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DATA ARTICLE

Synthesizing 35 years of seagrass spatial data from the Great Barrier Reef World Heritage Area, Queensland, Australia

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Scientific Significance Statement

Seagrass meadows occupy shallow coastal waters of all continents except Antarctica. Their proximity to coastal processes exposes them to anthropogenic impacts and the loss of well documented ecological services. We surveyed seagrass meadows over a 35-year period, including along 2500 km of coastline within the Great Barrier Reef World Heritage Area (GBRWHA). Included are data from intertidal to 123 m deep with seagrass found as deep as 76 m. There are few spatial data sets available that can be used by the global research community that follow long-term changes in seagrass meadow characteristics, and no validated long-term data sets for the Indo-Pacific that we know of. We provide this data on historical seagrass occurrence across the GBRWHA so that past and future changes can be assessed.

Abstract

The Great Barrier Reef World Heritage Area in Queensland, Australia contains globally significant seagrasses supporting key ecosystem services, including habitat and food for threatened populations of dugong and turtle. We compiled 35 years of data in a spatial database, including 81,387 data points with georeferenced seagrass and species presence/absence, depth, dominant sediment type, and collection date. We include data collected under commercial contract that have not been publicly available. Twelve seagrass species were recorded. The deepest seagrass was found at 76 m. Seagrass meadows are at risk from anthropogenic, climate and weather processes. Our database is a valuable resource that provides coastal managers and the global marine community with a long-term spatial resource describing seagrass populations from the mid-1980s against which to benchmark change. We address the data issues involved in hindcasting over 30 years to ensure confidence in the accuracy and reliability of data included.

Background and motivation

The Great Barrier Reef in tropical Northeastern Australia is the world's most extensive coral reef structure, supporting a globally outstanding and biodiverse marine ecosystem. It was inscribed as World Heritage in 1981 and covers an area of around 350,000 km^2, including 2500 km of coastline and a

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Data Availability Statement: Data and metadata are available at eAtlas: https://doi.org/10.25909/y1yk-9w85. Data use is licensed by James Cook University for use under a Creative Commons Attribution 3.0 International license. For license conditions see: https://creativecommons.org/licenses/by/3.0/.

shelf extending out to 250 km offshore. The more than 2500 individual reefs and over 900 islands protect an extensive shallow inter-reef lagoon.

Seagrass meadows are the most extensive benthic plant habitat in this lagoon, with more than 35,000 km^2 previously estimated (Coles et al. 2015). These meadows are essential for the health of the Great Barrier Reef World Heritage Area (GBRWHA) and provide important services including substrate stabilization, filtering organic matter from the water, recycling nitrogen, and baffling of wave and tidal energy (Kenworthy et al. 2006). Seagrass meadows also are one of the most efficient and powerful marine carbon sinks (Fourqurean et al. 2012; Pendleton et al. 2012; Lavery et al. 2013; York et al. 2018). As a major benthic primary producer in the reef

Table 1. Spatial data sets used in seagrass data compilation, 1984–2018.

Data set/survey name	Years	References
1980s GBR-scale coastal surveys		
Cape York to Cairns	1984, 1985	Coles et al. (1985)
Cairns to Bowen	1987	Coles et al. (1992)
Bowen to Water Park Point	1987	Coles (1987)
Water Park Point to Hervey Bay	1988	Coles et al. (1990)
GBR-scale deep-water surveys		
GBR Deep Water	1994–1999	Coles et al. (2009)
GBR Seabed Biodiversity	2003–2005	Pitcher et al. (2007)
Oil spill response atlas (OSRA) intertidal surveys		
Princess Charlotte Bay to Cape Flattery	2011–2014	Carter et al. (2013, 2012), Carter and Rasheed (2014, 2015)
Hydrographers passage	2003	Rasheed et al. (2006)
Margaret Bay	2001	Rasheed et al. (2005)
Targeted seagrass mapping surveys		
Bustard Bay	2009	Taylor et al. (2010)
Cape Flattery	1996	Ayling et al. (1997)
Clairview	2017–2018	Carter and Rasheed (2019)
Clump Point	1997	Roder et al. (1998)
Dugong Protection Area	1999	Coles et al. (2002)
Dunk Island to Cleveland Bay	1996	Unpublished data
Edgecumbe Bay	2008	Coles et al. (2007)
Green Island	1997, 2003	McKenzie and Lee Long (1996), McKenzie et al. (2014*b*)
Lizard Island	1995	McKenzie et al. (1997)
Low Isles	1997	McKenzie et al. (2016)
Lucinda to Bowling Green Bay	2007	Coles et al. (2007)
Oyster Point	1995–1998	Lee Long et al. (2002)
Shoalwater Bay	1996	Lee Long et al. (1996*a*)
Whitsunday Islands	1999–2000	Campbell et al. (2002)
Queensland ports seagrass long-term monitoring surveys		
Cairns	1993, 1996, 2000–2018	Lee Long et al. (1996*b*), Rasheed and Roelofs (1996), Rasheed et al. (2019)
Gladstone	2002–2018	Chartrand et al. (2019)
Mackay and Hay Point	2001–2018	Rasheed et al. (2001), York and Rasheed (2019)
Abbot Point	2005–2018	McKenna et al. (2019)
Mourilyan Harbor	1993–2018	Wells et al. (2019)
Townsville	2007–2018	Bryant et al. (2019)

ecosystem, seagrass meadows play a critical role as food and shelter for fish and crustaceans caught by recreational, traditional, and commercial fishers (Hayes et al. 2020). They provide essential food for dugongs (*Dugong dugon*) and green sea turtles (*Chelonia mydas*) (Marsh et al. 2011; Kelkar et al. 2013; Scott et al. 2018).

A series of intense tropical cyclones with associated high rainfall and flooding severely reduced seagrass biomass and extent in parts of the southern two-thirds of the GBRWHA between 2009 and 2012 (Collier et al. 2012; Rasheed et al. 2014; Coles et al. 2015; McKenna et al. 2015) and was implicated in increased stranding and mortality of marine turtles (Flint et al. 2015, 2017) and dugong (Flint and Limpus 2013; Wooldridge 2017). These events focused global concern on the resilience of coastal ecosystems to environmental disturbance, particularly in a warming climate (Coles et al. 2015; Brodie and Pearson 2016; York et al. 2017). Furthermore, they highlighted the broad scales over which seagrass meadows can be impacted, an issue that affects management activities and underpins scientific understanding needed for seagrass recovery and to maintain resilience. Generating the necessary data to support this understanding presents a challenge for scientists and managers because of the enormous spatial scale, the remoteness of many coastal habitats (particularly in the Indo-Pacific), and the inherent spatial and temporal variability.

Key to addressing these challenges is access to data for analysis and comparison at appropriate spatial and temporal scales in a user-friendly format. Such data can be used for describing the present condition of ecosystems; understanding long-term trends while accounting for short-term impact-recovery cycles; defining the desired state of the diversity of habitats; establishing ecologically relevant targets that can be used to maintain resilience; and implementing appropriate management frameworks that maintain resilience (Levin and Möllmann 2015; Hallett et al. 2016; Brodie et al. 2017; O'Brien et al. 2017; York et al. 2017; Collier et al. 2020). To this end, there is an increasing use of Geographic Information Systems (GIS) to record, synthesize, and analyze data and to benchmark previous states to inform research, conservation, ecosystem-based management, and marine spatial planning (St. Martin 2004; St. Martin and Hall-Arber 2008). Within the GBRWHA, seagrass research extends back to the 1970s (Birch and Birch 1984) but data collection with a major spatial/mapping focus did not commence until the mid-1980s. Mapping projects since that time range from surveys quantifying seabed benthic cover across the entire GBRWHA funded by a range of government agencies, to those collected under industry contracts for specific areas and where covenants on their use and availability may be in force (Table 1).

In this data article, we compiled several hundred seagrass data sets collected within the GBRWHA into a standardized form with site-specific spatial and temporal information (Fig. 1). We have revisited, evaluated, simplified, standardized, and corrected individual records, including those from two to three decades ago by drawing on the knowledge of one of our authors (RC) who led the early seagrass data collection and mapping programs. We provide this extensive seagrass data set, along with an interactive website, as a tool for the global marine research community to interrogate species distributions and to benchmark trends through time in this iconic World Heritage Area.

Data description

This data set is a compilation of spatial data from seagrass surveys in the GBRWHA from 1984 to 2018. Data sets were collected for five major purposes: (1) an original project that mapped all coastal seagrass to ~ 15 m depth in the 1980s; (2) extensive cross-shelf subtidal surveys in the early to mid-1990s and again in 2003–2005; (3) mapping of intertidal areas as part of an oil spill response atlas, commencing in 2001; (4) smaller and more targeted mapping projects such as for Dugong Protected Area surveys; and (5) a comprehensive series of mapping and monitoring projects for Queensland ports that in some cases extend back more than 20 years

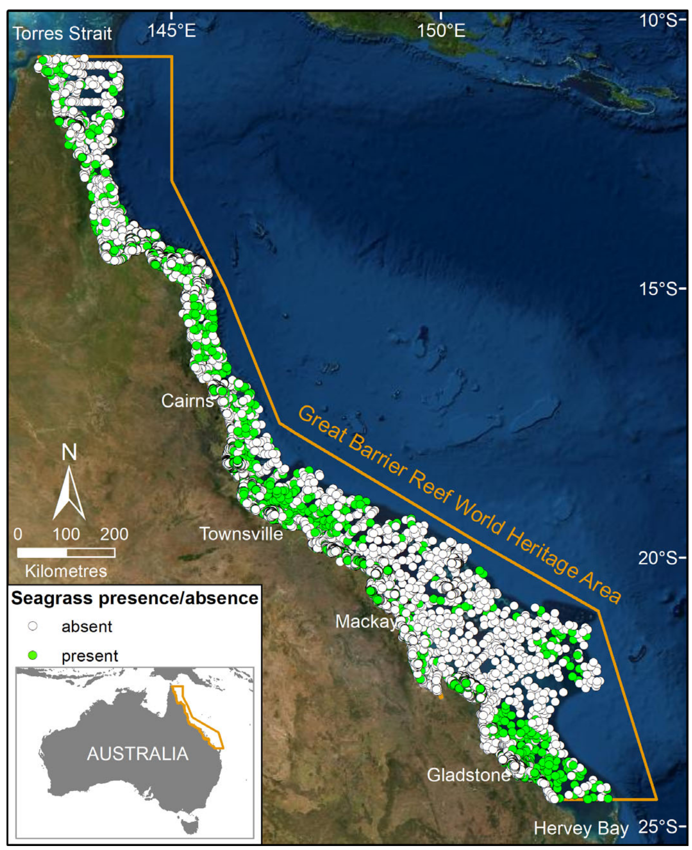

Fig 1. Seagrass presence and absence at sampling sites across the Great Barrier Reef World Heritage Area (orange boundary). Satellite image courtesy: ESRI.

(Table 1). In total, the data set has 81,387 data points that can be viewed interactively through eAtlas or downloaded.

Mapping data for historic records (1980s) were transcribed from original logged and mapped data based on coastal topography, dead reckoning fixes, and RADAR estimations (McKenzie et al. 2014*a*). More recent data (1990s onwards) are GPS located. The GPS was left on during each survey to ensure maximum accuracy in location fixes (± 5 m). The spatial accuracy of data collected pre-GPS in the 1980s is ± 100 m. A range of site descriptions and contextual information is contained in original trip reports and publications (Table 1). Details for each survey site include latitude and longitude, depth in meters below mean sea level (MSL), overall seagrass presence/absence, individual seagrass species presence/absence, dominant sediment, survey month and year, survey name, and sampling method. Seagrass data are limited to the extent of the GBRWHA, with the exception that estuarine seagrass data that extended west into State of Queensland waters is included. Seagrass distributions generated from modeled data are not included in this data set (Coles et al. 2009; Grech and Coles 2010).

Data, metadata, and the interactive website are available at eAtlas at https://doi.org/10.25909/y1yk-9w85 (Carter et al. 2020). We intend these data to be used as a stand-alone product or integrated with other publically available biophysical data sets and models (e.g., https://ereefs.org.au/ereefs) to explain distributions and change. We include and make available data not previously available to the public.

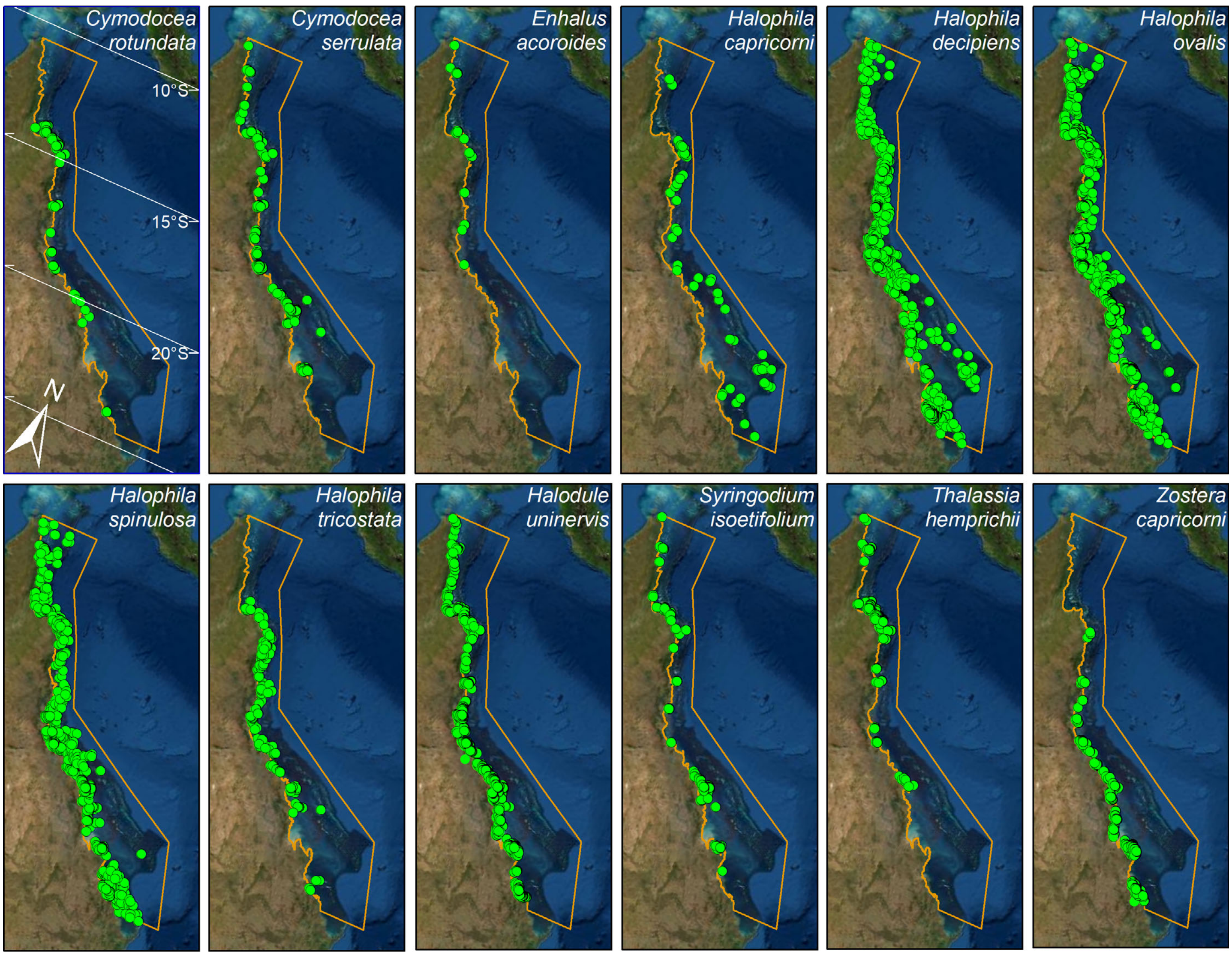

Fig 2. Distribution of 12 seagrass species in our data set (green dots) throughout the Great Barrier Reef World Heritage Area (orange boundary) observed in the site data synthesis. Sites were surveyed to a depth of 117 m but seagrass presence was not recorded deeper than 76 m. Satellite image courtesy: ESRI.

Methods

All spatial site data were converted to point shapefiles with the same coordinate system (GDA94), then compiled into a single-point shapefile using ArcMap (ArcGIS version 10.7, Environmental Systems Research Institute, Redlands, California). Seagrass was present at 32,673 sites. Where seagrass was present, we include presence/absence of 12 seagrass species that were identified using in situ observations (Fig. 2). There are 466 sites in the data set where seagrass is recorded as present but all species columns are "absent" because species was not recorded. Species names have been updated to meet recent taxonomic changes and to ensure consistency in species names in the compilation. Seagrass taxonomy has changed through time, with species such as *Halophila ovata* no longer recognized and some doubts expressed about other species whose morphology is relatively plastic. Field surveys have at times grouped species that are difficult to distinguish outside a laboratory. To address these issues, we amalgamated some species into complexes: *Halophila ovata*, *Halophila minor*, *Halophila colesi/australis*, and *Halophila ovalis* are included as *H. ovalis*. *Halodule pinifolia* is grouped with *Halodule uninervis*. *Zostera muelleri* subsp. *capricorni* has been abbreviated to *Z. capricorni* throughout.

Site data were collected using a variety of survey methods, including:

1. Walking: At each site presence/absence of seagrass and seagrass species were recorded within a site of approximately 10 m^2. Walking surveys were conducted on intertidal banks exposed during low tide (Fig. 3a).
2. Helicopter: As for walking, but seagrass and seagrass species presence/absence was recorded from a helicopter in low hover (<1 m) above each exposed intertidal site of approximately 10 m^2 (Fig. 3b).
3. Boat—diver: As for walking, but seagrass and seagrass species presence/absence was recorded by a diver (free diver or SCUBA diver) at each subtidal site of approximately 10 m^2 (Fig. 3c).
4. Boat—camera: Drop camera and towed camera were used at subtidal sites. Drop cameras were used in shallow subtidal waters (<8 m) or where complex benthic topography meant a towed system was not suitable. For the drop system, a camera was attached to a 0.25 m^2 quadrat frame and lowered to the sea floor, with seagrass and seagrass species presence/absence recorded by an observer watching the footage on a monitor in real time (Fig. 3d,e). At each site, three camera drops were made within an approximate 10 m^2 area. Towed camera systems were used in deeper subtidal sites or areas with relatively flat and soft sea floor. For the towed system, a CCTV camera was attached to a sled, lowered to the sea floor, and towed at drift speed (< 1 knot) for approximately 100 m while footage was observed on a monitor and digitally recorded (Fig. 3f). Post-processing of footage involved pausing the video at 10 random times and recording seagrass and seagrass species presence/absence data in an approximate area of a 0.25 m^2 quadrat frame.
5. Boat—sled: These include samples collected by trawl or a collecting net attached to a sled used for video transect

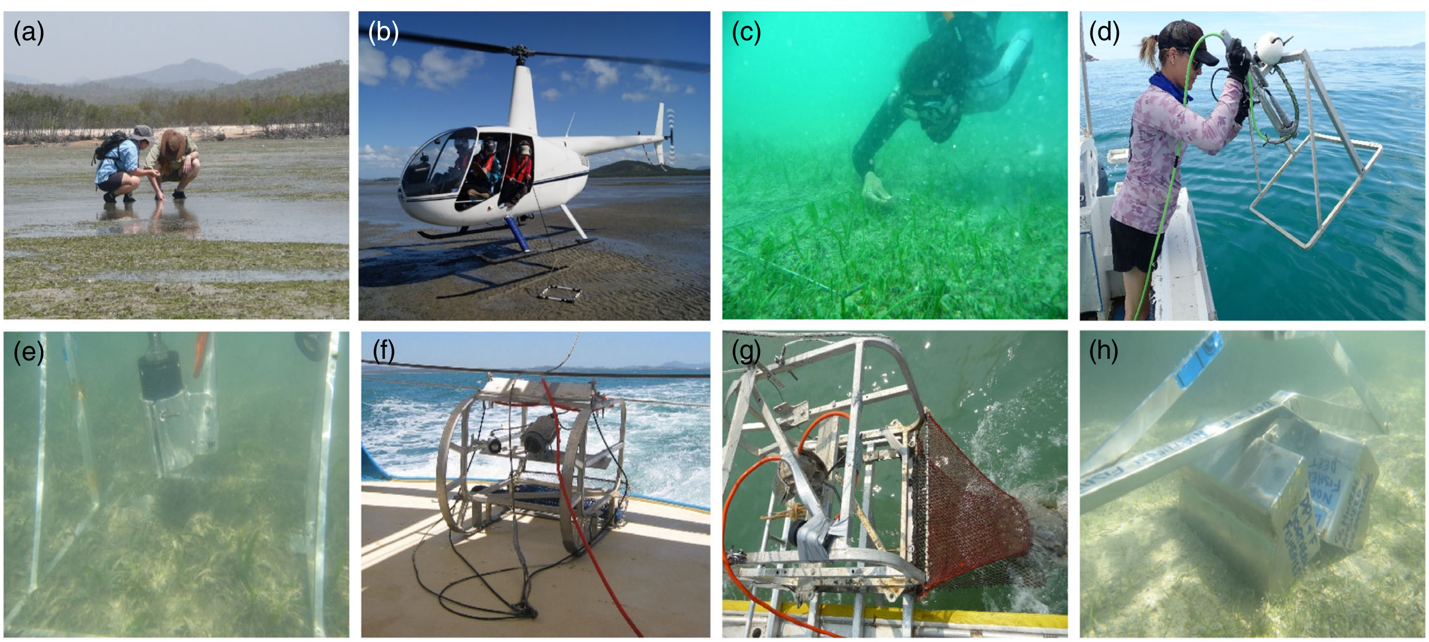

Fig 3. Survey methods for seagrass surveys include: (**a**) walking, (**b**) helicopter, (**c**) diving, (**d**,**e**) camera drop, (**f**) camera tow, (**g**) sled net, and (**h**) van Veen grab. Photographs courtesy TropWATER, JCU.

(Fig. 3g). Seagrass samples were collected during recording of 100 m camera tow (see method, above). Seabed biodiversity samples were collected between 2003 and 2006 by benthic sled, trawl net and towed digital cameras (Detailed methods here: http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2003-021-DLD.pdf). Data were curated to remove outliers and accept only data with a physical and photo record.

6. Boat—grab: van Veen grab samples (grab area 0.0625 m^2) were commonly used to confirm seagrass presence/absence and species identification at subtidal sites where visibility was too low for camera sampling or diving, or in combination with camera sampling (Fig. 3h). Between 1 and 3 grab samples were taken at each site.

Where replicate quadrats, camera frames or grabs were used to assess a site, a positive recording of seagrass and seagrass species in any one replicate was used to characterize the overall site. Survey methods were frequently combined at sampling sites. For example, boat-based surveys used van Veen grabs to confirm species identification where video or divers are used; towed sleds generally have a video mounted to also record transects; and boats were used to confirm assessments for sites surveyed by helicopter but where visibility was low.

The sampling methods to study, describe, and monitor seagrass meadows were implemented by the James Cook University (JCU) Seagrass Group (formerly the Marine Ecology Group at Fisheries Queensland prior to 2013) and CSIRO and tailored to the location and habitat surveyed, and are described in detail in the relevant publications for each data set are provided in Table 1. For long-term monitoring data sets, the most recent report is referenced. In this compilation we have updated and standardized the terms used to describe survey methods.

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, gravel, rock, rubble), removed descriptors such as "fine," "very fine," "coarse," and so on, and replaced redundant terms, for example, "mud" and "silt" are termed "mud."

Depth (m below MSL) for each subtidal site was extracted from the *gbr30* data set (Beaman 2017). Depth for intertidal sites was recorded as 0 m MSL.

Technical validation

The original seagrass data come from a variety of surveys conducted for different purposes and using different methods. Only two projects, GBR Deep-Water and GBR Seabed Biodiversity (Table 1), were sampled in a systematic way across the entire GBRWHA. In the 2009–2018 period, survey coverage is relatively small as the focus of most surveys shifted from large-scale baseline mapping to smaller-scale annual long-term monitoring, particularly in ports (Fig. 4). For early data (1980s and 1990s), each data point was reviewed and compared with original trip logs and recollections of trip participants. Since the original surveys there have been numerous changes to the shoreline, the most obvious through personal observations and satellite imagery being seaward encroachment of mangrove forests and reclamations for marina and coastal development. We have not edited our data set to prevent older data from overlapping newer features.

Users of these data should consider the spatial coverage of each site, which varied according to collection method, for

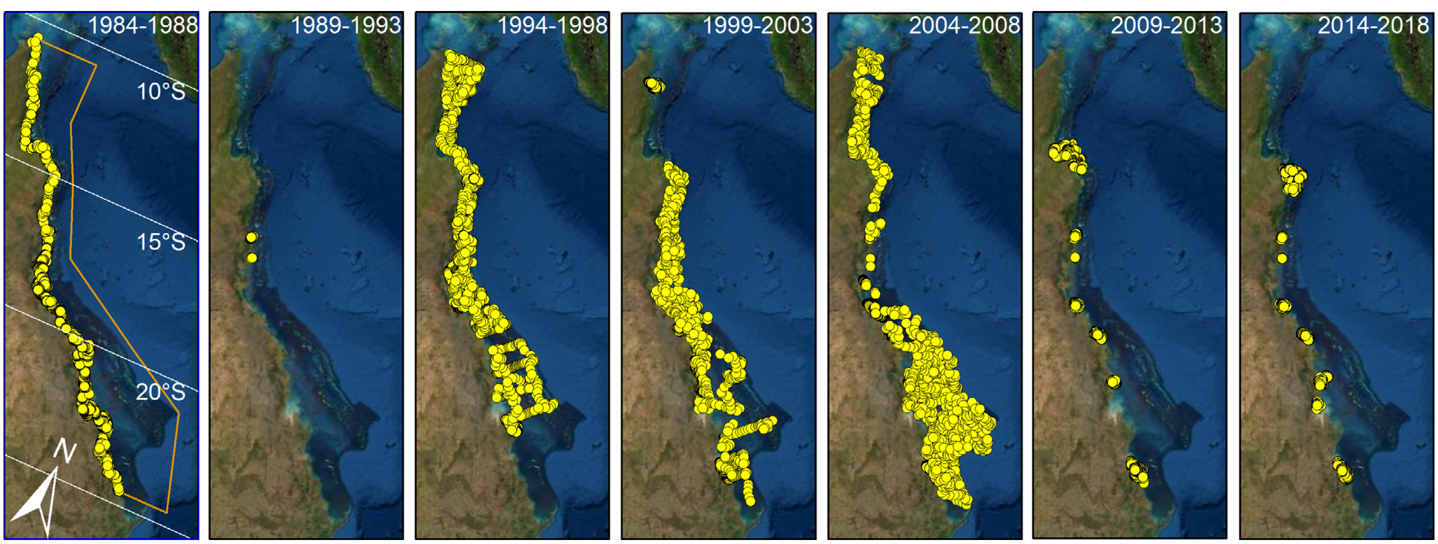

Fig 4. Distribution of sampling sites (yellow dots) throughout the Great Barrier Reef World Heritage Area (orange boundary) in 5-year increments, 1984–2018. Satellite image courtesy: ESRI.

example, sites sampled by van Veen grab (three replicate grabs with an area of 0.0625 m^2 each) have a relatively lower probability of detecting seagrass compared with helicopter, walking and diving surveys where an approximate 10 m^2 area was assessed and presence of seagrasses between individual sampling sites was easily identified to ensure a high confidence in detection level. Trend analysis is most suitable to locations where Queensland ports long-term monitoring surveys occur at least annually (Table 1): Cairns, Mourilyan Harbor, Townsville, Mackay, Hay Point, Abbot Point, and Gladstone. Outside of these locations the temporal resolution of data is limited.

Most data (80%) come from the austral growing season (August–January for most Australian tropical seagrass species). It is important to understand that data collected in the senescent season (February–July) may record deep-water *Halophila* species as absent as they may only be present as a seed bank through the colder months of the year (York et al. 2015; Chartrand et al. 2018). Seagrasses were recorded at around 40% of sites; however, many surveys were targeted at known meadows (e.g., ports long-term monitoring annual surveys of designated monitoring meadows), so sites were not always randomly assigned to include areas unlikely to have seagrass. Sites include depths down to 123 m but seagrass was not recorded below 76 m. Only species of the genus *Halophila* were found in sites below 40 m.

There is an earlier version of the seagrass site data on eAtlas which includes similar information which is still available (1984–2014; https://eatlas.org.au/nesp-twq-1/gbr-seagrass-mapping-3-1).

Data use and recommendations for reuse

Worldwide, the management and conservation of marine ecosystems require accurate spatial data at a scale that matches human activities and impacts (Hughes et al. 2005; Halpern et al. 2008; Visconti et al. 2013; Lagabrielle et al. 2018). The synthesis of large spatial data sets provides a valuable tool that can be used to inform marine spatial planning, ecosystem-based management, research, and education (Halpern et al. 2008). A key strategy to assist this is to ensure we validate and share data that have been collected over the years (Rajabifard et al. 2005). This project makes publicly available one of the world's most comprehensive seagrass data sets. Importantly, we include site data from previously unreleased industry-funded surveys. Also important for users of these data is we include location information not just for sites that were surveyed and seagrass recorded, but also location information where seagrass was absent.

Spatial data are an increasingly important tool in the assessment and management of the marine environment (Hughes et al. 2005; Rajabifard et al. 2005; St. Martin and Hall-Arber 2008). The immediate scientific value of this project and its approach already have been widely demonstrated, with earlier subsets of this synthesis used to answer a range of key ecological questions including probability modeling of seagrass distributions in the GBRHWA's deep-water lagoon (Coles et al. 2009) and inshore region (Grech and Coles 2010); seagrass risk exposure modeling (Grech et al. 2011, 2012); propagule distribution (Grech et al. 2016); connectivity among meadows (Tol et al. 2017; Grech et al. 2018); understanding changes in seagrass meadow health using MODIS imagery (Petus et al. 2014); and defining the desired state of seagrass communities in the Townsville region (Lambert et al. 2019; Collier et al. 2020). We now make available the data behind these analyses and data updated to 2018 for the global community to use and compare.

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Conflict of Interest

The authors declare no conflicts of interest to declare.

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