanza et al., 1997; Costanza et al., 2014). These services include the provision of nursery habitat for economically important fish and crustaceans (Coles et al., 1993; Heck et al., 2003; McKenzie et al., 1996) and food for herbivores like dugongs (*Dugong dugon*) and green sea turtles (*Chelonia mydas*) (Heck et al., 2008; Unsworth et al., 2010). Torres Strait is estimated to contain between 13 425 km^2 (Coles et al., 2003) and 17 500 km^2 (Poiner et al., 1996) of seagrass habitat. This includes one of the largest single continuous seagrass meadow in Australia (Taylor et al., 2010) within the Dugong Sanctuary (Figure 1).

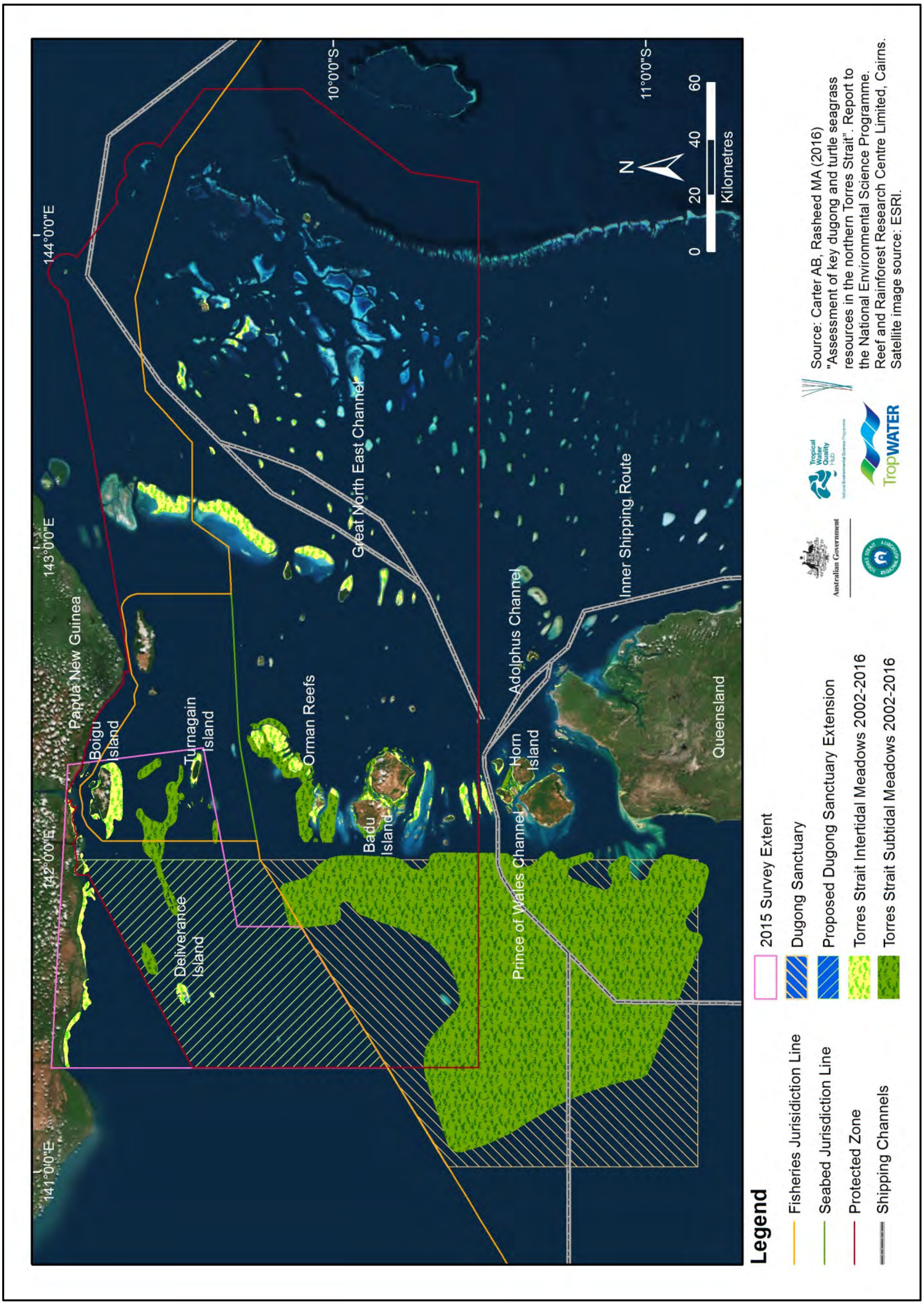
Torres Strait has the largest dugong population in the world (Marsh et al., 2011), and globally significant populations of green turtles and their nesting grounds (Miller et al., 1991). The dugong is listed as vulnerable to extinction by the International Union for Conservation of Nature (Marsh & Sobtzick 2015), while green turtles are listed as endangered (Seminoff, 2004). Spatial distributions of dugong and green turtles often overlap (Cleguer et al., 2016; Gredzens et al., 2014; Marsh et al., 2011) but in Torres Strait they use common areas differently. Stomach content analysis indicates dugong feed exclusively on seagrass while green turtles consume seagrass and macroalgae (André et al., 2005). Dugong also most commonly use the >5m depth zone while green turtles often are reef-associated and use the 0-5m zone (Cleguer et al., 2016; Gredzens et al., 2014). The spatial distribution of quality food strongly influences movement patterns, foraging behaviours and reproductive capacity of dugong (Marsh et al., 2008; Marsh et al., 2004; Sheppard et al., 2007) and turtle (Limpus et al., 2000). Substantial seagrass diebacks (up to 60%) have been documented twice in central Torres Strait and linked to dramatic increases in local dugong mortality rates (Long et al., 1996; Marsh et al., 2004). Extremely low numbers of nesting turtles due to reduced reproductive capacity are linked to reductions in algae and seagrass following major La Nina events on the Great Barrier Reef (Limpus et al., 2000).

Dugong and green turtle populations are considered cultural keystone species in Torres Strait (Butler et al., 2012). Torres Strait Islanders have the right to hunt dugong and turtle in their sea country under the *Native Title Act* (1993) and dugong and turtle hunting is a traditional fishery under the Torres Strait Treaty between Australia and Papua New Guinea. Dugong remain the most significant and highest ranked marine food source in Torres Strait's traditional subsistence economy (Johannes et al., 1991; Kwan, 2002; Nietschmann, 1984; Raven, 1990). Green turtle is the dominant turtle species taken in Torres Strait and is harvested for meat and eggs (Harris, 1997). Community-based Turtle and Dugong Management Plans have been implemented for dugong and turtle fisheries that include restrictions on hunting vessel size and hunting equipment, and area closures for dugong hunting such as the Dugong Sanctuary in western Torres Strait (Marsh et al., 2015). The Torres Strait dugong catch is considered sustainable (Marsh et al., 2015). The status of the population of green turtles in Torres Strait is less certain (Fuentes et al., 2015; Hagihara et al., 2016).

Assessing and managing seagrass resources in Torres Strait requires baseline information on seagrass presence/absence, seagrass biomass, species composition, and meadow area.

The Seagrass Ecology Group within the Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER) at James Cook University (JCU), in collaboration with the Torres Strait Regional Authority (TSRA) Land and Sea Management Unit (LSMU), has collected spatial data on Torres Strait seagrass since 2002 (Figure 2). In 2014 these extensive spatial datasets were consolidated into a Geographic Information System (GIS) database to document the current state of seagrass knowledge across Torres Strait (Figure 2; Carter et al. 2014c). This resource provides an important reference point from which to detect seagrass change. Data deficient regions were identified where basic knowledge of seagrass habitat was unknown or extremely limited. The most important of these was north-west Torres Strait between Boigu, Deliverance and Turnagain Islands, including a proposed northern extension of the existing Dugong Sanctuary. This region is an important hunting and fishing ground for Torres Strait Islanders and contains large dugong and turtle populations. A spatial model of dugong distribution based on aerial surveys indicated the most important dugong habitat in Torres Strait is the ~10 500 km^2 area that extends from Badu/Moa Islands to Boigu Island, east to Gabba Island and west to Deliverance Island. This region contains 56% of the high and very high density dugong habitat in Torres Strait (Marsh et al., 2012). Turtle densities are greatest between Badu/Moa, Gabba and Turnagain Islands, and the eastern boundary of the Dugong Sanctuary (Hagihara et al., 2016).

The aim of the present mapping project was to survey intertidal and subtidal waters in north-west Torres Strait (see Figure 1 for survey extent) to describe seagrass distribution, biomass and species composition. Summaries on other benthic characteristics (algae, macro-invertebrates) are also included.



Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait" . Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI.

Figure 1: Intertidal and subtidal seagrass meadows, 2015 survey extent, shipping lanes, and management areas across Torres Strait.

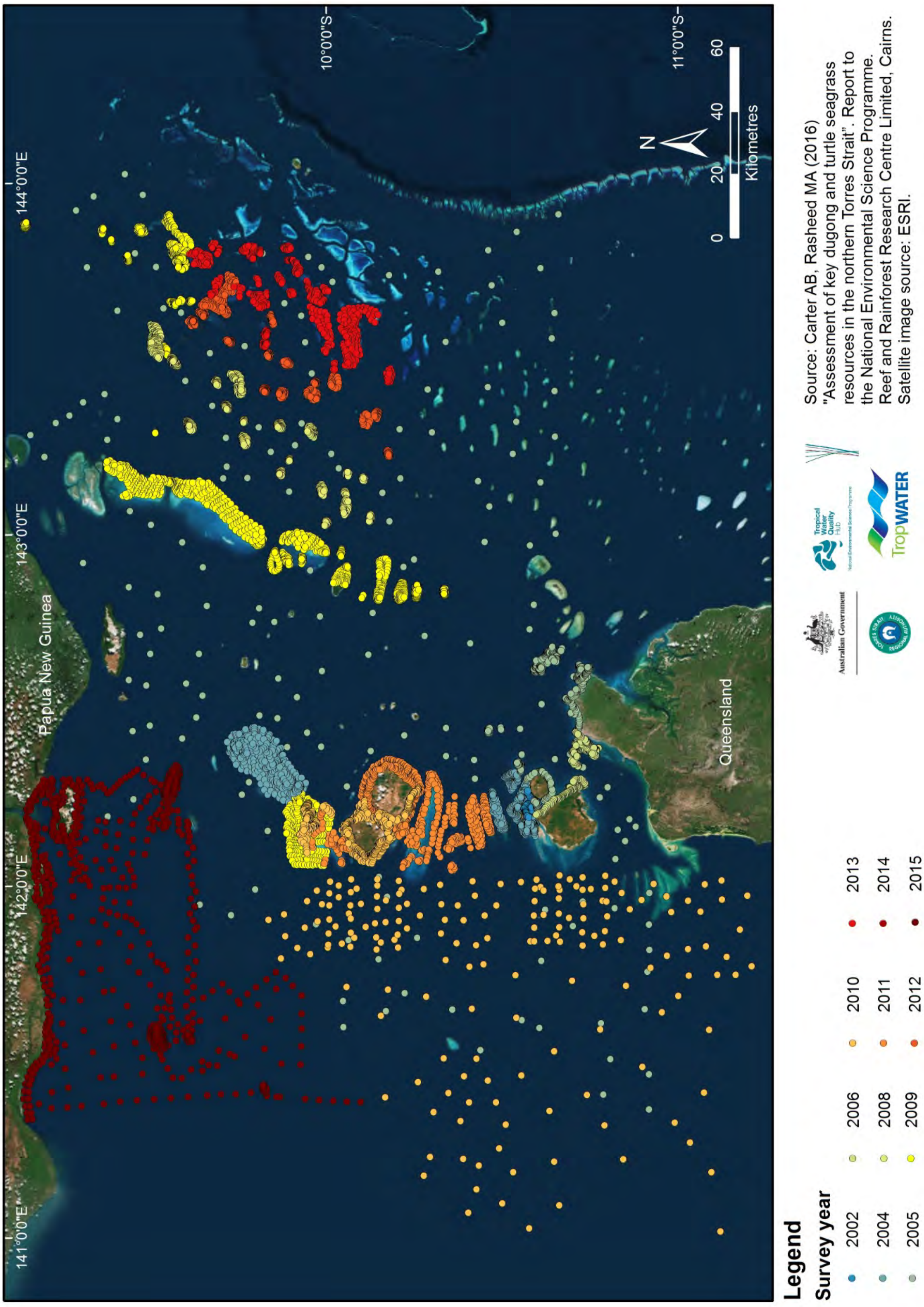


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Figure 2: Survey years for seagrass surveys across Torres Strait, 2002-2016.

2. METHODOLOGY

2.1 Sampling methods

The sampling methods used to study, describe and monitor seagrass meadows were developed by the TropWATER Seagrass Group and tailored to the location and habitat surveyed. This includes methods for subtidal meadows, e.g. Dugong Sanctuary (Taylor et al., 2010); port surveys, e.g. Thursday Island (Carter et al. 2014a); and intertidal surveys in areas at high risk from shipping accidents in Torres Strait (Carter et al., 2013).

2.1.1 Location

At each site latitude and longitude was recorded by GPS. Depth was recorded when sampling by boat and converted to depth below mean sea level (dbMSL) in metres.

2.1.2 Seagrass metrics

Above-ground biomass was determined using a "visual estimates of biomass" technique (Mellors, 1991) using trained observers. A linear regression was calculated for the relationship between the observer ranks and the harvested values. This regression was used to calculate above-ground biomass for all estimated ranks made from the survey sites. Biomass ranks were then converted into above-ground biomass estimates in grams dry weight per square metre (gdw m^{-2}). Observers ranked seagrass biomass, and the percent contribution of each species to that biomass, using video transects, grabs, free divers, and helicopter:

- **Video transect:** Commonly used for subtidal meadows sampled from larger boats. At each transect site an underwater CCTV camera system was lowered from the vessel to the bottom. For each transect the camera was towed at drift speed (less than one knot) for approximately 100m. Footage was observed on a TV monitor and digitally recorded. The video was paused at ten random time frames and an observer ranked seagrass biomass and species composition. On completion of the video analysis, the video observer ranked five additional quadrats that had been previously videoed for calibration. These quadrats were videoed in front of a stationary camera, then harvested, dried and weighed.
- **Helicopter:** Commonly used for intertidal surveys. At each site seagrass above-ground biomass and species composition were estimated from three 0.25 m^2 quadrats placed randomly within a 10m^2 circular area. Seagrass percent cover and sediment type were recorded at each site. The "visual estimates of biomass" technique when applied to helicopter surveys (and free diving/camera drops – see below) involves ranking while referring to a series of quadrat photographs of similar seagrass habitats for which the above-ground biomass has previously been measured. Three separate biomass scales were used: low-biomass, high-biomass, and *Enhalus*-biomass. The relative proportion (percentage) of the above-ground biomass of each seagrass species within each survey quadrat was also recorded. Field biomass ranks were converted into above-ground biomass estimates in grams dry weight per square metre (gdw m^{-2}). At the completion of sampling each observer ranked a series of calibration quadrats as per video transect surveys.

- **Camera drop/free diving:** Commonly used for shallow subtidal meadows sampled from a small boat. Sampling follows the same protocol as helicopter surveys but the three quadrats were either assessed by a free diver with quadrat, or by an underwater CCTV camera system camera attached to a frame (Figure 3a, b). Video footage was observed on a TV monitor and seagrass ranked in real time, with the camera frame serving as a quadrat.
- **van Veen grab:** Commonly used for shallow subtidal meadows sampled from a small boat in conjunction with camera drops, or to record seagrass presence/absence where visibility was too poor for camera drops. A sample of seagrass was collected using a van Veen grab (grab area 0.0625 m^2) to identify species present at each site (Figure 3c). Species identified from the grab sample were used to inform species composition assessments made from the video drops (Kuo et al., 1989).

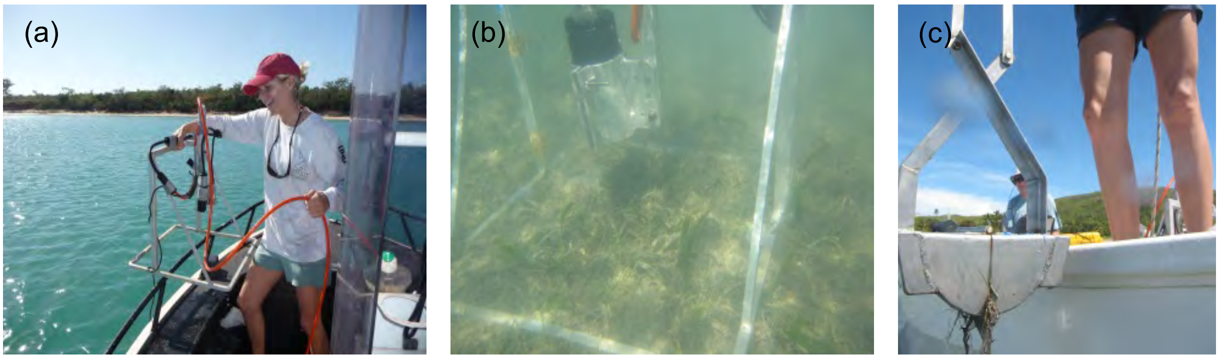

Figure 3: Subtidal mapping of seagrass meadows using (a, b) drop camera system and (c) van Veen sediment grab.

2.1.3 Benthic macro-invertebrates

A visual estimate of benthic macro-invertebrate (BMI) percent cover was recorded at each shallow subtidal and intertidal site according to four broad taxonomic groups:

- Hard corals – All scleractinian corals including massive, branching, tabular, digitate and mushroom.
- Soft corals – All alcyonarian corals, i.e. corals lacking a hard limestone skeleton.
- Sponges
- Other BMI – Any other BMI identified, e.g. hydroids, ascidians, barnacles, oysters, molluscs. Other BMI are listed in the “comments” column of the GIS site layer.

2.1.4 Algae

A visual estimate of algae percent cover was recorded at each shallow subtidal and intertidal site. When present, algae were categorised into five functional groups (Figure 4) and the percent contribution of each functional group was estimated:

- Erect macrophytes – Macrophytic algae with an erect growth form and high level of cellular differentiation, e.g. *Sargassum*, *Caulerpa* and *Galaxaura* species.
- Erect calcareous – Algae with erect growth form and high level of cellular differentiation containing calcified segments, e.g. *Halimeda* species.
- Filamentous – Thin, thread-like algae with little cellular differentiation.
- Encrusting – Algae that grows in sheet-like form attached to the substrate or benthos, e.g. coralline algae.

- Turf mat – Algae that forms a dense mat on the substrate.

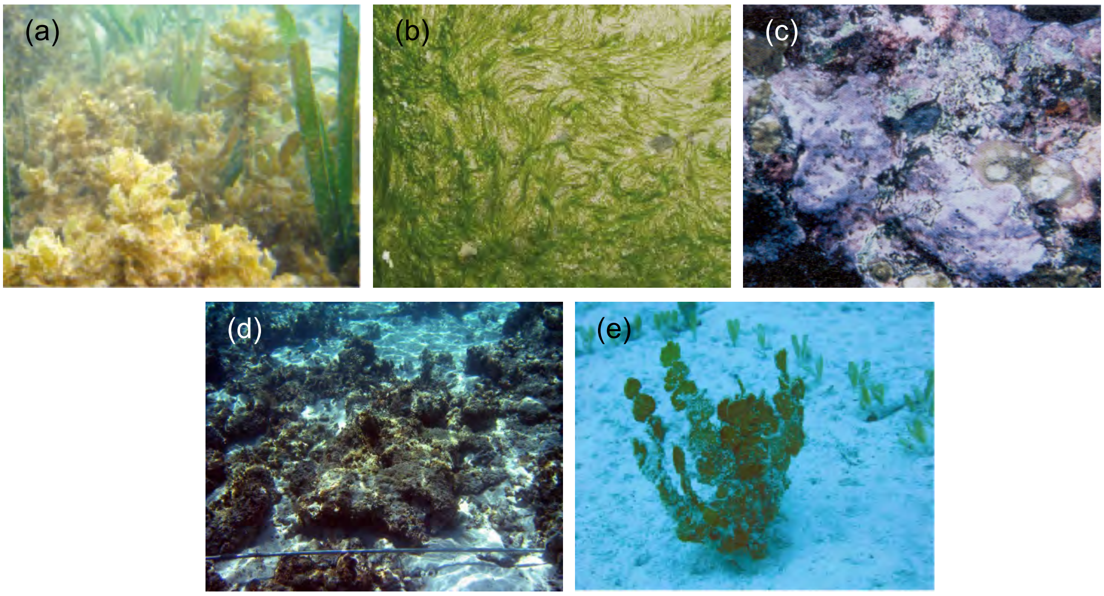

Figure 4: Algae functional groups (a) erect macrophyte, (b) filamentous, (c) encrusting, (d) turf mat and (e) erect calcareous.

2.1.5 Working with the Torres Strait Islander Rangers and Community

Rangers from Boigu Island and Saibai Island and use of the TSRA LSMU ranger vessel were essential to the success of boat-based surveys. The Rangers assisted TropWATER researchers with logistical support prior to the surveys and all aspects of sampling (data collection, operation of field equipment). TropWATER researchers relied heavily on the Ranger's local knowledge of the survey area, particularly around Deliverance Island. TropWATER researchers gave a talk and answered questions on seagrass, dugong and turtle at the Boigu Island school in November 2015.

2.2 Geographic Information System (GIS)

All survey data were entered into a Geographic Information System (GIS) developed for Torres Strait using ArcGIS 10.2. Rectified colour satellite imagery of the region (Source: ESRI, Landsat 2015), field notes and aerial photographs taken from the helicopter during surveys were used to identify geographical features, such as reef tops, channels and deep-water drop-offs, to assist in determining seagrass meadow boundaries. Two GIS layers - a site layer and a meadow layer - were created to describe spatial features of the region. Three interpolation layers were created using site data and meadow boundaries to describe spatial variation in biomass, species diversity and depth gradients.

2.2.1 Site layer

This layer contains data collected at assessment sites, and includes:

1. Temporal details - survey date and time.
2. Spatial details – latitude/longitude, dbMSL, sediment type.

3. Habitat information – seagrass presence absence, seagrass above-ground biomass (for each species), Shannon-Weaver seagrass diversity values, dugong feeding trail presence/absence (intertidal sites only), and percent cover for seagrass, algae groups and benthic macro-invertebrates.
4. Sampling methods and any relevant comments.

2.2.2 Seagrass meadow layer

Seagrass presence/absence site data was used to construct the polygon (meadow) layer. The meadow layer provides summary information for all sites within the meadow, and includes:

1. Spatial details – depth range of sites and meadow location.
2. Habitat information – seagrass species present, meadow community type and density, mean meadow biomass ± standard error (s.e.), meadow area ± reliability estimate (R) and number of sites within the meadow.
3. Sampling methods and any relevant comments.

Meadow location was classed according to whether meadows were intertidal (all sites surveyed by helicopter), shallow subtidal (generally an extension of an intertidal meadow into shallow waters <5m deep), or subtidal (no intertidal sites adjoining the meadow).

Seagrass community types were determined according to species composition within a meadow. Species composition was based on the percent each species' biomass contributed to mean meadow biomass. A standard nomenclature system was used to categorize each meadow (Table 1). This nomenclature also included a measure of meadow density categories (light, moderate, dense) determined by mean biomass of the dominant species within the meadow (Table 2).

Table 1: Nomenclature for seagrass community types

Community type	**Species composition**
Species A	Species A is 90-100% of composition
Species A with Species B	Species A is 60-90% of composition
Species A with Species B/Species C	Species A is 50% of composition
Species A/Species B	Species A is 40-60% of composition

Table 2: Density categories and mean above-ground biomass ranges for each species used in determining seagrass community density

	Mean above-ground biomass (gdw m^{-2})					
Density	*H. uninervis* (thin)	*H. ovalis* *H. decipiens*	*H. uninervis* (wide) *C. serrulata* *C. rotundata* *S. isoetifolium* *T. hemprichii*	*H. spinulosa*	*Z. capricorni*	*E. acoroides*
Light	< 1	< 1	< 5	< 15	< 20	< 40
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60	40 - 100
Dense	> 4	> 5	> 25	> 35	> 60	> 100

Mapping precision estimates (in metres) were based on the mapping method used for that meadow (Table 3). Mapping precision estimates ranged from 1-10m for intertidal seagrass meadows to >100m for patchy subtidal meadows. Subtidal meadow mapping precision estimates were based on the distance between sites with and without seagrass. The mapping precision estimate was used to calculate an error buffer around each meadow; the area of this buffer is expressed as a meadow reliability estimate (R) in hectares.

Table 3: Mapping precision and methods for seagrass meadows.

Mapping precision	Mapping method
1-10 m	Meadow boundaries mapped in detail by GPS from helicopter; Intertidal meadows completely exposed or visible at low tide; Relatively high density of mapping and survey sites; Recent aerial photography aided in mapping.
10-50 m	Meadow boundaries determined from helicopter and camera/grab surveys; Inshore boundaries mapped from helicopter; Offshore boundaries interpreted from survey sites and aerial photography; Relatively high density of mapping and survey sites.
≥100 m	Sites generally surveyed by boat Seagrass meadow boundary determined from distance between sites No distinct topographic features from satellite imagery aided in mapping Relatively low density of survey sites

2.2.3 Seagrass interpolation layers

An inverse distance weighted interpolation (IDW) was applied to seagrass site data to describe spatial variation across each meadow and throughout the north-west Torres Strait region. Interpolations were conducted for total seagrass biomass, Shannon-Weaver diversity index scores, and depth (dbMSL). The Shannon-Weaver index is a mathematical measure of species diversity that uses species richness (the number of species present, where a score of 0 = one species present) and the relative abundance of different species (Spellerberg et al., 2003).

3. RESULTS

3.1 Seagrass in north-west Torres Strait

Subtidal surveys were conducted November 4-12, 2015. Intertidal surveys were conducted November 18-22, 2015 and January 18, 2016. Seagrass was present at 43% of the 853 sites surveyed (Figure 5). A total of 60 263 ha of seagrass meadows were mapped across 34 meadows in north-west Torres Strait (see Appendix 1 and 2 for detailed meadow descriptions). Eighteen meadows were entirely intertidal, seven meadows were intertidal but extended into shallow subtidal areas, and nine meadows were entirely subtidal, ranging in depth from ~2-10m. The maximum depth recorded during the survey was 22m, but seagrass was not found growing deeper than 10m.

Seagrass mean meadow biomass ranged from 0.06 ± 0.00 to 11.70 ± 1.53 gdw m^{-2} (Figure 6). Regions with relatively high seagrass biomass (mean site biomass >10 gdw m^{-2}) included meadows around Deliverance and Turnagain Islands, and near the mouth of the Mai River (Papua New Guinea coast) and eastern Boigu Island. Seagrass biomass in subtidal meadows was low, often <1 gdw m^{-2} (Figure 6).

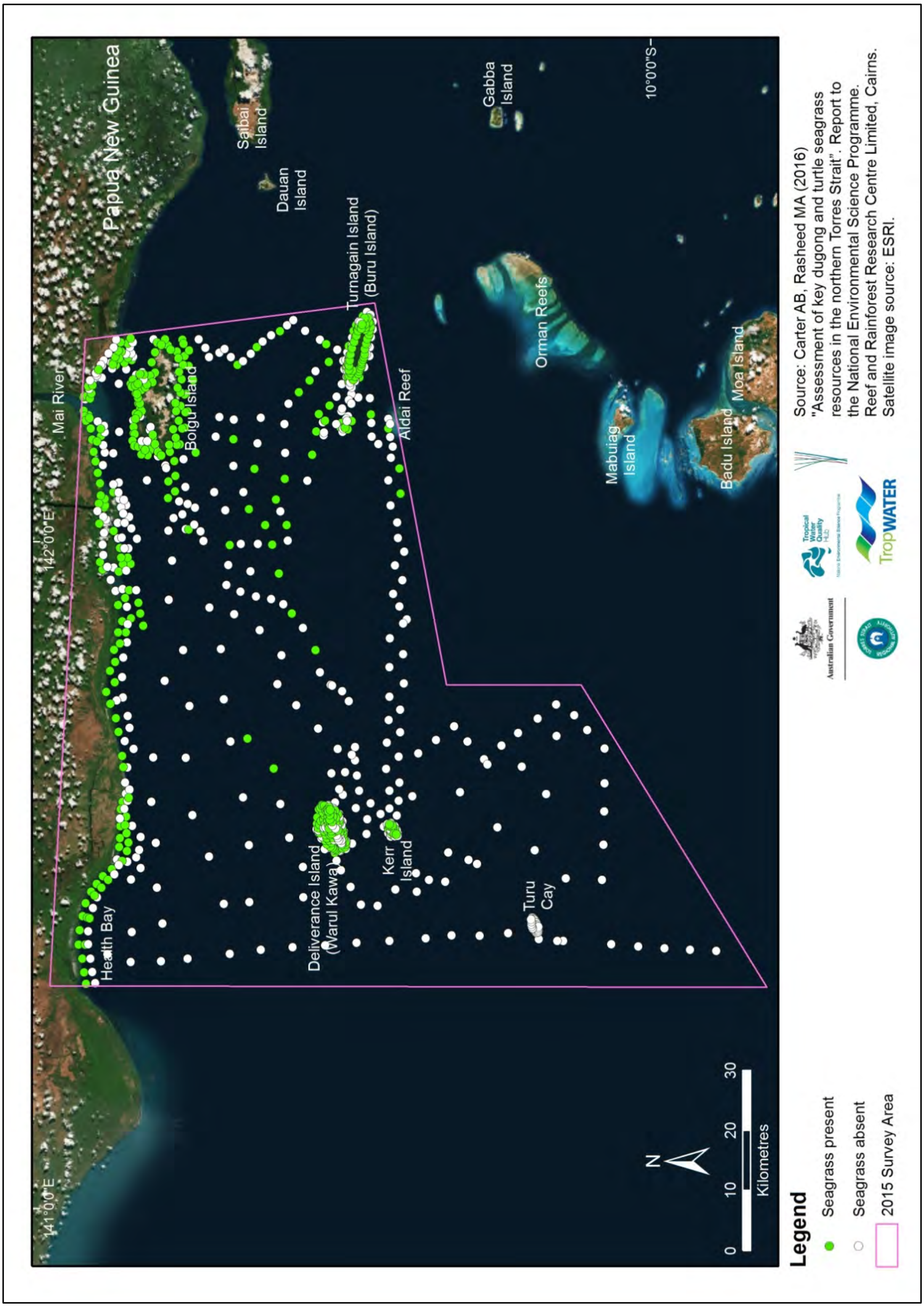

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Figure 5: Seagrass presence and absence at sites within the 2015 survey region, north-west Torres Strait.

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Figure 6: Variation in seagrass biomass within meadows, north-west Torres Strait.

3.1.1 Seagrass species

Ten seagrass species from three families were identified in north-west Torres Strait in 2015 (Figure 7). Seagrass diversity was greatest around Deliverance, Turnagain and Boigu Islands and along the Papua New Guinea coast immediately west of the Mai River mouth (Figure 8). Subtidal meadow communities were characteristically *C. serrulata* or *H. decipiens* dominated (Figures 9, 10, 11). Reef-top meadows around Deliverance and Turnagain Islands were *T. hemprichii* dominated (Figures 9, 10); *H. uninervis* dominated intertidal meadows along the Papua New Guinea coast and adjacent islands (Figures 9, 10, 12).

The most dominant species in terms of contribution to mean biomass across all sites were *T. hemprichii* (35%) then *H. uninervis* (28%; thin and wide leaf morphology combined) (Table 4). *H. uninervis* was the most commonly occurring species (present at 24% of sites surveyed). The dominance of *T. hemprichii* contribution to biomass relative to occurrence was due to the relatively high biomass of the species compared to others, particularly the more common *H. uninervis* (Table 4). The least common species were *Z. capricorni*, *H. decipiens* and *H. spinulosa*; these species occurred at <1% of survey sites and contributed <1% each to seagrass biomass in the region (Table 4). *C. rotundata*, *E. acoroides* and *Z. capricorni* were recorded exclusively in exposed intertidal waters (i.e. 0 dbMSL), while *H. decipiens* was recorded only in subtidal waters (Table 4).

Table 4: Seagrass species composition (as a percentage of biomass), frequency (as a percentage of sites where present), and depth range (metres below mean sea level) of species across north-west Torres Strait, 2015

Species	Mean % biomass	% Occurrence	Depth (m; min)	Depth (m; max)
C. rotundata	12.2	9.0	0	0
C. serrulata	10.6	8.0	0	9.4
E. acoroides	2.6	1.6	0	0
H. decipiens	0.6	0.9	2.2	9.4
H. ovalis	8.7	12.9	0	6.4
H. spinulosa	0.7	0.9	0	9.5
H. uninervis	27.5	24.4	0	9.4
S. isoetifolium	2.0	2.7	0	4.4
T. hemprichii	34.8	14.8	0	4.4
Z. capricorni	0.3	0.2	0	0

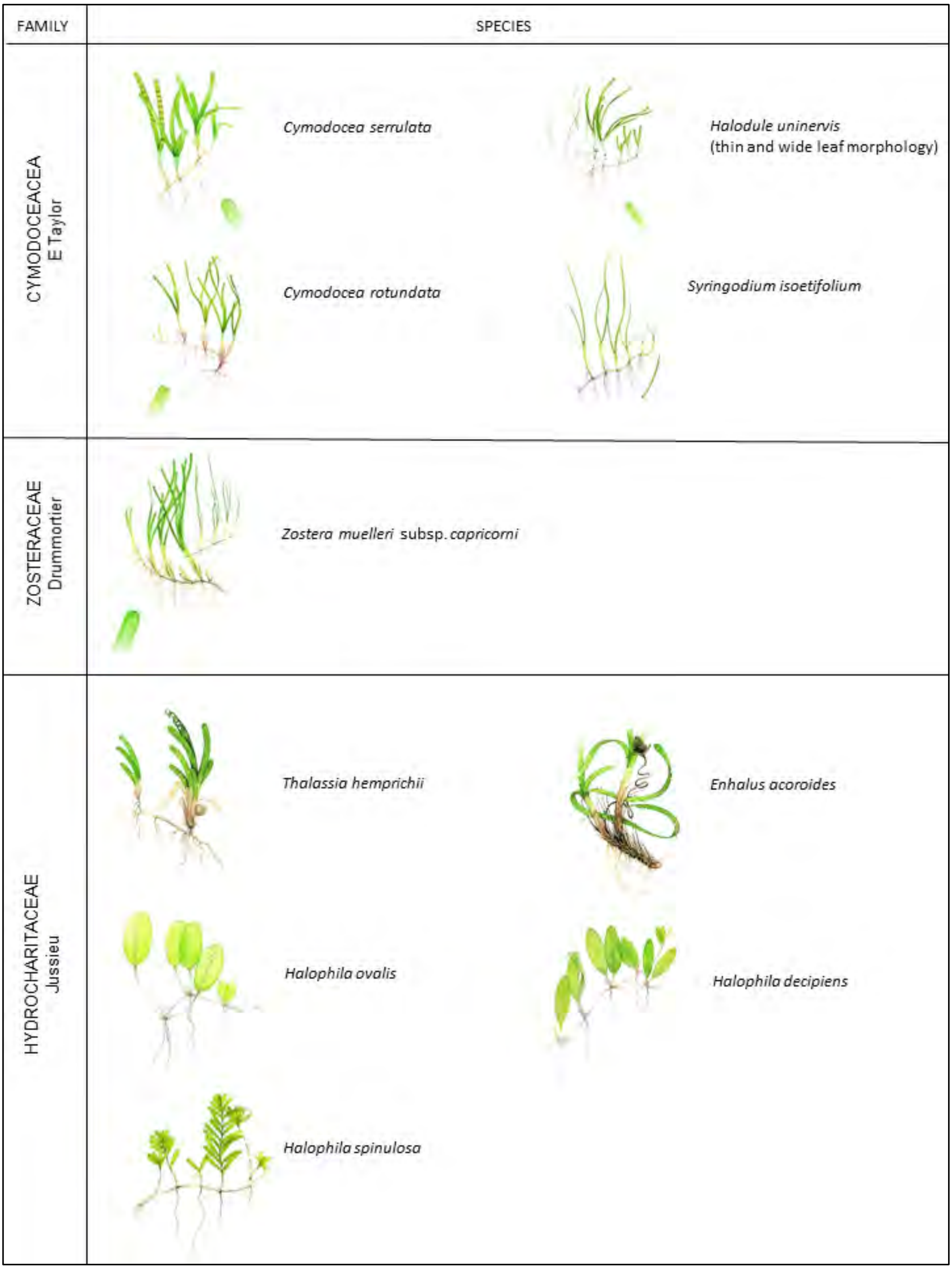

Figure 7: Seagrass species present across north-west Torres Strait meadows, 2015

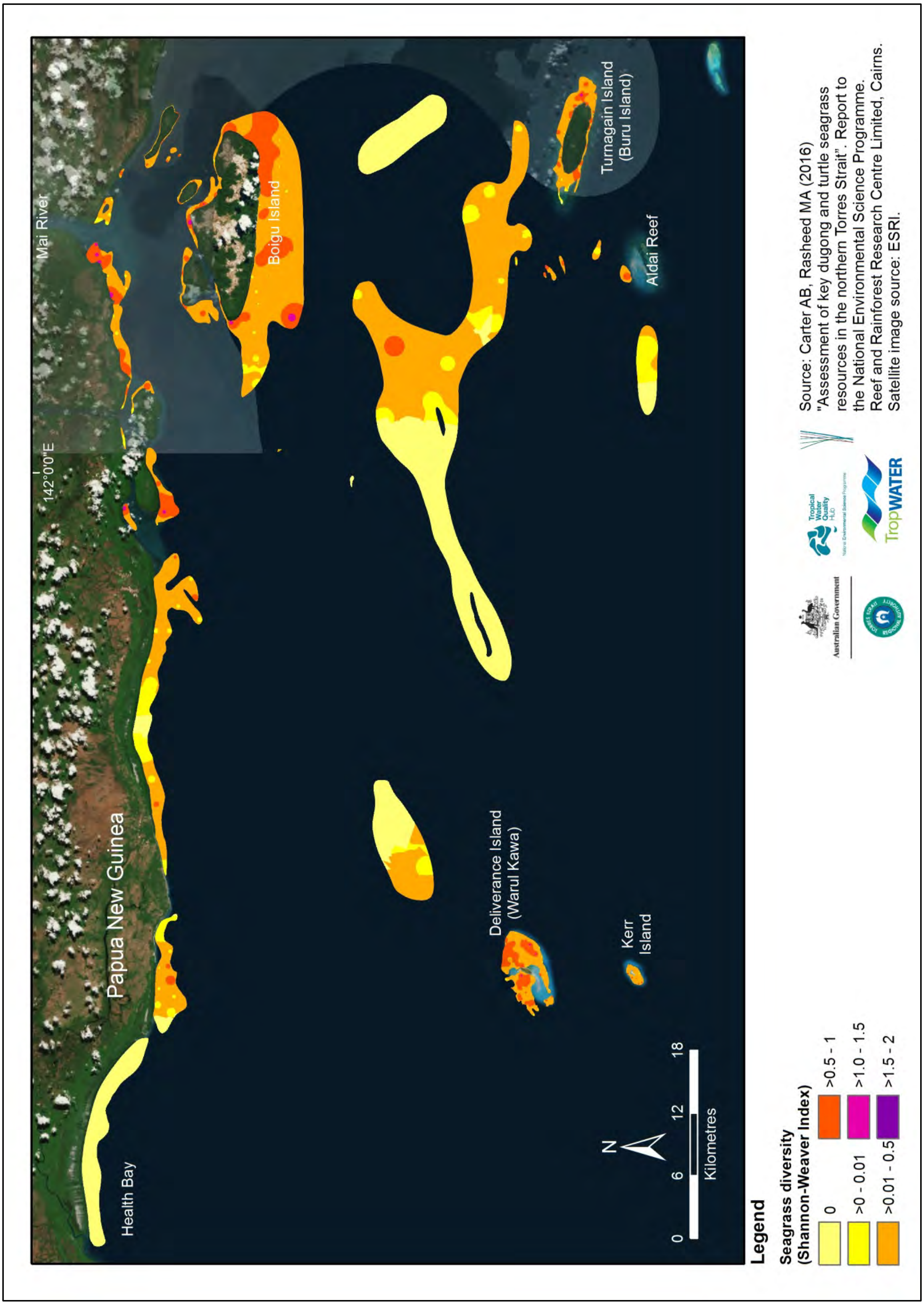

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Figure 8: Seagrass diversity (Shannon-Weaver Index) in north-west Torres Strait seagrass meadows, 2015.

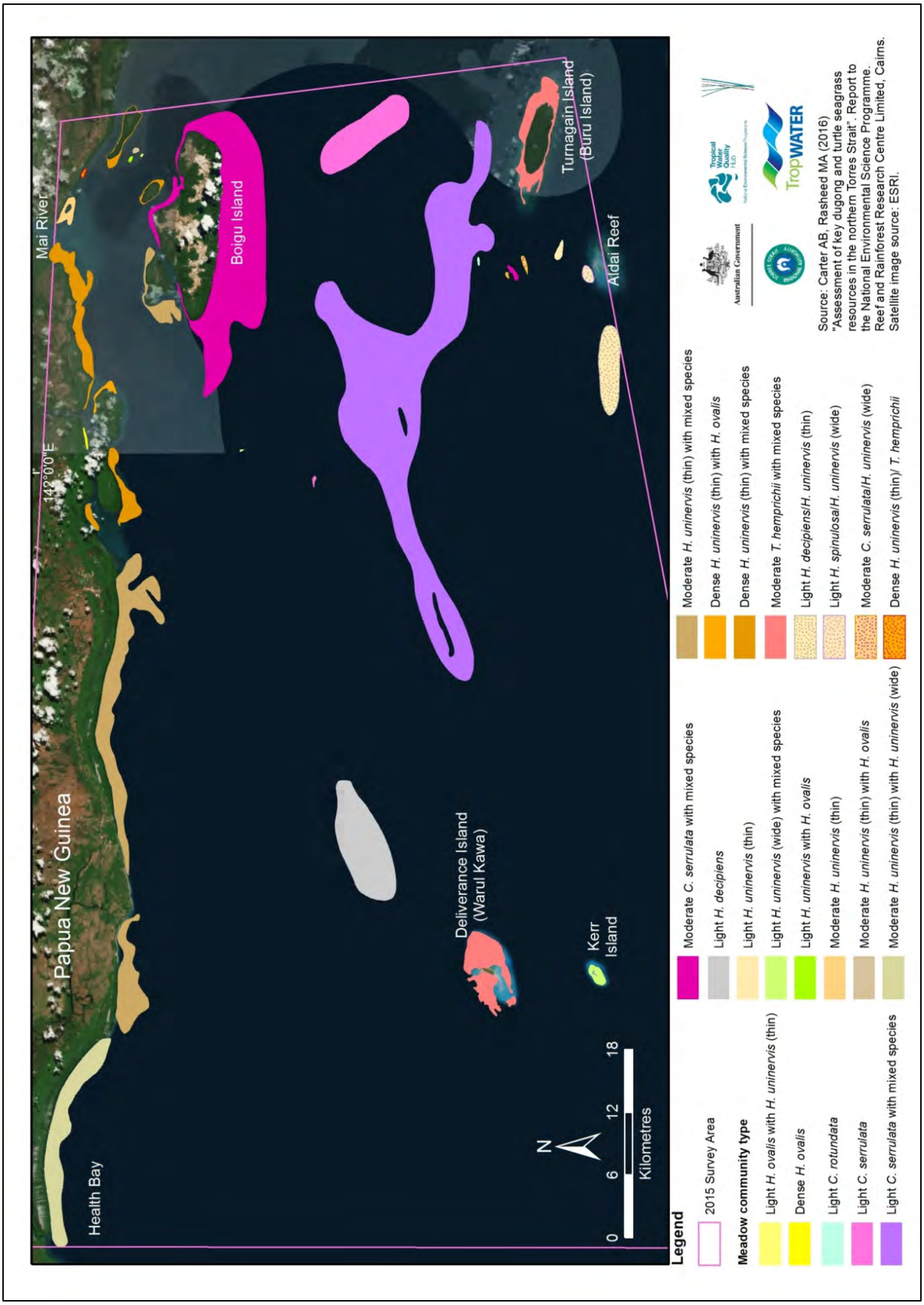

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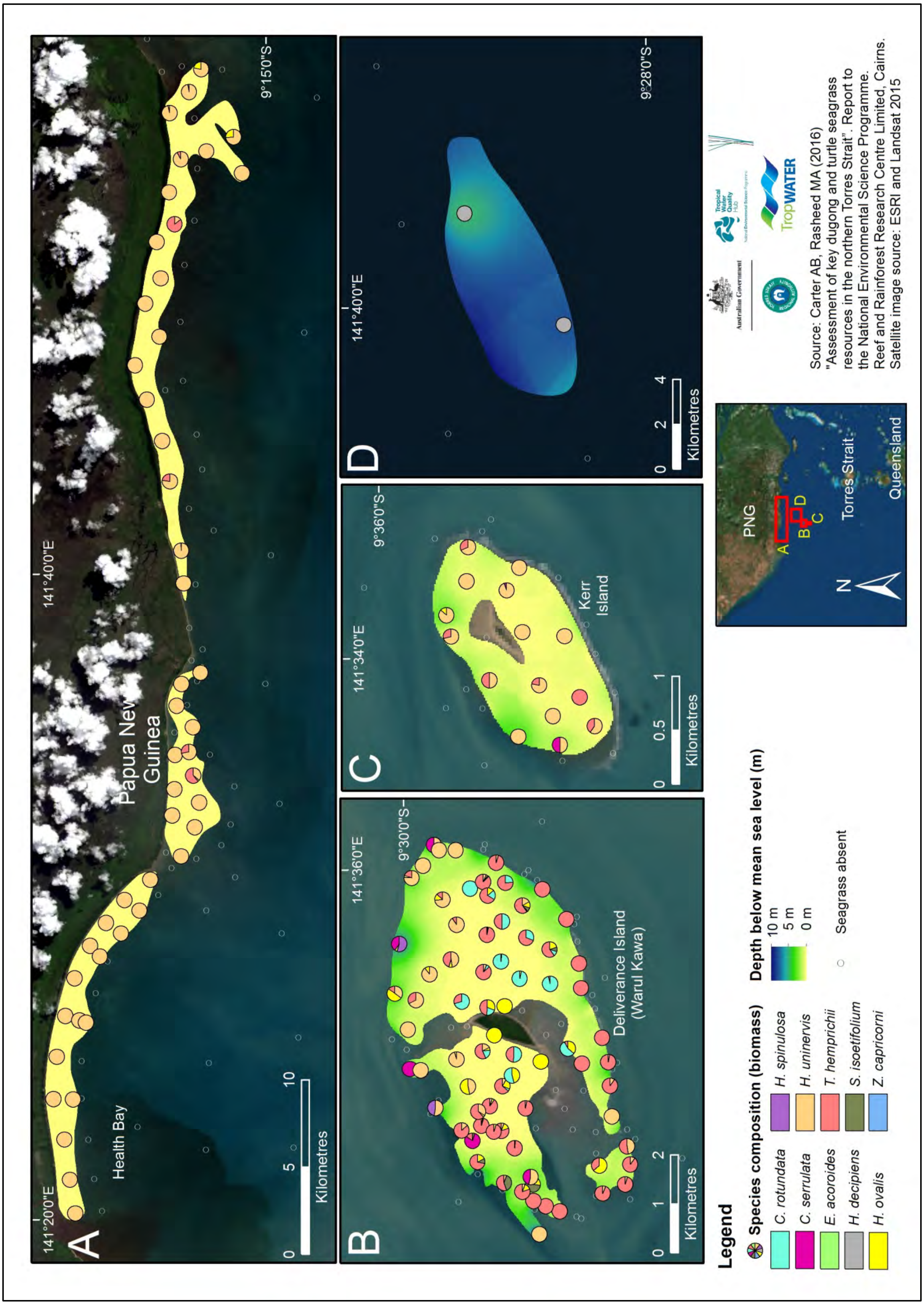
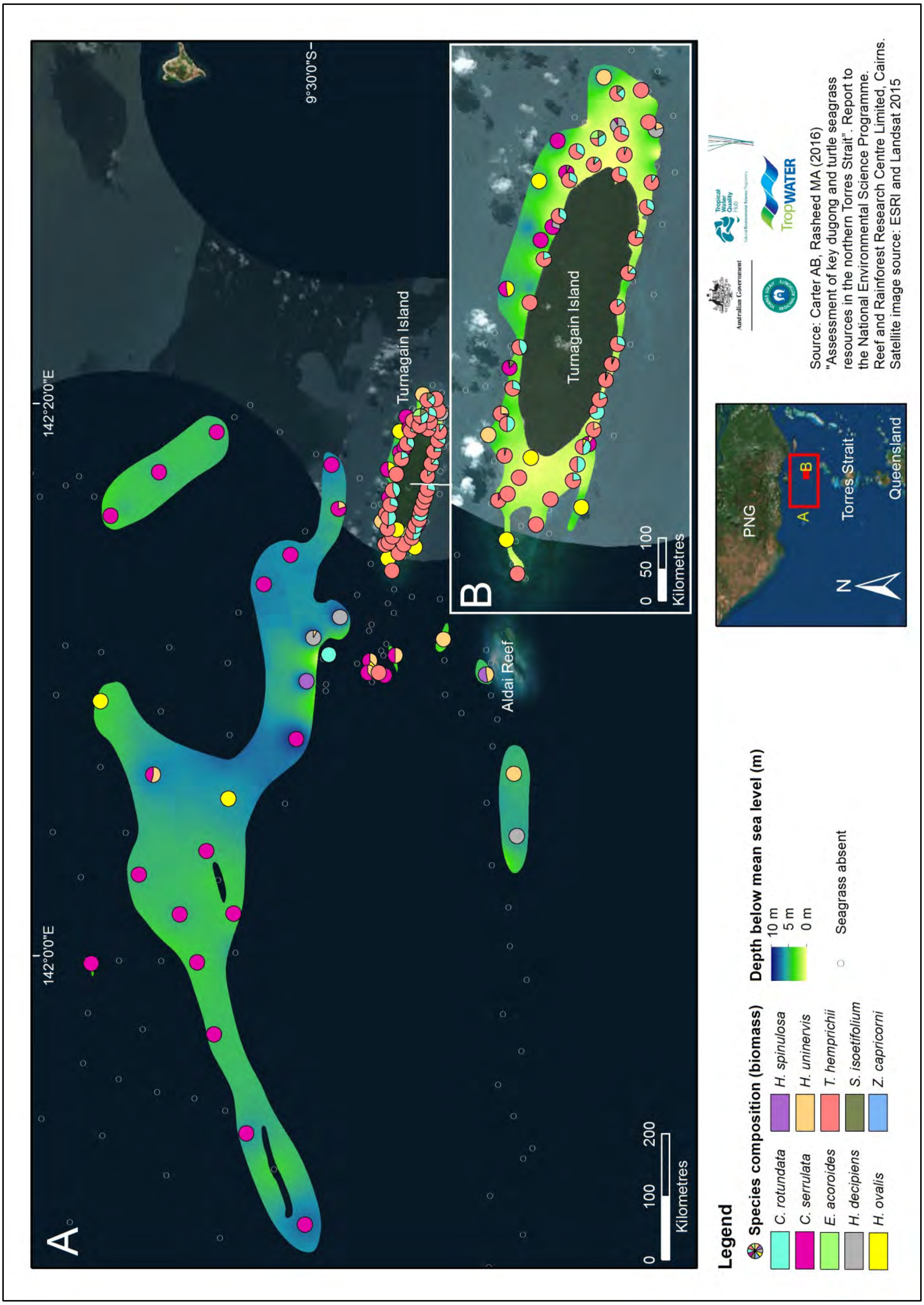
Figure 9: Seagrass meadow community types in north-west Torres Strait, 2015.



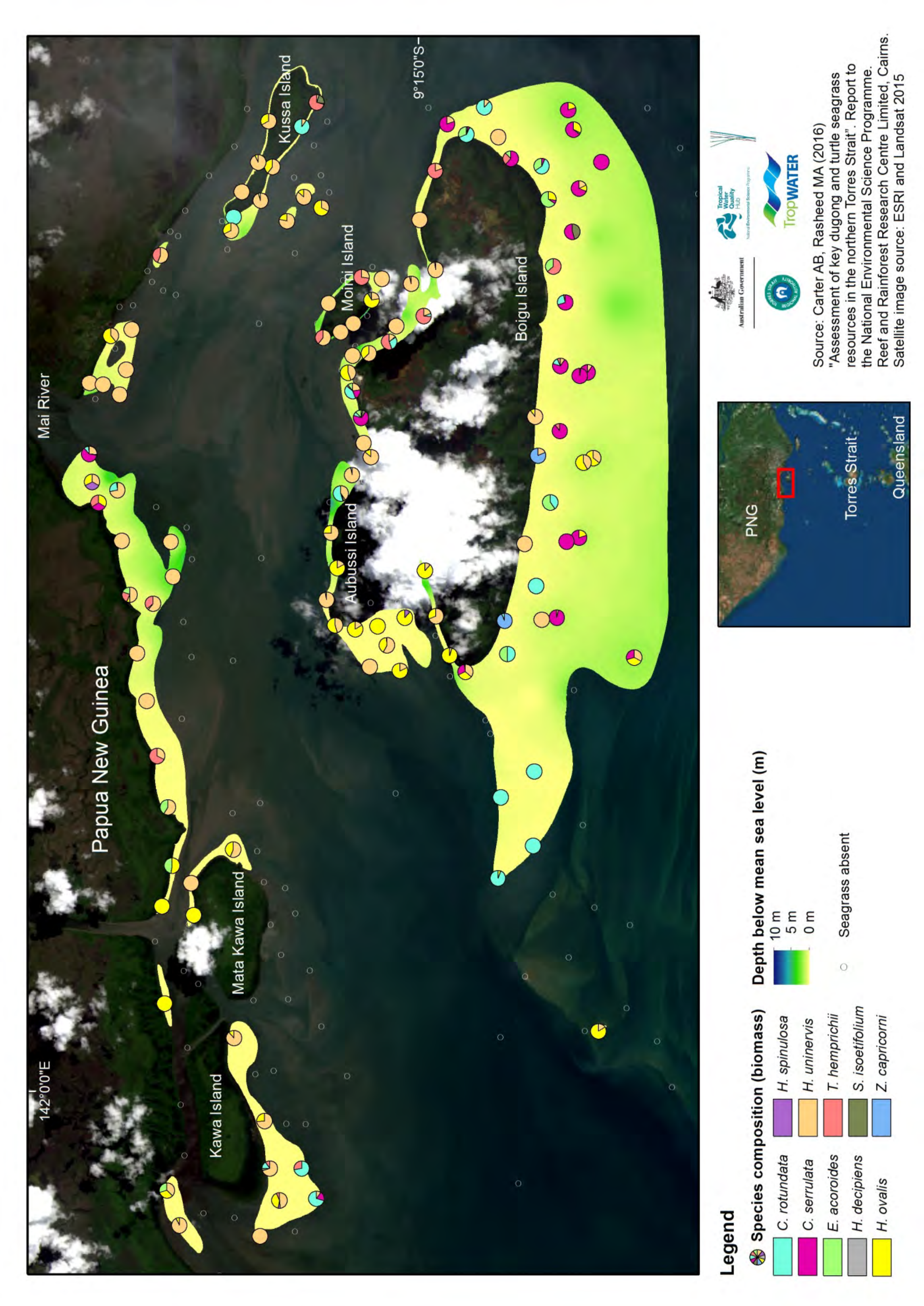
Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI and Landsat 2015

Figure 10: Species composition (as a proportion of total biomass) and gradient of seagrass meadow depth (metres below mean sea level) along the Papua New Guinea coastline, Deliverance and Kerr Islands, and a subtidal meadow in north-west Torres Strait.



Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI and Landsat 2015

Figure 11: Species composition (as a proportion of total biomass) and gradient of seagrass meadow depth (metres below mean sea level) in the Turnagain Island region, north-west Torres Strait.



Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI and Landsat 2015

Figure 12: Species composition (as a proportion of total biomass) and gradient of seagrass meadow depth (metres below mean sea level) in the Boigu Island region, north-west Torres Strait.

3.2 Dugong feeding in north-west Torres Strait

Dugong feeding trail (DFT) presence/absence was recorded during the intertidal survey. DFTs are relatively easy to see during low-level aerial surveys when meadows are exposed. Extensive DFTs were present in intertidal *H. uninervis* dominated seagrass meadows along the Papua New Guinea shoreline and adjacent islands, and around Boigu Island (Figures 13, 14). Dugong were frequently sited during helicopter and boat surveys around Deliverance Island, and a limited number of DFTs were recorded close to the island. No DFTs were recorded at Turnagain Island despite an extensive seagrass meadow (Figure 14).

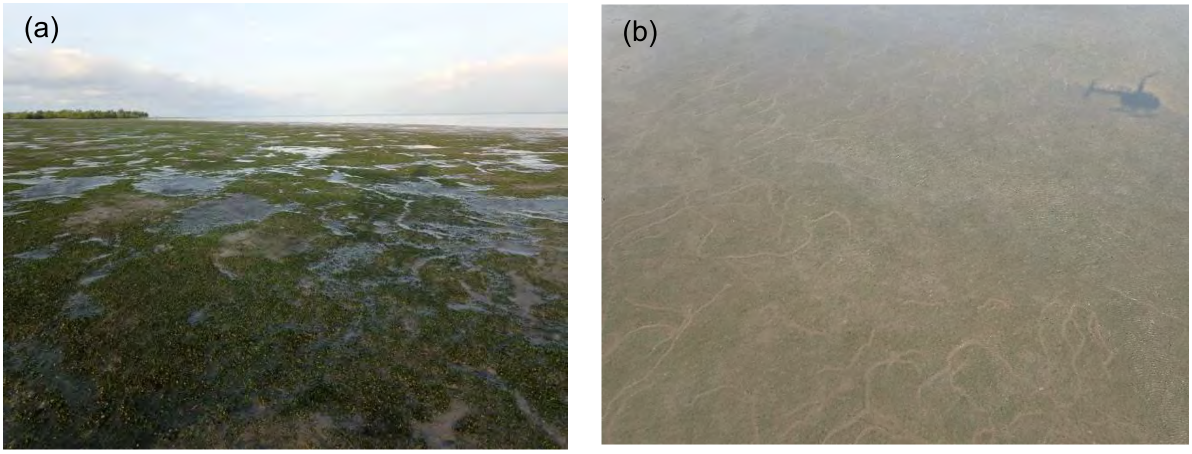
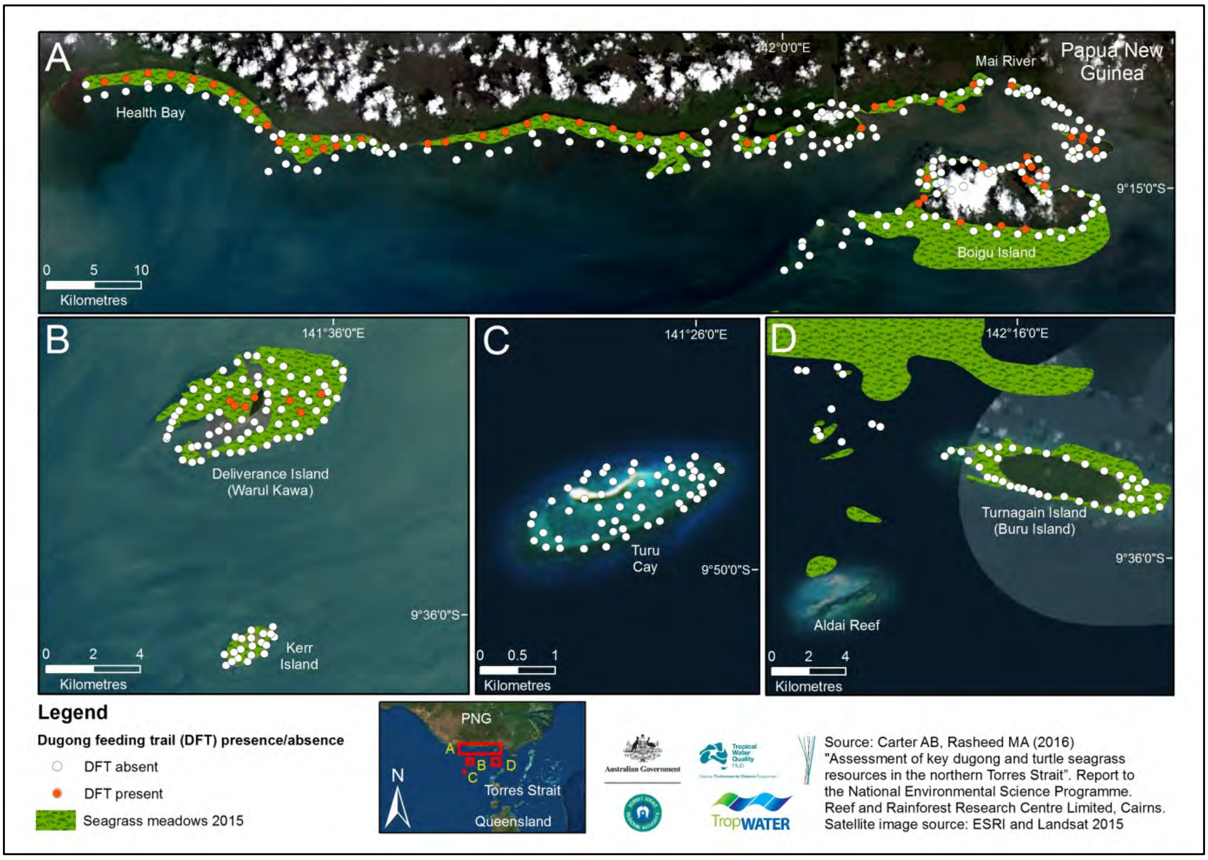


Figure 13: (a) Extensive intertidal seagrasses meadows around Boigu Island and (b) Dugong feeding trails in meadows along the Papua New Guinea coastline.



Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI and Landsat 2015

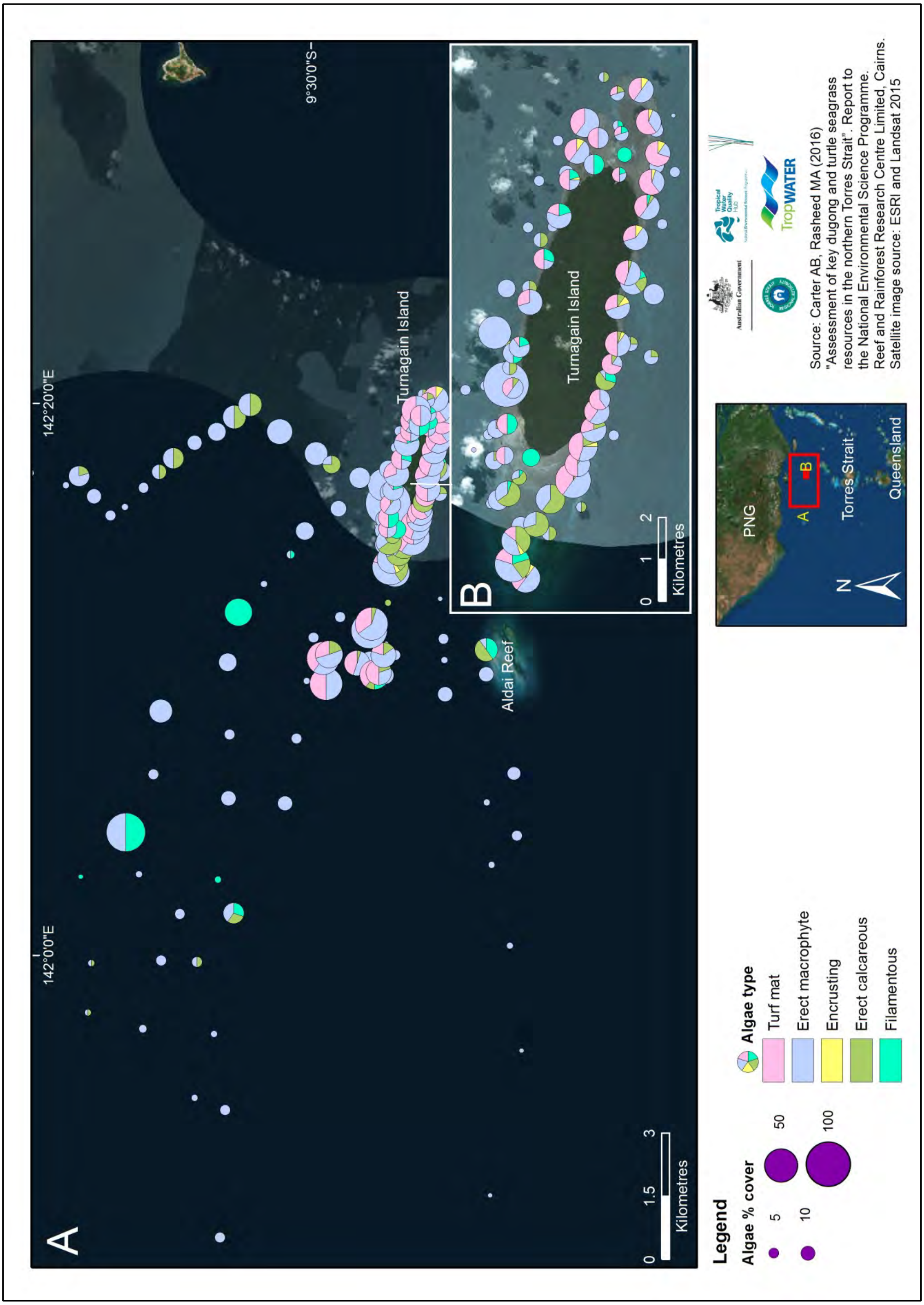
Figure 14: Dugong feeding trail presence/absence in north-west Torres Strait intertidal seagrass meadows, 2015.

3.3 Algae

Extensive algae habitat occurred throughout the survey region. Algae was prevalent in intertidal sites and generally contained a mix of different algae groups (Figures 15, 16). The Turu Cay reef flat was almost entirely covered in algae (Figure 16). Turf mat algae was most common on the reef flat at Deliverance, Turnagain and Kerr Islands, and Turu Cay. Erect macrophyte algae dominated reef edges along the southern/eastern sides of these islands and cays, while the northern/western reef edges were often a combination of erect macrophyte, erect calcareous, and filamentous algae (Figures 15, 16). Turf mat algae was the most common algae found along the Papua New Guinea coast and between north Boigu Island and the Mai River. Erect macrophyte and erect calcareous algae were common at subtidal sites (Figure 15).

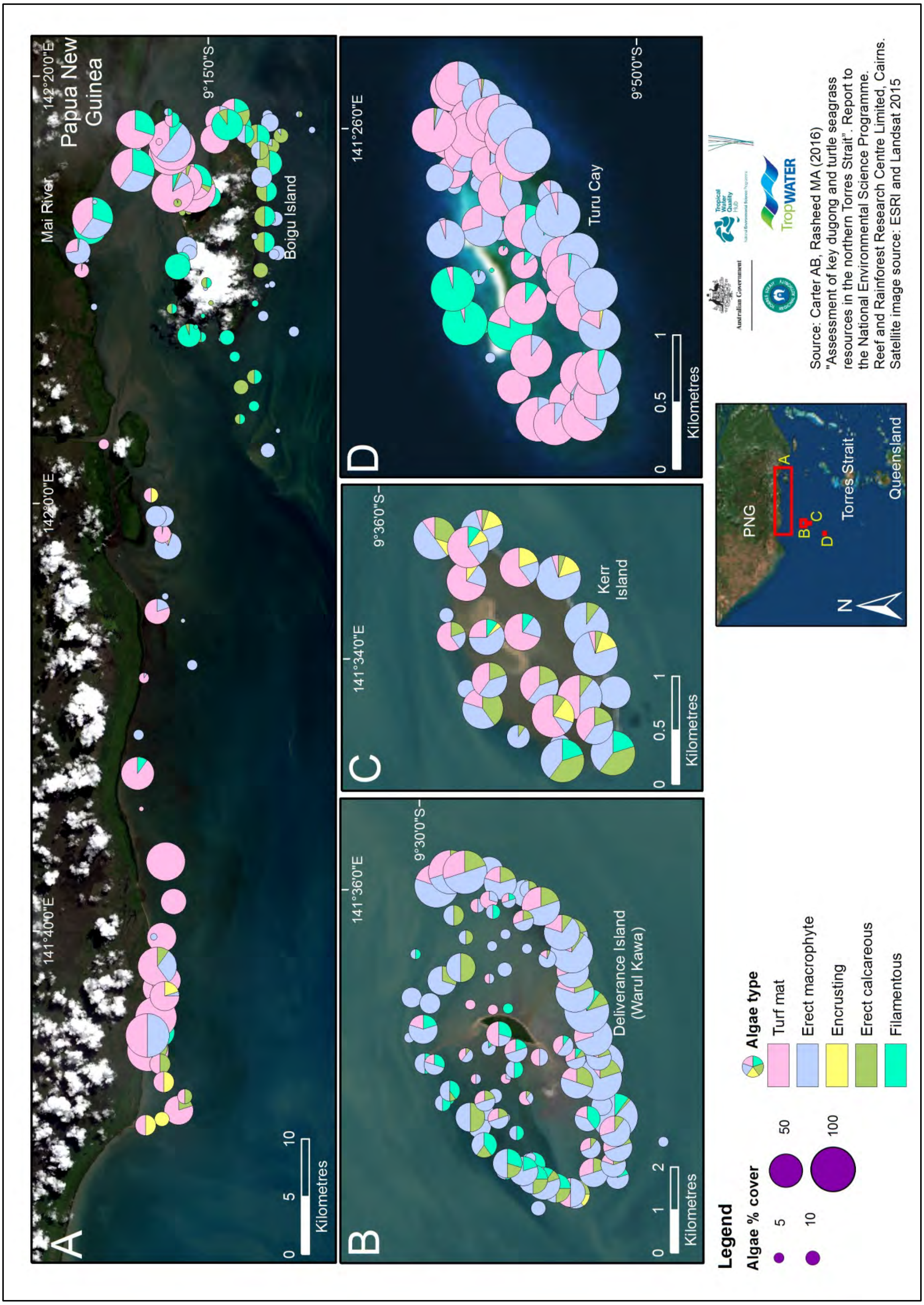
3.4 Benthic macro-invertebrates

Coral communities were the dominant form of benthic macro-invertebrates (BMI) at survey sites. Hard and soft corals were the dominant BMI on reef flats surrounding Turnagain, Deliverance and Kerr Islands, Turu Cay, and small reef patches north-west of Turnagain Island (Figures 17, 18). Sponge patches often were found at subtidal sites and on the eastern side of the Deliverance Island reef flat (Figures 17, 18). Other BMI at subtidal sites were predominantly hydroids, crinoids and bryozoans, and ascidians at intertidal sites.



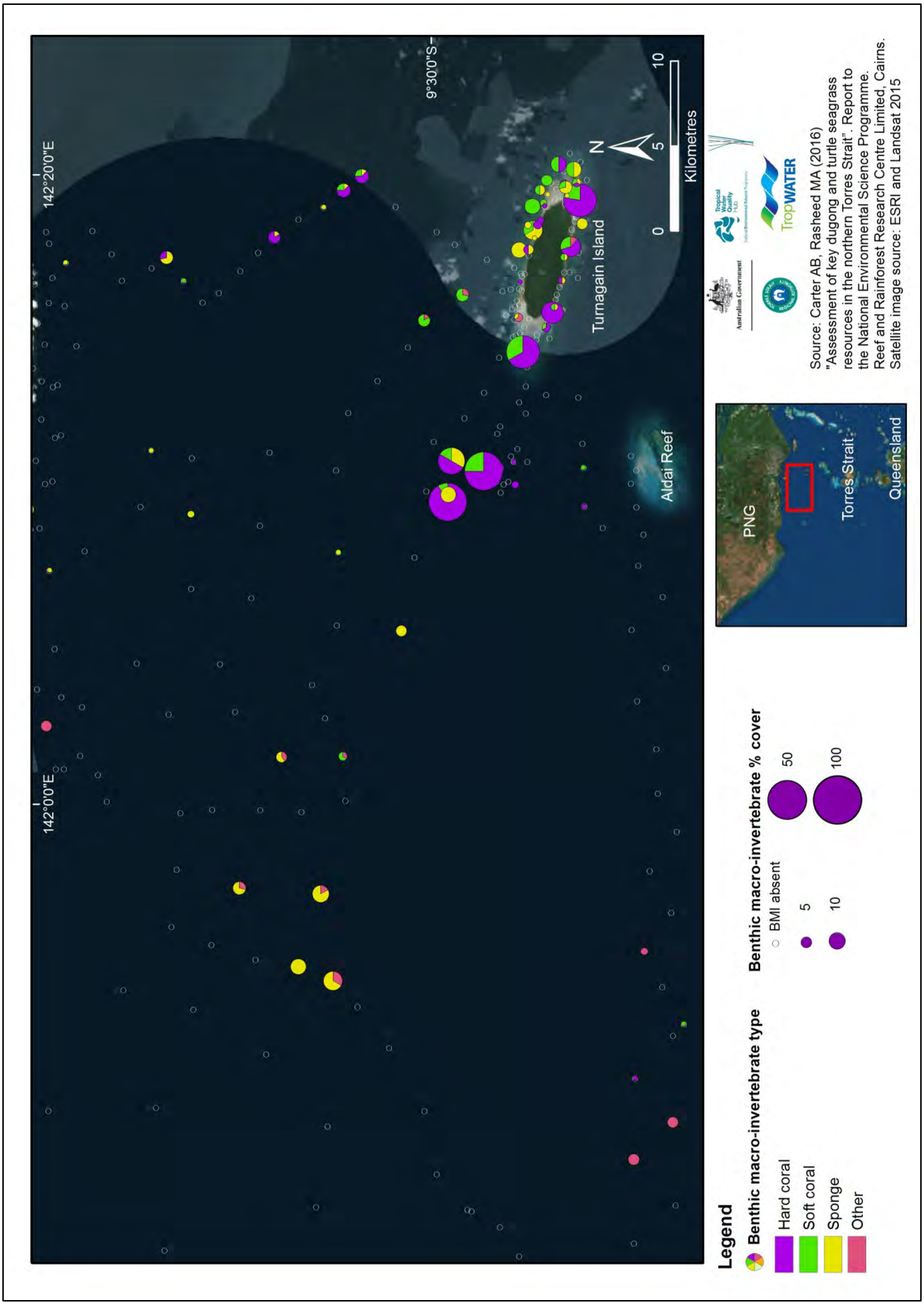
Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI and Landsat 2015

Figure 15: Composition of algae functional groups and percent cover at intertidal and shallow subtidal sites in the Turnagain Island region.



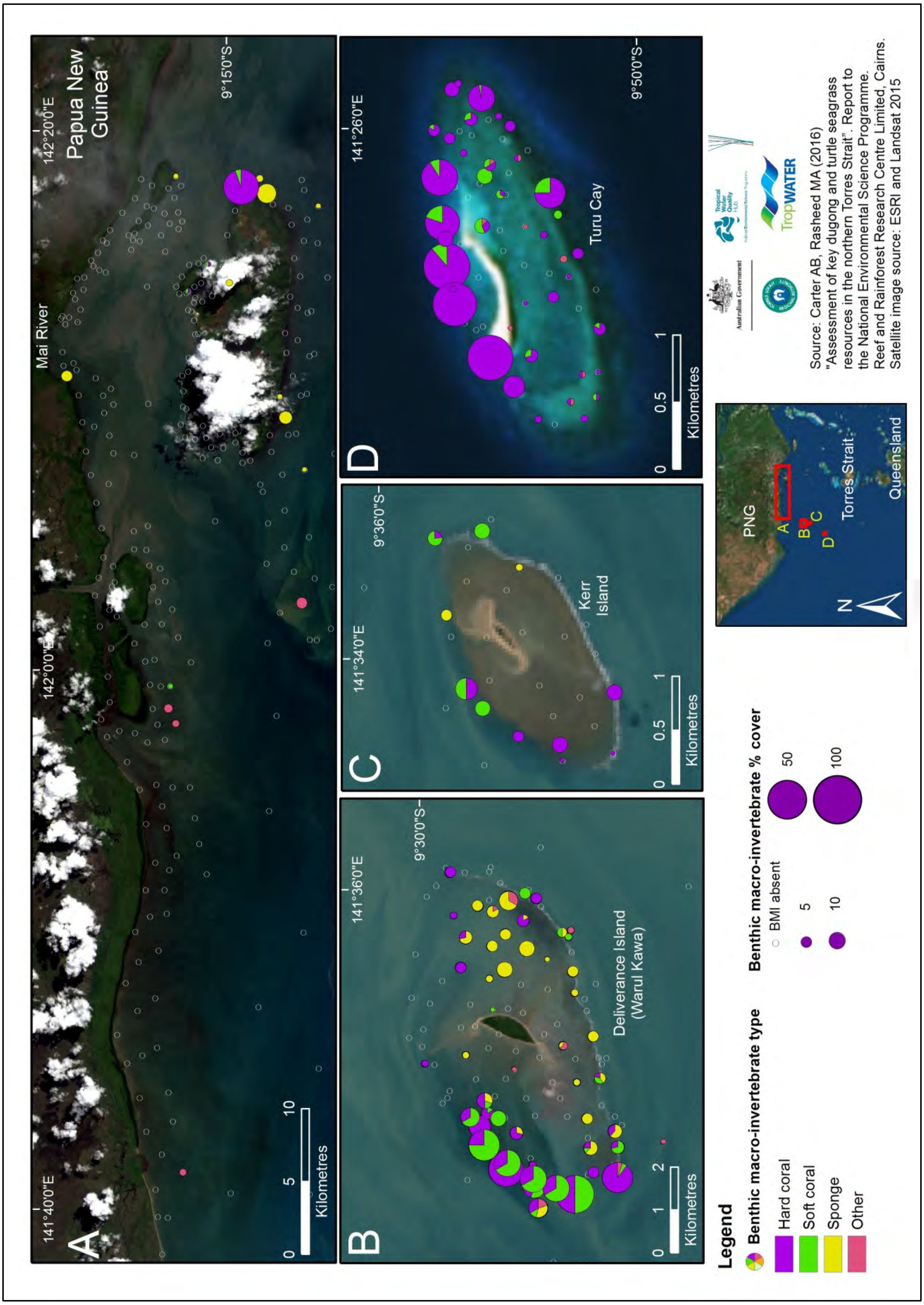
Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI and Landsat 2015

Figure 16: Composition of algae functional groups and percent cover at intertidal and shallow subtidal sites along the Papua New Guinea coastline, Boigu, Deliverance and Kerr Islands, and Turu Cay.



Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI and Landsat 2015

Figure 17: Benthic macro-invertebrate groups and percent cover at intertidal and shallow subtidal sites in the Turnagain Island region.



Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI and Landsat 2015

Figure 18: Benthic macro-invertebrate groups and percent cover at intertidal and shallow subtidal sites along the Papua New Guinea coastline, Boigu, Deliverance and Kerr Islands, and Turu Cay.

4. DISCUSSION

4.1 Seagrass in north-west Torres Strait

Extensive seagrass habitat were found in North-west Torres Strait. Boigu Island and the Papua New Guinea coastline mark the northern limit of extensive intertidal and shallow subtidal meadows that stretch north from Prince of Wales Island, and subtidal meadows that extend west from this island/reef chain (Figure 19; Carter et al., 2014c). Peak biomass (10-30 gdw m^{-2}) regions were found mostly on intertidal reeftops and flats adjacent to Boigu Island and the Mai River mouth (Papua New Guinea coast), but did not reach the high biomass (>50 gdw m^{-2}) recorded in previous surveys around Orman Reefs and between Moa and Prince of Wales Islands (Figure 19; Carter et al., 2014c).

Subtidal seagrass meadows were extensive in the area bounded by Deliverance, Turnagain and Boigu Islands, but sparse elsewhere. Underwater visibility was poor or absent north of Deliverance Island and up to the Papua New Guinea coastline due to suspended sediments. The depth penetration of seagrass is related directly to the quality and quantity of light (Dennison, 1987; Dennison et al., 1985), and different seagrass species have differing minimum light requirements to persist or to achieve positive growth (Chartrand et al., 2012; Collier et al., 2012). The water south of Deliverance Island and east to Turnagain Island was often very clear but currents were strong in this region and video footage was often of bare substrate with sand ripples or large underwater sand banks. The bottom topography, unstable sediments and strong currents in this region would make it difficult for seagrass fragments and seeds to establish and maintain subtidal meadows (Daniell et al., 2008). The present survey provides an interesting contrast with results for subtidal meadows in the south-west Torres Strait where continuous dense meadows have been recorded (Figure 19). Changing topography and hydrological conditions over relatively small scales are well documented for Torres Strait and may have a strong influence on seagrass meadow distributions.

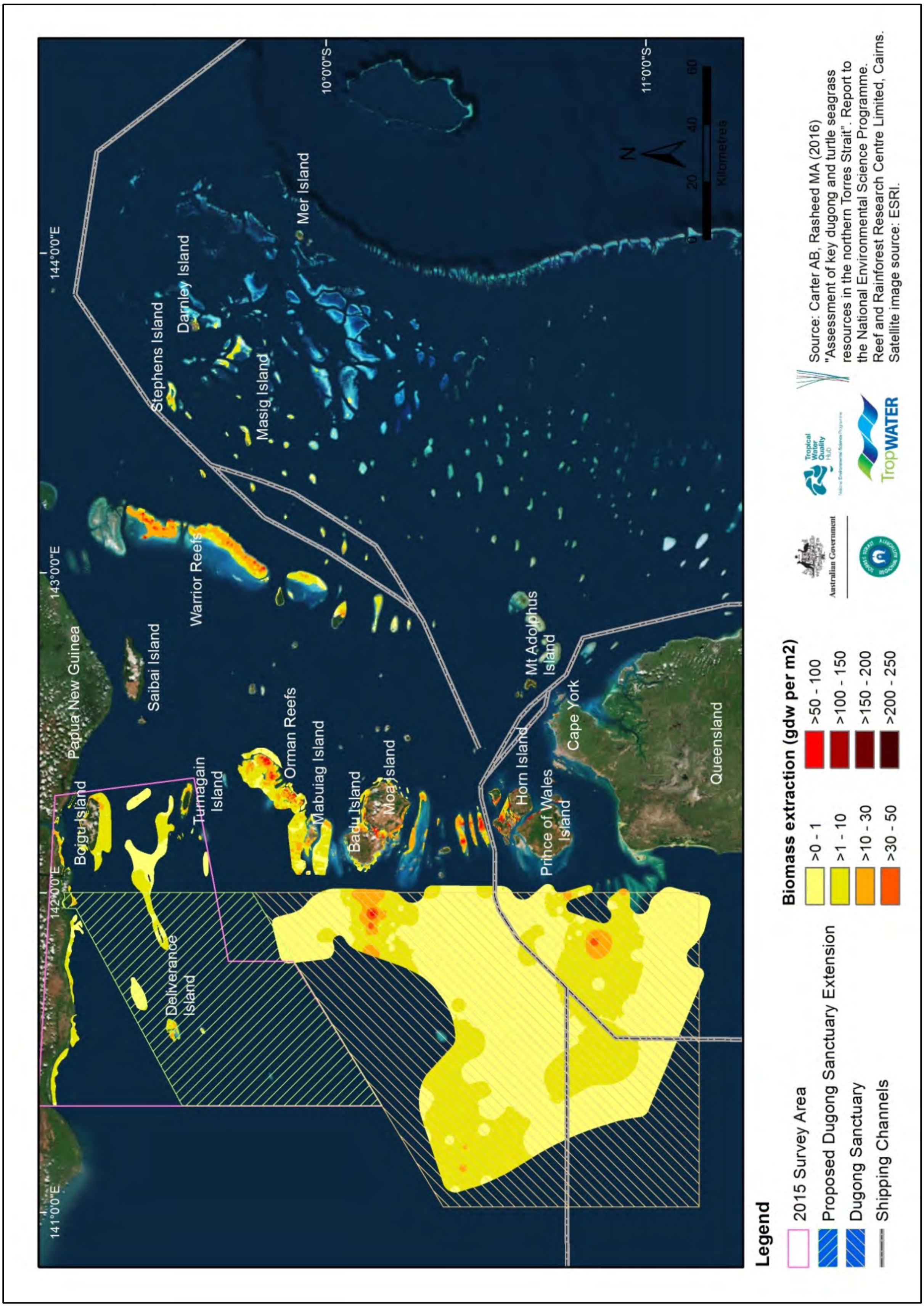
4.2 Dugong and turtle seagrass resources

Seagrass meadows in north-west Torres Strait play a vital role in supporting local dugong and turtle populations. The prevalence of DFTs in intertidal meadows along the Papua New Guinea coastline and Boigu Island, and frequent turtle and dugong sightings at Deliverance Island during the surveys identifies the region as ideal foraging habitat for these important species. Subtidal meadow distribution mapped in this study overlaps spatially with high-very high dugong density distributions recorded during aerial surveys in 2011 and 2013 between Boigu, Deliverance and Turnagain Islands (Marsh et al., 2015). Seagrass monitoring at the nearby Dugong Sanctuary (Carter et al., 2015) and Mabuiag Island (Carter et al., 2014b) confirm subtidal and intertidal seagrass meadows persist throughout the year in this region despite seasonal biomass declines each autumn/winter, providing an important and consistent food source.

The absence of DFTs at Turnagain Island and limited number of DFTs at Deliverance Island, despite extensive seagrass meadows, should be interpreted with caution. The DFT presence/absence data likely contains false zeros at these locations because of the reef/rubble substrate surrounding these islands, and because the dominant reeftop seagrass was *T. hemprichii* (dugong are unable to extract *T. hemprichii* rhizomes from hard substrates (André et al., 2005; Erftemeijer et al., 1993)). Both factors would have limited our ability to detect dugong feeding activity.

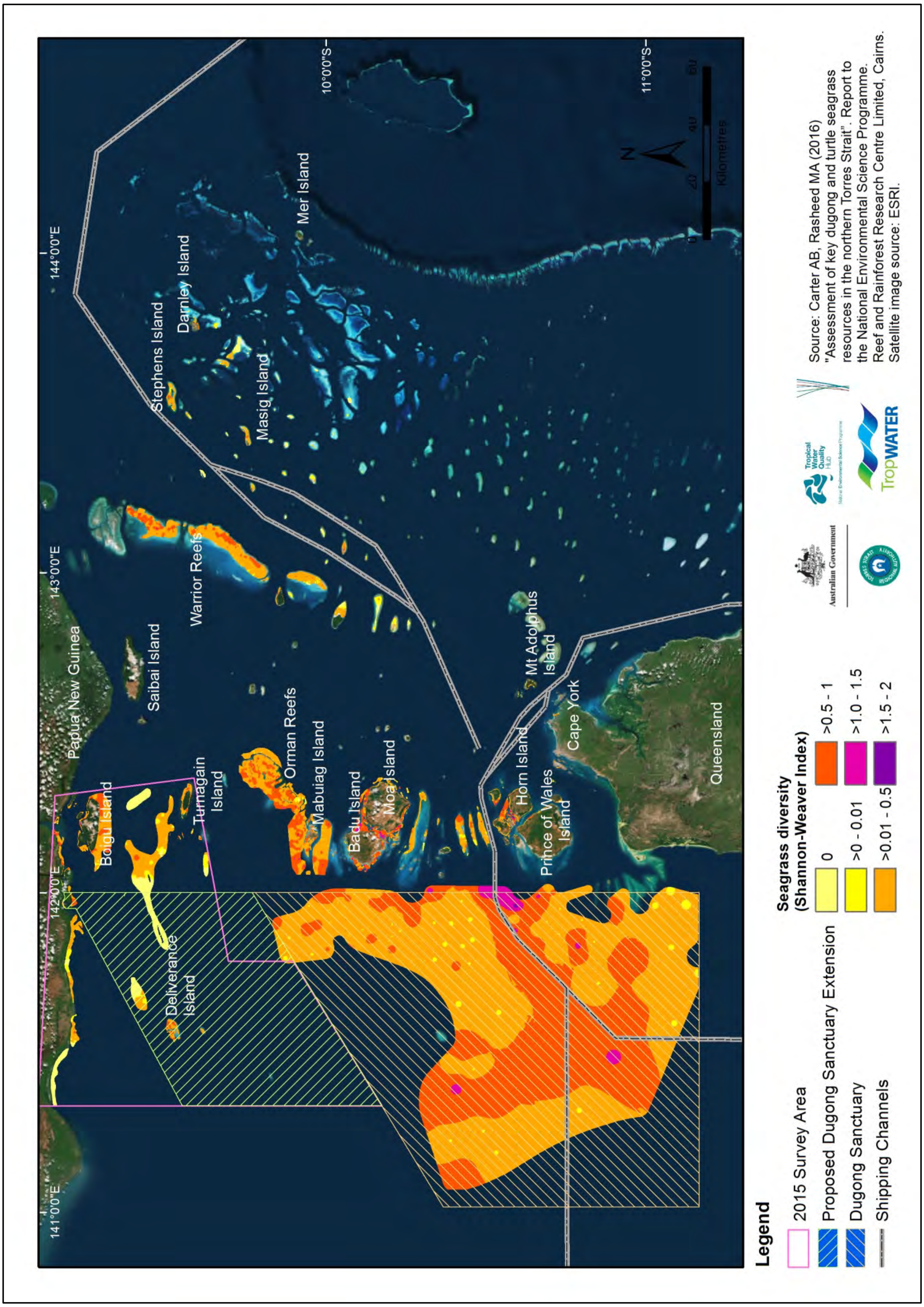
The majority of seagrass area in Torres Strait occurs in subtidal meadows estimated to cover between 13 425 km^2 (Coles et al., 2003) and 17 500 km^2 (Poiner et al., 1996). Torres Strait dugong have a large home range (mean home range = 530 km2; Cleguer et al., 2016) and preferentially target subtidal meadows, spending most of their time in the >5m depth zone (Cleguer et al., 2016; Gredzens et al., 2014). The presence of DFTs at intertidal meadows in this study indicates these meadows also provide an important food source for dugong despite limited, tide-dependent access to these meadows. Seagrass meadows in the intertidal zone cover a smaller area and are limited to reef tops and flats along the mainland coast and around islands (Figure 1; Carter et al., 2014c). Extensive intertidal seagrass and macroalgae provide ideal foraging grounds for green turtles, which often use the 0-5m zone in Torres Strait (Cleguer et al., 2016; Gredzens et al., 2014) with high site fidelity and small home ranges compared with dugong (mean home range = 193 km2; Cleguer et al., 2016).

Torres Strait has a high diversity of seagrass species (Figure 20; Carter et al., 2014c). Species diversity around Boigu, Turnagain and Deliverance Islands was similar to that found at the nearby Orman Reefs and Mabuiag Island (Figure 20). Species rich seagrass assemblages in the Indo-Pacific Ocean may be a product of past grazing activities of large herbivores, particularly dugong (Heck et al., 2006). When feeding, dugong often remove the entire plant including roots and rhizomes; this prevents the development of a single-species dominated climax community (Aragones et al., 2006). The vast area of highly diverse seagrasses in Torres Strait provides a consistent source of primary production supporting the region's marine ecosystems (Rasheed et al., 2008; Taylor et al., 2013).



Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI.

Figure 19: Seagrass biomass (grams dry weight m^{-2}) across Torres Strait meadows, 2002-2015.



Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI.

Figure 20: Seagrass diversity (Shannon-Weaver Index) across Torres Strait seagrass meadows, 2002-2015.

4.3 Seagrass management

Any change in the distribution, biomass and community structure of Torres Strait seagrasses may have implications for dugong and turtle populations. Another seagrass dieback event in Torres Strait will likely cause increases in local dugong and turtle mortality rates. A similar pattern occurred along Queensland’s east coast following large-scale seagrass loss associated with flooding in late 2010 and early 2011. Dugong and turtle deaths increased 215% and 176% respectively (compared to 2010), primarily as a result of largescale starvation (DERM, 2011).

Management of seagrass resources should focus on reducing anthropogenic impacts and risks to ensure resilient local seagrass populations and, by proxy, resilient dugong and turtle populations. Effective management and planning requires current, spatially relevant seagrass information at the scale of individual communities’ sea country to inform community-based Turtle and Dugong Management Plans. Understanding seagrass resources at this scale is important because seagrass biomass, distribution, and species composition varies significantly at small spatial scales. Potential management responses (e.g. temporal or spatial closures, dugong and sea turtle catch reductions) triggered by seagrass or dugong/green turtle declines will be most successful if implemented at the community level. This is because (1) seagrass varies significantly at small spatial-scales, (2) the spatial extent of hunting activity from island communities is limited (Marsh et al., 2015), and (3) some dugongs and green turtles have relatively sedentary behaviour and green turtles have small home ranges (Cleguer et al., 2016). Seagrass information collected in 2015 intersected four community-based turtle and dugong management areas - Badu, Malu Kiai, Mabuiag and Saibai-Dauan (Figure 21). Successful management of northern Torres Strait seagrass will require cooperation with adjacent Papua New Guinea coastal communities. This report provides important habitat information for community-based Turtle and Dugong Management Plans, and provides a baseline against which future change in seagrass can be assessed in this region.

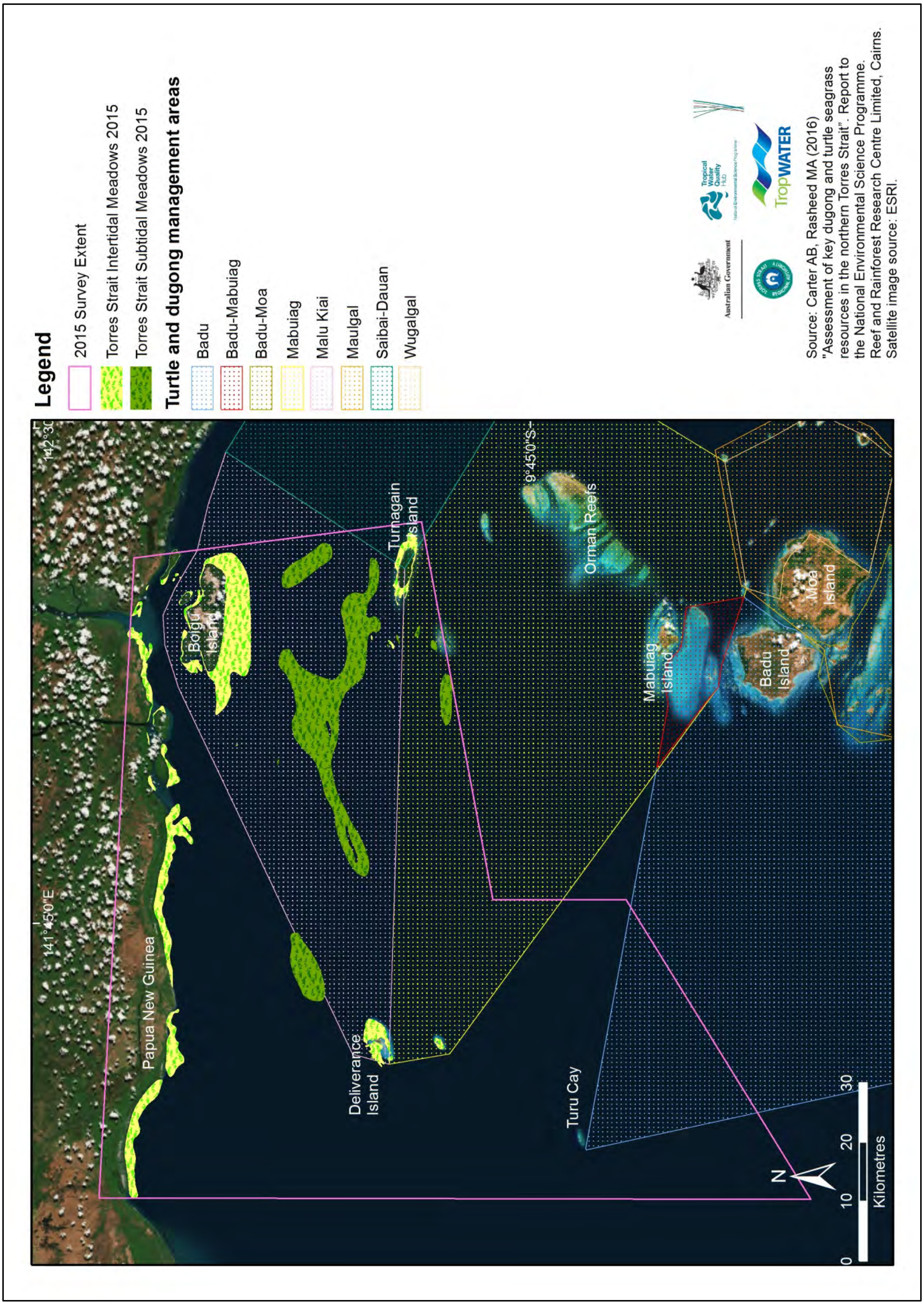


Figure 21: Turtle and dugong management areas in relation to 2015 survey area and seagrass meadows.

5. RECOMMENDATIONS

Future seagrass research in Torres Strait should focus on building baseline knowledge of seagrass habitat in areas identified as lacking data (see review by Carter et al., 2014c). Priority should be given to areas that overlap high dugong and turtle densities, and improved understanding of temporal (seasonal, annual) fluctuations in seagrass habitats at a range of spatial scales (island/reef, intertidal/subtidal, proximity to riverine/terrestrial inputs, etc). Continued collaboration with TSRA LSMU Rangers should be prioritised. Specific research should focus on:

1. Collection of baseline seagrass information in the very high dugong and turtle density area between Orman Reefs, Gabba and Turnagain Islands, and the eastern edge of the Dugong Sanctuary identified by Marsh et al. (2015) and Hagihara et al. (2016). Subtidal seagrass information in this region is lacking and, for Orman Reefs, is out of date (2004 survey). Information on the biomass, distribution, and species composition of seagrass can inform future community based Turtle and Dugong Management Plans. Subtidal sampling would occur in collaboration with TSRA LSMU Rangers using sampling methods already successfully used by Boigu and Saibai Island Rangers in this study.
2. Establish a long-term seagrass monitoring program at locations where seagrass meadows support high-very high dugong and turtle densities. This could include annual intertidal surveys at Deliverance Island, Boigu Island, and/or the Orman Reefs. Candidate subtidal sites include waters between Boigu and Turnagain Island and/or southern Orman Reefs. Monitoring would be conducted in collaboration with TSRA LSMU Rangers using sampling methods already successfully adopted by Badu Island Rangers in the Dugong Sanctuary (Carter et al., 2015).

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APPENDIX 1: SEAGRASS MEADOW IDENTIFICATION NUMBERS, NORTH-WEST TORRES STRAIT

Source: Carter AB, Rasheed MA (2016) "Assessment of key dugong and turtle seagrass resources in the northern Torres Strait". Report to the National Environmental Science Programme. Reef and Rainforest Research Centre Limited, Cairns. Satellite image source: ESRI.

APPENDIX 2: SEAGRASS MEADOW DETAILS, NORTH-WEST TORRES STRAIT

Meadow ID	**Location**	**Depth range (dbMSL)**	**Biomass ± s.e. (gdw m^{-2})**	**No. sites**	**Ha ± R**	**Species present**	**Meadow community type**
1	Interidal	0	0.31	1	17 ± 1	*H. ovalis, H. uninervis* (thin)	Light *H. uninervis* (thin) with *H. ovalis*
2	Interidal	0	0.85	1	6 ± 0.5	*H. ovalis*, *H. uninervis* (thin)	Light *H. ovalis* with *H. uninervis* (thin)
3	Interidal	0	1.17	1	27 ± 1	*H. ovalis*, H. uninervis (thin)	Moderate *H. uninervis* (thin) with *H. ovalis*
4	Intertidal-shallow subtidal	0-2.4	10.72 ± 1.89	10	163 ± 27	*C. rotundata*, *C. serrulata*, *H. ovalis*, *H. uninervis* (thin and wide), *S. isoetifolium*, *T. hemprichii*	Dense *H. uninervis* (thin) with mixed species
5	Intertidal-shallow subtidal	0-2.9	5.59 ± 1.08	8	87 ± 13	*H. ovalis*, *H. uninervis* (thin and wide), *S. isoetifolium*, *T. hemprichii*	Dense *H. uninervis* (thin) with mixed species
6	Interidal	0	10.22	1	21.8 ± 1.1	*H. uninervis* (thin), *T. hemprichii*	Dense *H. uninervis* (thin)/ T. hemprichii
7	Intertidal-shallow subtidal	0-1.6	2.78 ± 2.16	7	229 ± 5	*H. ovalis*, *H. uninervis* (thin and wide)	Moderate *H. uninervis* (thin)
8	Intertidal-shallow subtidal	0-3.8	11.70 ± 1.53	16	1542 ± 20	*C. rotundata*, *C. serrulata*, *E. acoroides*, *H. ovalis*, *H. spinulosa*, *H. uninervis* (thin and wide), *S. isoetifolium*, *T. hemprichii*	Dense *H. uninervis* (thin) with mixed species
9	Interidal	0	7.18 ± 3.12	4	130 ± 5	*H. ovalis*, *H. uninervis* (thin)	Dense *H. uninervis* (thin) with *H. ovalis*
10	Interidal	0	9.69	1	41 ± 2	*H. ovalis*	Dense H. ovalis
11	Interidal	0	6.16 ± 1.56	2	140 ± 3	*E. acoroides*, *H. ovalis*, H.	Dense *H. uninervis* (thin) with

						uninervis (thin)	mixed species
12	Interidal	0	11.13 ± 2.20	7	691 ± 9	*C. rotundata*, *C. serrulata*, *H. ovalis*, *H. spinulosa*, *H. uninervis* (thin and wide), *S. isoetifolium*, *T. hemprichii*	Dense *H. uninervis* (thin) with mixed species
13	Subtidal	3.6	3.88	1	24 ± 13	*C. serrulata*	Light *C. serrulata*
14	Interidal	0	2.10	1	6 ± 1	*H. ovalis*, *H. uninervis* (thin)	Light *H. ovalis* with *H. uninervis* (thin)
15	Intertidal-shallow subtidal	0-2.1	1.35 ± 0.41	15	187 ± 36	*C. serrulata*, *H. ovalis*, *H. uninervis* (thin and wide), *T. hemprichii*	Light *H. uninervis* (wide) with mixed species
16	Intertidal-shallow subtidal	0-8.23	8.93 ± 0.96	29	614 ± 74	*C. rotundata*, *C. serrulata*, *H. ovalis*, *H. spinulosa*, *H. uninervis* (thin and wide), *S. isoetifolium*, *T. hemprichii*	Moderate *T. hemprichii* with mixed species
17	Interidal	0	11.67 ± 1.04	5	61 ± 17	*H. ovalis*, *H. uninervis* (wide), *T. hemprichii*	Moderate *T. hemprichii* with mixed species
18	Intertidal-shallow subtidal	0-5.4	8.02 ± 0.73	40	1230 ± 194	*C. rotundata*, *C. serrulata*, *H. ovalis, H. spinulosa*, *H. uninervis* (thin and wide), *S. isoetifolium*, *T. hemprichii*	Moderate *T. hemprichii* with mixed species
19	Interidal	0	2.23 ± 0.36	17	3136 ± 22	*H. uninervis* (thin and wide)	Moderate *H. uninervis* (thin) with *H. uninervis* (wide)
20	Interidal	0	3.44 ± 0.76	12	1791 ± 14	*H. ovalis*, *H. uninervis* (thin and wide), *T. hemprichii*	Moderate *H. uninervis* (thin) with mixed species
21	Interidal	0	3.07 ± 0.79	21	4460 ± 39	*H. ovalis*, *H. uninervis* (thin and wide), *T. hemprichii*	Moderate *H. uninervis* (thin) with mixed species
22	Intertidal-shallow subtidal	0-3.1	3.94 ± 0.93	15	653 ± 46	*C. rotundata*, *C. serrulata*, *H. ovalis*, *H. spinulosa*, *H. uninervis* (thin and wide)	Moderate *H. uninervis* (thin) with mixed species
23	Intertidal-shallow	0-3.7	8.12 ± 1.09	62	11385 ±	*C. rotundata*, *C. serrulata*, *E. acoroides*, *H. ovalis*, *H. uninervis*	Moderate *C. serrulata* with

	subtidal				1031	(thin and wide), *S. isoetifolium*, *T. hemprichii*	mixed species
24	Subtidal	2.3	7.84	1	12 ± 3	*C. serrulata*, *H. uninervis* (wide)	Moderate *C. serrulata*/*H. uninervis* (wide)
25	Intertidal-shallow subtidal	0-6.7	6.05 ± 1.56	3	63 ± 8	*C. serrulata*, *H. ovalis*, *H. uninervis* (wide), *T. hemprichii*	Moderate *C. serrulata* with mixed species
26	Subtidal	4.7	6.01	1	45 ± 8	*C. serrulata*, *H. uninervis* (wide)	Moderate *C. serrulata*/*H. uninervis* (wide)
27	Subtidal	6.4-7.4	0.06 ± 0.00	2	1420 ± 998	*H. decipiens*, *H. uninervis* (thin)	Light *H. decipiens*/*H. uninervis* (thin)
28	Subtidal	4.4	3.22	1	133 ± 47	*H. spinulosa*, *H. uninervis* (wide)	Light *H. spinulosa*/*H. uninervis* (wide)
29	Subtidal	4.5	0.72	1	97 ± 48	*H. uninervis* (thin)	Light *H. uninervis* (thin)
30	Subtidal	5.5-8.6	0.08 ± 0.00	2	4066 ± 3096	*H. decipiens*	Light *H. decipiens*
31	Subtidal	4.7-9.5	1.91 ± 0.39	19	23445 ± 14490	*C. serrulata*, *H. decipiens*, *H. ovalis*, *H. spinulosa*, *H. uninervis* (thin and wide)	Light *C. serrulata* with mixed species
32	Interidal	0	4.46	1	17 ± 4	*C. rotundata*	Light *C. rotundata*
33	Subtidal	4.7-6.4	0.42 ± 0.20	7	2911 ± 1278	*C. serrulata*	Light *C. serrulata*
34	Intertidal-shallow subtidal	0-8.0	9.08 ± 0.88	57	1416 ± 241	*C. rotundata*. *C. serrulata*, *E. acoroides*, *H. decipiens*, *H. ovalis*, *H. uninervis* (thin and wide), *S. isoetifolium*, *T. hemprichii*	Moderate *T. hemprichii* with mixed species

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