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DATA ARTICLE

Seagrass spatial data synthesis from north-east Australia, Torres Strait and Gulf of Carpentaria, 1983 to 2022

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Scientific Significance Statement

Seagrass meadows are a key habitat of northern Australian tropical waters. They are nursery grounds for fish and crustaceans and contribute to commercial fisheries productivity. They are food for populations of dugong and green turtles, species that are deeply significant for coastal Aboriginal and Torres Strait Islander people's culture and heritage. Spatial data on seagrass have been collected across the Torres Strait and Gulf of Carpentaria since the 1980s but data have often been poorly curated and in some instances lost. Data in most cases have not been publicly available. In recognizing this and the urgent need to improve our understanding of habitats in a rapidly changing global climate we compiled and validated historical spatial data to create a publicly available database. This is a region of the world identified as having relatively low anthropogenic impacts but, like all tropical coastal regions, it is exposed to the effects of climate change. We provide a validated baseline for the seagrass, one of the region's most important marine habitats.

Abstract

The Gulf of Carpentaria and Torres Strait in north-eastern Australia support globally significant seagrass ecosystems that underpin fishing and cultural heritage of the region. Reliable data on seagrass distribution are critical to understanding how these ecosystems are changing, while managing for resilience. Spatial data on seagrass have been collected since the early 1980s, but the early data were poorly curated. Some was not publicly available, and some already lost. We validated and synthesized historical seagrass spatial data to create a publicly available database. We include a site layer of 48,612 geolocated data points including information on seagrass

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presence/absence, sediment, collection date, and data custodian. We include a polygon layer with 641 individual seagrass meadows. Thirteen seagrass species are identified in depths ranging from intertidal to 38 m below mean sea level. Our synthesis includes scientific survey data from 1983 to 2022 and provides an important evidence base for marine resource management.

Background and Motivation

Seagrasses are one of the key marine ecosystems in northern Australia, with extensive areas of seagrass surveyed and mapped in the Torres Strait and Gulf of Carpentaria (Poiner et al. 1989; Green and Short 2003; Roelofs et al. 2005; Carter et al. 2014, 2021*a*; Huisman et al. 2021; Coles et al. 2022). The ecosystem goods and benefits these seagrass communities provide include substrate stabilization and water quality improvements, and baffling wave and tidal energy, which reduces suspended particulate matter and improves water clarity (Costanza et al. 2014; Nordlund et al. 2016; Lamb et al. 2017; Bainbridge et al. 2018). Seagrass meadows play a critical role as food and shelter for fish and crustaceans, which support the livelihoods and well-being of coastal peoples of the region (Hayes et al. 2020; Jänes et al. 2020*a*, 2020*b*). They are also important carbon sinks, sequestering and capturing carbon in the sediments, helping to offset the impacts of carbon emissions (Macreadie et al. 2021). They provide food for dugongs (*Dugong dugon*) and green sea turtles (*Chelonia mydas*) (Marsh et al. 2011; Kelkar et al. 2013; Tol et al. 2016; Scott et al. 2018, 2020). These species have significant spiritual, economic and ceremonial importance for the Traditional Owners and custodians of Sea Country in the Gulf of Carpentaria and Torres Strait (Bradley 1997; Butler et al. 2012).

A strong body of evidence has established that globally, there has been a net decline in seagrass meadows in recent decades, particularly near-shore meadows influenced by coastal processes and human impact (Waycott et al. 2009; Dunic et al. 2021; Turschwell et al. 2021). Climate change-induced increases in water temperature and frequency and severity of tropical storms have the potential to exacerbate this decline (Strydom et al. 2020; Serrano et al. 2021; Carter et al. 2022*b*). Access to reliable data at a range of spatial and temporal scales are critical to understand the challenges marine ecosystems such as seagrass face around the world. This data can be used for assessing the present condition of ecosystems and for understanding long-term trends. It can be used to define the desired state of the diversity of habitats (Collier et al. 2020; Carter et al. 2022*b*), establish ecologically relevant targets to maintain resilience (Brodie et al. 2017; Lambert et al. 2021) and to implement effective management frameworks (Levin and Möllmann 2015; Hallett et al. 2016; O'Brien et al. 2017; York et al. 2017).

The Torres Strait and Gulf of Carpentaria are remote from Australia's major population centers. The Gulf of Carpentaria is an extensive (~300,000 km^2) and low energy shallow semi-enclosed sea. It is characterized by complex, mangrove-lined creeks and estuaries and extensive seagrass meadows that grow along the coast (Poiner et al. 1987; Roelofs et al. 2005; Wightman 2006; Duke et al. 2020, 2021, 2022) (Fig. 1). Tides can range up to a maximum of nearly 4 m but tidal regimes vary throughout the Gulf of Carpentaria and can be influenced by strong trade winds in June and July. The Gulf includes three major island groups, the Wellesley Group in the south-east, Sir Edward Pellew Group in the south-west, and the Anindilyakwa archipelago off the south west coast. Seagrass grows around all these islands, which are known dugong habitat (Marsh et al. 2008; Groom et al. 2017; Kyne et al. 2018; Griffiths et al. 2020; Udyawer et al. 2021). The three island groups are captured within the southern Gulf of Carpentaria's Important Marine Mammal Area, a region recognized by the International Union for Conservation of Nature for having significant populations of marine mammals (https://www.marinemammalhabitat.org/portfolio-item/southern-gulf-carpentaria/). There are several major river systems that flow into the Gulf of Carpentaria with most of the river flow restricted to the seasonal monsoon.

The Torres Strait is a shallow water body with a complex hydrodynamic environment between north-east Australia's Cape York Peninsula and Papua New Guinea (Saint-Cast 2008; Wolanski et al. 2013; Fig. 1). The area covers more than 48,000 km^2 and is prone to high velocity tidal currents, with many shoals, reefs and islands. Like the Gulf of Carpentaria, the tidal range can be as high as 4–5 m (mean spring tide range of 3.6 m) in eastern Torres Strait, but tides are highly variable and hard to predict due to the complexity of the reef topography (Brander et al. 2004). There is little influence from river input to Torres Strait from the Australian coast, but the northern region is exposed to limited outflow from Papua New Guinea rivers (Waterhouse et al. 2021). Mangroves are widespread but notably abundant in the northern areas like the large mangrove islands of Boigu and Saibai (Duke et al. 2015). Seagrass meadows are common throughout Torres Strait, but are most abundant in nearshore waters, on and surrounding reefs and in subtidal waters in the western region (Haywood et al. 2008; Carter et al. 2014, 2022*b*; Carter and Rasheed 2016).

The remoteness of north-eastern Australia means data collection have been sporadic and costly in both time and dollar value. It is important that the value of existing information is exploited to its full extent. Torres Strait and Gulf of Carpentaria seagrass research extends back to the 1970s (Moriarty 1977; Bridges et al. 1982), but survey coverage was limited in the early years. Data collection in a consistent manner and with a spatial/mapping focus commenced in the early

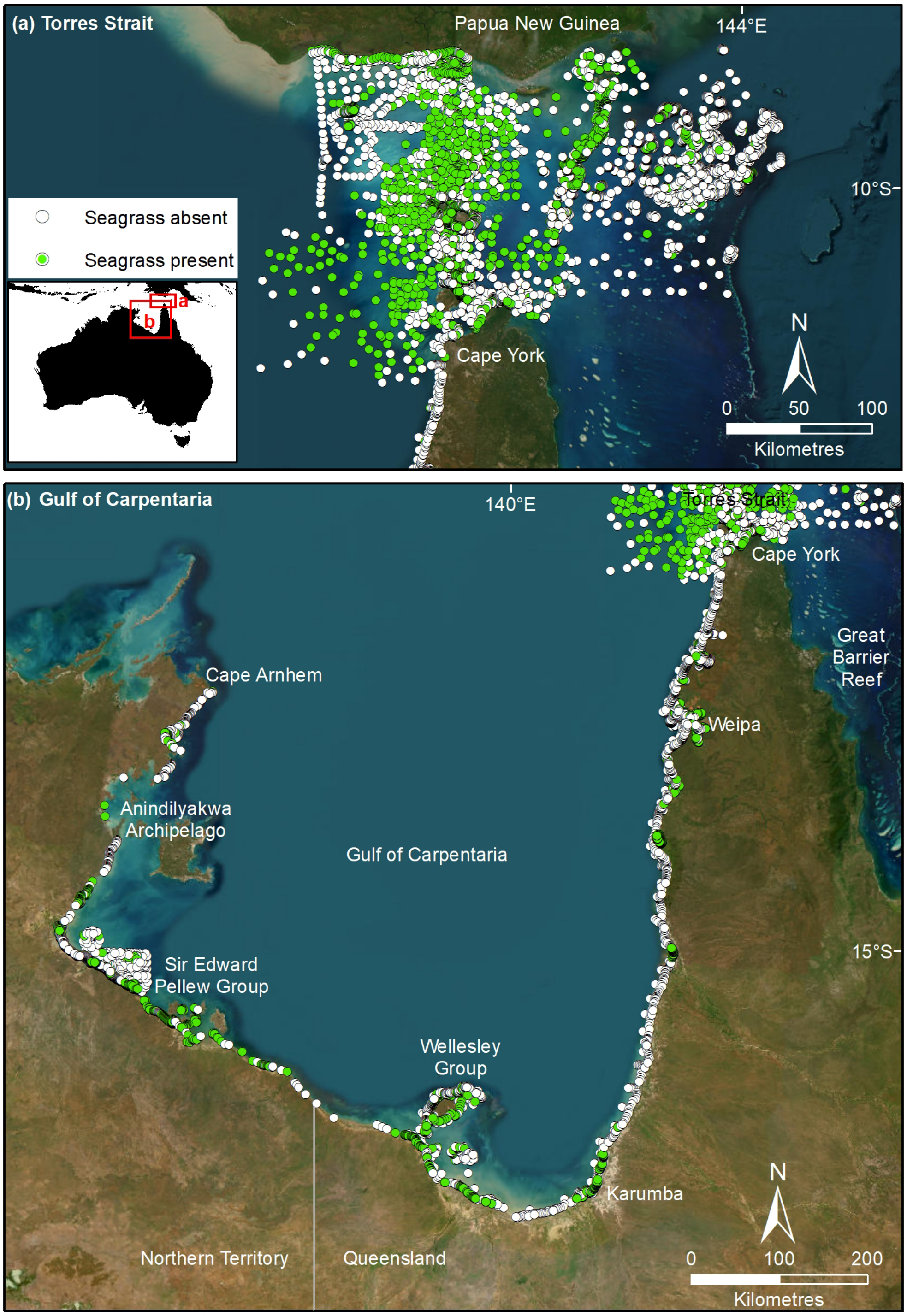

Fig. 1. Seagrass presence and absence at individual survey sites across Torres Strait and the Gulf of Carpentaria, 1983–2022. Map with all survey locations listed in Table 1 in Data S1. Satellite image courtesy: ESRI.

1980s in the Gulf of Carpentaria (Coles and Lee Long 1985; Poiner et al. 1987) and early 2000s in Torres Strait (Scott and Rasheed 2021). Mapping and spatially explicit monitoring projects since then range from surveys quantifying seabed benthic cover across the entire Torres Strait and Gulf of Carpentaria coast, to more targeted seagrass assessments at smaller spatial scales (Table 1). There is a risk that older data are in danger of being lost if not secured, compiled, validated, and made available in a contemporary readily available format to potential data users.

Table 1. Spatial data used in seagrass data compilation for sites and meadows, 1983–2022.

Survey purpose/data location	Years	Site (S) Meadow (M)	Reference
Region-scale baseline surveys			
GOC intertidal	2004	S, M	Roelofs et al. (2005)
GOC	1986	S, M	Coles et al. (2004, 2022)
Torres Strait inter-reefal benthic assemblages	2005	S	Haywood et al. (2008)
Torres Strait seagrass monitoring			
Dungeness Reef intertidal	2016–2021	S, M	Carter et al. (2021*e*)
Dungeness Reef subtidal	2017–2022	S	Carter et al. (2021*e*)
Orman Reef intertidal	2017–2021	S, M	Carter et al. (2021*e*)
Orman Reef subtidal	2017–2022	S	Carter et al. (2021*e*)
Masig Island intertidal	2020–2021	S, M	Carter et al. (2021*e*)
Dugong Sanctuary subtidal	2011–2022	S	Carter et al. (2021*e*)
Poruma Island PM1	2016–2022	S	Carter et al. (2021*e*)
Poruma Island PM2	2016–2022	S	Carter et al. (2021*e*)
Iama Island IM1	2010–2022	S	Carter et al. (2021*e*)
Iama Island IM2	2010–2022	S	Carter et al. (2021*e*)
Mer Island MR1	2009–2022	S	Carter et al. (2021*e*)
Mer Island MR2	2009–2022	S	Carter et al. (2021*e*)
Mua Island MU1	2011–2022	S	Carter et al. (2021*e*)
Mua Island MU3	2011–2022	S	Carter et al. (2021*e*)
Mabuyag Island MG1	2009–2021	S	Carter et al. (2021*e*)
Mabuyag Island MG2	2009–2021	S	Carter et al. (2021*e*)
Badu Island BD1	2010–2022	S	Carter et al. (2021*e*)
Badu Island BD2	2010–2022	S	Carter et al. (2021*e*)
Targeted seagrass mapping surveys			
Dungeness Reef subtidal, Torres Strait	2017	S, M	Carter et al. (2017)
North-west Torres Strait and PNG	2015–2016	S, M	Carter and Rasheed (2016)
Eastern Cluster, Torres Strait	2020	S, M	Carter et al. (2021*c*)
Northern Dugong Sanctuary and Orman Reefs, Torres Strait	2020	S, M	Carter et al. (2021*b*)
Dugong Sanctuary, Torres Strait	2010	S, M	Taylor and Rasheed (2010*b*)
Limmen Bight Marine Park and Limmen Marine Park	2021	S, M	Collier et al. (in prep)
Ugar Island and surrounding reefs, Torres Strait	2022	S, M	Reason et al. (in prep)
Love River, GOC	1999	S, M	Rasheed (2000)
Wellesley Group, GOC	1983–1984, 2007	S, M	Coles and Lee Long (1985); Taylor et al. (2007)
Port Musgrave, GOC	2009–2010	S, M	Chartrand and Rasheed (2010)
Boyd Bay, GOC	2007–2008	S, M	Rasheed and Unsworth (2008)
Skardon River, GOC	2002, 2003, 2010	S, M	Roelofs et al. 2002, 2004; Thomas and Chartrand (2010)
Kirke River, GOC	1999, 2001	S, M	Rasheed (2000); Sheppard et al. (2001)
Badu Island, Torres Strait	2010	S, M	Taylor and Rasheed (2010*a*)
Mua/Moa Island, Torres Strait	2011	S, M	Taylor (2011)

(Continues)

Table 1. Continued

Survey purpose/data location	Years	Site (S) Meadow (M)	Reference
Mabuyag Island, Torres Strait	2009	S, M	Chartrand et al. (2009)
Orman Reefs, Torres Strait	2004	S, M	Rasheed et al. 2006*a*, 2008
Prince of Wales and Adolphus Shipping Channels, Torres Strait	2002–2006	S, M	Rasheed et al. (2006*b*)
Poruma to Ugar Islands, Torres Strait	2008	S, M	Taylor et al. (2008)
Kirkcaldie Reef to Bramble Cay, Torres Strait	2009	S, M	Taylor et al. (2009)
Moa Island to Mabuiag Island, Torres Strait	2010	S, M	Taylor et al. (2010)
No. 2 Reef to Mabuiag Reef, Torres Strait	2011	S, M	Taylor et al. (2011)
Woiz Reef to Kaliko Reef, Torres Strait	2012	S, M	Taylor and McKenna (2012)
Seo Reef to Kai-Wareg Reef, Torres Strait	2013	S, M	Carter et al. (2013)
Queensland ports seagrass monitoring			
Karumba, GOC	1994–2021	S, M	Scott et al. (2022)
Weipa, GOC	2000–2021	S, M	McKenna et al. (2021)
Thursday Island, Torres Strait	2002–2021	S, M	Scott and Rasheed (2021)
Other surveys (incidental seagrass data)			
Torres Strait sea cucumber	2000–2010	S	Murphy et al. (2010); Skewes et al. (2010)
Torres Strait rock lobster	2000–2014	S	Plaganyi-Lloyd et al. (2016)
Gulf of Carpentaria mangrove	2017	S	Duke et al. (2020)

GOC, Gulf of Carpentaria.

In this data article, we compiled several hundred seagrass data sets into a standardized form with site- and meadow-specific spatial and temporal information. This process was a collaboration among diverse data custodians to assemble a publicly available database of all the seagrass information collected, from the early 1980s to the present that we could validate and be assured is reliably accurate. Data, metadata, and an interactive website are available via eAtlas at https://doi.org/10.26274/2CR2-JK51 (Carter et al. 2022*a*). This provides a valuable resource for management agencies, rangers, Traditional Owners and custodians, ports, industry, and researchers with a long-term spatial resource describing seagrass populations over four decades against which to evaluate environmental stress and to assess change.

Data description

The spatial database include compiled and standardized data from field surveys conducted from 1983 to 2022. It includes (1) a site layer with 48,612 geolocated data points with features such as seagrass species presence/absence, depth, dominant sediment type, collection date, and data custodian; and (2) a meadow layer that includes 641 individual seagrass meadows with features including meadow persistence (sensu Kilminster et al. 2015), meadow depth (intertidal/subtidal), meadow density based on mean biomass and/or mean percent cover, meadow area, meadow area range (based on the composite of seagrass meadows across different survey dates at the same location), dominant seagrass species, seagrass species present, survey dates, and survey method. We include records collected under commercial contracts being made available here for the first time, and previously unpublished data. We have summarized data over many years and in locations where multiple surveys or monitoring were conducted. Each data set has an associated custodian listed in the spatial layers and original reports listed in Table 1 who should be contacted for additional details.

Data were originally collected for five main purposes (Table 1): (1) region-scale mapping; (2) Torres Strait seagrass monitoring including small-scale transect ($3 \times$ set transects within a 50×50 m area) and block-based monitoring (random camera drops within $3 \times \sim350$ ha survey blocks) by rangers; (3) targeted mapping projects such as within marine parks and other protected areas; (4) seagrass monitoring for Queensland ports (Karumba, Weipa, Thursday Island) that were generally conducted annually; and (5) incidental seagrass data collected during other survey activities.

Following the approach taken by Carter et al. (2021*a*), mapping data for 1980s records were transcribed from original logged and mapped data based on coastal topography, dead reckoning fixes and RADAR estimations. More recent data (1990s onwards) is GPS located. All spatial data were converted to shapefiles with the same coordinate system (GDA 1994 Geoscience Australia Lambert), then compiled into a single point shapefile and a single polygon shapefile (seagrass meadows) using ArcMap (ArcGIS version 10.8 Redlands, CA: Environmental Systems Research Institute, ESRI). Some early spatial data were offset by several hundred meters and where this occurred data were repositioned to match the current coastline projection. The satellite base map used throughout this report is a courtesy from ESRI 2022.

Methods

Survey methods

The data were collected using a variety of survey methods to describe and monitor seagrass sites and meadows (*see* Carter et al. 2021*a* for description of methods). Survey methods and technology have evolved over the decades included in this data synthesis, and we refer data users to the original reports listed in Table 1 for details on specific data sets. For intertidal sites/meadows, these include walking, observations from helicopters in low hover and observations from hovercraft when intertidal banks were exposed. For subtidal sites/meadows, methods included free diving, SCUBA diving, video transects from towed cameras attached to a sled with/without a sled net, video drops with filmed fixed-size quadrats, trawl and net samples and van Veen grab samples. These methods were selected and tailored by the data custodians to the location, habitat surveyed, and technology available. Important site and method descriptions and contextual information is contained in the original reports and publications for each data set provided in Table 1. For monitoring data, only the most recent report is referenced.

Seagrass site layer

This includes information on data collected at assessment sites, and include:

- Temporal survey details—survey month and year.
- Spatial position—latitude/longitude.
- Survey name.
- Depth for each subtidal site is meters below mean sea level (MSL). Depth for each site was extracted from the Australian Bathymetry and Topography Grid, June 2009 (Whiteway 2009). This approach was taken due to inconsistencies in depth recordings among data sets, for example, converted to depth below MSL, direct readings from depth sounder with no conversion, or no depth recorded. Depth for intertidal sites was recorded as 0 m MSL, with an intertidal site defined as one surveyed by helicopter, walking, or hovercraft when banks were exposed during low tide.
- Seagrass information including presence/absence of seagrass (Fig. 1), number of species recorded at a site, and whether individual species were present/absent at a site (Fig. 2; Data S1). Thirteen species are present in the data: *Cymodocea serrulata*, *Cymodocea rotundata*, *Enhalus acoroides*, *Halophila capricorni*, *Halophila decipiens*, *Halophila ovalis*, *Halophila spinulosa*, *Halophila tricostata*, *Halodule uninervis*, *Syringodium isoetifolium*, *Thalassodendron ciliatum*, *Thalassia hemprichii*, and *Zostera muelleri* subsp. *capricorni* (abbreviated to *Z. capricorni* throughout). Seagrass taxonomy has changed through time and species names have been updated to meet recent taxonomic changes and to ensure consistency in species names in the data. To address these issues, we amalgamated some species into complexes: *Halophila ovata*, *Halophila minor*, and *Halophila ovalis* are included as *Halophila ovalis*. *Halodule pinifolia* is grouped with *Halodule uninervis*.
- Dominant sediment type—Sediment type in the original data sets were based on grain size analysis or deck descriptions. For consistency, in this compilation we include only the most dominant sediment type (mud, sand, shell, rock, and rubble), removed descriptors such as “very fine” etc., and replaced redundant terms, for example, “mud” and “silt” are termed “mud.”
- Survey methods—In this compilation, we have updated and standardized the terms used to describe survey methods from the original reports.
- Data custodians.

Seagrass meadow layer

The seagrass meadow layer is a composite of all the spatial polygon data we could access where meadow boundaries were mapped as part of the survey (Data S1). All spatial layers were compiled into a single spatial layer using the Arc Toolbox “merge” function in ArcMap. Where the same meadow was surveyed multiple times as part of a monitoring program (e.g., Data S1), the overlapping polygons were compiled into a single polygon using the ArcMap “merge” function. Seagrass meadows are frequently determined by seagrass presence/absence and/or geographic features (e.g., reef edges, islands, intertidal extent, and infrastructure), but may also be limited by management boundaries (e.g., Torres Strait Dugong Sanctuary) and survey limits (e.g., Torres Strait—Northern Dugong Sanctuary and Orman Reefs (Table 1)). In the latter, meadows often have straight edges. Because of this, seagrass meadows should be interpreted in conjunction with the seagrass site data. Meadow data include:

- Temporal survey details—survey month and year, or a list of survey dates for meadows repeatedly sampled.
- Survey methods.
- Meadow persistence—classified into three categories (unknown, enduring, transitory). *Unknown*—unknown persistence as the meadow was surveyed less than five times. *Enduring*—seagrass is present in the meadow in ≥90% of the surveys. This threshold was selected because it allows for an average of one significant environmental impact to seagrass meadows to occur every 10 years (e.g., tropical cyclone or significant flood), thereby allowing for decadal-scale cycles of seagrass loss and recovery typical in tropical seagrass

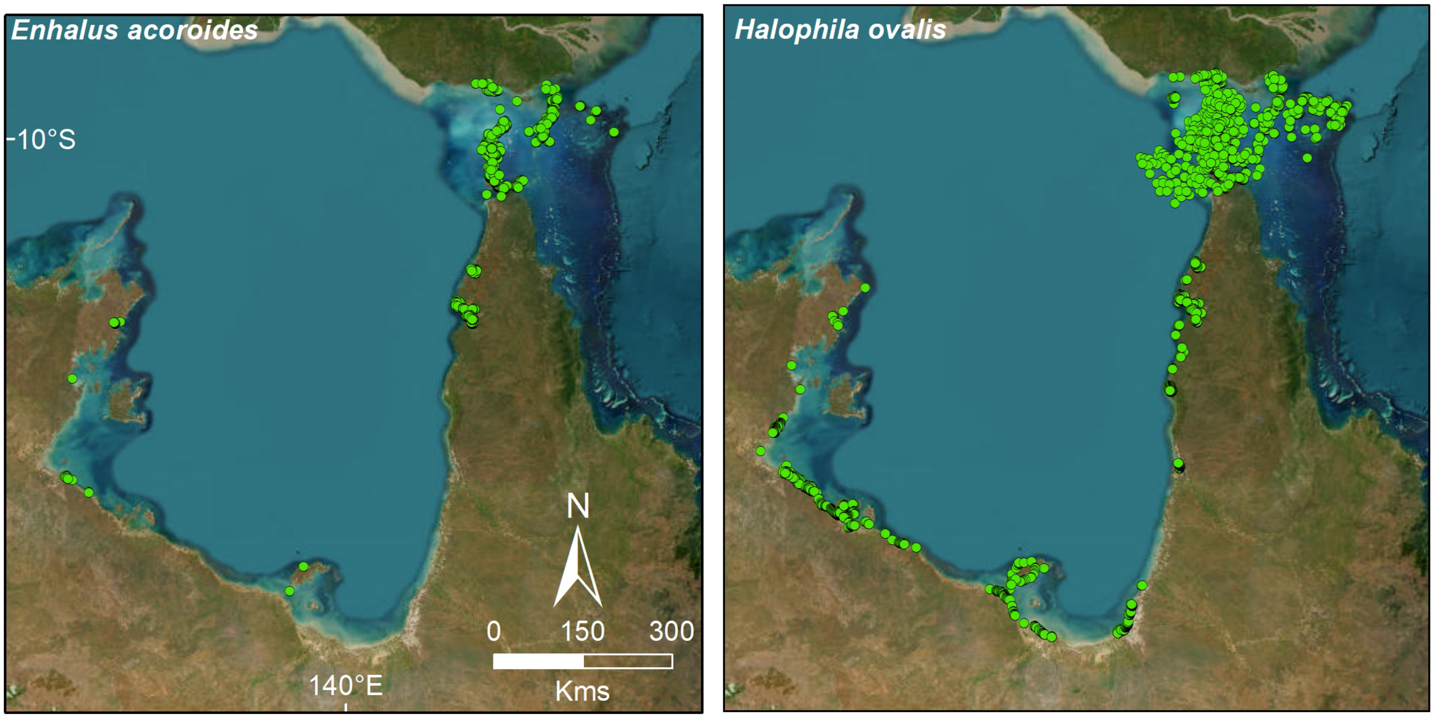

Fig. 2. Distribution of *Enhalus acoroides* and *Halophila ovalis* (green dots) throughout Torres Strait and the Gulf of Carpentaria in the site data, 1983–2022. Satellite image courtesy: ESRI. Maps of all 13 species distributions in Data S2 and S3.

systems that occur even in enduring meadows (Carter et al. 2022*b*). *Transitory*—seagrass is present in the meadow in $<90\%$ of the surveys.

- Meadow depth—classified into three categories. *Intertidal*—meadow was mapped on an exposed bank during low tide, for example, Karumba monitoring meadow. *Subtidal*—meadow remains completely submerged during spring low tides, for example, Dugong Sanctuary meadow. *Intertidal–Subtidal*—meadow includes sections that expose during low tide and sections that remain completely submerged, for example, meadows adjacent to the Thursday Island shipping channel.
- Dominant species of the meadow based on the most recent survey (Fig. 3).
- Presence or absence of individual seagrass species in a meadow.
- Meadow density categories—seagrass meadows were classified as light, moderate, dense, or variable based on the consistency of mean above-ground biomass of the dominant species among all surveys, or percent cover of all species combined (Data S1). For example, a *Halophila ovalis* dominated meadow would be classed as "light" if the mean meadow biomass was always <1 g dry weight m^{-2} (g DW m^{-2}) among years, "variable" if mean meadow biomass ranged from 1 to 5 g DW m^{-2}, and "dense" if mean meadow biomass was always >5 g DW m^{-2} among years. For meadows with density assessments based on both percent cover (generally from older surveys) and biomass, we assessed density categories based on the biomass data as this made the assessment comparable to a greater number of meadows, and comparable to the most recent data. Meadows with only 1 year of data were assigned a density category based on that year but no assessment of variability could be made.
- Mean meadow biomass range measured in g DW m^{-2} ($\pm$ standard error if available), or the mean meadow biomass if surveyed once.
- Mean meadow percent cover range, or the mean meadow percent cover if surveyed once.
- Meadow area (hectares; ha) of each meadow was calculated in the GDA 1994 Geoscience Australia Lambert projection using the "calculate geometry" function in ArcMap. For meadows that were mapped multiple times, meadow area represents the total extent for all surveys. Being a synthesis our polygons may represent multiple surveys and this is likely to overestimate the meadow area that would be found in any individual survey. Meadow boundaries can be determined by many different methods. Original reports listed in Table 1 include details of these methods specific to individual surveys.
- Meadow area range for meadows surveyed more than once. Where possible, we retained area range data reported in the original shapefiles (and calculated using original projections). Where area data did not exist in original shapefiles (e.g., 1986 Gulf of Carpentaria surveys; Coles et al. 2004), we calculated area using the ArcMap "calculate geometry"

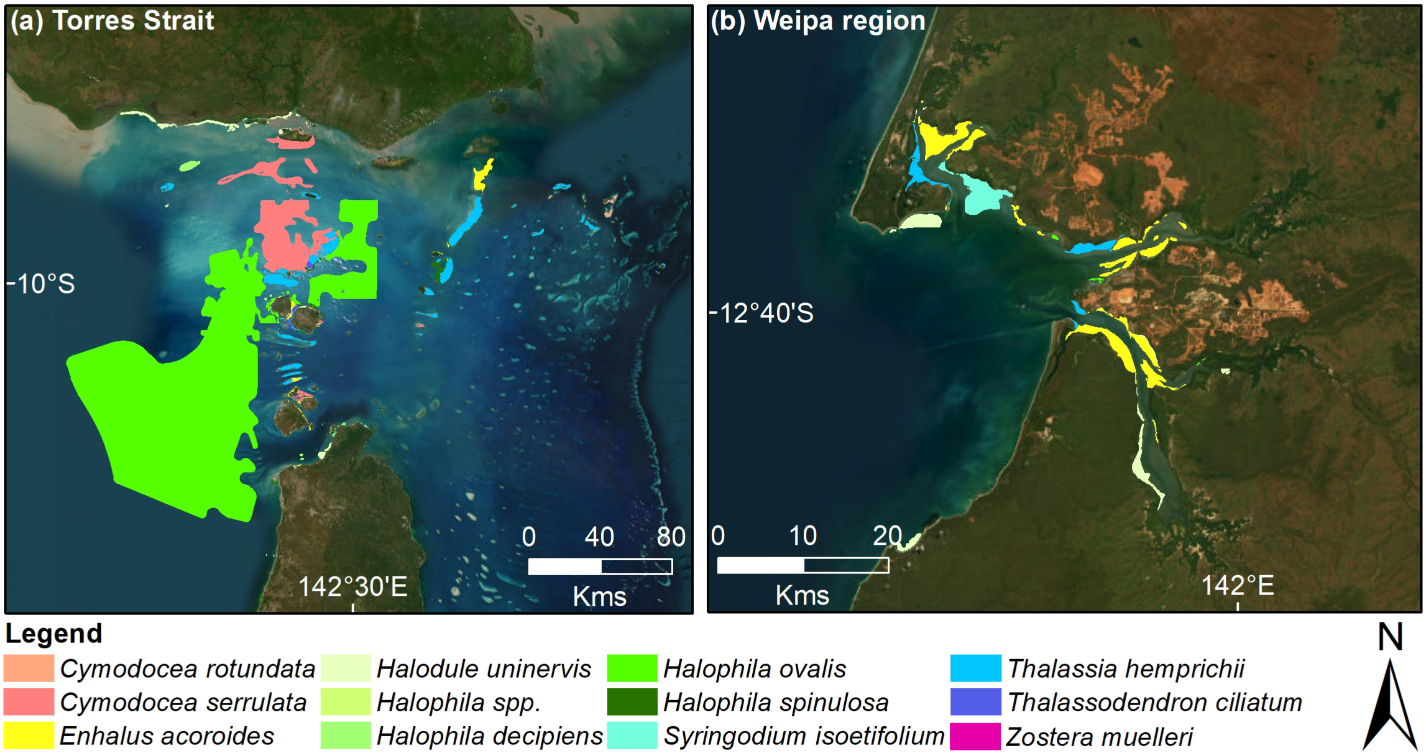

Fig. 3. Dominant species in seagrass meadows at a selection of locations in Torres Strait and Gulf of Carpentaria. Seagrass meadow edges are determined by seagrass presence/absence and geographical features, but may be limited by management boundaries or survey limits. Seagrass meadow maps should be interpreted in conjunction with the seagrass site data. Satellite image courtesy: ESRI.

function in the GDA 1994 Geoscience Australia Lambert projection.

- Data custodians.

Technical validation

The data included extend back to the early 1980s. Large parts of the coast have not been mapped for seagrass presence since that time (Fig. 4). Technology and methods for mapping and position fixing have improved dramatically in 40 years. Some early data included here had been checked and re-entered and previously included in other spatial platforms (Carter et al. 2014; McKenzie et al. 2014; Coles et al. 2022). For early data (1980s and 1990s), each data point were again reviewed and compared with original trip logs and recollections of trip participants, where possible. We have only included point and polygon (meadow) data in this report where we are confident, we have the most reliable interpretation of that early data. Since the original surveys in the 1980s, there have been changes to the shoreline, the most obvious being movement of mangrove forests and shoreline alterations for port development and access. We have not edited seagrass point or meadow layers to prevent older data from overlapping these features.

Seagrass data came from a variety of surveys conducted for different purposes. Early seagrass data mostly comes from broad-scale vessel-based surveys. This has been built on in the past two decades by extensive boat and helicopter surveys in the Torres Strait, eastern Gulf of Carpentaria, and in Limmen Bight. Three ports in our area of our study—Thursday Island, Weipa, Karumba—have been surveyed annually for more than 20 years. Seagrass data from the port at Alyangula (Groote Eylandt) could not be accessed for this project. Data from Torres Strait Rangers' intertidal monitoring at Badu, Mabuyag, Mua, Iama, Poruma, and Mer Islands is comprehensive over time, with surveys occurring up to four times in a year, but the data included here are not spatially resolved beyond a single latitude/longitude to identify the $50 \times 50\ m^2$ area where three replicate transects are surveyed. This is also the case for the Torres Strait Ranger's subtidal monitoring; where only the starting latitude/longitude is included for the 10 quadrats surveyed along a transect.

Data sets with large temporal and spatial coverage all have some survey-specific limitations and nuances beyond what can easily be described in this report. For example, seagrasses may form transitory meadows (Kilminster et al. 2015), where seagrass presence and species composition fluctuate over time. Most seagrass data included here were collected during the seagrass growing season. Annual species like *H. decipiens* and

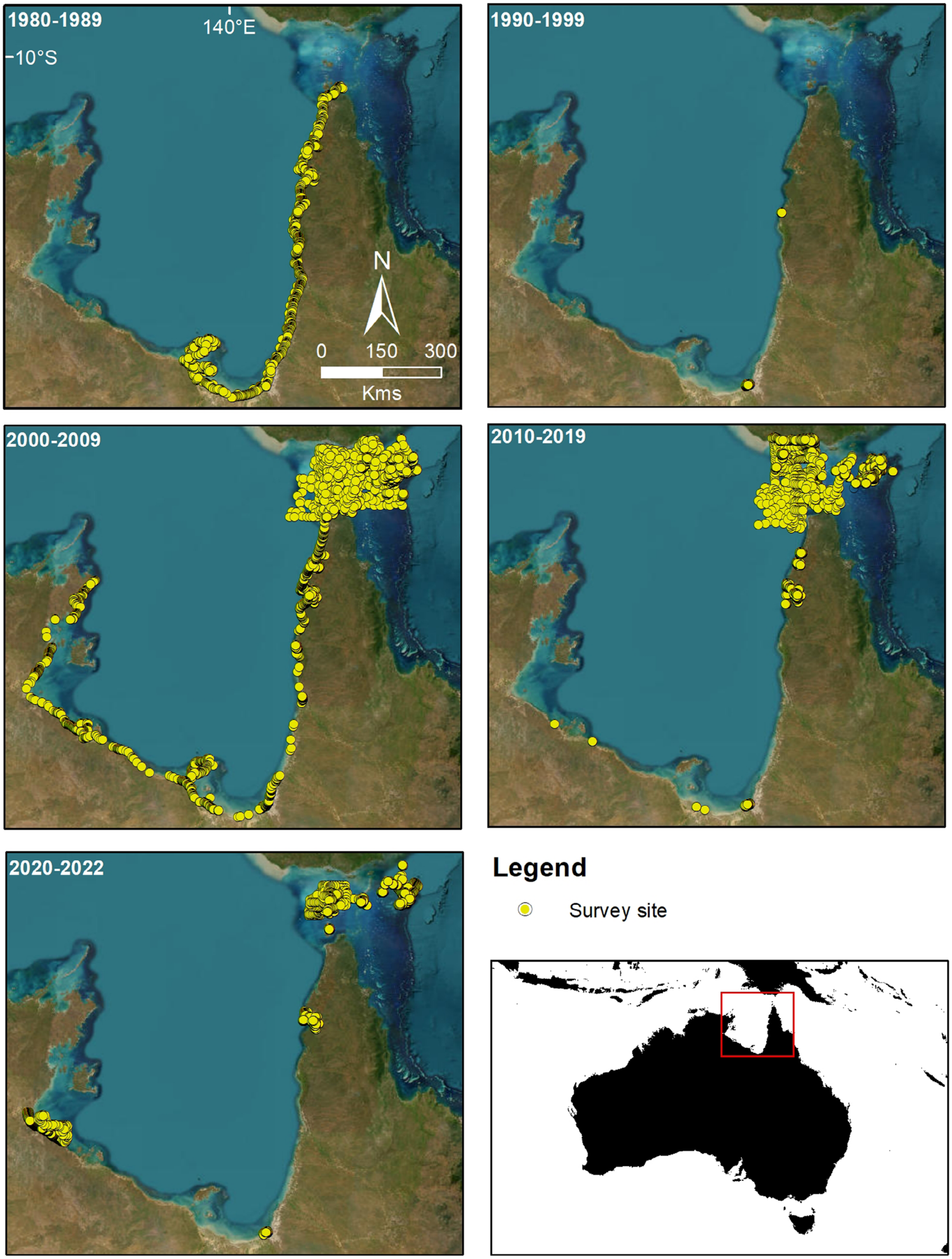

Fig. 4. Distribution of survey sites (yellow dots) throughout Torres Strait and the Gulf of Carpentaria in 10-years increments, 1983–2022. Satellite image courtesy: ESRI.

H. tricostata may not be present for considerable parts of the year during the senescent season (York et al. 2015; Chartrand et al. 2017). This is important to understand if these data are used to compare annual changes in seagrass distribution. We recommend checking the survey month in the data sets and contacting the data custodians (listed in the shapefile attribute tables, and in Table 1) when using this data to ensure those limitations are understood.

Significant differences in seagrass distribution and species presence can occur between high rainfall La Niña years and drier El Niño periods in northern Australia (Rasheed and Unsworth 2011; Lambert et al. 2021; Carter et al. 2022*b*). In the Gulf of Carpentaria, monitoring in Weipa has highlighted that decadal cycles of daytime tidal exposure can have major impacts on seagrass condition (Unsworth et al. 2012), and nearly 30 years of monitoring in Karumba has shown seagrass condition is strongly linked to rainfall and flooding of local rivers (Rasheed and Unsworth 2011). It is important to understand the implications these cycles have on seagrass condition, including lag times and recovery responses for different species. These cycles, while the result of natural phenomena, have implications for the animals that rely on seagrass meadows for shelter and food, including turtles (Flint et al. 2015, 2017) and dugong (Flint and Limpus 2013; Wooldridge 2017).

Data exclusions

Our synthesis excludes several historical data sets to ensure that the information we present is as accurate as possible and all data custodians agreed to publication. Data were excluded for the following reasons:

- The original survey data from published reports was lost over the years. This includes the extensive spatial data collected between Crab Island (western Cape York) and Cape Arnhem in 1982–1984 and is only available as a published illustration of meadows (Poiner et al. 1987, 1989).
- We were unable to establish that the information was verified at the time of collection. For example, data were excluded from recent field observations taken during mangrove surveys in the Gulf of Carpentaria (Duke et al. 2020) where aerial photographs with spatial information were taken of likely seagrass meadows but no sample was taken to verify this, or spatial information was not available for photographs.
- Permission for public distribution from data custodians was not provided.
- Published seagrass meadow information and online data sets had insufficient metadata for us to include. Examples include data compiled by the United Nations Environment World Conservation Monitoring Centre (https://data.unep-wcmc.org/datasets/7) and CSIRO's Coastal and Marine Resources Information System (https://data.csiro.au/collections/collection/CIcsiro:12640v1).

Data use and recommendations for reuse

This project makes publicly available a comprehensive tropical seagrass data set for north-eastern Australia. We include location information not just for sites that were surveyed, and seagrass recorded, but also location information where surveys did not find seagrass. Figure 4 highlights extensive areas that have never been surveyed or where survey data are now decades old. The management and conservation of marine ecosystems requires accurate spatial data at scales that match human activities and impacts (Hughes et al. 2005; Halpern et al. 2008; Visconti et al. 2013; Lagabrielle et al. 2018). A key strategy to assist this at a global scale is to ensure data are validated and reliable despite being collected over years or decades (Rajabifard et al. 2005). By building on our previous work (and using the same approach) compiling 35 years of seagrass spatial site data and 30 years of seagrass meadow data for the Great Barrier Reef World Heritage Area and adjacent estuaries (Carter et al. 2021*a*), we provide a synthesis that can be used to inform marine spatial planning and ecosystem-based management, identify priority areas for future surveys, and support research and education for a large part of northern Australia.

Comparison with existing data sets

The immediate scientific value of projects like this have been demonstrated on Queensland's east coast, where the Great Barrier Reef World Heritage Area (GBRWHA) data synthesis (Carter et al. 2021*a*) has been used to answer a number of key ecological questions, including the probability of seagrass distribution and communities (Carter et al. 2021*d*), defining the desired state of seagrass communities in the Townsville region (Collier et al. 2020) and GBRWHA (Carter et al. 2022*b*), examining management targets for rivers influencing seagrass habitat (Collier et al. 2021; Lambert et al. 2021), and in designing a Great Barrier Reef-scale monitoring program (Udy et al. 2019). Seagrass data has also been used on the Great Barrier Reef to model risk exposure (Grech et al. 2011; Grech et al. 2012; Bainbridge et al. 2018); propagule distribution (Grech et al. 2016; Schlaefer et al. 2022); developing a National Ocean Account in Australia (https://www.abs.gov.au/articles/towards-national-ocean-account); and connectivity among meadows (Tol et al. 2017; Grech et al. 2018). We now make available data for the Gulf of Carpentaria and Torres Strait to answer similarly important questions for this region. These data are already being used to initiate hydrodynamic modeling approaches to better understand seagrass connectivity and resilience in the Torres Strait (Schlaefer et al. 2022). By ensuring consistency in the structure of both point and polygon (meadow) data sets for the Great Barrier Reef and this project, and making these publicly available on eAtlas, we provide a mechanism for additional data to be added, archived, and easily compared.

Data availability statement

URL of the data set with permanent identifier: Data and metadata are available at eAtlas: https://doi.org/10.26274/2CR2-JK51. Data use is licensed by James Cook University for use under a Creative Commons Attribution 4.0 International license. For license conditions see: https://creativecommons.org/licenses/by/4.0/. Code URL with permanent identifier: N/A. Measurement(s): Location (latitude/longitude), presence/absence, seagrass species identification, dominant sediment type, depth below mean sea level, date of collection. Technology Type(s): Collected using a range of methods and available in an interactive spatial database or as a downloadable GIS shapefile. Temporal range: 1983 to 2022. Frequency or sampling interval: Multiple time scales mostly seasonal or annual. Spatial scale: Regional database including Torres Strait and the Gulf of Carpentaria, Queensland and Northern Territory, Australia. Data was limited to that collected in the Gulf of Carpentaria between Cape Arnhem (Northern Territory) and Cape York (Queensland) (Fig. 1). Torres Strait data were restricted to north of Queensland's Great Barrier Reef World Heritage Area boundary and includes data collected along parts of the Papua New Guinea coastline.

References

Bainbridge, Z., and others. 2018. Fine sediment and particulate organic matter: A review and case study on ridge-to-reef transport, transformations, fates, and impacts on marine ecosystems. Mar. Pollut. Bull. **135**: 1205–1220. doi:10.1016/j.marpolbul.2018.08.002

Bradley, J. J. 1997. *Li-anthawirriyarra, people of the sea: Yanyuwa relations with their maritime environment*. Charles Darwin University. doi:10.25913/5ea281f25d017

Brander, R. W., P. S. Kench, and D. Hart. 2004. Spatial and temporal variations in wave characteristics across a reef platform, Warraber Island, Torres Strait, Australia. Mar. Geol. **207**: 169–184. doi:10.1016/j.margeo.2004.03.014

Bridges, K. W., R. C. Phillips, and P. C. Young. 1982. Patterns of some seagrass distributions in the Torres Strait, Queensland. Aust J Mar Freshw Res **33**: 273–283. doi:10.1071/MF9820273

Brodie, J. E., and others. 2017. Setting ecologically relevant targets for river pollutant loads to meet marine water quality requirements for the Great Barrier Reef, Australia: A preliminary methodology and analysis. Ocean Coast Manag **143**: 136–147. doi:10.1016/j.ocecoaman.2016.09.028

Butler, J. R., A. Tawake, T. Skewes, L. Tawake, and V. McGrath. 2012. Integrating traditional ecological knowledge and fisheries management in the Torres Strait, Australia: the catalytic role of turtles and dugong as cultural keystone species. Ecol. Soc. **17**: 1–19. doi:10.5751/ES-05165-170434

Carter, A., H. Taylor, S. McKenna, and M. Rasheed. 2013. *Critical marine habitats in high risk areas, Torres Strait–Seo Reef to Kai-Wareg Reef*. James Cook University, p. 67 https://www.tsra.gov.au/__data/assets/pdf_file/0014/4370/TS-habitats-at-Risk-Atlas-2013.pdf

Carter, A., H. Taylor, and M. Rasheed. 2014. *Torres Strait Mapping: Seagrass Consolidation, 2002–2014*. James Cook University, p. 47 https://www.tsra.gov.au/__data/assets/pdf_file/0019/7408/Torres-Strait-Seagrass-Consolidation-Project-2014-Upload2.pdf

Carter, A. B., and M. A. Rasheed. 2016. *Assessment of Key Dugong and Turtle Seagrass Resources in North-west Torres Strait. Report to the National Environmental Science Programme and Torres Strait Regional Authority*. Reef and Rainforest Research Centre Limited, p. 40 http://nesptropical.edu.au/wp-content/uploads/2016/04/NESP-TWQ-3.5-FINAL-REPORT.pdf

Carter, A., J. Wells, and M. Rasheed. 2017. *Torres Strait Seagrass–Dungeness Reef Baseline Survey and Dugong Sanctuary Long-term Monitoring*. James Cook University, p. 36 https://www.dropbox.com/sh/mo8dcq1322qv5c3/AAAgu3lEnJsLgxdawXaOltu-a/2017?dl=0&preview=17+30+Dungeness+and+Dugong+Sanctuary+Seagrass+Monitoring+Report+2017+FINAL.pdf&subfolder_nav_tracking=1

Carter, A., S. McKenna, M. Rasheed, C. Collier, L. McKenzie, R. Pitcher, and R. Coles. 2021*a*. Synthesizing 35 years of seagrass spatial data from the Great Barrier Reef World Heritage Area, Queensland, Australia. Limnol Oceanogr Lett **1-11**: 216–226. doi:10.1002/lol2.10193

Carter, A., S. McKenna, and L. Shepherd. 2021*b*. *Subtidal seagrass of western Torres Strait*. James Cook University, p. 36 https://www.dropbox.com/s/7impuhmwiekv5te/21%2011%20Western%20Torres%20Subtidal%20report%202021%20FINAL.pdf?dl=0

Carter, A., J. Wilkinson, M. David, and M. Lukac. 2021*c*. *Torres Strait Eastern Cluster: Intertidal seagrass baseline survey*. James Cook University, p. 44 https://www.dropbox.com/s/0r1oc7d7kjqp6bk/21%2012%20Torres%20Strait%20Seagrass%20Eastern%20Cluster%202021%20FINAL.pdf?dl=0

Carter, A. B., C. Collier, E. Lawrence, M. A. Rasheed, B. Robson, and R. Coles. 2021*d*. A spatial analysis of seagrass habitat and community diversity in the Great Barrier Reef World Heritage Area. Sci. Rep. **11**: 22344. doi:10.1038/s41598-021-01471-4

Carter, A. B., M. David, T. Whap, L. R. Hoffmann, A. Scott, and M. Rasheed. 2021*e*. *Torres Strait Seagrass 2021 Report Card*. James Cook University, p. 76 https://researchonline.jcu.edu.au/70797/

Carter, A., and others. 2022*a*. *Four decades of seagrass spatial data from Torres Strait and Gulf of Carpentaria. NESP MaC Project 1.13*. eAtlas. doi:10.26274/2CR2-JK51

Carter, A. B., C. Collier, R. Coles, E. Lawrence, and M. A. Rasheed. 2022*b*. Community-specific "desired" states for seagrasses through cycles of loss and recovery. J. Environ. Manage. **314**: 115059. doi:10.1016/j.jenvman.2022.115059

Chartrand, K. M., H. A. Taylor, and M. A. Rasheed. 2009. *Mabuiag Island seagrass baseline survey, March-May 2009*. DEEDI Publication, Fisheries Queensland. Northern Fisheries Centre, p. 10 https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/TorresStrait/Chartrand_et_al_2009.pdf

Chartrand, K. M., and M. A. Rasheed. 2010. *Port Musgrave seagrass and benthic habitat baseline assessment, April and September 2009*. Queensland Fisheries, p. 42 https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/GulfCarpentaria/Chartrand_Rasheed_2010.pdf

Chartrand, K. M., C. V. Bryant, A. Sozou, P. J. Ralph, and M. A. Rasheed. 2017. *Final Report: Deep-water seagrass dynamics - Light requirements, seasonal change and mechanisms of recruitment*. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 17/16, James Cook University, p. 67 https://www.dropbox.com/sh/mo8dcq1322qv5c3/AAAgu3lEnJsLgxdawXaOltu-a/2017?dl=0&preview=17+16+Final+Report+Deep-water+seagrass+dynamics.pdf&subfolder_nav_tracking=1

Coles, R. G., and W. J. Lee Long. 1985. *Juvenile prawn biology and the distribution of seagrass prawn nursery grounds in the southeastern Gulf of Carpentaria*. Second Australian National Prawn Seminar, https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/GulfCarpentaria/Coles_Lee_Long_1985.pdf

Coles, R. G., N. Smit, L. J. McKenzie, A. Roelofs, M. Haywood, and R. Kenyon. 2004. *Seagrasses*. National Oceans Office, https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/GulfCarpentaria/Coles_et_al_2004.pdf

Coles, R. G., L. J. McKenzie, and R. Yoshida. 2022. *Inshore seagrass meadows of the eastern Gulf of Carpentaria (Albany Island to Tarrant Point), Queensland, derived from field surveys conducted 21 October to 7 November, 1986*. PANGAEA. doi:10.1594/PANGAEA.946610

Collier, C. J., and others. 2020. An evidence-based approach for setting desired state in a complex Great Barrier Reef seagrass ecosystem: A case study from Cleveland Bay. Environ Sustain Indicators **7**: 100042. doi:10.1016/j.indic.2020.100042

Collier, C. J., L. Hoffman, B. Robson, and A. Carter. 2021. Case study: Seagrass Habitat Suitability, p. 69–76. *In* B. J. Robson and others [eds.], *Benthic light as ecologically-validated GBR-wide indicator for water quality*. National Environmental Science Program, Tropical Water Quality, https://nesptropical.edu.au/wp-content/uploads/2021/03/NESP-TWQ-Project-5.3-Final-Report.pdf

Costanza, R., R. de Groot, P. Sutton, S. van der Ploeg, S. J. Anderson, I. Kubiszewski, S. Farber, and R. K. Turner. 2014. Changes in the global value of ecosystem services. Glob. Environ. Chang. **26**: 152–158. doi:10.1016/j.gloenvcha.2014.04.002

Duke, N. C., D. Burrows, and J. Mackenzie. 2015. *Mangrove and freshwater wetland habitat status of the Torres Strait Islands–biodiversity, biomass and changing condition of wetlands. Report to the National Environmental Research Program*. Reef and Rainforest Research Centre Limited, p. 84 http://nerptropical.edu.au/sites/default/files/publications/files/NERP-TE-PROJECT-2.2-FINAL-REPORT-COMPLETE.pdf

Duke, N. C., J. Mackenzie, J. Kovacs, G. Staben, R. Coles, A. Wood, and Y. Castle. 2020. *Assessing the Gulf of Carpentaria mangrove dieback 2017–2019. Volume 1: Aerial surveys. Report to the National Environmental Science Program*. James Cook University, p. 226 https://nesptropical.edu.au/wp-content/uploads/2021/05/Project-4.13-Final-Report-Volume-1.pdf

Duke, N. C., L. B. Hutley, J. R. Mackenzie, and D. Burrows. 2021. Processes and factors driving change in mangrove forests: An evaluation based on the mass dieback event in Australia's Gulf of Carpentaria, p. 221–264. *In* J. G. Canadell and R. B. Jackson [eds.], *Ecosystem collapse and climate change. ecological studies*, v. **241**. Springer. doi:10.1007/978-3-030-71330-0_9

Duke, N. C., and others. 2022. ENSO-driven extreme oscillations in mean sea level destabilise critical shoreline mangroves—An emerging threat. PLOS Climate **1**: e0000037. doi:10.1371/journal.pclm.0000037

Dunic, J. C., C. J. Brown, R. M. Connolly, M. P. Turschwell, and I. M. Côté. 2021. Long-term declines and recovery of meadow area across the world's seagrass bioregions. Glob. Chang. Biol. **27**: 4096–4109. doi:10.1111/gcb.15684

Flint, J., and C. J. Limpus. 2013. *Marine wildlife stranding and mortality database annual report 2012*. Department of Environment and Heritage Protection, Queensland Government, p. 42.

Flint, J., M. Flint, C. J. Limpus, and P. C. Mills. 2015. Trends in marine turtle strandings along the east Queensland, Australia coast, between 1996 and 2013. J Mar Biol **2015**: 1–7. doi:10.1155/2015/848923

Flint, J., M. Flint, C. J. Limpus, and P. C. Mills. 2017. The impact of environmental factors on marine turtle stranding rates. PloS One **12**: e0182548. doi:10.1371/journal.pone.0182548

Grech, A., R. Coles, and H. Marsh. 2011. A broad-scale assessment of the risk to coastal seagrasses from cumulative threats. Mar. Policy **35**: 560–567. doi:10.1016/j.marpol.2011.03.003

Grech, A., K. Chartrand-Miller, P. Erftemeijer, M. Fonseca, L. McKenzie, M. Rasheed, H. Taylor, and R. Coles. 2012. A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. Environ. Res. Lett. **7**: 024006. doi:10.1088/1748-9326/7/2/024006

Grech, A., J. Wolter, R. Coles, L. McKenzie, M. Rasheed, C. D. Thomas, M. Waycott, and E. Hanert. 2016. Spatial patterns of seagrass dispersal and settlement. Divers Distrib **22**: 1150–1162. doi:10.1111/ddi.12479

Grech, A., and others. 2018. Predicting the cumulative effect of multiple disturbances on seagrass connectivity. Glob. Chang. Biol. **24**: 3093–3104. doi:10.1111/gcb.14127

Green, E. P., and F. T. Short. 2003. *World Atlas of Seagrasses*. University of California Press.

Griffiths, A. D., R. A. Groom, and G. Dunshea. 2020. *Dugong distribution and abundance in the Gulf of Carpentaria, Northern Territory: October 2019*. Department of Environment, Parks and Water Security, Northern Territory Government, p. 32.

Groom, R. A., G. J. Dunshea, A. D. Griffiths, and K. Mackarous. 2017. *The distribution and abundance of dugong and other marine megafauna in the Northern Territory, November 2015*. Northern Territory Government, https://hdl.handle.net/10070/265115

Hallett, C. S., and others. 2016. A review of Australian approaches for monitoring, assessing and reporting estuarine condition: II. State and Territory programs. Environ. Sci. Policy **66**: 270–281. doi:10.1016/j.envsci.2016.07.013

Halpern, B. S., and others. 2008. A global map of human impact on marine ecosystems. Science **319**: 948–952. doi:10.1126/science.1149345

Hayes, M. A., E. C. McClure, P. H. York, K. I. Jinks, M. A. Rasheed, M. Sheaves, and R. M. Connolly. 2020. The differential importance of deep and shallow seagrass to nekton assemblages of the great barrier reef. Diversity **12**: 292. doi:10.3390/d12080292

Haywood, M. D. E., and others. 2008. Mapping and characterisation of the inter-reefal benthic assemblages of the Torres Strait. Cont. Shelf Res. **28**: 2304–2316. doi:10.1016/j.csr.2008.03.039

Hughes, T. P., D. R. Bellwood, C. Folke, R. S. Steneck, and J. Wilson. 2005. New paradigms for supporting the resilience of marine ecosystems. Trends Ecol. Evol. **20**: 380–386. doi:10.1016/j.tree.2005.03.022

Huisman, J. M., R. R. Dixon, R. A. Townsend, and G. Belton. 2021. Diversity and distribution of marine benthic algae and seagrasses in the tropical Kimberley, Western Australia. Rec Western Austr Mus **185**: 200. doi:10.18195/issn.0313-122x.85.2021.185-200

Jänes, H., P. I. Macreadie, E. Nicholson, D. Ierodiaconou, S. Reeves, M. D. Taylor, and P. E. Carnell. 2020*a*. Stable isotopes infer the value of Australia's coastal vegetated ecosystems from fisheries. Fish Fish. **21**: 80–90. doi:10.1111/faf.12416

Jänes, H., P. I. Macreadie, P. S. E. Zu Ermgassen, J. R. Gair, S. Treby, S. Reeves, E. Nicholson, D. Ierodiaconou, and P. Carnell. 2020*b*. Quantifying fisheries enhancement from coastal vegetated ecosystems. Ecosyst. Serv. **43**: 101105. doi:10.1016/j.ecoser.2020.101105

Kelkar, N., R. Arthur, N. Marba, and T. Alcoverro. 2013. Green turtle herbivory dominates the fate of seagrass primary production in the Lakshadweep islands (Indian Ocean). Mar. Ecol. Prog. Ser. **485**: 235–243. doi:10.3354/meps10406

Kilminster, K., and others. 2015. Unravelling complexity in seagrass systems for management: Australia as a microcosm. Sci. Total Environ. **534**: 97–109. doi:10.1016/j.scitotenv.2015.04.061

Kyne, P. M., B. Brooke, C.-L. Davies, L. C. Ferreira, B. Finucci, L. Lymburner, C. Phillips, M. Thums, and V. Tulloch. 2018. *Final Report. Scoping a seascape approach to managing and recovering Northern Australian threatened and migratory marine species. Report to the National Environmental Science Programme*. Marine Biodiversity Hub, Charles Darwin University, https://www.nespmarine.edu.au/system/files/Kyne%20Scoping%20a%20seascape%20approach_Milestone%2017%20Final%20report_RPv3%202017_14Nov18.pdf

Lagabrielle, E., A. T. Lombard, J. M. Harris, and T.-C. Livingstone. 2018. Multi-scale multi-level marine spatial planning: A novel methodological approach applied in South Africa. PloS One **13**: e0192582. doi:10.1371/journal.pone.0192582

Lamb, J. B., J. A. J. M. van de Water, D. G. Bourne, C. Altier, M. Y. Hein, E. A. Fiorenza, N. Abu, J. Jompa, and C. D. Harvell. 2017. Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science **355**: 731–733. doi:10.1126/science.aal1956

Lambert, V. M., and others. 2021. Connecting targets for catchment sediment loads to ecological outcomes for seagrass using multiple lines of evidence. Mar. Pollut. Bull. **169**: 112494. doi:10.1016/j.marpolbul.2021.112494

Levin, P. S., and C. Möllmann. 2015. Marine ecosystem regime shifts: challenges and opportunities for ecosystem-based management. Philos Trans R Soc B Biol Sci **370**: 20130275. doi:10.1098/rstb.2013.0275

Macreadie, P. I., M. D. Costa, T. B. Atwood, D. A. Friess, J. J. Kelleway, H. Kennedy, C. E. Lovelock, O. Serrano, and C. M. Duarte. 2021. Blue carbon as a natural climate solution. Nat Rev Earth Environ **2**: 826–839. doi:10.1038/s43017-021-00224-1

Marsh, H., A. Grech, S. Delean, and A. Hodgson. 2008. *Distribution and abundance of the dugong in Gulf of Carpentaria waters: a basis for cross-jurisdictional conservation planning and management*. James Cook University, https://researchonline.jcu.edu.au/16415/1/Marsh_AMMC_GOC_Aerial_Surveys_2008.pdf

Marsh, H., T. J. O'Shea, and J. E. Reynolds III. 2011. *Ecology and conservation of the sirenia: Dugongs and Manatees*. Cambridge University Press. doi:10.1017/CBO9781139013277

McKenna, S. A., T. M. Smith, C. L. Reason, and M. A. Rasheed. 2021. *Port of Weipa long-term seagrass monitoring program, 2000–2021*. James Cook University, p. 35 https://nqbp.com.au/__data/assets/pdf_file/0023/38543/Weipa-seagrass-monitoring-2021.pdf

McKenzie, L. J., R. L. Yoshida, A. Grech, and R. G. Coles. 2014. *Composite of coastal seagrass meadows in Queensland, Australia–November 1984 to June 2010*. PANGAEA. doi:10.1594/PANGAEA.826368

Moriarty, D. 1977. Quantification of carbon, nitrogen and bacterial biomass in the food of some penaeid prawns. Mar. Freshw. Res. **28**: 113–118. doi:10.1071/MF9770113

Murphy, N. E., T. D. Skewes, F. Filewood, C. David, P. Seden, and A. Jones. 2010. *The Recovery of the* Holothuria scabra *(sandfish) population on Warrior Reef, Torres Strait. CSIRO Wealth from Oceans Flagship. Draft Final Report*. CSIRO CMAR, p. 44.

Nordlund, L., E. Koch, E. Barbier, and J. Creed. 2016. Seagrass ecosystem services and their variability across genera and geographical regions. PloS One **11**: 163091. doi:10.1371/journal.pone.0163091

O'Brien, K. R., and others. 2017. Seagrass ecosystem trajectory depends on the relative timescales of resistance, recovery and disturbance. Mar. Pollut. Bull. **134**: 166–176. doi:10.1016/j.marpolbul.2017.09.006

Plaganyi-Lloyd, E., R. Campbell, R. Deng, M. Haywood, R. Pillans, N. Murphy, T. Hutton, and D. Dennis. 2016. *Torres Strait Tropical Rock Lobster Fishery Survey and Stock Assessment*. CSIRO/AFMA Final Report, CSIRO. doi:10.25919/5c9a68aba3207

Poiner, I. R., D. J. Staples, and R. Kenyon. 1987. Seagrass communities of the Gulf of Carpentaria, Australia. Austr J Mar Freshw Res **38**: 121–131. doi:10.1071/MF9870121

Poiner, I. R., D. I. Walker, and R. G. Coles. 1989. Regional studies–seagrasses of tropical Australia, p. 279–296. *In* A. W. D. Larkum, A. J. McComb, and S. A. Shepherd [eds.], *Biology of Seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region*. Elsevier.

Rajabifard, A., A. Binns, and I. Williamson. 2005. Administering the marine environment—The spatial dimension. J Spatial Sci **50**: 69–78. doi:10.1080/14498596.2005.9635050

Rasheed, M. A. 2000. *Seagrass survey of the Kirke & Love River systems–August 1999. Unpublished report*. Queensland Department of Primary Industries, p. 9.

Rasheed, M. A., K. R. Dew, S. P. Kerville, L. J. McKenzie, and R. G. Coles. 2006*a*. *Seagrass distribution, community structure and productivity for Orman Reefs, Torres Strait–March and November 2004*. DPI Information Series, p. 38

Rasheed, M. A., R. Thomas, and H. A. Taylor. 2006*b*. *Critical marine habitats adjacent to the Prince of Wales and Adolphus shipping channels in the Torres Strait, Far North Queensland, Australia–2006 Atlas*. *QDPI&F Information Series QI06063*. Northern Fisheries Centre, p. 34.

Rasheed, M. A., and R. K. F. Unsworth. 2008. *Boyd Bay to Pera Head: 2nd Seagrass Baseline Survey*. *Report to GHD Pty Ltd*. Queensland Fisheries, p. 17.

Rasheed, M. A., K. R. Dew, L. J. McKenzie, R. G. Coles, S. P. Kerville, and S. J. Campbell. 2008. Productivity, carbon assimilation and intra-annual change in tropical reef platform seagrass communities of the Torres Strait, north-eastern Australia. Cont. Shelf Res. **28**: 2292–2303. doi:10.1016/j.csr.2008.03.026

Rasheed, M. A., and R. K. F. Unsworth. 2011. Long-term climate-associated dynamics of a tropical seagrass meadow: implications for the future. Mar. Ecol. Prog. Ser. **422**: 93–103. doi:10.3354/meps08925

Roelofs, A. J., M. A. Rasheed, and R. Thomas. 2002. *Port of Skardon River: Marine Habitat Resources Survey, April/May 2002. Final report to Ports Corporation of Queensland*. Department of Primary Industries, p. 17 https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/GulfCarpentaria/SkardonRiver_reportPCQ.pdf

Roelofs, A. J., M. A. Rasheed, and R. Thomas. 2004. *Final report to Ports Corporation of Queensland*. Queensland Fisheries, p. 15.

Roelofs, A. J., R. Coles, and N. Smit. 2005. *A survey of intertidal seagrass from Van Diemen Gulf to Castlereagh Bay, Northern Territory, and from Gove to Horn Island, Queensland. Report to the National Oceans Office*. Queensland Department of Primary Industries & Fisheries, p. 27 https://www.dcceew.gov.au/sites/default/files/documents/seagrass-survey-report-2005.pdf

Saint-Cast, F. 2008. Multiple time-scale modelling of the circulation in Torres Strait—Australia. Cont. Shelf Res. **28**: 2214–2240. doi:10.1016/j.csr.2008.03.035

Schlaefer, J., A. Carter, S. Choukroun, R. Coles, K. Critchell, J. Lambrechts, M. Rasheed, S. Tol, and A. Grech. 2022. Marine plant dispersal and connectivity measures differ in their sensitivity to biophysical model parameters. Environ. Model. Software **149**: 105313. doi:10.1016/j.envsoft.2022.105313

Scott, A., and M. Rasheed. 2021. *Seagrass Habitat in the Port of Thursday Island: Annual Monitoring Report 2021*. James Cook University, p. 40 https://www.tropwater.com/wp-content/uploads/2022/07/21-32-Seagrass-Habitat-in-the-Port-of-Thursday-Island-Annual-Monitoring-Report-Report-21-32.pdf

Scott, A., S. McKenna, and M. Rasheed. 2022. *Port of Karumba Long-term Annual Seagrass Monitoring 2021*. James Cook University, p. 28 https://www.dropbox.com/s/fwtys67ljssbp9t/21%2005%20Scott%20%26%20Rasheed%202021%20FINAL%202020%20Karumba%20Long-term%20seagrass%20monitoring%20report%20low%20res.pdf?dl=0

Scott, A. L., and others. 2018. The role of herbivory in structuring tropical seagrass ecosystem service delivery. Front. Plant Sci. **9**: 1–10. doi:10.3389/fpls.2018.00127

Scott, A. L., P. H. York, and M. A. Rasheed. 2020. Green turtle (*Chelonia mydas*) grazing plot formation creates structural changes in a multi-species Great Barrier Reef seagrass meadow. Mar. Environ. Res. **162**: 105183. doi:10.1016/j.marenvres.2020.105183

Serrano, O., A. Arias-Ortiz, C. M. Duarte, G. A. Kendrick, and P. S. Lavery. 2021. *Ecosystem Collapse and Climate Change*. Springer, p. 345–364. doi:10.1007/978-3-030-71330-0_13

Sheppard, R., M. Rasheed, and S. A. Helmke. 2001. *Kirke River fisheries resources assessment August 1999*. Northern Fisheries Centre, p. 58.

Skewes, T., N. Murphy, I. McLeod, E. Dovers, C. Burridge, and W. Rochester. 2010. *Torres Strait Hand Collectables, 2009 survey: Sea Cucumber*. CSIRO, https://www.pzja.gov.au/sites/default/files/content/uploads/2011/06/Torres-Strait-Hand-Collectables-2009-survey-Sea-cucumber.pdf?acsf_files_redirect

Strydom, S., and others. 2020. Too hot to handle: Unprecedented seagrass death driven by marine heatwave in a

World Heritage Area. Glob. Chang. Biol. **26**: 3525–3538. doi:10.1111/gcb.15065

Taylor, H. 2011. *Moa Island Seagrass Baseline Survey*. DEEDI Publication, Fisheries Queensland. Northern Fisheries Centre, p. 15 https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/TorresStrait/Subtidalseagrassbaseliine_report_MoaIsland2011_Lowres.pdf

Taylor, H., and S. McKenna. 2012. *Critical marine habitats in high risk areas, Torres Strait–Woiz Reef to Kaliko Reef–2012 Atlas*. Northern Fisheries Centre, p. 55.

Taylor, H. A., M. A. Rasheed, and R. Coles. 2007. *Seagrass communities of the Wellesley Island Group. August 2007. DPI&F Publication PR07-3165*. Queensland Department of Primary Industries and Fisheries, p. 28 https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/GulfCarpentaria/Taylor_et_al_2007a.pdf

Taylor, H. A., M. A. Rasheed, K. Chartrand, S. A. McKenna, and T. L. Sankey. 2008. *Critical marine habitats and marine debris in the Great North East Channel, Torres Strait–Poruma to Ugar Islands–2008 Atlas*. Department of Primary Information & Fisheries (DPI&F) Information Series. Northern Fisheries Centre, p. 55.

Taylor, H. A., S. A. McKenna, and M. A. Rasheed. 2009. *Critical marine habitats in the Great North East Shipping Channel, Torres Strait–Kirkcaldie Reef to Bramble Cay–2009 Atlas*. Northern Fisheries Centre, p. 64 https://www.tsra.gov.au/__data/assets/pdf_file/0019/4366/Torres-Strait-Habitat-Atlas-2009.pdf

Taylor, H. A., C. McCormack, and M. A. Rasheed. 2010. *Critical marine habitats in High Risk areas, Torres Strait–Moa Island to Mabuiag Island*. DEEDI Publication, Fisheries Queensland, p. 54.

Taylor, H. A., and M. A. Rasheed. 2010*a*. *Badu Island seagrass baseline survey*. DEEDI Publication, Fisheries Queensland, Northern Fisheries Centre, p. 13 https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/Torres Strait/FinalsummaryreportBaduIsland_2010_lowres.pdf

Taylor, H. A., and M. A. Rasheed. 2010*b*. *Torres Strait Dugong Sanctuary Seagrass Baseline Survey*. DEEDI Publication, Fisheries Queensland, Northern Fisheries Centre, p. 21 https://www.seagrasswatch.org/wp-content/uploads/Resources/Publications/Misc/Report/TorresStrait/FinalDugongSanctuaryReportMarch_2010_lowres.pdf

Taylor, H. A., S. A. McKenna, and M. A. Rasheed. 2011. *Critical marine habitats in high risk areas, Torres Strait–No. 2 Reef to Mabuiag Reef–2011 Atlas*. Fisheries Queensland, p. 63.

Thomas, R., and K. M. Chartrand. 2010. *Benthic marine habitat of the Skardon River mouth, May 2010*. Queensland Fisheries, https://os-data-2.s3-ap-southeast-2.amazonaws.com/portsnorth-com-au/bundle13/seagrassmonitoring_longterm_skardon_rvr_2010.pdf

Tol, S. J., R. G. Coles, and B. C. Congdon. 2016. *Dugong dugon* feeding in tropical Australian seagrass meadows: implications for conservation planning. PeerJ **4**: e2194. doi:10.7717/peerj.2194

Tol, S. J., J. C. Jarvis, P. H. York, A. Grech, B. C. Congdon, and R. G. Coles. 2017. Long distance biotic dispersal of tropical seagrass seeds by marine mega-herbivores. Sci. Rep. **7**: 4458. doi:10.1038/s41598-017-04421-1

Turschwell, M. P., and others. 2021. Anthropogenic pressures and life history predict trajectories of seagrass meadow extent at a global scale. Proc. Natl. Acad. Sci. U.S.A. **118**: e2110802118. doi:10.1073/pnas.2110802118

Udy, J., and others. 2019. *Monitoring seagrass within the Reef 2050 Integrated Monitoring and Reporting Program: Final report of the seagrass expert group*. Great Barrier Reef Marine Park Authority, https://elibrary.gbrmpa.gov.au/jspui/retrieve/f31cfc5d-f236-46a6-bb5d-23f08bbbdfce/RIMReP_seagrass_monitoring_report.pdf

Udyawer, V., M. Thums, L. C. Ferreira, V. Tulloch, and P. M. Kyne. 2021. *Distribution and habitat suitability of Threatened and Migratory marine species in northern Australia*. Report to the National Environmental Science Program, Marine Biodiversity Hub, https://www.nespmarine.edu.au/system/files/Udyawer%20et%20al_A12_Theme%201_M12_Distribution%20and%20Habitat%20Suitability%20of%20Threatened%20and%20Migratory%20Marine%20Species_FINAL_updated%20July%202021.pdf

Unsworth, R. K. F., M. A. Rasheed, K. M. Chartrand, and A. J. Roelofs. 2012. Solar radiation and tidal exposure as environmental drivers of enhalus acoroides dominated seagrass meadows. PloS One **7**: e34133. doi:10.1371/journal.pone.0034133

Visconti, P., M. Di Marco, J. Álvarez-Romero, S. Januchowski-Hartley, R. Pressey, R. Weeks, and C. Rondinini. 2013. Effects of errors and gaps in spatial data sets on assessment of conservation progress. Conserv. Biol. **27**: 1000–1010. doi:10.1111/cobi.12095

Waterhouse, J., and others. 2021. *Assessing the influence of the Fly River discharge on the Torres Strait. Report to the National Environmental Science*. Reef and Rainforest Research Centre Limited, p. 188 https://nesptropical.edu.au/wp-content/uploads/2021/06/NESP-TWQ-Project-5.14-Final-Report_COMPLETE.pdf

Waycott, M., and others. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proc. Natl. Acad. Sci. U.S.A. **106**: 12377–12381. doi:10.1073/pnas.0905620106

Whiteway, T. 2009. *Australian Bathymetry and Topography Grid, June 2009. Record 2009/021*. Commonwealth of Australia (Geoscience Australia). doi:10.4225/25/53D99B6581B9A

Wightman, G. M. 2006. *Mangroves of the Northern Territory, Australia: identification and traditional use*. Department of Natural Resources, Environment, the Arts and Sport.

Wolanski, E., J. Lambrechts, C. Thomas, and E. Deleersnijder. 2013. The net water circulation through Torres Strait. Cont. Shelf Res. **64**: 66–74. doi:10.1016/j.csr.2013.05.013

Wooldridge, S. A. 2017. Preventable fine sediment export from the Burdekin River catchment reduces coastal seagrass abundance and increases dugong mortality within the Townsville region of the Great Barrier Reef, Australia. Mar. Pollut. Bull. **114**: 671–678. doi:10.1016/j.marpolbul.2016.10.053

York, P., A. Carter, K. Chartrand, T. Sankey, L. Wells, and M. Rasheed. 2015. Dynamics of a deep-water seagrass population on the Great Barrier Reef: Annual occurrence and response to a major dredging program. Sci. Rep. **5**: 13167. doi:10.1038/srep13167

York, P. H., and others. 2017. Identifying knowledge gaps in seagrass research and management: An Australian perspective. Mar. Environ. Res. **127**: 163–172. doi:10.1016/j.marenvres.2016.06.006

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