

POST-FLOOD SEAGRASS MONITORING IN THE GREAT SANDY MARINE PARK - 2024

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Authored by:

Tim Smith, Paul York, Chris van de Wetering, Carissa Reason,
Laura Forte Valiente, Cath Bryant and Michael A. Rasheed

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Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) James Cook University

Townsville Phone: (07) 4781 4262 Email: TropWATER@jcu.edu.au

Web: www.jcu.edu.au/tropwater/

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Contacts

For more information contact: Michael Rasheed, TropWATER, James Cook University
michael.rasheed@jcu.edu.au

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EXECUTIVE SUMMARY

Flooding of the Mary River in early 2022 resulted in persistent flood plumes in the Great Sandy Marine Park (GSMP), leading to substantial impacts to seagrass meadows, and declines in dependent species including dugongs and green sea turtles. In response, the Queensland Department of the Environment, Tourism, Science and Innovation (DETSI) commissioned James Cook University (JCU) to conduct a series of post-flood assessments of seagrasses in Hervey Bay and the Great Sandy Strait funded by the joint Australian-Queensland government funded Disaster Recovery Funding Arrangements Environmental Recovery Program. Surveys were conducted in:

- May 2022 (York et al. 2022) during a typical low seagrass growth period
- October/November 2022 (Bryant et al. 2023) during a typical high seagrass growth period
- October/November 2023 (Bryant et al. 2024) assessing recovery 30 months post impact.

While improvements to seagrasses within the GSMP were recorded by the end of 2023, with many areas showing the beginnings of recovery, seagrasses remained in a vulnerable state. This combined with the importance of seagrasses to the values of the marine park led to a longer term seagrass monitoring strategy being recommended. JCU in collaboration with DESTI developed a monitoring strategy based on examining 13 large areas spread across key sections of the park, coupled with a network of light and temperature monitoring to assess seagrasses (Bryant et al. 2024). The intent is to have this program sample seagrasses on an annual basis to provide regular and timely advice, with the first of these surveys commissioned for late 2024 and results presented in this report.

In Hervey Bay, seagrass distribution three months after the flood (744 km²) was less than a third of that found during historical (1998) surveys (2,307 km²), and where seagrass existed, density was extremely low (York et al. 2022). In October 2022, nine months after the flood, seagrass distribution had increased significantly (1343 km²), and by November 2023 total seagrass distribution in Hervey Bay (1700 ± 404 km²) had increased to be almost 75% of the 1998 distribution. Average seagrass biomass and percent cover had increased significantly at subtidal and deep-water meadows, but the majority of intertidal seagrass remained low in density (around 1 to 2%). In the Great Sandy Strait, the total area of intertidal seagrass mapped from August to November 2023 (53 km²) had more than tripled since the first post-flood survey in May 2022 (12 km²) and was very similar to the total area of seagrass mapped in December 1998 (53 km²). However, little sub-tidal seagrass remained and seagrass biomass and cover remained well below historical levels for the majority of areas.

In 2024 there was a further marked recovery in seagrasses throughout the GSMP. Seagrasses within the Great Sandy Strait had substantial improvements in abundance measured as percent cover and biomass with significant increases recorded compared with 2022 and 2023. Some areas, particularly around Tin Can Bay, Urangan and at Moon Point had seagrass approaching densities not seen since the late 90's. In Hervey Bay seagrasses in the deepwater monitoring blocks had also maintained or improved upon the recovery recorded between 2022 and 2023. There were also large increases in the shallow coastal meadows of the Bay, however, these remain below historical highs. The shallow subtidal meadow offshore from Burrum Heads fared worst of all the habitats with modest reduction in size but a large reduction in biomass compared to 2023.

Monitoring of benthic light (Photosynthetically Active Radiation - PAR) at stations ranging from intertidal meadows through to the offshore deep-water seagrass areas likely explains some of the spatial variability in seagrass recovery over the past year. PAR levels remained substantially above growth requirements for key intertidal species (*Halodule uninervis* and *Zostera muelleri*) in the coastal meadows of Hervey Bay and the Great Sandy Strait during 2023 to 2024. Light conditions at shallow subtidal (Toogoom) and deeper sites (HMAS Toobruk and Woodgate) in Hervey Bay remained above the minimum light requirements for *Halophila* species (Collier et al. 2016) for large parts of the 2024

seagrass growing season, however, there were also periods when they fell below these limits possibly contributing to the relatively poorer seagrass recovery in these habitats.

The recovery recorded in 2024 was a promising sign for seagrasses, dugongs and turtles in the region, with feeding dugong herds recorded back in the Great Sandy Strait and turtle strandings in the region reducing to half of the previous two years. While the results of the current survey are overall positive for seagrass in the GSMP following the large-scale floods in early 2022, the continuation of annual monitoring is important, particularly following local flash flooding around Hervey Bay following Tropical Cyclone Alfred in March 2025. We have recommended a continuation of the seagrass monitoring approach adopted in the current survey in 2025 and, ideally, on an annual basis into the future with large scale surveys every 5 years to synchronise with dugong aerial surveys. We have also suggested a range of other measures that could be implemented (i.e. continued benthic light monitoring and seed-bank assessments) to improve the understanding of seagrass dynamics and recovery in the region and ensure that management of seagrasses and associated fauna are well informed in the future.

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INTRODUCTION

Study area

The Great Sandy Marine Park on the eastern subtropical coast of Australia, extends from Baffle Creek in the north to Double Island Point in the south. It encompasses the Bundaberg Coast, Hervey Bay, Great Sandy Strait, Tin Can Inlet and the waters seaward to three nautical miles off the east coast of K'gari (Figure 1). The marine environments are among the most biodiverse in Australia and in 2009 contributed to the recognition by UNESCO of the globally significant Great Sandy Biosphere (Ribbe 2014). The region also hosts the east coast's largest dugong population south of Torres Strait and six of the world's seven species of endangered and vulnerable marine turtles. Of these, loggerhead, green and flat-back turtles regularly nest along the region's foreshores.

Hervey Bay extends from the relatively narrow opening of the Great Sandy Strait in the south at Urangan and is bound by the Queensland coast on the western side north to Bundaberg and by K'gari (Fraser Island) on the eastern side with an opening of about 80 km width in the north (Figure 1). The average depth of the bay is approximately 20 m (Ribbe 2014). There are four main river catchments that influence the marine waters of Hervey Bay; the Mary, Burrum, Elliott and Burnett (Figure 1). These rivers discharge turbid flood waters during major flood events that establish a frontal structure along the western region of the bay with a recovery time of approximately 2 months (Ribbe 2014). Hervey Bay contains one of the largest expanses of deep-water (> 10 m) seagrasses on the east coast of Queensland (Lee Long et al. 1993), which support large numbers of dugongs (Preen and Marsh 1995, Sheppard et al. 2006, Sheppard et al. 2007) and green turtles (Hazel and Gyuris 2006).

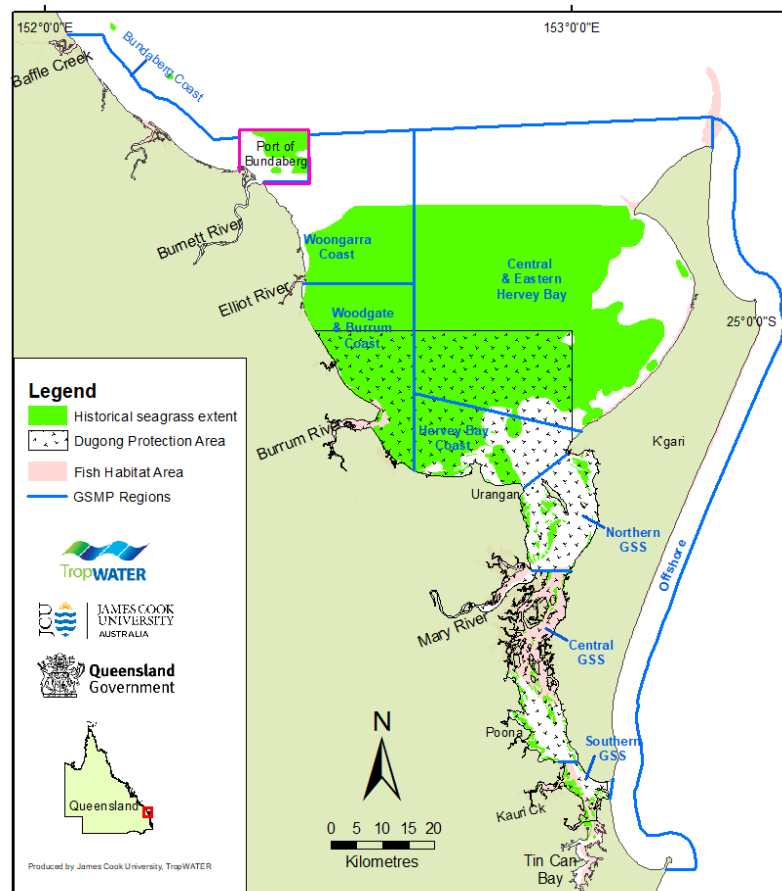


Figure 1. Map of the Great Sandy Marine Park.

The Great Sandy Strait is a sand passage estuary that encompasses an area of around 930 km² between the mainland and K'gari, from Urangan in the north to Tin Can Inlet in the south (Figure 1). The Mary River flows into the northern section of the Great Sandy Strait and the smaller catchments of Boonooroo Creek, Kauri Creek and Tin Can Estuary flow into the southern section (Figure 1). The Great Sandy Strait is the largest area of tidal swamps within the Southeast Queensland bioregion, consisting of intertidal sand and mud flats, extensive seagrass beds, mangroves, salt flats and saltmarshes. The region supports a wide range of migratory and other birds, fish, crustaceans, dugong, turtle and

dolphins and in 1999 was listed as a Wetland of International Importance under the Ramsar agreement (RAMSAR 1999).

Seagrasses of the Great Sandy Marine Park

Hervey Bay

Historically, seagrass meadows in the bay are extensive with the distribution dominated by deep-water communities of the colonising species *Halophila spinulosa*, *Halophila ovalis* and *Halophila decipiens* (Figure 2). Intertidal meadows also occur predominately on sand banks between Urangan and Burrum Heads and generally contain low-biomass assemblages of *Zostera muelleri* (syn. *Zostera capricorni*), *Halodule uninervis* and *H. ovalis* (Preen et al. 1995, McKenzie 2017, McKenzie 2000). Seagrass Watch intertidal monitoring transects on the southwestern shore of the bay show fluctuations in seagrass abundance over the past 20 years. Seagrass at Burrum Heads fluctuated with peaks of around 30-40% cover and was <10% in December 2021 prior to the 2022 flood event. Adjacent to the Hervey Bay township at Dundowran, seagrass cover has remained <1% since at least 2015 (Seagrass Watch 2024).

Great Sandy Strait

Seagrasses in the Great Sandy Strait were first mapped in 1973 with six species observed including extensive dense meadows of *Cymodocea serrulata* on the western shore to the west of the Tin Can Bay and *Z. muelleri*, *H. uninervis* and *H. ovalis* dominating meadows along intertidal mudflats (Dredge 1977). A series of broad-scale seagrass mapping surveys in the 1990s and early 2000s using aerial photography, aerial and dive surveys combined with long-term monitoring transects found dynamic meadows that at their peak included dense *Z. muelleri* with *H. ovalis* meadows on the mud/sand banks throughout the region (McKenzie and Campbell 2003). Seagrass Watch intertidal monitoring transects throughout the Great Sandy Strait also show fluctuating seagrass abundance since 1999. Seagrass monitored at Urangan has come and gone on an irregular basis with a peak of around 80% cover but has remained low (<5% cover) for several years prior to the 2022 flood event. Seagrass cover at Boonooroo and Tinnanbar has also fluctuated over the course of monitoring, but abundance was low (<1% cover) in December 2021 prior to the 2022 flood event (Seagrass Watch 2024).

Recent Impacts to seagrasses of the Great Sandy Marine Park

In early 2022 two significant flood events in January and February-March dispersed suspended sediments from the Mary River and other catchments into Hervey Bay and Great Sandy Strait (Bryant et al. 2024). The first event was driven by a rain depression brought by the remnants of tropical cyclone Seth with discharge in the Mary River at Home Park peaking at 663,655 ML day⁻¹ on 9th January 2022. The second flood event saw river discharge in the Mary River at Home Park peak at 657,944 ML day⁻¹ on 28th February 2022. The plume was largely constrained to the mainland coast and Great Sandy Strait during January and extended further offshore into the southern and western regions of Hervey Bay during March (Lewis et al. 2022).

Following concerns about the impact of the floods to seagrasses, dugongs and turtles, DESTI entered into a collaborative agreement with JCU TropWATER to map and monitor the post-flood seagrass distribution in Hervey Bay and Great Sandy Strait in May 2022 (York et al. 2022, Bryant et al. 2023) October/November 2022 (Bryant et al. 2023) and again between August and November 2023 (Bryant et al. 2024). These surveys were the first time bay wide seagrass distribution had been assessed in more than 20 years. In Hervey Bay, seagrass distribution three months after the flood (744 km²) was less than a third of that found during historical (1998) surveys (2,307 km²), and where seagrass existed, density was extremely low (York et al. 2022). In October 2022, nine months after the flood, seagrass

distribution had increased significantly (1343 km^2), and by November 2023 total seagrass distribution in Hervey Bay ($1700 \pm 404 \text{ km}^2$) had increased to be almost 75% of the 1998 distribution. Average seagrass biomass and percent cover had increased significantly at subtidal and deep-water meadows, but the majority of intertidal seagrass remained low in density (around 1 to 2%). In the Great Sandy Strait, the total area of intertidal seagrass mapped from August to November 2023 (53 km^2) had more than tripled since the first post-flood survey in May 2022 (12 km^2) and was very similar to the total area of seagrass mapped in December 1998 (53 km^2). However, little sub-tidal seagrass remained, and seagrass biomass and cover remained well below historical levels for the majority of areas (Bryant et al. 2024).

Following the three large scale post flood assessments a longer-term monitoring strategy based on annual surveys of representative seagrass areas across the GSMP combined with PAR and Temperature monitoring was recommended (Bryant et al. 2024; Rasheed et al. 2023). This report presents findings from the first of these assessments in the Great Sandy Marine Park conducted from August to November in 2024.

	<i>Zostera muelleri ssp capricorni</i> • Narrow and wide leaf blades • 5 longitudinal veins and cross veins which form a mesh across the leaf blade • Rounded leaf tip • Leaf grows straight from the rhizome i.e. no shoots
	<i>Halodule uninervis</i> • Narrow leaf blades 0.25-5mm wide • Trident leaf tip ending in three points • 1 central longitudinal vein which does not usually split into two at the tip • Usually pale ivory rhizome, with clean black leaf scars along the stem • Dugong preferred food
	<i>Halophila spinulosa</i> • Fern like • Leaves arranged in opposite pairs • Erect shoot up to 15cm long • Found at subtidal depths
	<i>Halophila ovalis</i> • Small oval shaped leaves (0.5 - 2cm long) • 8 or more cross-veins on leaf • No hairs on leaf surface • Dugong preferred food
	<i>Halophila decipiens</i> • Small oval leaf blade (1-2.5cm long) • 6-8 cross veins • Leaf hairs on both sides • Found at subtidal depths
	<i>Cymodocea serrulata</i> • Flat, strap-like leaves 5-9mm wide • Serrated leaf tip • Robust strong rhizome • 13-17 longitudinal veins • Leaves 6-15cm long
	<i>Syringodium isoetifolium</i> • Cylindrical in cross section (spaghetti like) • Leaf tip tapers to a point • Leaves 7-30cm long • Found on shallow subtidal reef flats and sand banks

Figure 2: Seagrass species found in the Great Sandy Marine Park. *C. serrulata* and *S. isoetifolium* have not been observed in the region since 1998 and 2002 respectively (McKenzie and Campbell 2003).

METHODS

Site description

Our study area was bound in the north by a line connecting Bargara on the mainland to just north of Rooney Point on K'gari, and encompassed the area between the mainland and K'gari to the southern extent of the Great Sandy Strait including Tin Can Bay (Figure 3). Just outside of this line, a survey block in the General use zone (GUZ) was established to represent seagrass beyond previous surveys. A line between Urangan on the mainland and Moon Point on K'gari defined waters belonging to Hervey Bay (to the north) and Great Sandy Strait (to the south).

Within this broader area 13 sampling “blocks” were selected for regular long-term monitoring (Figure 3). These blocks encompassed seagrass meadows and areas that were representative of the different seagrass community types and ensured a spread of assessments across the major regions of the GSMP including coastal meadows in Hervey Bay, deep offshore meadows and large sections of seagrass within the Great Sandy Strait from south of the Urangan marina, across to K'Gari and south to Tin Can Bay (Figure 3). The areas were also selected to ensure key regions and zones within the GSMP were assessed.

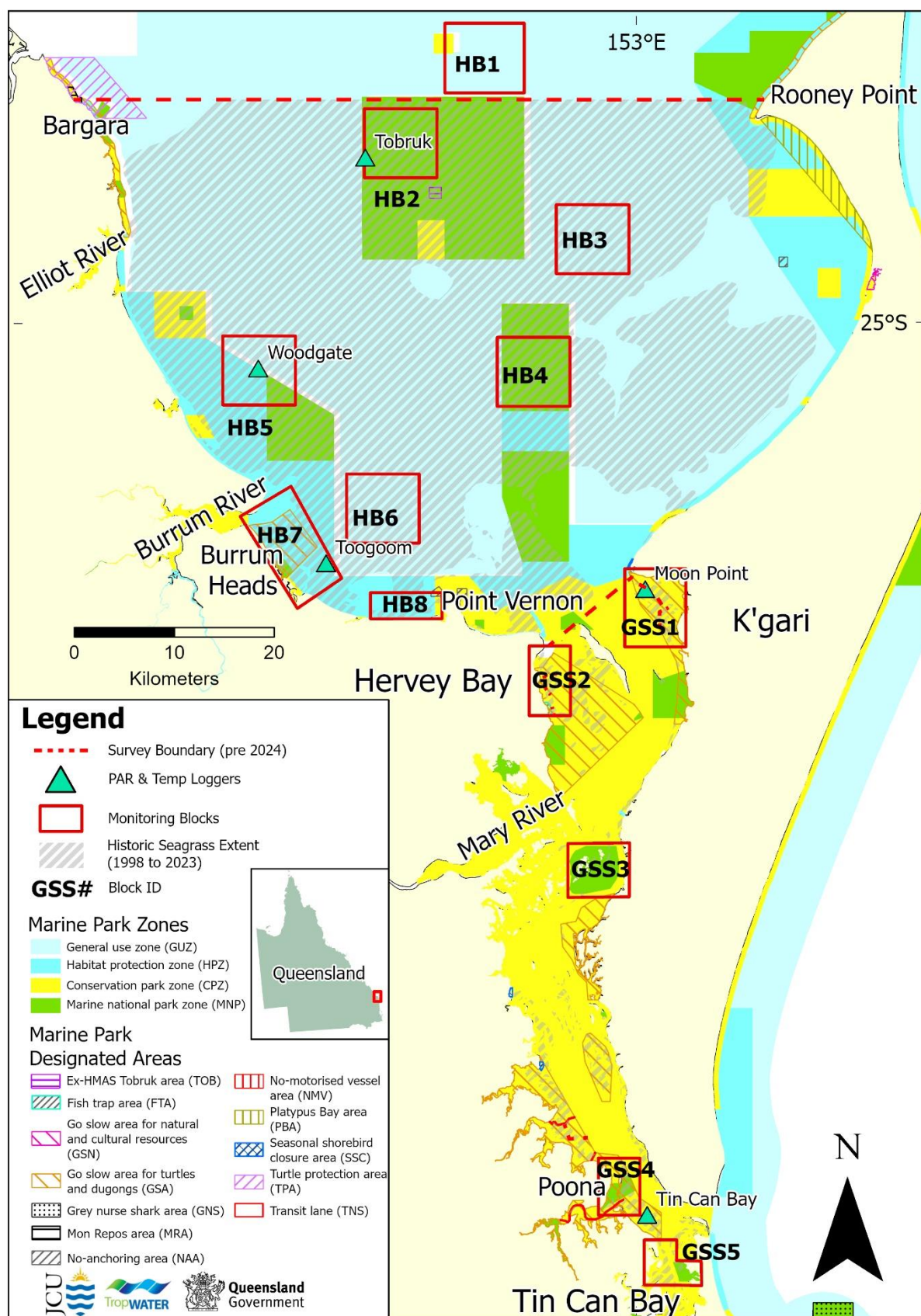


Figure 3. Location of seagrass monitoring blocks and water quality loggers in the Great Sandy Marine Park. Historical seagrass extent from Lee Long et al. 1992 and McKenzie 2017.

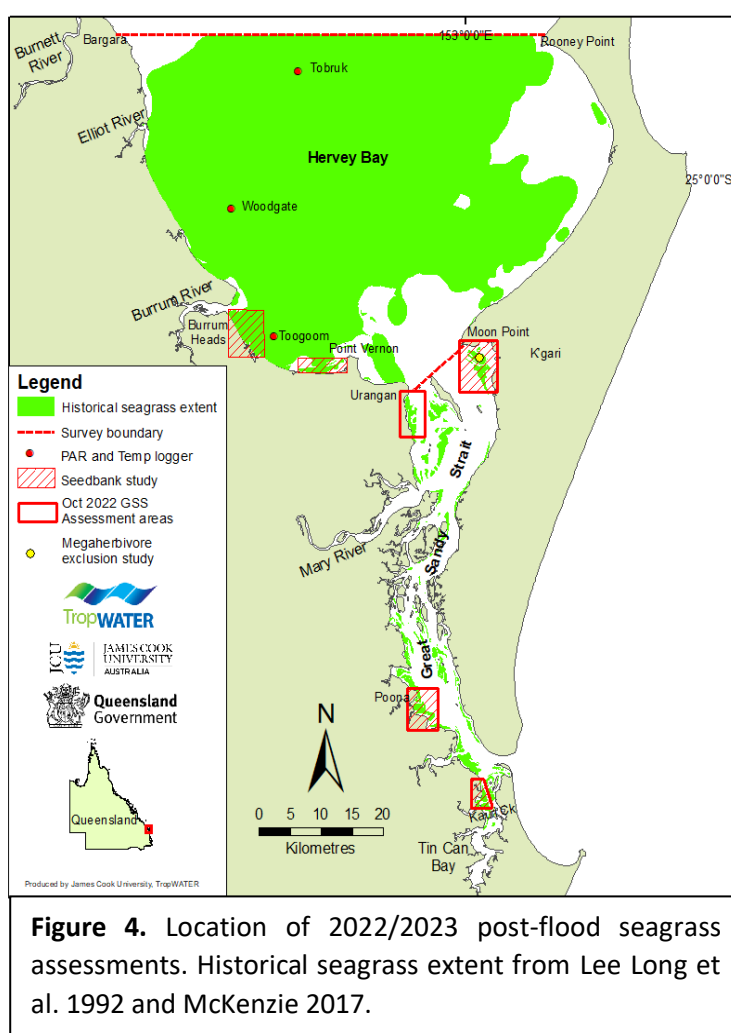
Seagrass monitoring, habitat mapping and Geographic Information System

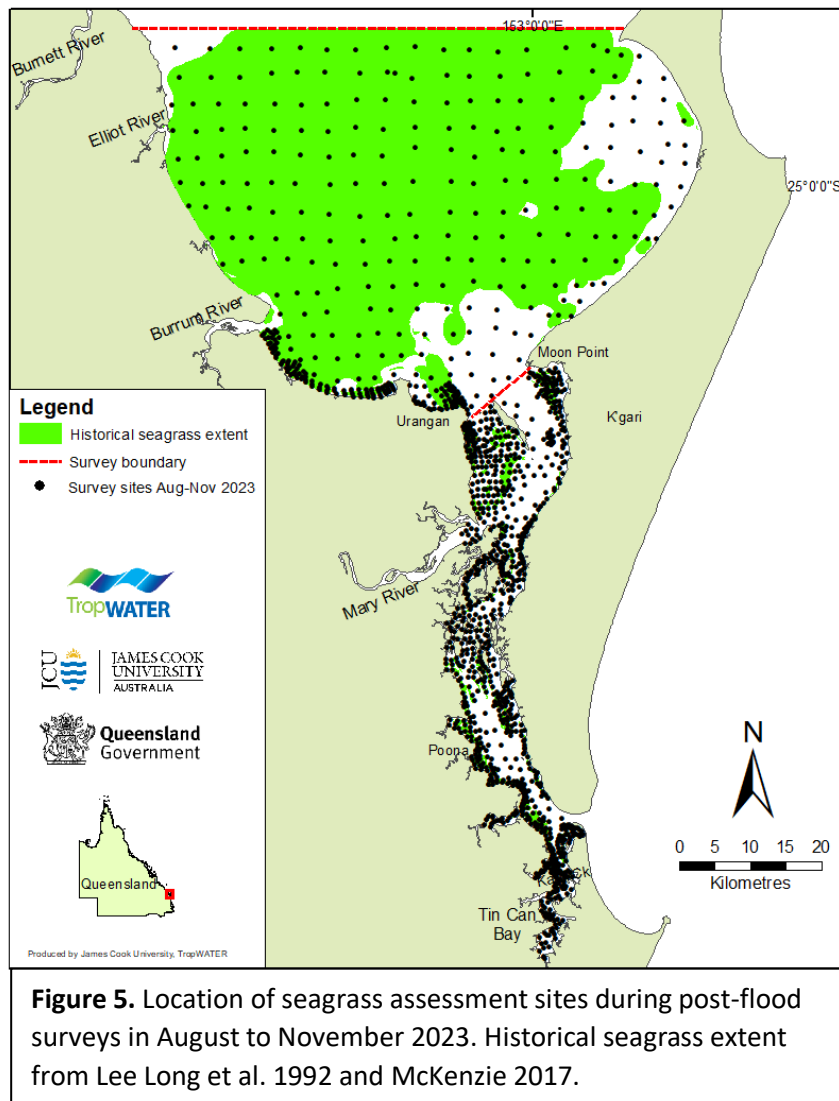
Site selection

Sampling intensity during post-flood seagrass assessments has varied slightly during each survey. The first post-flood survey (May 2022) covered all intertidal, shallow subtidal and deep-water areas of Hervey Bay (York et al. 2022) as well as intertidal areas of Great Sandy Strait (Bryant et al. 2023). The survey did not cover subtidal areas of Great Sandy Strait which were thought to contain minimal seagrass habitat.

The second post-flood survey (October/November 2022) again covered all intertidal, shallow subtidal and deep-water areas of Hervey Bay but focused on a subset of intertidal areas in Great Sandy Strait (Bryant et al. 2023). Based on the distribution of seagrass meadows in May 2022, four locations were selected to track intertidal seagrass recovery during peak seagrass growth in October 2022; Moon Point, Urangan, Poona and Tin Can Bay (Figure 4). These locations encompassed a large portion of the seagrass remaining in the Great Sandy Strait following the flood event in the May 2022 survey and represented the main community types in the region.

During the final post-flood survey (August to November 2023), all seagrass habitat in both Hervey Bay and Great Sandy Strait was assessed, including intertidal, shallow subtidal and deep-water areas. This survey covered the same extent as the 1998 survey and provided a direct comparison to historical pre-flood levels of seagrass in the region. In intertidal areas, survey sites were spread throughout the banks in a stratified way with a higher intensity of sites around seagrass meadow boundaries or changes in species composition with a random/haphazard allocation of sites within meadow boundaries. Where seagrass meadows extended into subtidal areas, sites continued along a seaward transect to map the subtidal edge of the meadow. In offshore deep-water areas in Hervey Bay, sites were spaced at equal intervals in a grid pattern (Figure 5).





The most recent 2024 survey is the first long-term monitoring survey utilising survey blocks to represent the main seagrass species and community types and to track their response to future disturbances (Figure 3). In both the Hervey Bay and the Great Sandy Strait, blocks were chosen in areas where the general seagrass extent was consistent over previous surveys (since May 2022), in proximity to light loggers to monitor links between benthic light and seagrass growth, and in areas that were newly classified Marine National Park zones (MNPZ), Go slow area for turtles and dugongs (GSA), and within Conservation Park Zones (CPZ) (Figure 3). An additional block was selected outside of the Marine National Park Zone as a representative for deep-water seagrass in the General use zone (GUZ). In the Great Sandy Strait, an additional block was chosen in proximity to the Mary River mouth to track the effects of river flow on seagrasses, as well as an additional block in an area that has been noted as having high dugong activity. Subtidal blocks contained 16 sites, strategically spaced at intervals in a grid pattern to ensure statistical robustness. In the GUZ, the subtidal block was sampled at a slightly higher intensity, with 20 sites. Intertidal blocks were distributed across the banks in a stratified manner, with a higher density of sites near seagrass meadow boundaries and areas of species composition change. Within meadow boundaries, sites were allocated randomly or haphazardly.

Methods and equipment

Methods for seagrass assessment followed previous surveys and employed standard and extensively reviewed techniques applied for monitoring of seagrasses and benthic communities in Queensland. Techniques also take into account logistical issues associated with naturally high water turbidity and the presence of dangerous marine animals. Sampling methods were based on existing knowledge of benthic habitats and physical characteristics of the location such as depth, visibility and logistical and safety constraints.

Two sampling techniques were used (Figure 6):

1. Intertidal areas: Helicopter surveys at low tide;
2. Subtidal areas: Boat based underwater digital camera mounted on a drop frame.



Figure 6. Methods for mapping and monitoring seagrass for subtidal meadows using (A, B) digital camera mounted on a drop frame connected to CCTV, and for intertidal meadows (C) helicopter aerial surveillance.

At each survey site, seagrass habitat observations were recorded using TropWATER's standard coastal benthic survey data sheet adapted to be compatible with the Queensland Intertidal and Subtidal Ecosystem Classification Scheme (DEHP 2017). Data recorded included seagrass species composition, above-ground biomass, seagrass percent cover, percent algal cover, depth below mean sea level (MSL), substrate composition and % consolidation, time and position (GPS). The percent cover of other major benthos at each site was also recorded (Appendix 1).

Where seagrass was present, seagrass above-ground biomass was measured using a “visual estimates of biomass” technique (Kirkman 1978, Mellors 1991). At camera drop and helicopter sites this technique involved an observer ranking seagrass biomass within three randomly placed 0.25m² quadrats at each site (Figure 6A-C). Percent cover of seagrass and species composition was also recorded for each quadrat.

A photo/video record of quadrats for seagrass sites was also collected for subtidal sites and, when necessary, a Van-veen sediment grab was used to collect a sediment sample for visual classification as well as to confirm species viewed on the screen (Figure 7). For subtidal sites in addition to the 3 quadrat assessments the camera was set within a few metres of the bottom and allowed to drift for approximately 20m to pick up the presence of any sparsely distributed seagrass at the site. For the intertidal helicopter survey, seagrass species were confirmed using a rake dragged through the sediment to collect a sample (Figure 8).

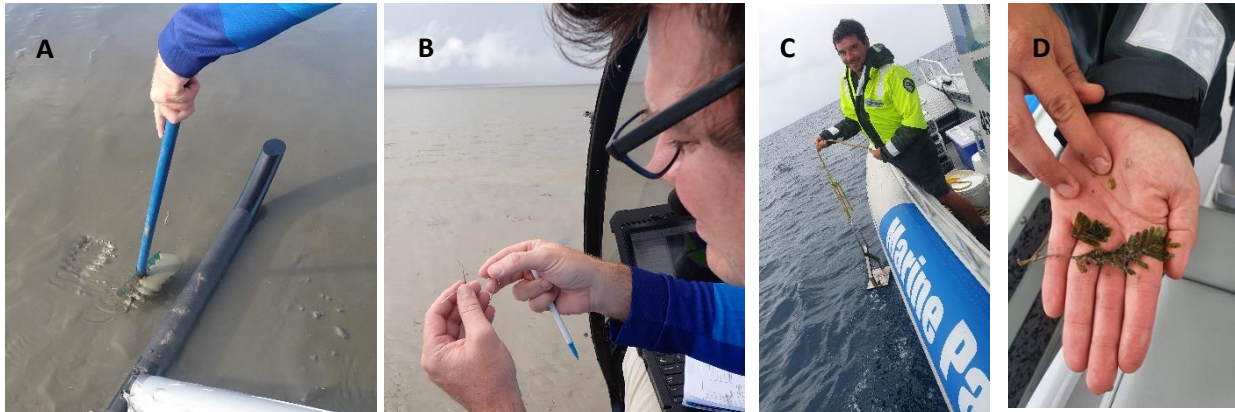


Figure 7. Collecting seagrass and sediment samples for species confirmation in Hervey Bay and Great Sandy Strait from a helicopter using a rake (A & B) and from a boat using a Van-veen grab (C & D)

Analysis

Survey data were entered into a Geographic Information System (GIS) using ArcPro 3.4.0®. Four GIS layers were created to describe seagrass in the survey area: a site layer, meadow layer, biomass interpolation layer and percent cover interpolation layer.

- **Site Layer:** The site (point) layer contains data collected at each site, including:
 - Site number
 - Temporal details – Survey date and time.
 - Spatial details – Latitude, longitude, depth below mean sea level (dbMSL; metres) for subtidal sites.
 - Habitat information – Sediment type; seagrass information including presence/absence, percentage cover, above-ground biomass (total and for each species) and biomass standard error (SE); dugong feeding trail (DFT) presence/absence.
 - Sampling method and any relevant comments.
- **Meadow layer:** The meadow (polygon) layer provides summary information for all sites within each meadow, including:
 - Meadow ID number – A unique number assigned to each meadow to allow comparisons among surveys
 - Temporal details – Survey date.
 - Habitat information – Mean meadow biomass $\pm$ standard error (SE), mean meadow percent cover, meadow area (hectares), number of sites within the meadow, seagrass species present, meadow community type and density (Tables 1 & 2), meadow landscape category (Figure 8).
 - Sampling method and any relevant comments.

- *Interpolation layers*: The interpolation (raster) layers describe spatial variation in seagrass biomass or percent cover across each meadow and were created using an inverse distance weighted (IDW) interpolation of seagrass site data within each meadow.

Seagrass meadow boundaries were determined from a combination of techniques. Exposed inshore boundaries were guided by recent satellite imagery of the region (Source: ESRI; Google Earth). Subtidal boundaries were interpreted from a combination of subtidal survey sites and the distance between sites, field notes, depth contours and recent satellite imagery. Meadow area was measured using the calculate geometry function in ArcPRO®.

Table 1. Nomenclature for Queensland 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 in Hervey Bay and the Great Sandy Strait.

Density	Mean above-ground biomass (g DW m ⁻²)				
	<i>H. uninervis</i> (thin)	<i>H. ovalis</i> <i>H. decipiens</i>	<i>H. uninervis</i> (wide)	<i>H. spinulosa</i>	<i>Z. muelleri</i>
Light	< 1	< 1	< 5	< 15	< 20
Moderate	1 - 4	1 - 5	5 - 25	15 - 35	20 - 60
Dense	> 4	> 5	> 25	> 35	> 60

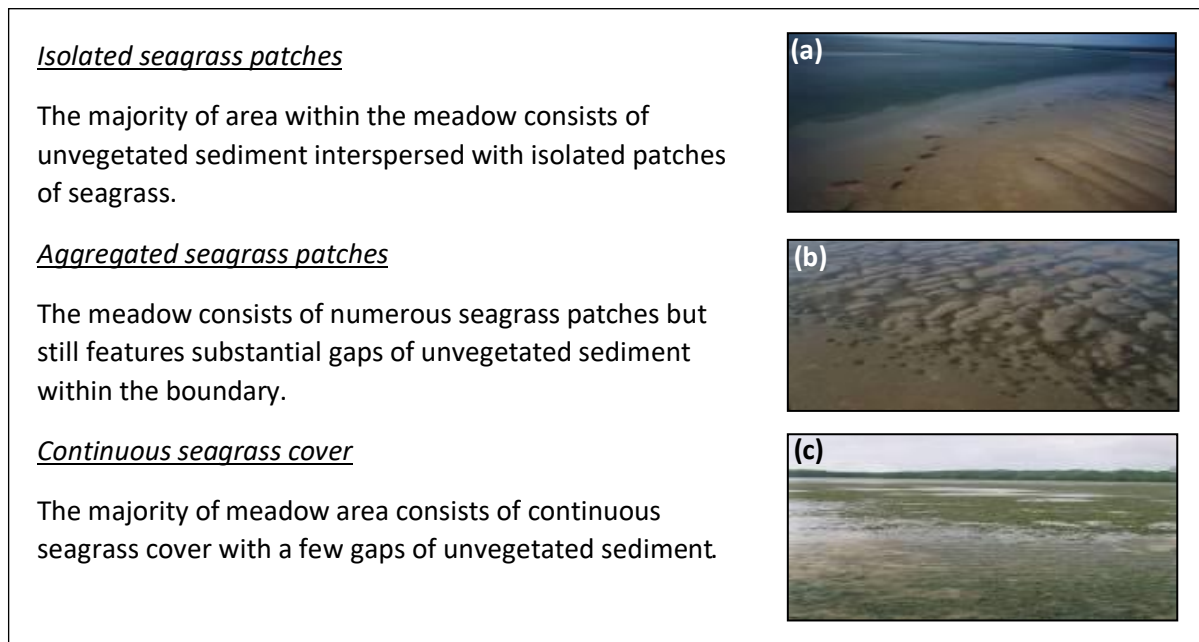


Figure 8. Seagrass meadow landscape categories: (a) Isolated seagrass patches, (b) aggregated seagrass patches, (c) continuous seagrass cover.

Statistical analyses

Seagrass percent cover and biomass were compared across surveys (Autumn 2022, Spring 2022, Spring 2023, Spring 2024) using Generalised Linear Mixed Models (GLMM) and Generalised Linear Models (GLM) with Tweedie distributions. GLM was preferred to Generalised Additive Models because there are only 4 survey time points which could lead to model overfitting and misrepresentation of the data. Tweedie distributions are suitable for skewed, non-negative data such as biomass and cover data from Hervey Bay. Tweedie distributions were used with a log link and the optimal power which is calculated for each model depending on the data distribution. Overall seagrass biomass and percent cover, and, for deep-water and shallow water blocks in Hervey Bay and blocks the Great Sandy Strait, were compared across surveys using a GLMM in separate analysis. Survey was treated as a categorical predictor variable and sampling block as a random variable. Block HB1 was removed from analysis for overall and Hervey Bay deep-water biomass and cover because it was only surveyed in 2024. Changes in seagrass biomass and percent cover between surveys in each block were analysed using a GLM where survey was the only predictor variable. Plots of model residuals and q-q plots of normalised results were inspected for each analysis to determine if the model was appropriate. Analysis of variance (ANOVA) was used to determine overall model significance and post hoc Tukey's tests were used to determine differences between surveys. Changes in seagrass area across the survey, in Hervey Bay and the Great Sandy Strait and within each block was presented visually because there is no replication and therefore no analysis can be done. Seagrass area data from surveys in 1998 (McKenzie 2017) and 2002 (McKenzie and Campbell 2023) were also included where possible to provide historical context of seagrass condition in the current survey. Direct comparison of seagrass biomass and percent cover could not be done between these surveys and more recent surveys due to differences in survey methods. All analysis was done in R studio using the packages *glmmTMB*, *statmod*, *tweedie*, *ggplot2*, *performance*, *DHARMa* and *emmeans*.

Monitoring of Benthic Photosynthetically Active Radiation (PAR)

Site selection

Benthic light and temperature monitoring equipment was initially deployed at a subtidal site offshore from Toogoom just south of Burrum Heads in May 2022 (Figure 3, above). The equipment was deployed over bare sediment in shallow subtidal waters that have historically supported patchy high biomass *H. spinulosa* and *H. ovalis* seagrasses. The station is also located near existing shallow subtidal *H. uninervis* meadows. Two additional benthic PAR and temperature monitoring stations were added to the monitoring program in June 2023, in deep-water offshore from Woodgate and Tobruk (Figure 3). The Woodgate monitoring site was established at the periphery of the deep-water meadow where *H. decipiens* had recolonised after flood related losses in 2022 (Bryant et al. 2023). The Tobruk monitoring site was established in deeper water near seagrass (*H. spinulosa*) biomass hot spots detected in November 2022 (Bryant et al. 2023). In late November 2023 two more monitoring sites were established in the shallow waters of Moon Point and Kauri Creek which support *Z. muelleri* and *H. ovalis* seagrasses. The addition of these two sites also allowed a greater understanding of the light conditions within the Great Sandy Strait.

Methods and Equipment

Submersible Odyssey™ photosynthetic irradiance autonomous loggers (light loggers) were deployed with automatic wiper units which clean the optical surface of the sensor every 15 minutes to prevent marine organisms fouling the sensors (Figure 9). At each location, two independent light loggers and wiper units were deployed on the seabed in two separate deployment cradles connected to a surface float. The presence of dual loggers reduces the risk of data loss through unit malfunction, fouling or disturbance during the three months between equipment exchange and download. Equipment was changed out and downloaded approximately every three months.



Figure 9. Deploying continuously logging PAR equipment in Hervey Bay May 2022.

Odyssey loggers logged a cumulative reading at 15 minute intervals, which was calibrated and summed to gain total daily benthic light ($\text{mol m}^{-2} \text{day}^{-1}$). The raw data captured by the loggers required calibrating to a known light value. Sensors were calibrated against a certified reference irradiance sensor (LI-CORTM LI-192SB Underwater Quantum Sensor) in controlled laboratory conditions. A custom built calibration device held the light loggers a consistent distance from the source light and excluded all external light. To allow for the differences in light absorption properties between air (calibration medium) and water (deployment media), a multiplication factor of 1.33 was applied to data. Following retrieval from the field, a report on the condition and appearance of each data logger was made to identify any fouling of the sensor or issues with the wiping apparatus.

Analysis

After downloading, the data was adjusted using the most recent calibration factor for each logger and adjusted for submersion (see methods above). The adjusted data was used to calculate a total daily benthic light value for each logger.

At each site the two loggers were compared to determine if there were any significant differences ($>20\%$) in total daily light value. A distance of 10 m can cause loggers to differ substantially during exposure and submersion events due to natural environmental variation, for some sites the distance between loggers meant that differences in excess of 20% were common.

Where failures of one unit were obvious, data was removed from the record (e.g. where a logger failed to record data or where there were exceptionally high readings outside of possible light levels). Data was also removed when fouling had occurred resulting in significantly decreased light readings. If both loggers were deemed to be recording accurately and loggers agreed (difference $<20\%$), the two were averaged and a mean total daily light value was calculated. Where there were no obvious malfunctions and units disagreed by more than 20% in one day, the data for the unit recording the higher value was used as it is more likely to be reading within the 5% error margin for that logger. The lower of the two was considered more likely to have been affected by physical disturbances such as shading by floating debris.

RESULTS

Seagrass monitoring, habitat mapping and Geographic Information System

Seagrasses in 2024

Across Hervey Bay and the Great Sandy Strait, a total of 494 sites were surveyed across 13 monitoring blocks (Figure 10). Seagrass was recorded in 63% of sites and was recorded in all monitoring blocks. Across the survey, 5 seagrass species were recorded, *Z. muelleri*, *H. uninervis*, *H. spinulosa*, *H. ovalis* and *H. decipiens*. Deep-water blocks in Hervey Bay consisted of all three *Halophila* species while *Z. muelleri* was dominant in the shallow and intertidal blocks of southern Hervey Bay and the Great Sandy Strait along with some *H. uninervis* and *H. ovalis*. The species and their locations are consistent with previous survey since 2022. Seagrass biomass ranged from 0 to 90.8 g DW m⁻² across the survey and percent cover between 0 and 100 percent cover. Combined seagrass area across all 13 blocks was 300.84 km². Across the twelve blocks that have been surveyed historically seagrass area was 248.91 km², lower than in Spring 2023 (269.38 km²) and 1998 when seagrass covered 315.42 km² (Figure 11). The lowest area seagrass covered was in August 2022, when just 136.80 km² was recorded and Spring 2022 when 22.56 km² was recorded (Figure 11).

Seagrass in Hervey Bay and the Great Sandy Strait in 2024 had the highest biomass, percent cover and area of all four post 2022 flooding (Figure 12). Across all survey blocks there were significant increases between surveys in both seagrass biomass ($\chi^2 = 430.0$, $df = 3$, $p < 0.001$) and percent cover ($\chi^2 = 258.15$, $df = 3$, $p < 0.001$) (Figure 12). Seagrass biomass was higher in 2024 than all other survey years. Mean seagrass biomass in 2024 was 10.50 ± 0.8 g DW m⁻² (10.01 ± 0.8 g DW m⁻² including HB 1), a 600% increase since the 2023 survey and an order of magnitude higher than in Autumn 2022 after major flooding (Figure 12). There has been a significant increase in seagrass percent cover each year ($p < 0.001$) with 2024 being the highest (Figure 12). Mean seagrass cover in 2024 was $17.4 \pm 1.2\%$ ($16.9 \pm 1.1\%$ including HB 1), more than double the mean in 2023 and four times greater than in Spring 2022 (Figure 12).

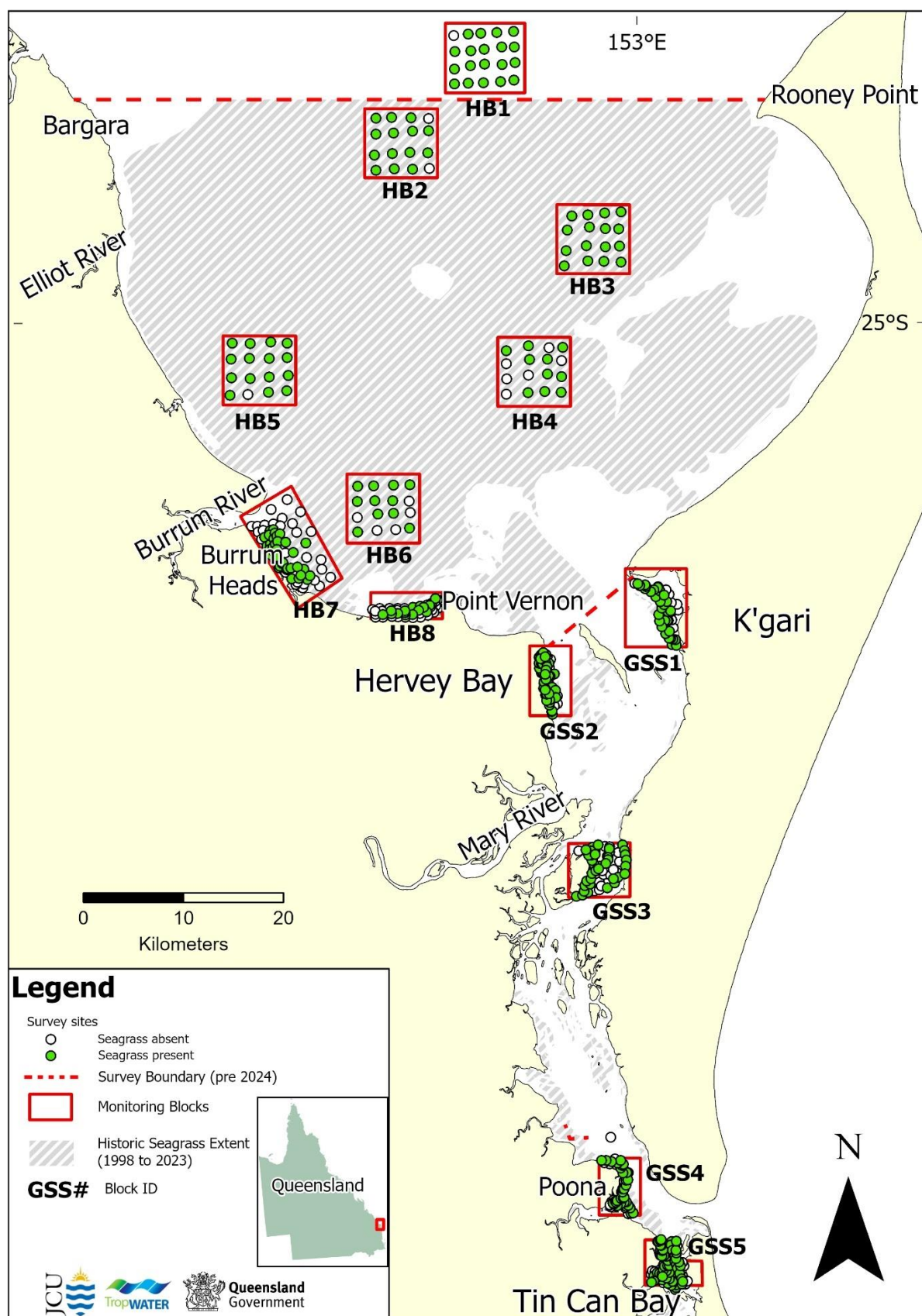


Figure 10. Seagrass monitoring sites with seagrass presence (green dots) or absent (white dots) in each monitoring block in the 2024 survey.

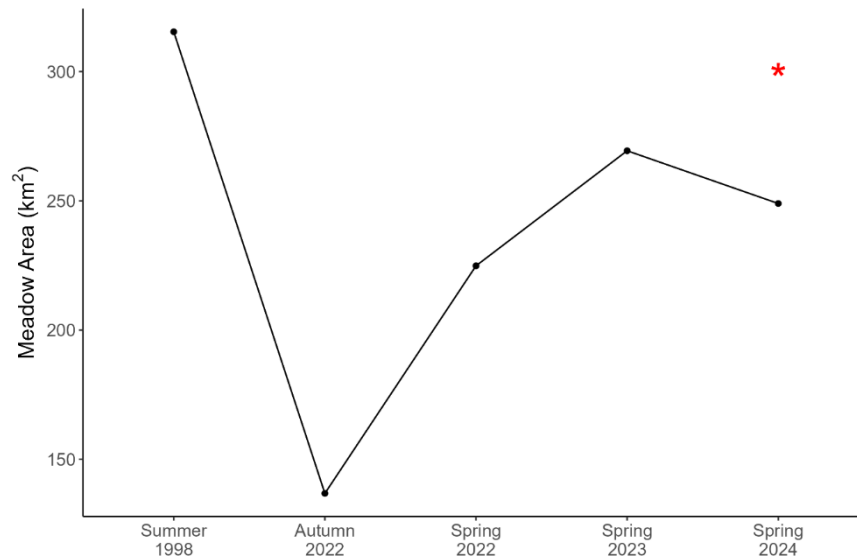


Figure 11. Seagrass area across all 12 monitoring blocks combined in each survey including 1998. Red star represents area including HB1 in spring 2024.

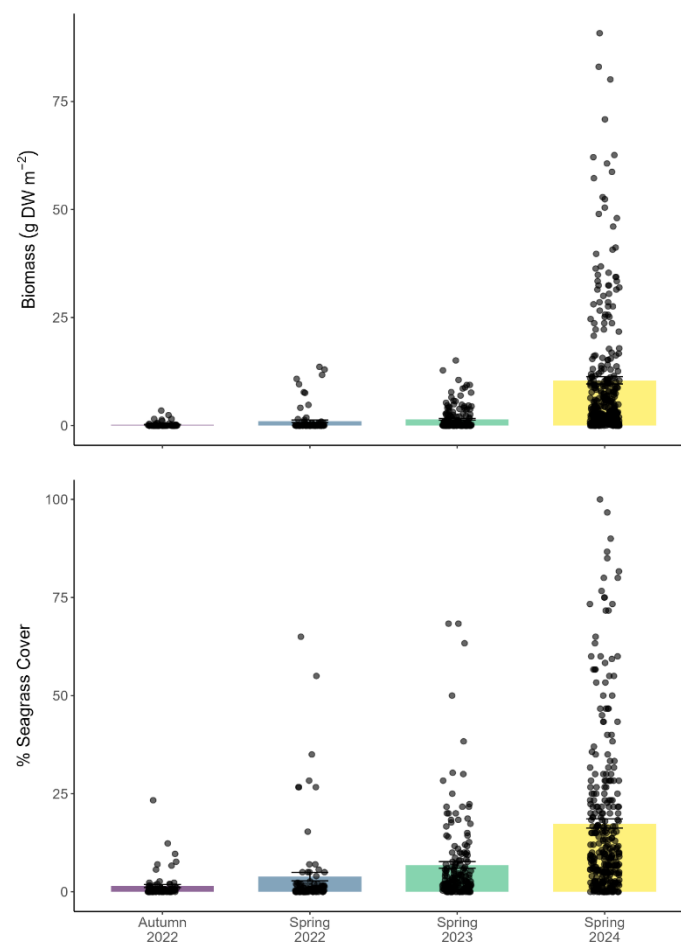


Figure 12. Mean ($\pm$ SE) seagrass biomass (top) and percent seagrass cover (bottom) in all blocks combined during surveys in Autumn 2022, Spring 2022, 2023 and 2024. Each point represents a survey site. Block HB 1 was excluding because it was only surveyed in Spring 2024.

Hervey Bay Deep-water (>10m dbMSL) Blocks (HB 1 – HB 6)

There are 6 deep-water survey blocks in Hervey Bay (HB 1- HB 6) (Figure 13; Figure 17-22). A total of 100 sites were sampled across the 6 blocks of which 83% contained seagrass. Seagrass area in the deep-water survey blocks in 2024 was 262.54 km² including block HB 1 that was surveyed for the first time. Across the five blocks that have been surveyed historically seagrass area covered 210.67 km², almost double the lowest area recorded in Autumn 2022 immediately post flooding event when only 120.77 km² of seagrass was mapped (Figure 14). Seagrass area recovered quickly increasing to 207.19 km² by Spring 2022 and has remained similar since then (Figure 14). Seagrass in the deep-water Hervey Bay monitoring blocks varied significantly across surveys in both biomass ($\chi^2 = 30.77$, df = 3, $p < 0.001$) and percent cover ($\chi^2 = 21.33$, df = 3, $p < 0.001$). Mean seagrass biomass in 2024 was 4.84 ± 0.51 g DW m⁻² (4.39 ± 0.43 g DW m⁻² when including HB 1) which is significantly higher than in Autumn 2022 immediately post flooding when biomass was 0.82 ± 0.38 g DW m⁻². There was no significant difference in biomass between surveys in 2024, 2023 and Spring 2023 ($p > 0.05$, Figure 15; Table 4). Mean seagrass percent cover in the 2024 survey was $9.74 \pm 0.8\%$ ($9.48 \pm 0.7\%$ including HB 1) which is significantly higher than in Autumn 2022 when it was $5.30 \pm 2.4\%$ ($p < 0.001$). Cover in the 2024 survey was lower than in Spring 2022 and Spring 2023 but there were no statistical differences ($p > 0.05$, Figure 15). Deep-water blocks were dominated by *H. spinulosa* with *H. ovalis* and *H. decipiens* the other species recorded (Figure 16). The prevalence of these species in the deep-water blocks is consistent with previous surveys.

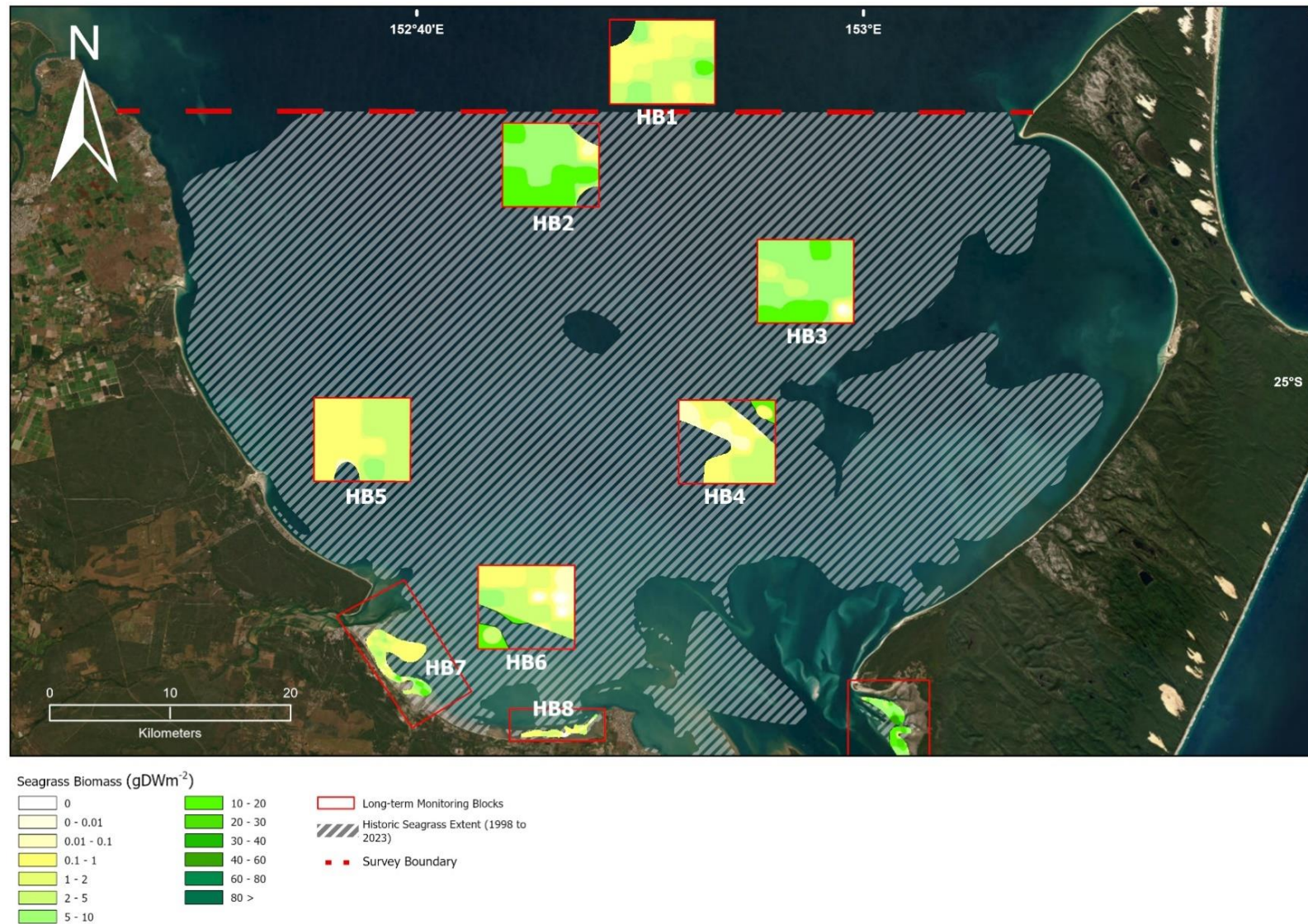


Figure 13. Seagrass biomass across deep and shallow monitoring blocks in Hervey Bay in 2024.

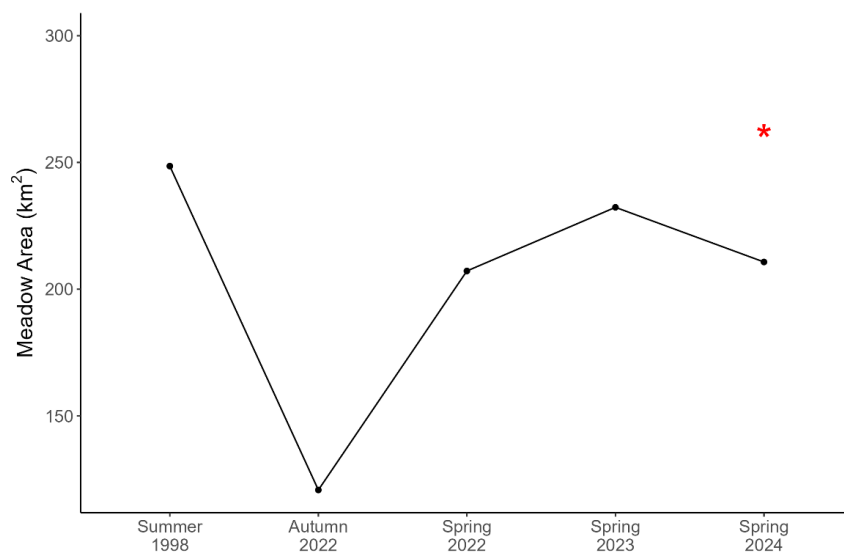


Figure 14. Area of seagrass meadows from deep-water blocks in Hervey Bay across surveys excluding HB 1 which was only surveyed in Spring 2024. The Red star represents area including HB 1 in Spring 2024.

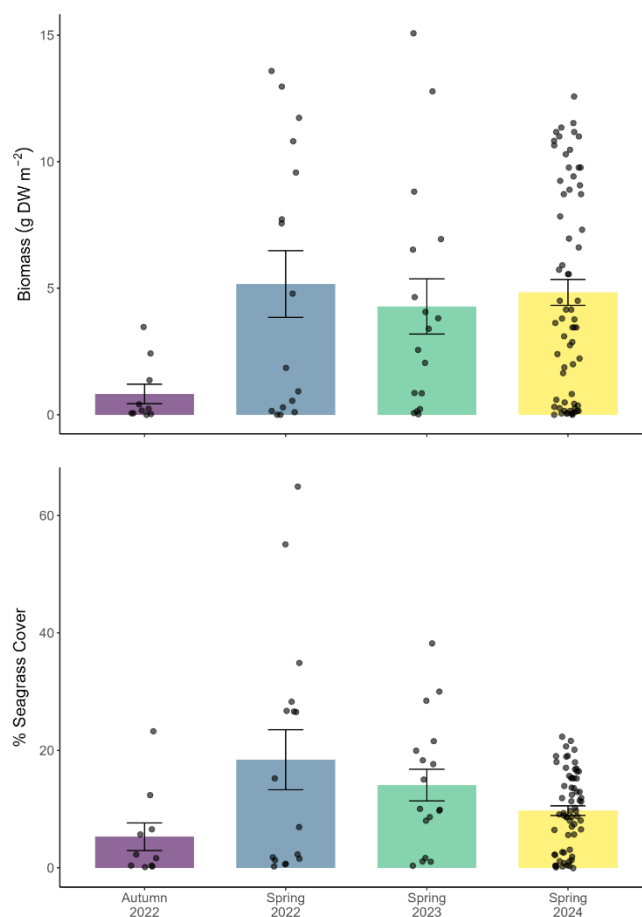


Figure 15. Mean ($\pm$ SE) of seagrass biomass (top) and percent cover (bottom) in seagrass meadows in deep-water monitoring blocks in Hervey Bay across surveys in Autumn 2022, Spring 2022, 2023 and 2024. Dots represent each survey site. Block HB 1 was excluding because it was only surveyed in Spring 2024.

HB 1

Block HB 1 was surveyed for the first time in this survey and is outside the previous survey extents (Figure 3). This block is in the central northern area of the survey in depths of 20-32 metres. Seagrass covered 51.87 km² and was found at 95% of sites (Table 3). The block consisted of a mix of *H. spinulosa* and *H. ovalis* (Figure 16). Mean seagrass biomass was 2.84 ± 0.70 g DW m⁻² and ranged from 0.26 to 10.65 g DW m⁻² (Figure 17; Table 4). Mean seagrass percent cover was 8.60 ± 1.35 , ranging from 1.66 to 19.6 % (Figure 17; Table 5). Species composition in HB 1 was approximately two thirds *H. spinulosa* and a third *H. ovalis* (Figure 17)

HB 2

Monitoring block HB 2 is located in the centre of Hervey Bay at 20-32 metres depth and has some of the highest biomass seagrass and cover in the deep-water monitoring blocks (Figure 3). Seagrass was recorded at 88% of sites in the block and was dominated by *H. spinulosa* and also included *H. ovalis* and *H. decipiens* (Figure 16). Seagrass covered an area of 45.15 km² or 90% of the block (Figure 18). This was lower than all previous surveys when seagrass has been present across the entire block covering 50.26 km² (Table 3). Mean seagrass biomass was 8.92 ± 0.87 g DW m⁻² and ranged between 0.05 and 12.58 g DW m⁻² (Figure 18; Table 4). Seagrass biomass in HB 2 has varied significantly across surveys ($\chi^2 = 17.46$, df = 3, $p < 0.001$) where biomass was higher in Spring 2022, 2023 and 2024 than in Autumn 2022 ($p < 0.001$) but there was no difference between surveys since Spring 2022 (Figure 18; Table 4). Mean seagrass cover in 2024 was 15.42 ± 1.52 % ranging from 0.33 to 22.33%, the highest recorded in deep-water monitoring blocks (Figure 18; Table 5). Seagrass cover also varied across surveys ($\chi^2 = 24.09$, df = 3, $p < 0.001$) but showed different patterns to biomass. Percent cover was higher in Spring 2022 than in Autumn 2022 and this survey ($p < 0.001$) but there were no other significant differences (Figure 18). *Halophila spinulosa* was the dominant species (>90%) recorded in HB 2 consistent with previous surveys (Figure 18).

HB 3

HB 3 is a deep-water monitoring block on the middle of Hervey Bay (Figure 3). Seagrass was recorded at all survey sites within the block and consisted of *H. spinulosa* and *H. ovalis* consistent with previous surveys (Figure 16). In Spring 2022 seagrass covered an area of 23.66 km², just under half the block but has covered the entire block in all other surveys covering 50.46 km² (Figure 19; Table 3). Mean seagrass biomass in HB 3 was 7.80 ± 0.86 g DW m⁻² ranging from 0 to 11.12 g DW m⁻² (Figure 19; Table 4). Seagrass biomass has varied across monitoring surveys in HB 3 ($\chi^2 = 25.14$, df = 3, $p < 0.001$). Biomass in Spring 2022 and 2024 were higher ($p=0.002$) than in Autumn 2022 and Spring 2022 that were not different (Figure 4). Seagrass cover in HB 3 in 2024 ranged from 0 to 21.67% and had a mean of 12.83 ± 1.19 % (Table 5). There have been significant changes in the seagrass cover across surveys ($\chi^2 = 27.82$, df = 3, $p < 0.001$). The highest cover recorded in Spring 2022 was greater than all other surveys ($p=0.01$) and both Spring 2023 and 2024 were higher than Autumn 2022 ($p < 0.001$) (Figure 19; Table 5). The seagrass in HB 3 primarily consisted of *H. spinulosa* (82%) with the other 18% being *H. ovalis* (Figure 19).

HB 4

HB 4 is located in the middle of Hervey Bay at depths of 16 to 20m (Figure 3). Seagrass was recorded in 63% of survey sites, the lowest of any of the deep-water monitoring blocks (Figure 20). *Halophila spinulosa* was the dominate seagrass species being recorded at 80% of seagrass sites and *H. ovalis* at 60% of seagrass sites (Figure 16). Seagrass covered 31.40 km² in 2024 which is lower than all other survey years including Autumn (46.85 km²) and Spring (37.53 km²) 2022 (Figure 20; Table 3). Biomass in HB 4 was low relative to other deep-water blocks ranging from 0.05 – 4.51 g DW m⁻² and having a mean of 1.35 ± 0.52 g DW m⁻² (Figure 20; Table 4). Biomass has varied across surveys in HB 4 ($\chi^2 = 40.42$, df = 3, p < 0.001) with all surveys having higher biomass than Autumn 2022 (p < 0.001) but no other significant differences. Seagrass cover was also low relative to the other blocks having a mean of 4.23 ± 1.39% and ranging from 0.33 to 11.33% (Figure 20; Table 5). Seagrass percent cover showed significant differences across surveys ($\chi^2 = 39.38$, df = 3, p < 0.001). All surveys had higher percent cover than Autumn 2022 (p < 0.001) and Spring 2023 was higher than in Spring 2022 and 2024 (Figure 20; Table 5). *Halophila spinulosa* represented 70% of the species composition in HB 4 in 2024 and the remaining 30% was *H. ovalis* (Figure 20).

HB 5

HB 5 is located on the western side of Hervey Bay in closer proximity to the mainland than blocks HB 1-4 and in depths from 9 to 16m (Figure 3). Seagrass was found at 94% of sites in HB 5 and all three *Halophila* species were recorded in monitoring block (Figure 16). No seagrass was recorded in block HB 5 in Autumn 2022 and in 2024 it covered 47.48 km² the highest of any survey since 1998 (Figure 21; Table 3). Seagrass biomass was low relative to the other deep-water blocks having a mean of 1.92 ± 0.49 g DW m⁻² ranging from 0.26 to 5.56 g DW m⁻² (Figure 21; Table 4). Despite biomass being higher in 2024 than the other surveys there was no significant difference ($\chi^2 = 35.19$, df = 2, p = 0.081). Autumn 2022 was not included in the analysis however because no seagrass was recorded. Seagrass cover significantly changed across surveys ($\chi^2 = 13.14$, df = 2, p = 0.046) with Spring 2024 (5.80 ± 1.0%) being higher than Spring 2022 (p = 0.014, 1.56 ± 0.5%) but not 2023 (3.56 ± 1.0%, Figure 21; Table 5). Species composition has varied across surveys with only *H. decipiens* present in 2022, *H. spinulosa* and *H. ovalis* being dominant in 2023, and roughly equal composition across the three species in 2024 (*H. ovalis* 38%, *H. spinulosa* 37%, *H. decipiens* 25%, Figure 21).

HB 6

HB 6 is the most southern deep-water monitoring block and has the closest proximity to Burrum River and the Great Sandy Strait (Figure 3). Seagrass was found at 63% of sites in the block consisting predominantly of *H. decipiens* with some *H. ovalis* consistent with previous surveys (Figure 16). Seagrass covered 34.42 km² in HB 6 in 2024, lower than in 2023 when it covered 39.36 km² and it peaked in 1998 when it covered 50.24 km², however greater than in Autumn 2022 when no seagrass was found in the block (Figure 22; Table 3). Seagrass biomass ranged from 0 to 7.32 g DW m⁻² and had a mean of 2.48 ± 0.70 g DW m⁻² (Figure 22; Table 4). Biomass has increased in each survey since Autumn 2022 when no grass was recorded but there was no significant difference in biomass across the subsequent surveys despite an increase each year due to the variation in each survey ($\chi^2 = 31.65$, df = 2, p = 0.058, Figure 22; Table 4). Percent seagrass cover has increased since the survey in Spring 2022 ($\chi^2 = 38.58$, df = 2, p = 0.026). Cover was higher in Spring 2023 (11.33 ± 10.3%) and 2024 (8.39 ± 2.15%) than in Spring 2022 (p = 0.020, 1.11 ± 0.1%) but there was no difference between 2023 and

2024 ($p = 0.881$, Figure 22; Table 5). Species composition in HB 6 was dominated by *H. decipiens* (88%) with *H. ovalis* making up the remaining 12% (Figure 22). This is consistent with previous surveys when *H. decipiens* has made up 90 – 95% of the seagrass composition (Figure 22).

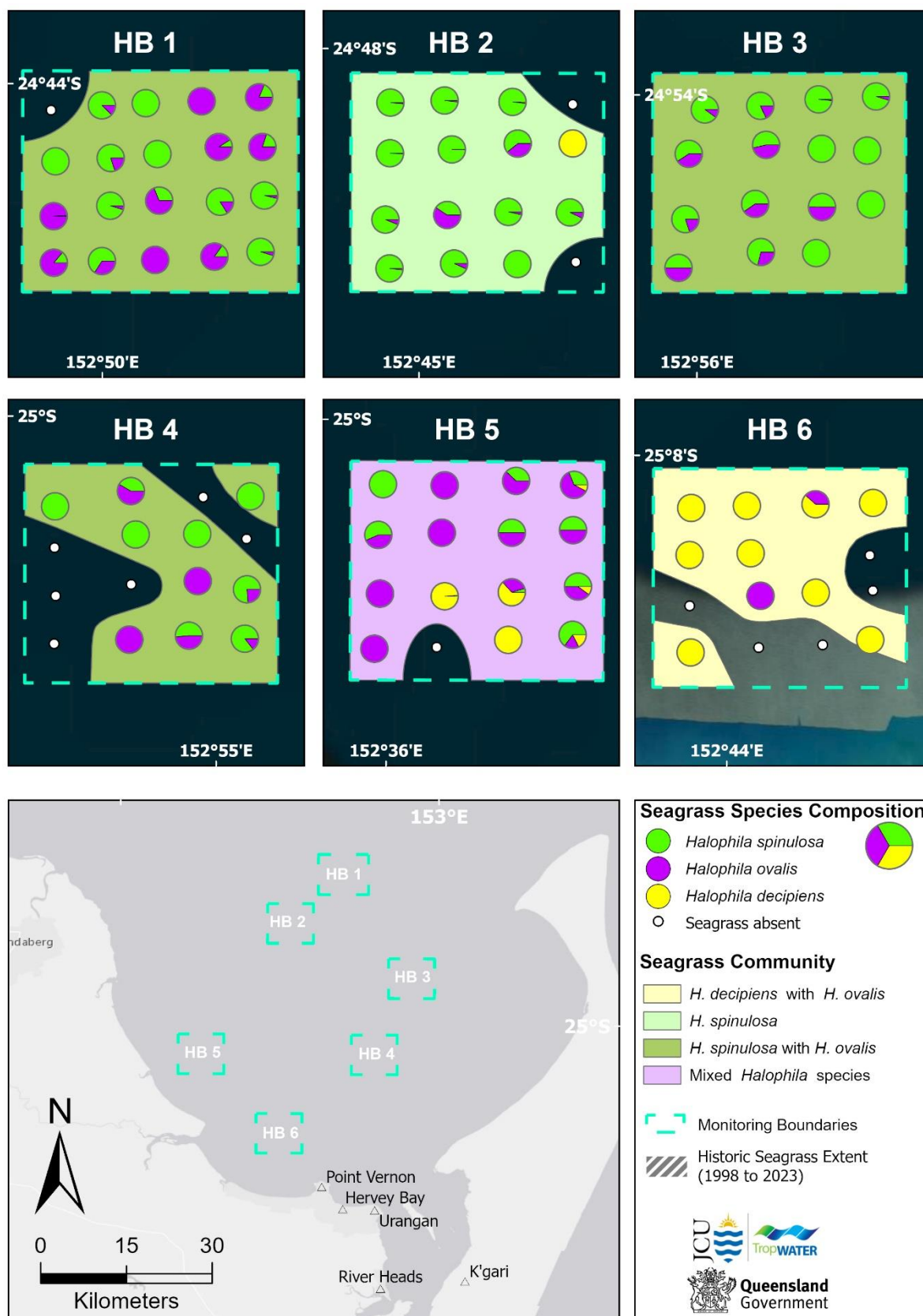


Figure 16. Seagrass site and meadow location and species composition in the blocks HB 1, HB 2, HB 3, HB 4, HB 5 and HB 6 in the deep-water monitoring blocks Hervey Bay.

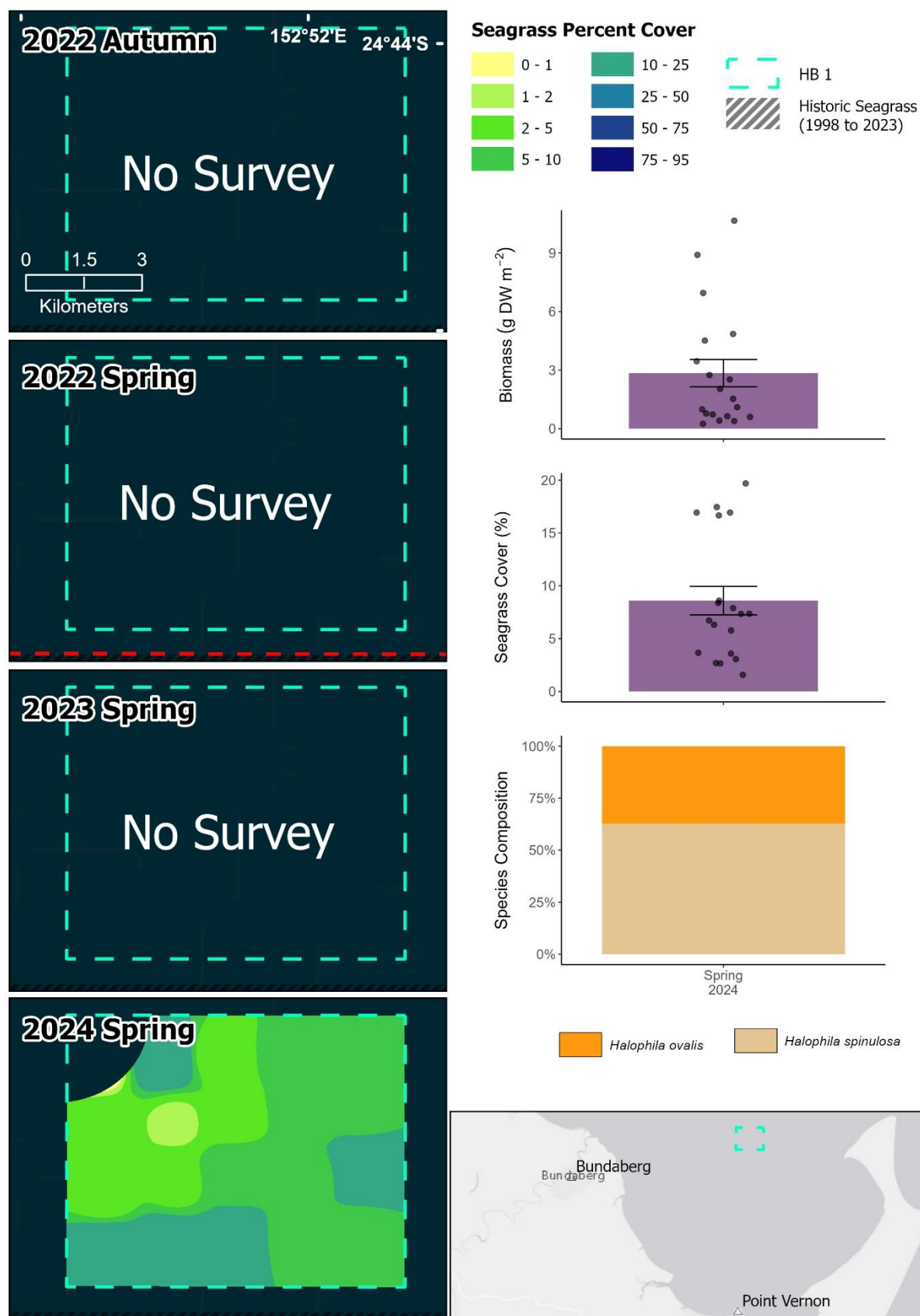


Figure 17. Seagrass area and percent cover in monitoring block HB 1 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in HB 1 each survey (right side). Block location is at the bottom right. Note that 2024 was the first survey to include HB 1.

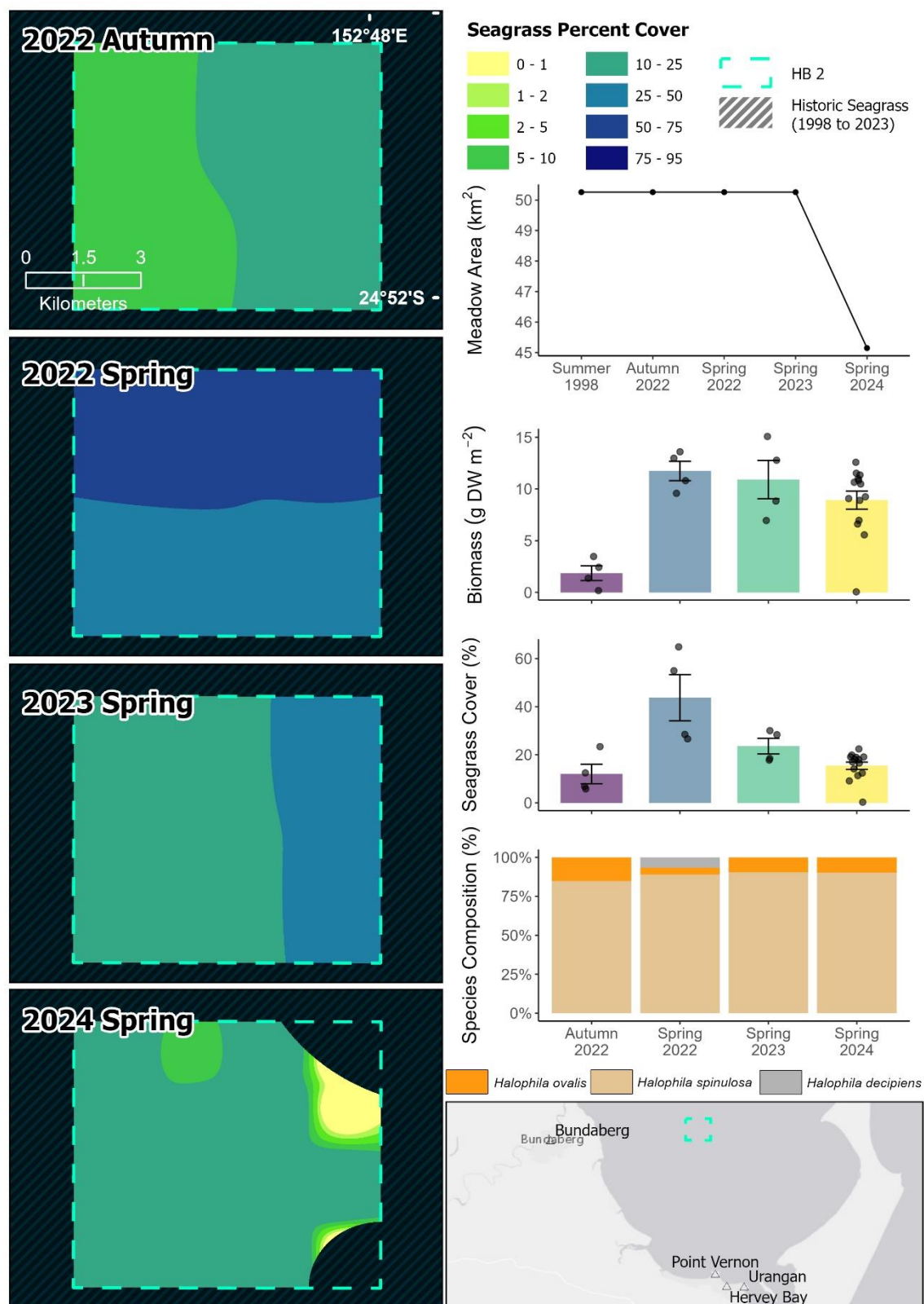


Figure 18. Seagrass area and percent cover in monitoring block HB 2 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in HB 2 each survey (right side). Block location is at the bottom right.

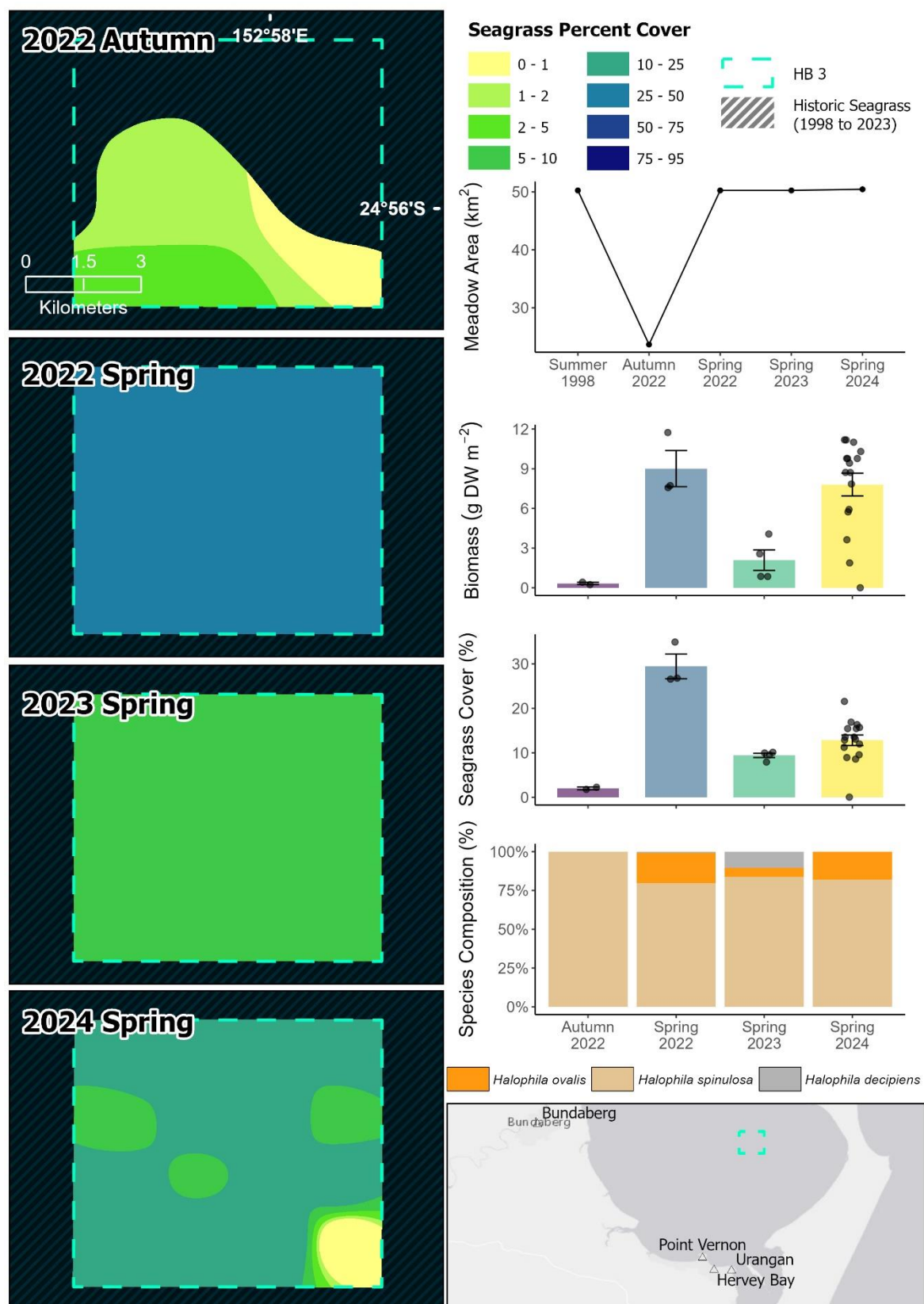


Figure 19. Seagrass area and percent cover in monitoring block HB 3 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in HB 3 each survey (right side). Block location is at the bottom right.

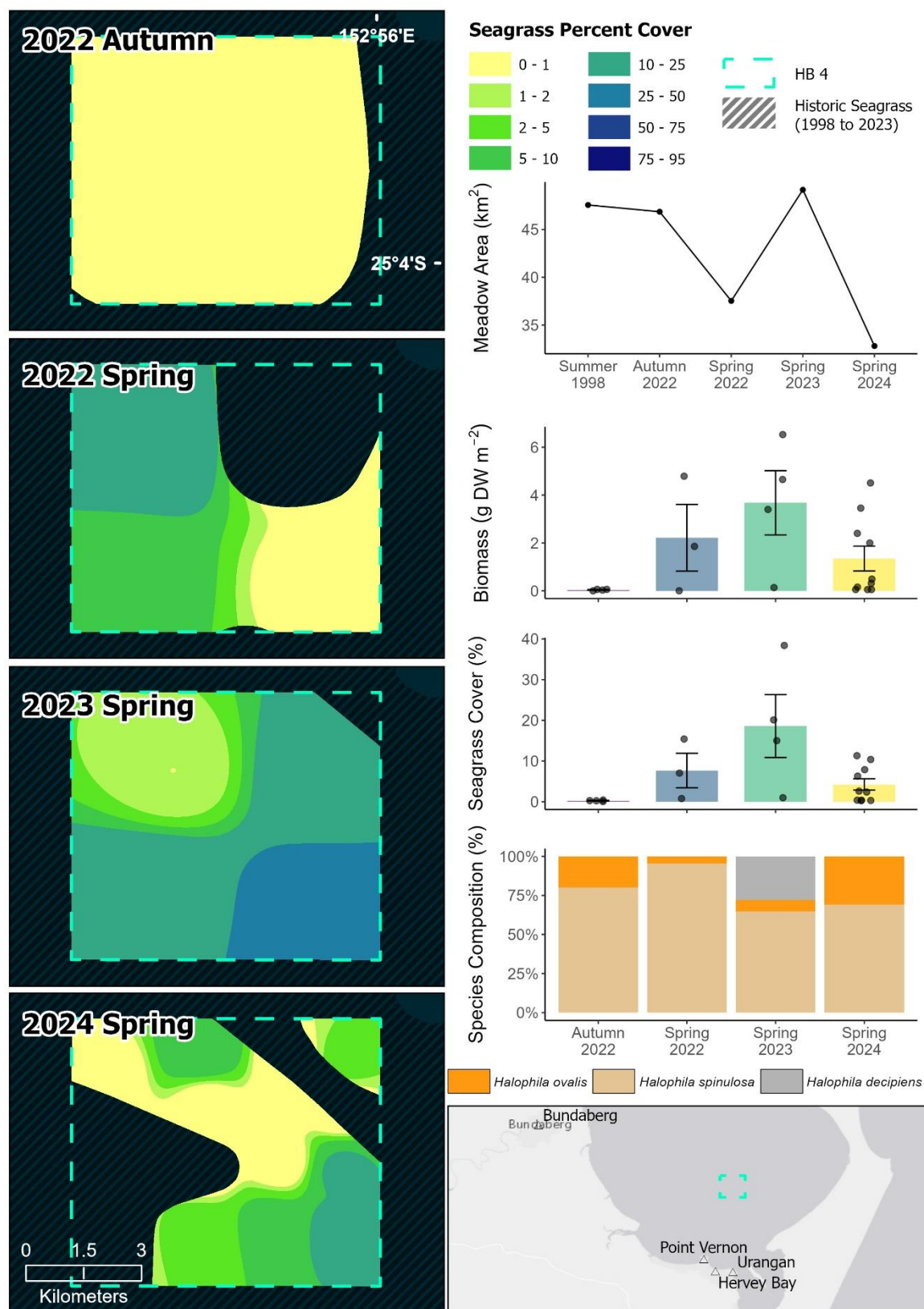


Figure 20. Seagrass area and percent cover in monitoring block HB 4 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in HB 4 each survey (right side). Block location is at the bottom right.

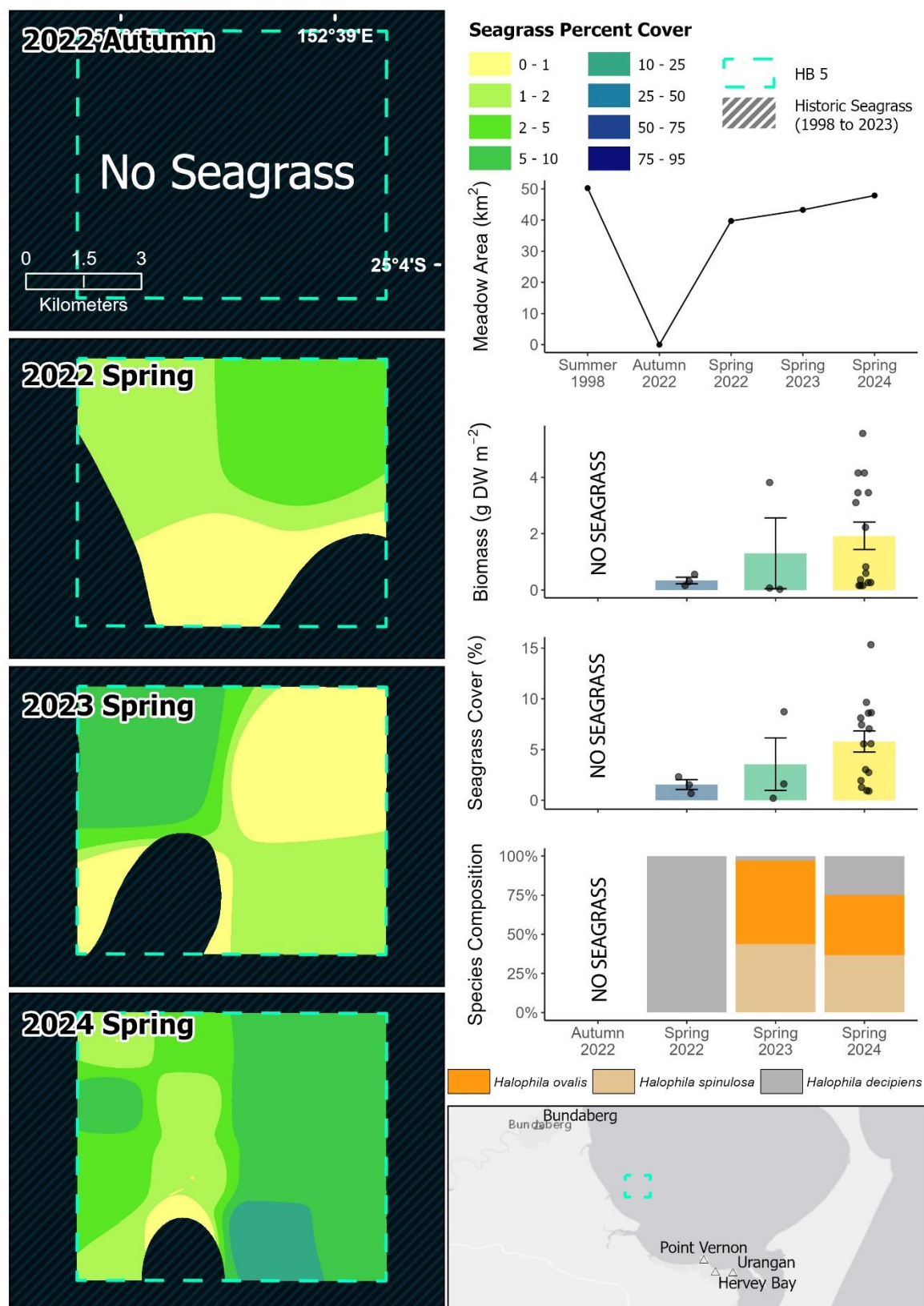


Figure 21. Seagrass area and percent cover in monitoring block HB 5 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in HB 5 each survey (right side). Block location is at the bottom right.

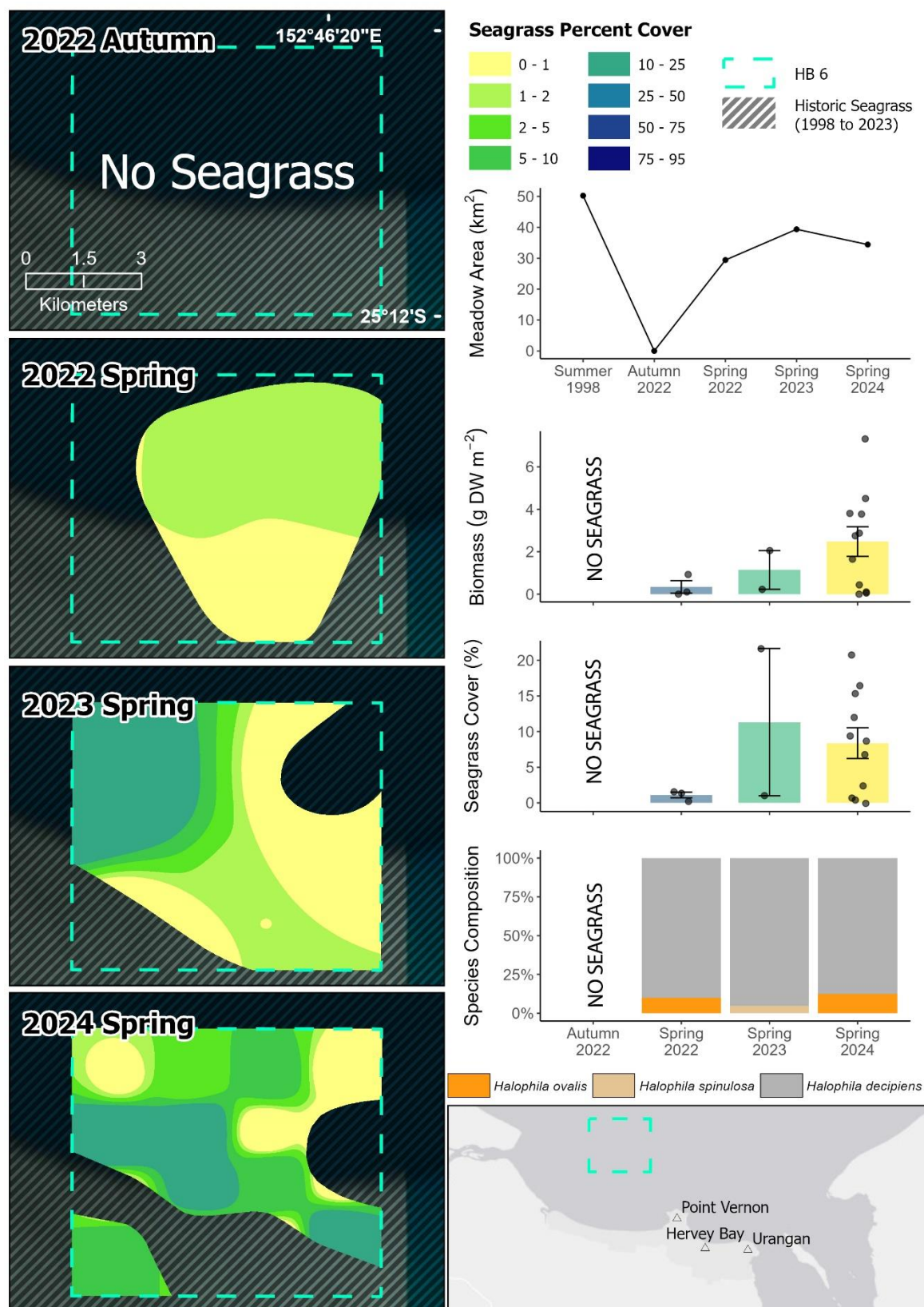


Figure 22. Seagrass area and percent cover in monitoring block HB 6 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in HB 6 each survey (right side). Block location is at the bottom right.

Shallow Hervey Bay Monitoring Blocks (0-10m dbMSL) meadows (Block HB 7, HB 8)

There are two shallow water monitoring blocks at the south of Hervey Bay located at Burrum Heads (HB 7) and west of Point Vernon (HB 8) (Figure 13). These are coastal intertidal sites that extend into the shallow subtidal and support larger seagrass species (*Z. muelleri*, *H. uninervis*) than the deep-water blocks (Figure 25). In the Autumn 2022 survey there was only 94.04 km² of low biomass and percent cover *H. uninervis* in HB 7 and no seagrass in HB 8 where there had been ~45.00 km² in 1998 (Figure 23-25). In the 2024 survey seagrass area covered 13.86 km², lower than in 2023 (16.76 km²) but greater than the 2022 surveys (Figure 23). Seagrass biomass and cover have both increased in 2024 from previous surveys. Seagrass biomass in the shallow Hervey Bay monitoring blocks has shown significant increases each survey ($\chi^2 = 82.97$, $df = 3$, $p < 0.001$) and was higher in 2024 than in all other surveys ($p < 0.001$) and Spring 2022 and 2023 were higher than Autumn 2022 ($p < 0.001$) but not between themselves (Figure 24). Seagrass cover showed a similar pattern increasing significantly across surveys ($\chi^2 = 71.5$, $df = 3$, $p < 0.001$) where Spring 2022 and 2023 were higher than Autumn 2022 ($p < 0.001$) and Spring 2024 was higher than all other surveys ($p < 0.001$). Mean seagrass cover in 2024 was $7.92 \pm 1.7\%$, three times higher than in 2023 ($2.54 \pm 0.4\%$), five times higher than Spring 2022 ($1.54 \pm 0.4\%$), and an order of magnitude higher than in Autumn 2022 ($0.22 \pm 0.1\%$) (Figure 24).

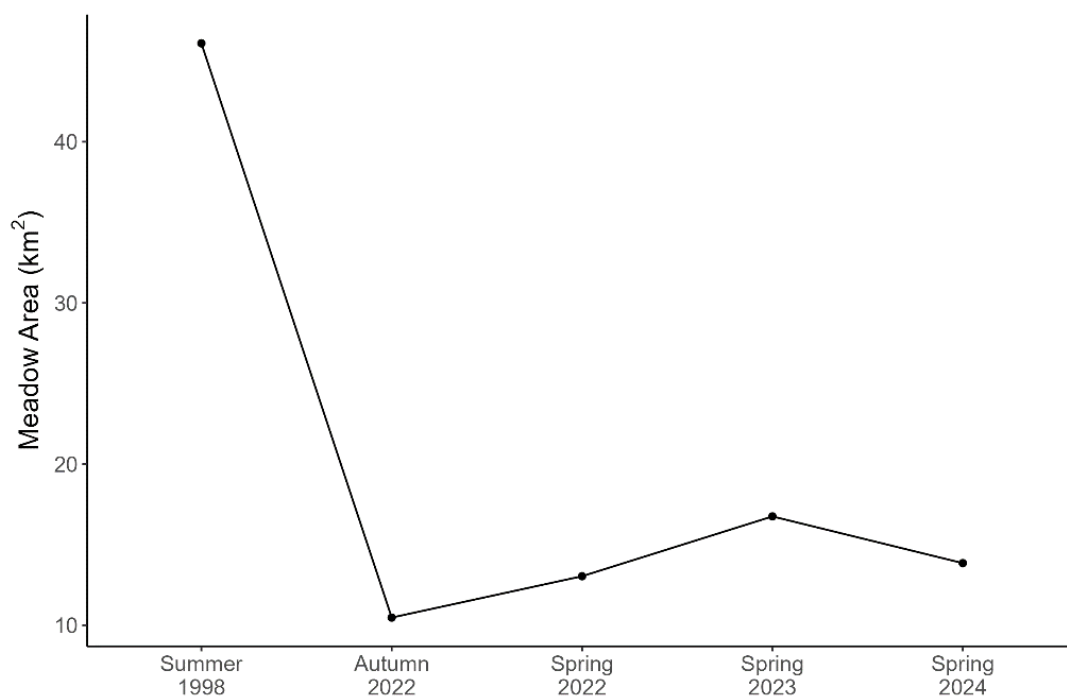


Figure 23. Seagrass meadow area from shallow Hervey Bay blocks across surveys.

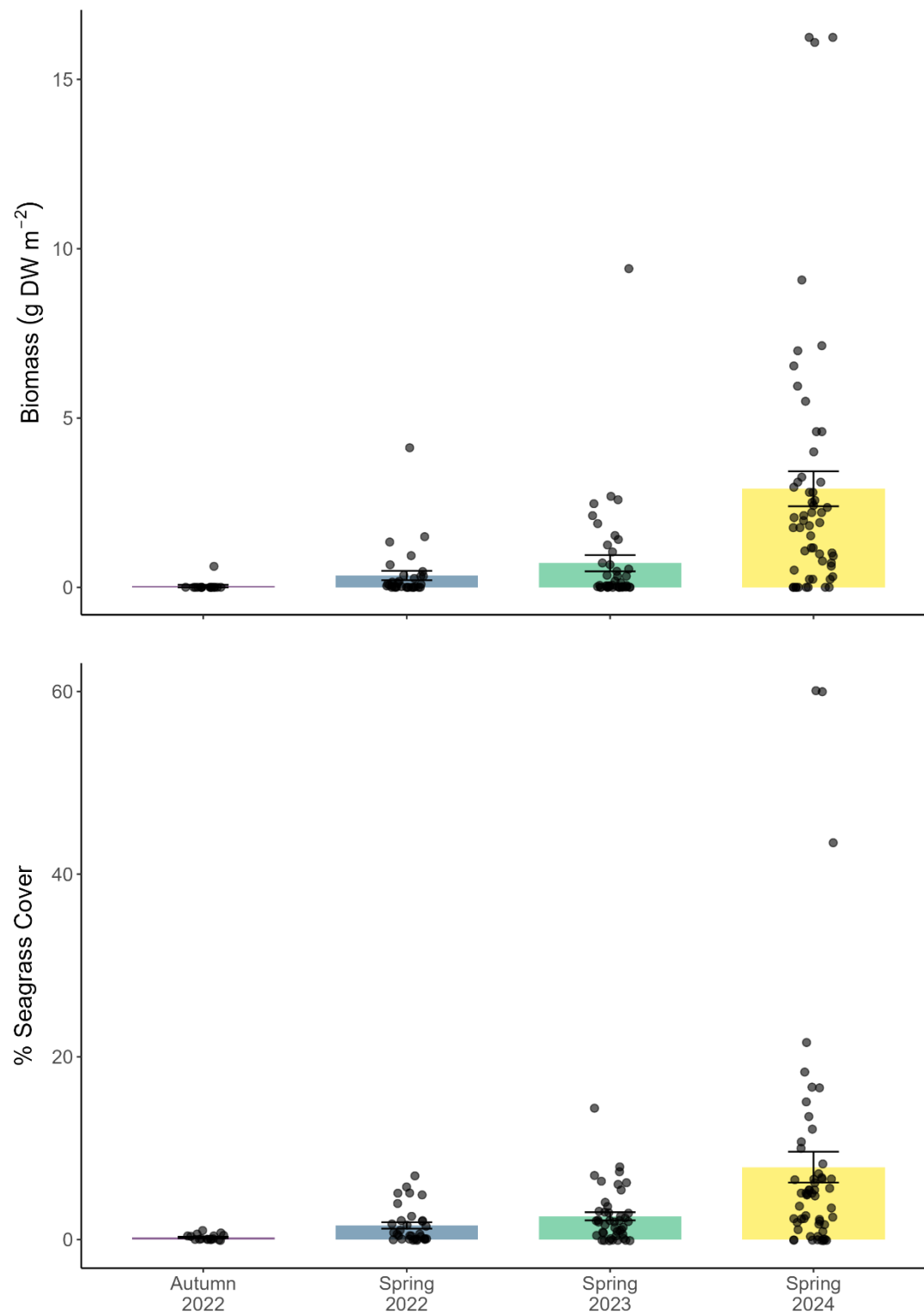


Figure 24. Mean ($\pm$ SE) of seagrass biomass (top) and percent cover (bottom) in seagrass meadows in shallow water monitoring blocks in Hervey Bay across surveys in Autumn 2022, Spring 2022, 2023 and 2024. Dots represent each survey site.

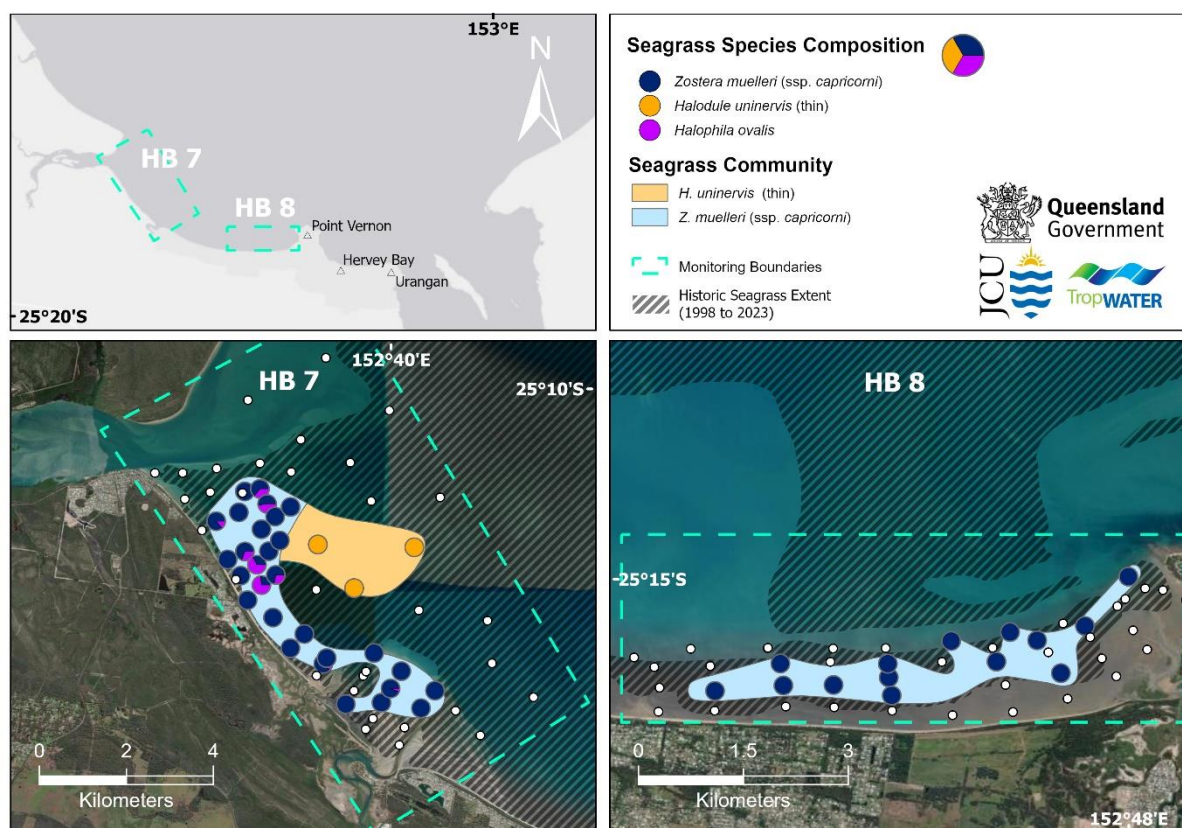


Figure 25. Seagrass site and meadow location and species composition in the blocks HB 7 and HB 8 in the shallow water monitoring blocks in Hervey Bay.

HB 7

HB 7 is located on the mainland coast between Burrum Heads and Toogoom in the southwest of Hervey Bay (Figure 3). Seagrass was recorded at 32 sites within the block consisting of predominantly *Z. muelleri* in the intertidal areas with some *H. ovalis* while *H. uninervis* was found at three shallow subtidal sites (Figure 25). Seagrass has covered a similar area between the August 2022 survey (9.40 km²) and the 2024 survey (10.95 km²) reaching a peak in 2023 of 13.36 km² (Figure 26; Table 3). Area of seagrass covered in the previous 4 surveys is only 34% of the area that was mapped with seagrass in 1998. Mean seagrass biomass was 3.45 ± 0.71 g DW m⁻² ranging from 0 to 16.24 g DW m⁻² (Figure 26; Table 4). Biomass has increased significantly across surveys ($\chi^2 = 275.73$, df = 3, $p < 0.001$). There was no difference in biomass between Autumn and Spring 2022 but was greater in Spring 2023 than Autumn 2022 ($p = 0.002$) and was higher in 2024 than all other years ($p = 0.011$). Seagrass percent cover showed a similar pattern across surveys ($\chi^2 = 295.89$, df = 3, $p < 0.001$). Seagrass cover was highest in 2024 ($9.58 \pm 2.3\%$) which was significantly greater than all other years ($p = 0.003$). There was no difference between the two surveys in 2022 (Autumn $0.24 \pm 0.1\%$, Spring $1.48 \pm 0.4\%$) but cover was higher in Spring 2023 ($3.30 \pm 0.6\%$) than Autumn 2022 ($p = 0.001$, Figure 26; Table 5). Seagrass species composition has shown a gradual change across surveys (Figure 25). In Autumn 2022 *H. uninervis* dominated making up 99% of the seagrass in HB 7 but *Z. muelleri* has gradually increased each survey to make up 90% of the composition by 2024 and *H. uninervis* only represents 1% (Figure 26).

HB 8

HB 8 is an intertidal block to the west of Point Vernon and the most southerly block in Hervey Bay (Figure 3). Within HB 8, a small *Z. muelleri* meadow covering an area of 2.90 km². The meadow area is the lower than the previous two surveys but still twice the area mapped in Autumn 2022 (Figure 27; Table 3). Seagrass biomass in HB 8 is the lowest of all the coastal blocks having a mean of 1.71 ± 0.45 g DW m⁻² and ranging from 0 to 6.98 g DW m⁻² (Figure 27; Table 4). Seagrass biomass has been consistently low across surveys and has varied over time ($\chi^2 = 109.6$, df = 3, $p < 0.001$). Mean seagrass biomass was higher in 2024 than all other surveys but only significantly higher than the 2023 survey ($p = 0.027$, Figure 26). Seagrass cover in HB 8 continues to be low having a mean of $4.22 \pm 1.18\%$ and ranging from 0 to 18.33%. Cover showed the same pattern as biomass changing across surveys ($\chi^2 = 125.47$, df = 3, $p = 0.003$) where it was higher in Spring 2024 than in Spring 2023 but there were no other significant differences despite gradual changes over time (Figure 27; Table 5). Across each survey *Z. muelleri* is the only species recorded in HB 8 (Figure 27).

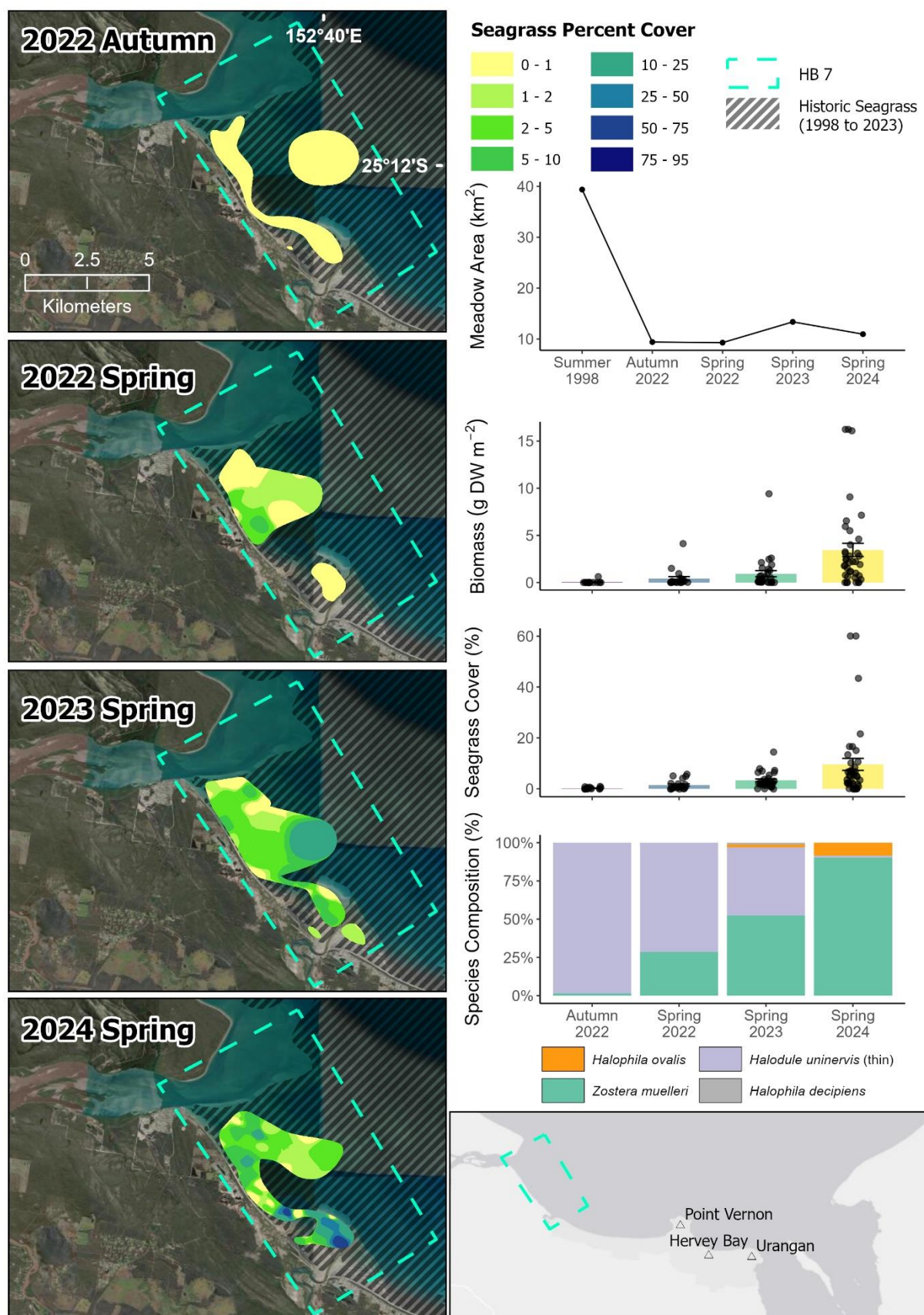


Figure 26. Seagrass area and percent cover in monitoring block HB 7 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in HB 7 each survey (right side). Block location is at the bottom right.

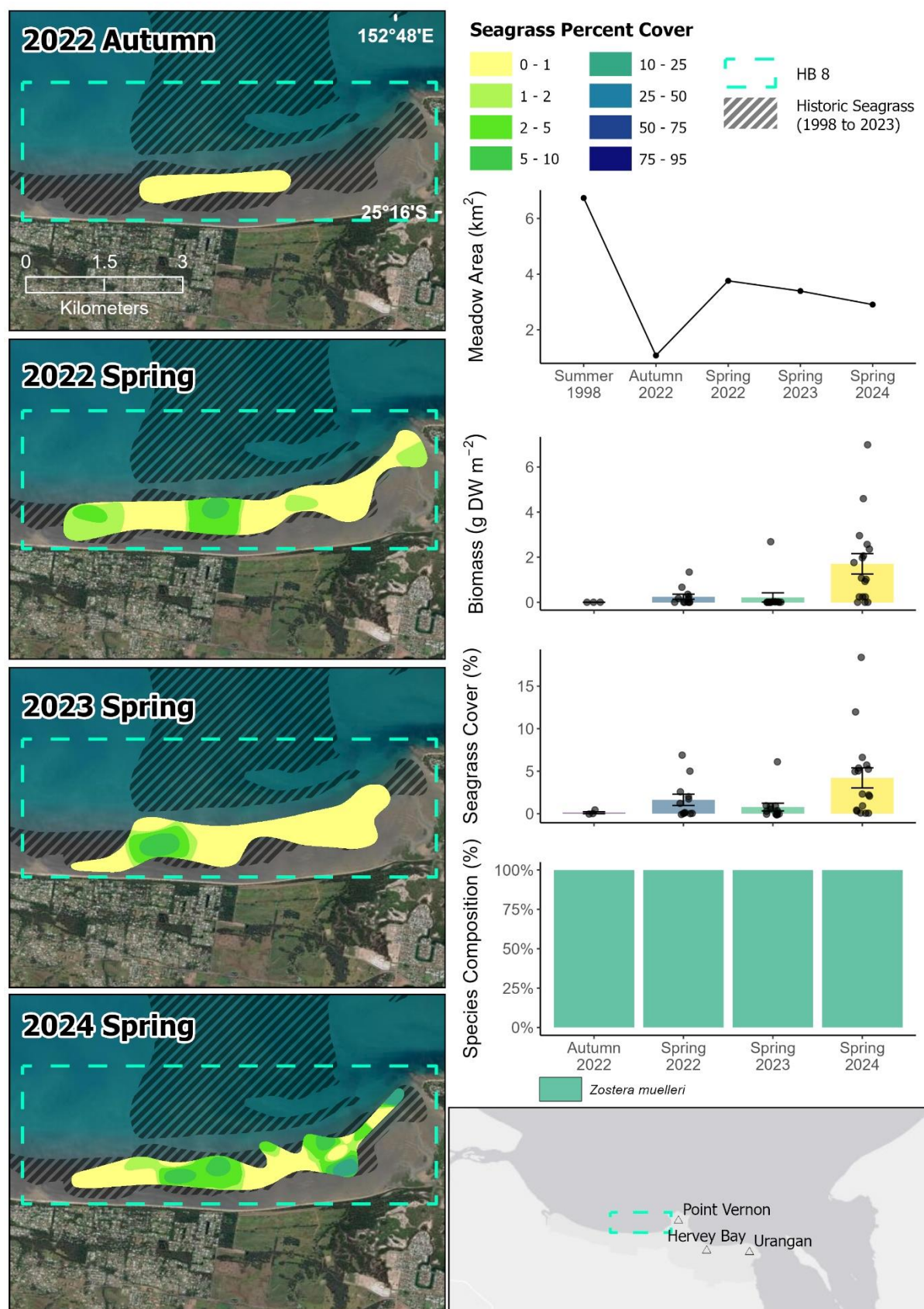
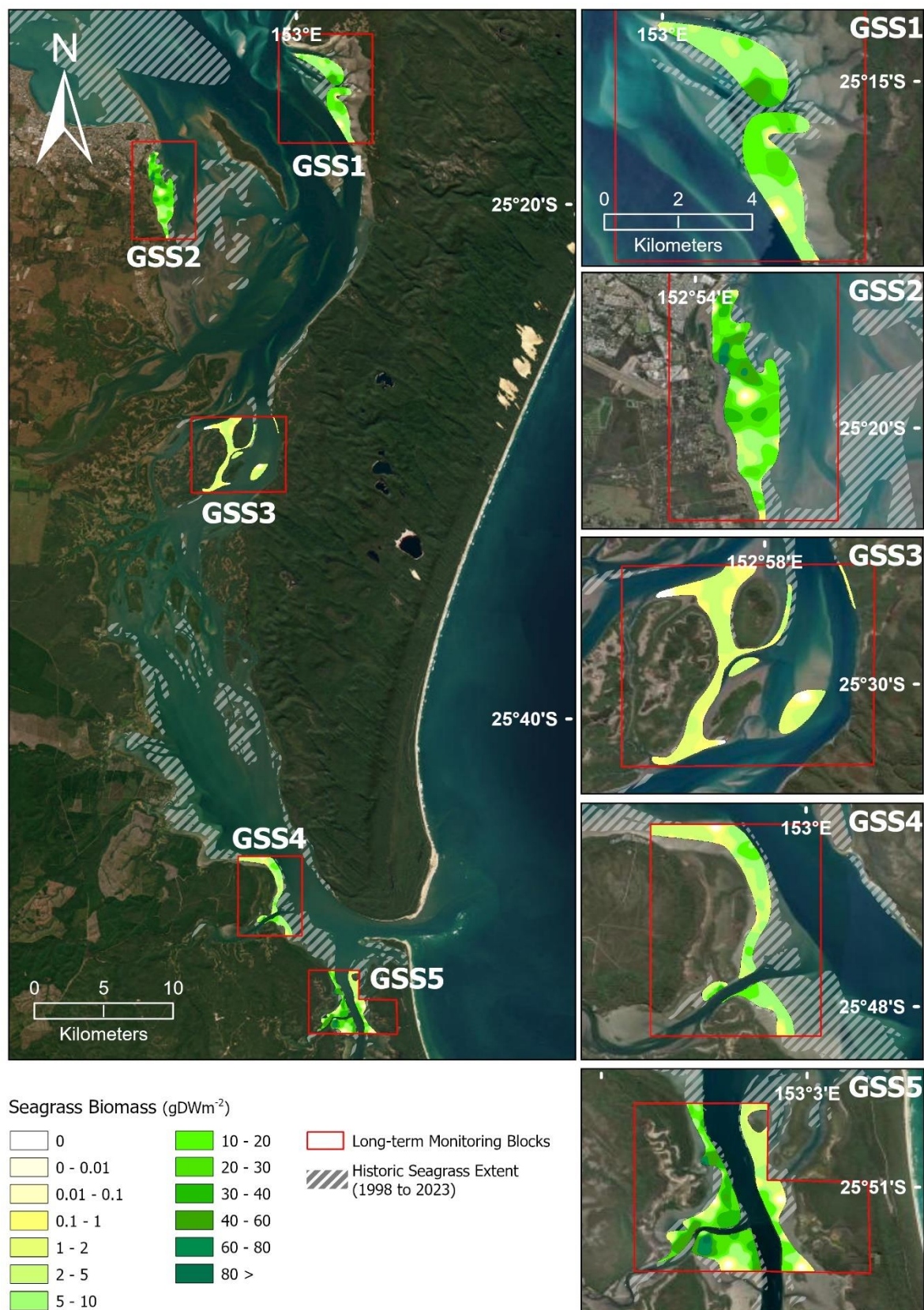


Figure 27. Seagrass area and percent cover in monitoring block HB 8 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in HB 8 each survey (right side). Block location is at the bottom right.

Great Sandy Strait

The 5 monitoring blocks in the Great Sandy Strait are predominantly intertidal and consisted of *Z. muelleri* with some *H. ovalis* (Figure 28; Figure 31, 32). A total of 276 sites were surveyed in the Great Sandy Strait and 66% had seagrass present (Figure 28). Seagrass biomass and percent cover were higher than in Hervey Bay owing to the dominance of *Z. muelleri* which has a larger leaf morphology than the small leaved deep-water *Halophila* species found in Hervey Bay. Mean seagrass biomass was 14.52 ± 1.3 g DW m⁻² ranging from 0 to 90.8 g DW m⁻² and was an order of magnitude higher than in Autumn 2022 when the mean was 0.14 ± 0.1 g DW m⁻² and the highest biomass was only 1.4 g DW m⁻² (Figure 30; Table 4). There has been a significant increase in biomass each survey across the Great Sand Strait ($\chi^2 = 583.95$, df = 3, p < 0.001) and biomass in 2024 was higher than all other surveys (p < 0.001). Seagrass cover showed similar patterns to biomass in the Great Sandy Strait increasing over each year ($\chi^2 = 328.31$, df = 3, p < 0.001) and the highest mean cover was in 2024 ($22.72 \pm 1.7\%$), higher than all other years (p < 0.001). Seagrass percent cover was three times higher in 2024 than the 2023 survey ($7.40 \pm 1.4\%$) and more than 20 times higher than surveys in 2022 ($1.12 \pm 0.3\%$) (Figure 30; Table 5).



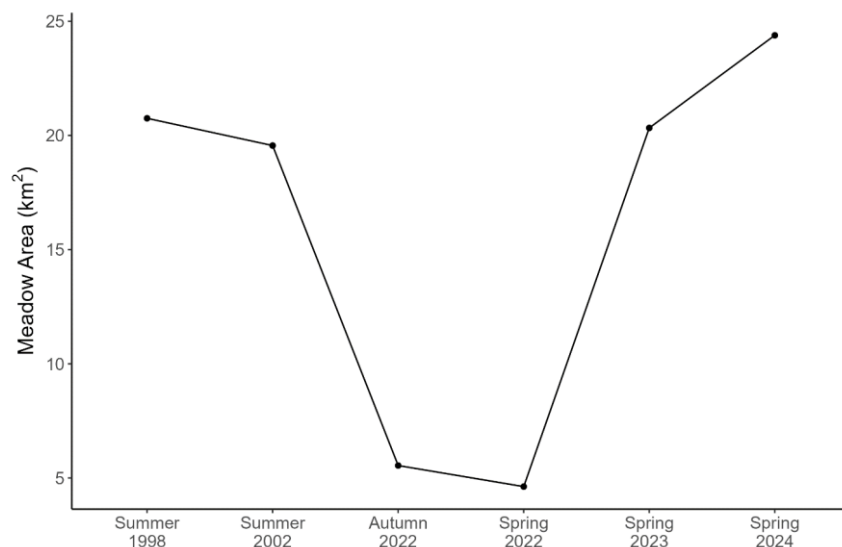


Figure 29. Seagrass meadow area in the 5 monitoring blocks in the Great Sandy Strait across surveys.

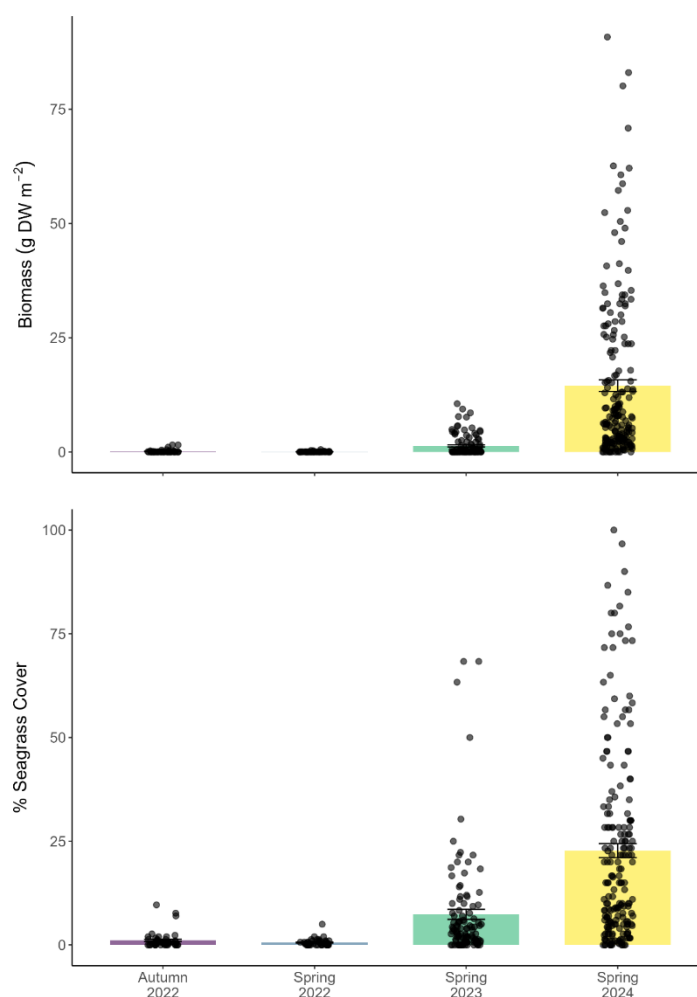


Figure 30. Mean ($\pm$ SE) of seagrass biomass (top) and percent cover (bottom) in seagrass meadows in monitoring blocks in the Great Sandy Strait across surveys in Autumn 2022, Spring 2022, 2023 and 2024. Dots represent each survey site.

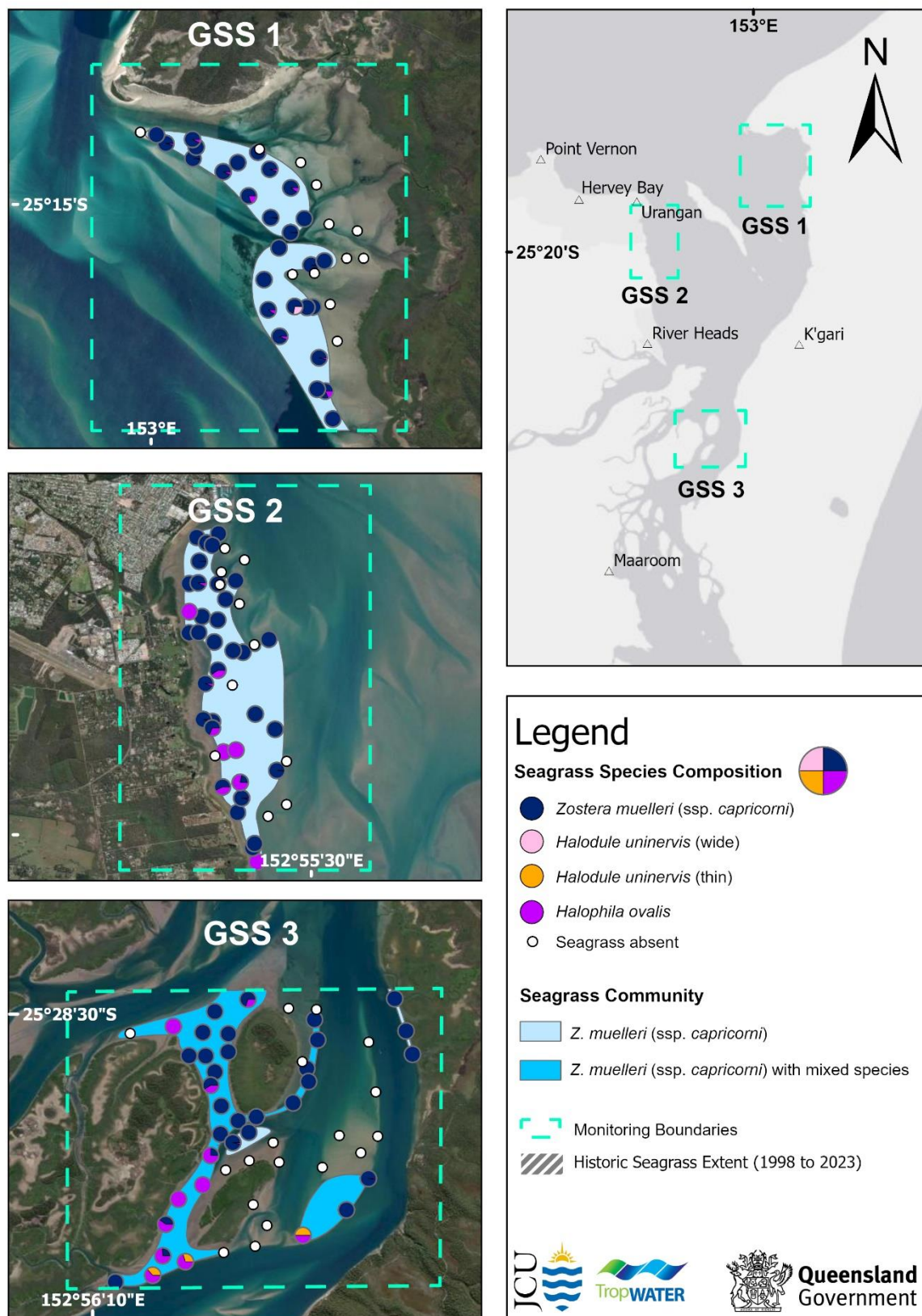


Figure 31. Seagrass site and meadow location and species composition in the blocks GSS 1, GSS 2, and GSS 3 in the northern section of the Great Sandy Strait.

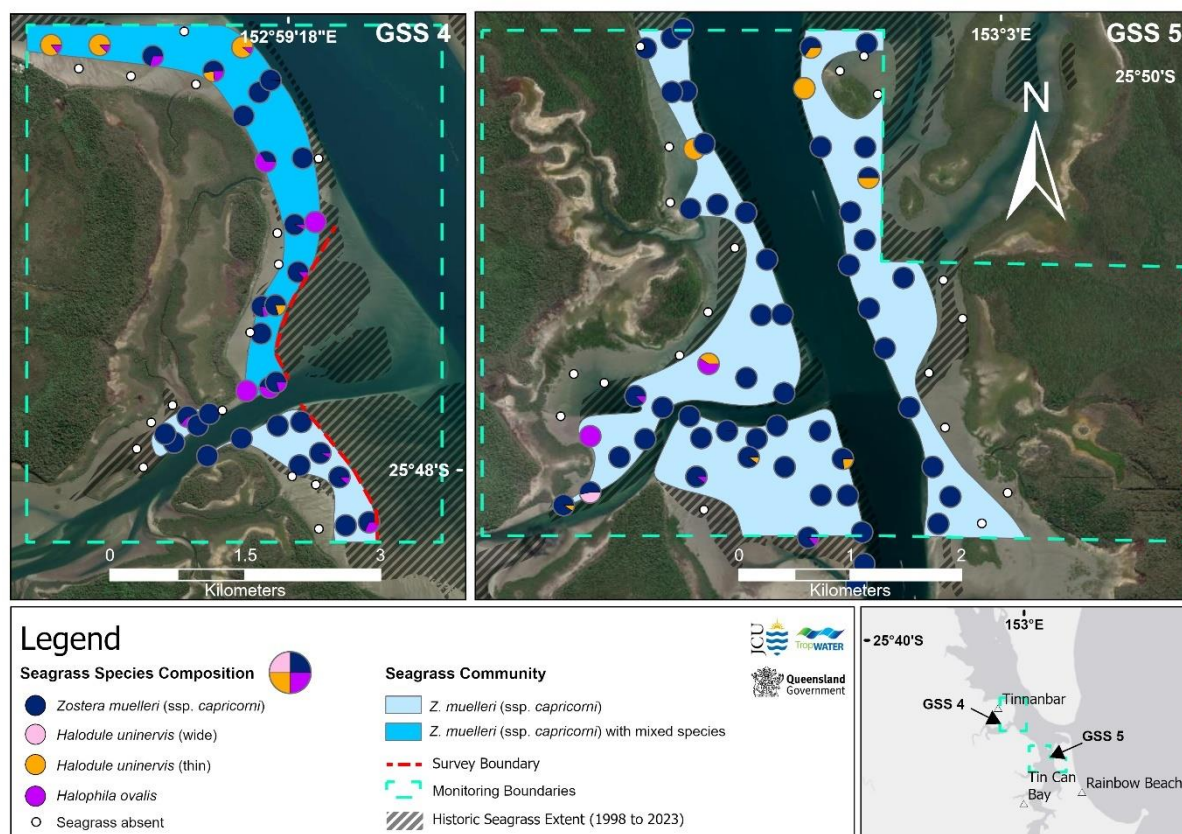


Figure 32. Seagrass site, meadow location and species composition in blocks GSS 4 and GSS 5 in the southern section of the Great Sandy Strait.

Great Sandy Strait Blocks

GSS 1

GSS 1 is located on the intertidal sand/mud banks at K'gari between Moon Point and Blackfellow Point and consists of two meadows dominated by *Z. muelleri* (Figure 3; Figure 31). Seagrass area in GSS 1 in 2024 was 6.48km² more than three times greater than in Autumn 2022 but 1.65 km² lower than in 2023 when seagrass area was at its highest (Figure 33; Table 3). Seagrass biomass in GSS 1 has increased throughout the surveys ($\chi^2 = 152.22$, $df = 3$, $p < 0.001$) and was highest in 2024 ($p > 0.001$, 12.94 ± 2.1 g DW m⁻²), more than 4 times higher than in 2023 and 2 orders of magnitude higher than in either of the 2022 surveys (Figure 33; Table 4). Seagrass cover has increased across surveys ($\chi^2 = 175.02$, $df = 3$, $p < 0.001$). There was no difference in cover between the two surveys in 2022 but has increased significantly in 2023 ($p < 0.001$) and 2024 ($p < 0.001$) to reach a mean seagrass percent cover of $22.87 \pm 2.21\%$ (Figure 33; Table 5). Seagrass in GSS 1 was dominated by *H. uninervis* (thin) in Autumn 2022 but in all surveys since then switched to be dominated by *Z. muelleri* (Figure 33). In 2024 species composition consisted primarily of *Z. muelleri* (95%) with small amounts of *H. ovalis* (3%) and *H. uninervis* wide (2%, Figure 33).

GSS 2

The monitoring block GSS 2 is located to the south of Urangan and was dominated by *Z. muelleri* with some *H. ovalis* (Figure 3; Figure 28). Seagrass in the block covered 5.07 km² which is lower than in 2023 (5.26 km²) but higher than all other surveys (Figure 34; Table 3). Seagrass biomass in GSS 2 was highest of all the monitoring blocks in 2024 with a mean of 24.95 ± 3.4 g DW m⁻² and ranging from 0 to 90.81 g DW m⁻² (Figure 34; Table 4). There were significant changes in seagrass biomass across the surveys ($\chi^2 = 237.61$, df = 3, $p < 0.001$). There was no difference in biomass between Autumn and Spring 2022 but was higher in 2023 than 2022 surveys ($p < 0.001$) and in 2024 than all other surveys ($p < 0.001$). Seagrass cover ranged from 0 to 90% with a mean of 24.94 ± 3.0% and was significantly higher than in the 2022 surveys ($\chi^2 = 315.73$, df = 3, $p < 0.001$, Figure 34; Table 5). Seagrass cover was higher in 2023 and 2024 than both 2022 surveys ($p < 0.001$) but there were no other significant differences (Figure 34). Species composition in GSS 2 was primarily *Z. muelleri* (93%) in 2024 with *H. ovalis* (7%) making up the rest of the composition (Figure 34). Species composition was exclusively *Z. muelleri* in the two 2022 surveys but only represented 11% of the composition in 2023 (Figure 34).

GSS 3

GSS 3 is in the centre of the Great Sandy Strait and situated around Turkey Island (Figure 3; Figure 28). GSS 3 is in an isolated area and was not monitored in Spring 2022 immediately post flooding. Seagrass in GSS 3 was dominated by *Z. muelleri* and also included some *H. uninervis* and *H. ovalis* particularly in the southern areas of the block (Figure 31). The areas of seagrass in the block was 4.46 km² in 2024, more than double the highest seagrass area previously recorded in 2002 and an order of magnitude higher than in 2022 when only 0.24 km² were mapped (Figure 35; Table 3). Seagrass biomass was low relative to other blocks in the Great Sandy Strait (Table 4). Mean biomass was 1.85 ± 0.21 g DW m⁻² and the highest in GSS 3 in this survey was 6.03 g DW m⁻². Biomass in GSS 3 has varied across survey years ($\chi^2 = 42.22$, df = 2, $p < 0.001$, Figure 32; Table 4). Seagrass biomass decreased from Spring 2022 to Spring 2023 but has increased in 2024 to be the highest of any survey ($p < 0.001$, Figure 35; Table 4). Seagrass cover was low throughout the block consistent with previous surveys ($\chi^2 = 93.55$, df = 2, $p < 0.001$). Mean seagrass cover in 2024 was 3.77 ± 0.5%, higher than in 2023 (0.54 ± 0.3%, $p = 0.001$) and similar to 2022 (4.23 ± 1.4%) (Figure 35; Table 5). Seagrass composition in GSS 3 in 2024 was made up of *Z. muelleri* (81%), *H. ovalis* (17%) and *H. uninervis* thin (2%). The proportion of *Z. muelleri* increased since the previous survey in 2023 when it was 38% but similar to Autumn 2022 when it was the only seagrass present (Figure 35).

GSS 4

GSS 4 is in the southern Great Sandy Strait along the intertidal areas around the mouth of Kauri Creek (Figure 28). Seagrass in GSS 4 wasn't surveyed in Spring 2022 due to its isolation from other sites. Seagrass communities in 2024 consisted predominantly of *Z. muelleri* and also included *H. uninervis* and *H. ovalis* (Figure 31). Seagrass area recovered quickly after only covering 0.96 km² in Autumn 2022 to covering an area of 3.94 km² in 2023 similar to earlier surveys (3.23 – 4.20 km²) (Figure 35; Table 3). In 2024 seagrass covered 3.93 km² (Table 3). Seagrass biomass has varied across surveys ($\chi^2 = 119.77$, df = 2, $p < 0.001$). Mean seagrass biomass was 7.05 ± 1.10 g DW m⁻², an order of magnitude higher than in previous studies ($p < 0.001$, Figure 35; Table 4). Seagrass cover has increased each survey ($\chi^2 = 147.07$, df = 2, $p < 0.001$) and was 4 times higher in 2024 (15.64 ± 2.2%) than the previous survey in 2023 (3.68 ± 0.8%, $p < 0.001$, Figure 35; Table 5). Species composition in GSS 4 has varied across

surveys (Figure 35). In August 2022 GSS 4 consisted primarily of *H. uninervis* thin (83%) with *Z. muelleri* making up the remaining 17%. In 2023 *H. uninervis* thin (65%) and *H. ovalis* (35%) were present but *Z. muelleri* was absent. In 2024 species composition was dominated by *Z. muelleri* (86%), with smaller components of *H. ovalis* (8%) and *H. uninervis* (6%).

GSS 5

GSS 5 is the most southern monitoring block (Figure 289). It is situated between Inskip Point and Tin Can Bay and has some of the largest, densest seagrass across Hervey Bay and the Great Sandy Strait. Seagrass area in GSS 5 in 2024 was the highest of all surveys, covering 4.98 km², 5 times higher than the post flooding survey in Autumn 2022 (Figure 37; Table 3). Seagrass biomass in GSS 5 increased across surveys ($\chi^2 = 290.21$, $df = 3$, $p < 0.001$). Mean seagrass biomass across the 2022 and 2023 did not get higher than 0.03 g DW m⁻² but was 21.06 ± 2.82 g DW m⁻² in 2024, two orders of magnitude higher than the previous surveys (Figure 37; Table 4). Seagrass cover showed a similar pattern and increasing by over 10 times since the 2023 survey which was higher than the 2022 surveys ($\chi^2 = 387.97$, $df = 3$, $p < 0.001$). Mean cover in 2024 was $38.21 \pm 4.30\%$ and significantly higher than all other years ($p < 0.001$, Figure 37; Table 5). *Zostera muelleri* was the dominant species in 2024 (96%), followed by *H. uninervis* thin (2%) and *H. uninervis* thin (1%) and *H. ovalis* (1%). In 2023 species composition was dominated by *H. uninervis* thin (75%) with only 2% *Z. muelleri*, however *Z. muelleri* was the dominant species in both 2022 surveys where it was greater than 86% of the biomass (Figure 37).

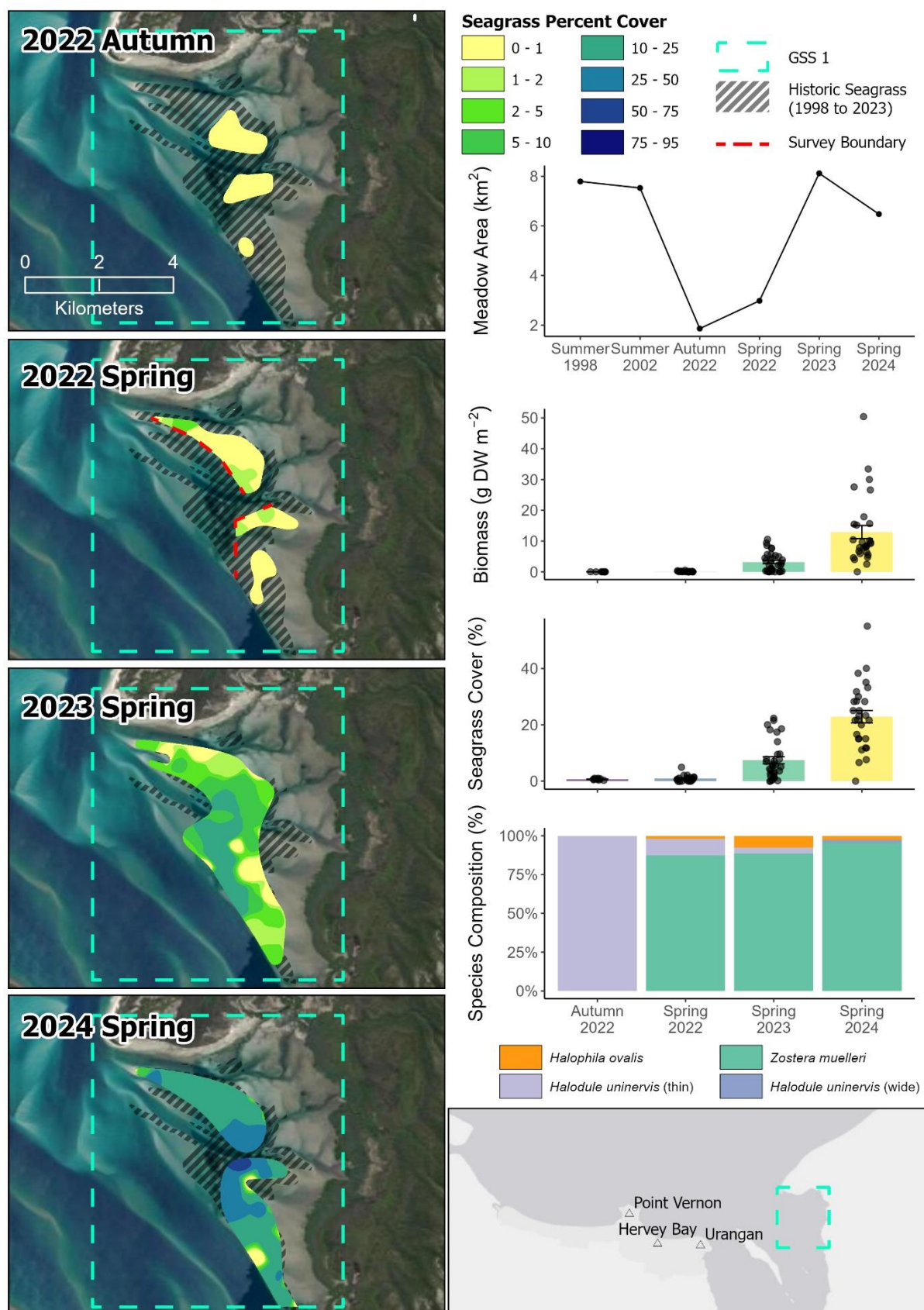


Figure 33. Seagrass area and percent cover in monitoring block GSS 1 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover and species composition in GSS 1 each survey (right side). Block location is at the bottom right.

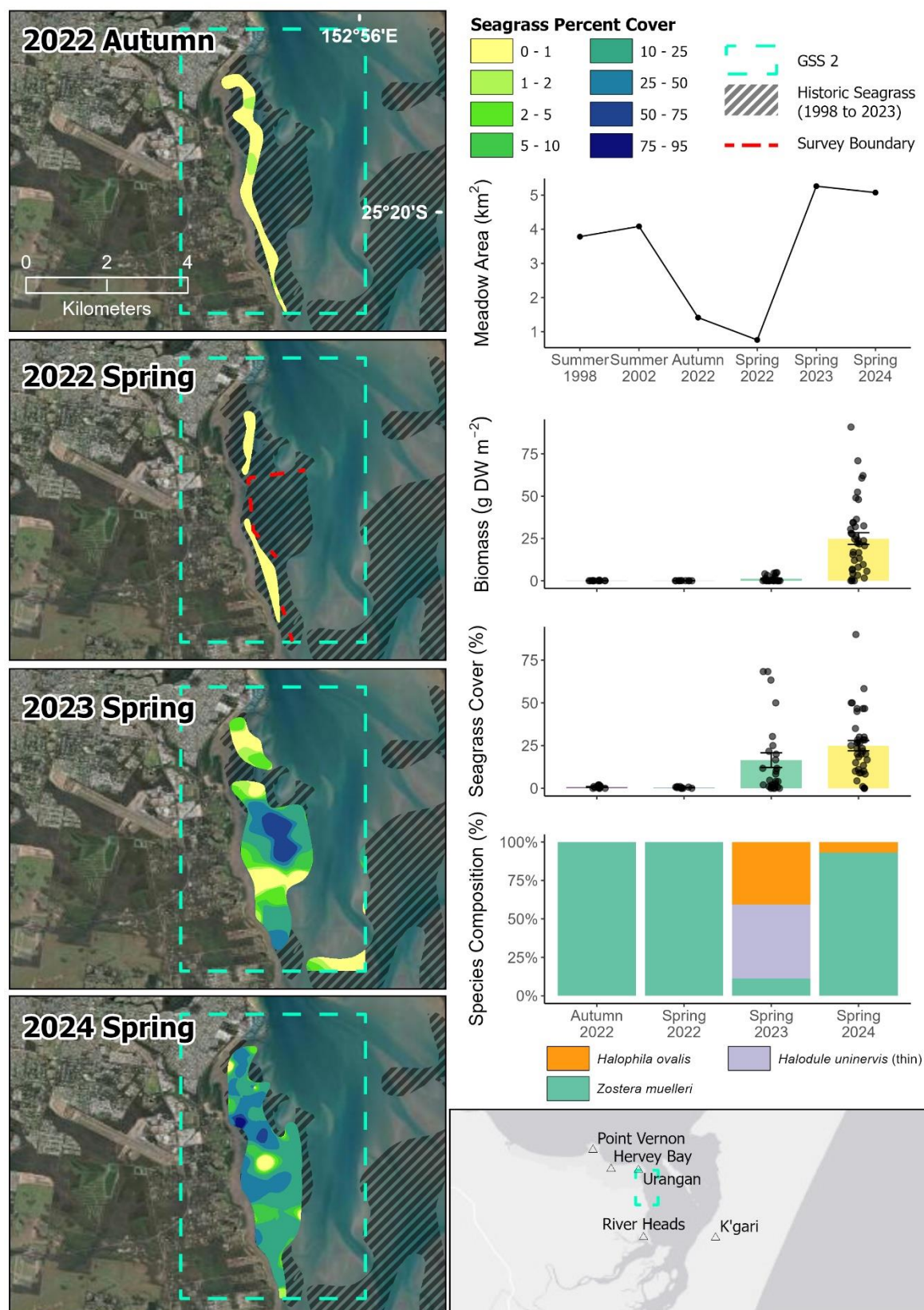


Figure 34. Seagrass area and percent cover in monitoring block GSS 2 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in GSS 2 each survey (right side). Block location is at the bottom right.

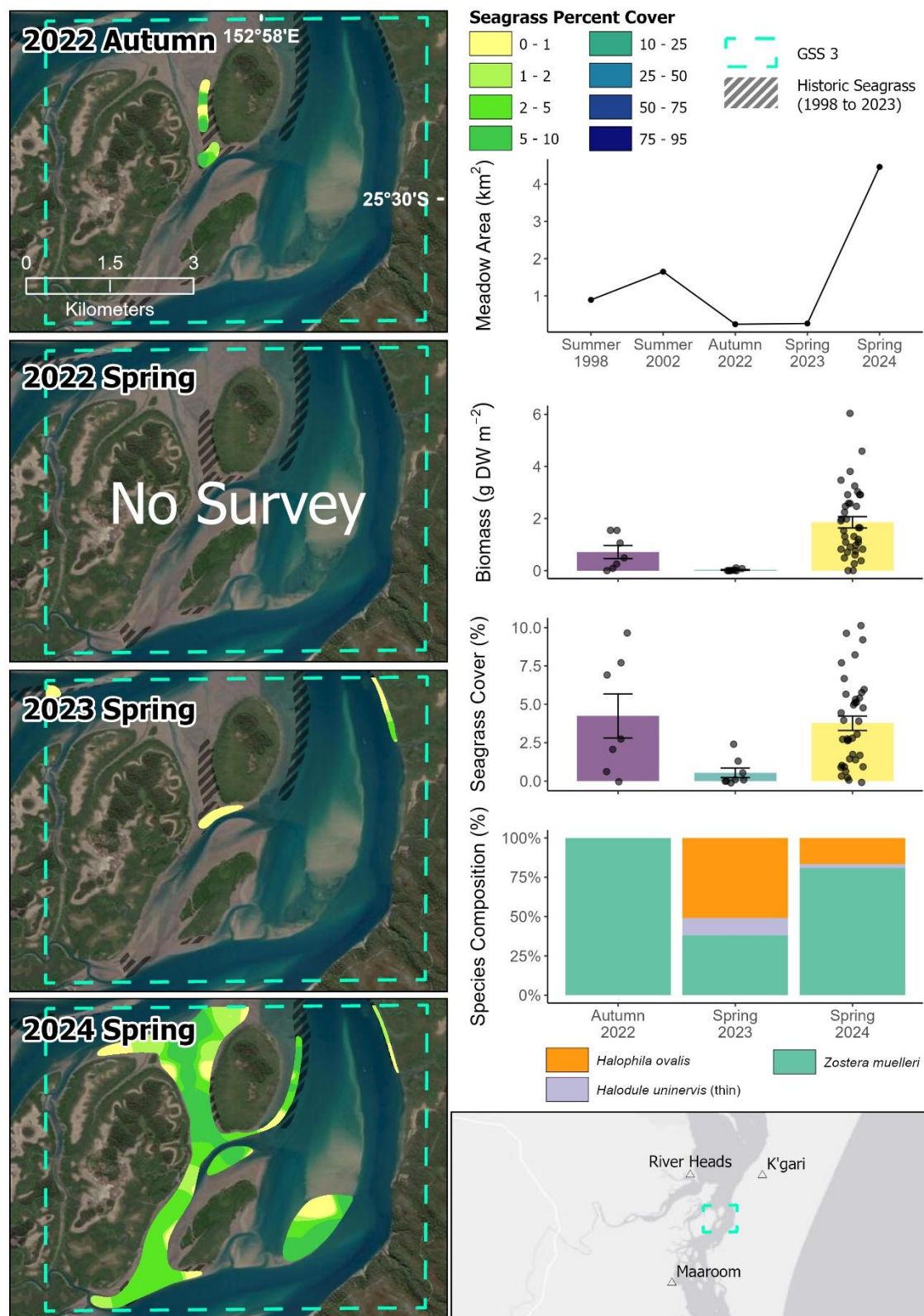


Figure 35. Seagrass area and percent cover in monitoring block GSS 3 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in GSS 3 each survey (right side). Block location is at the bottom right.

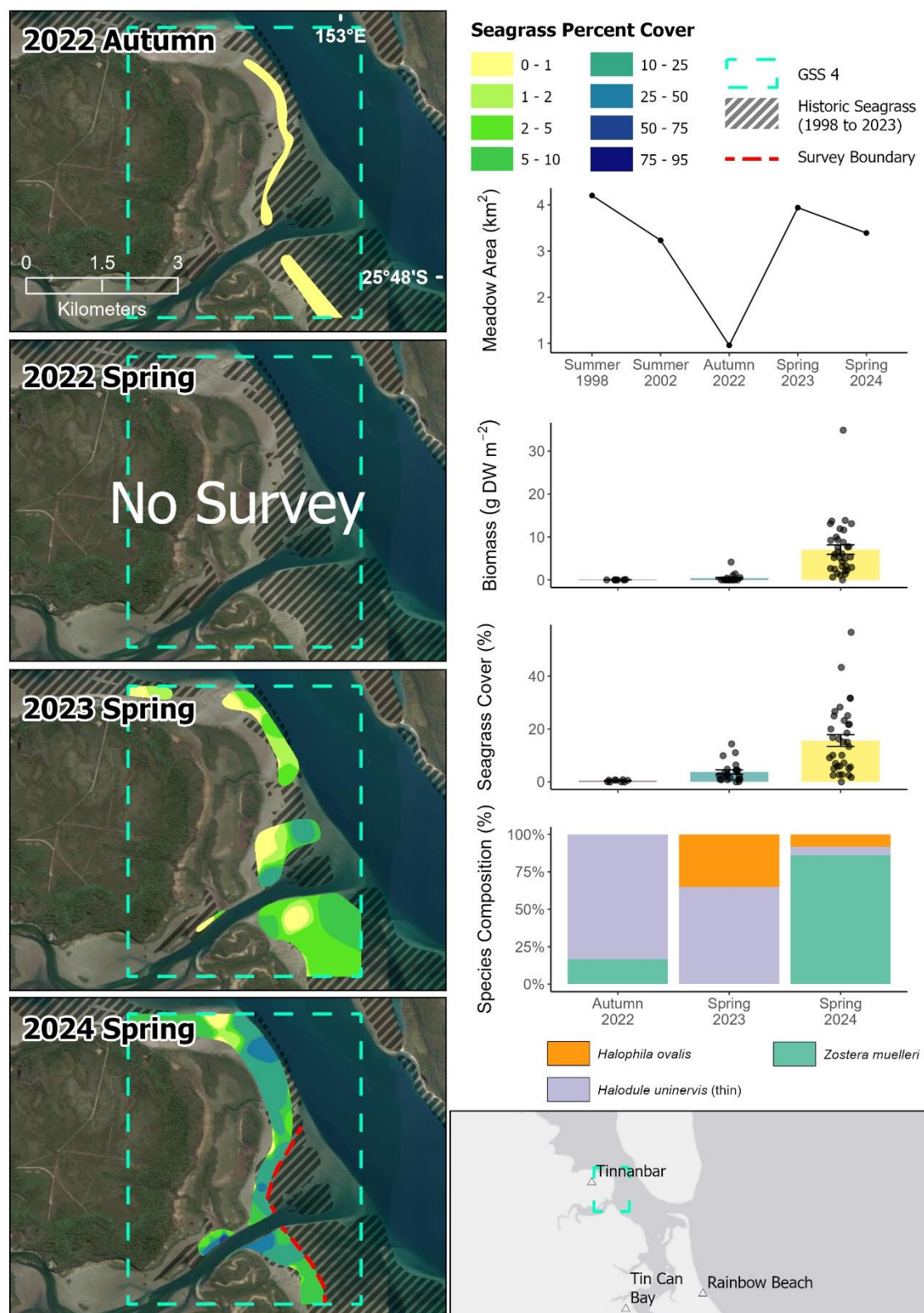


Figure 36. Seagrass area and percent cover in monitoring block GSS 4 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in GSS 4 each survey (right side). Block location is at the bottom right.

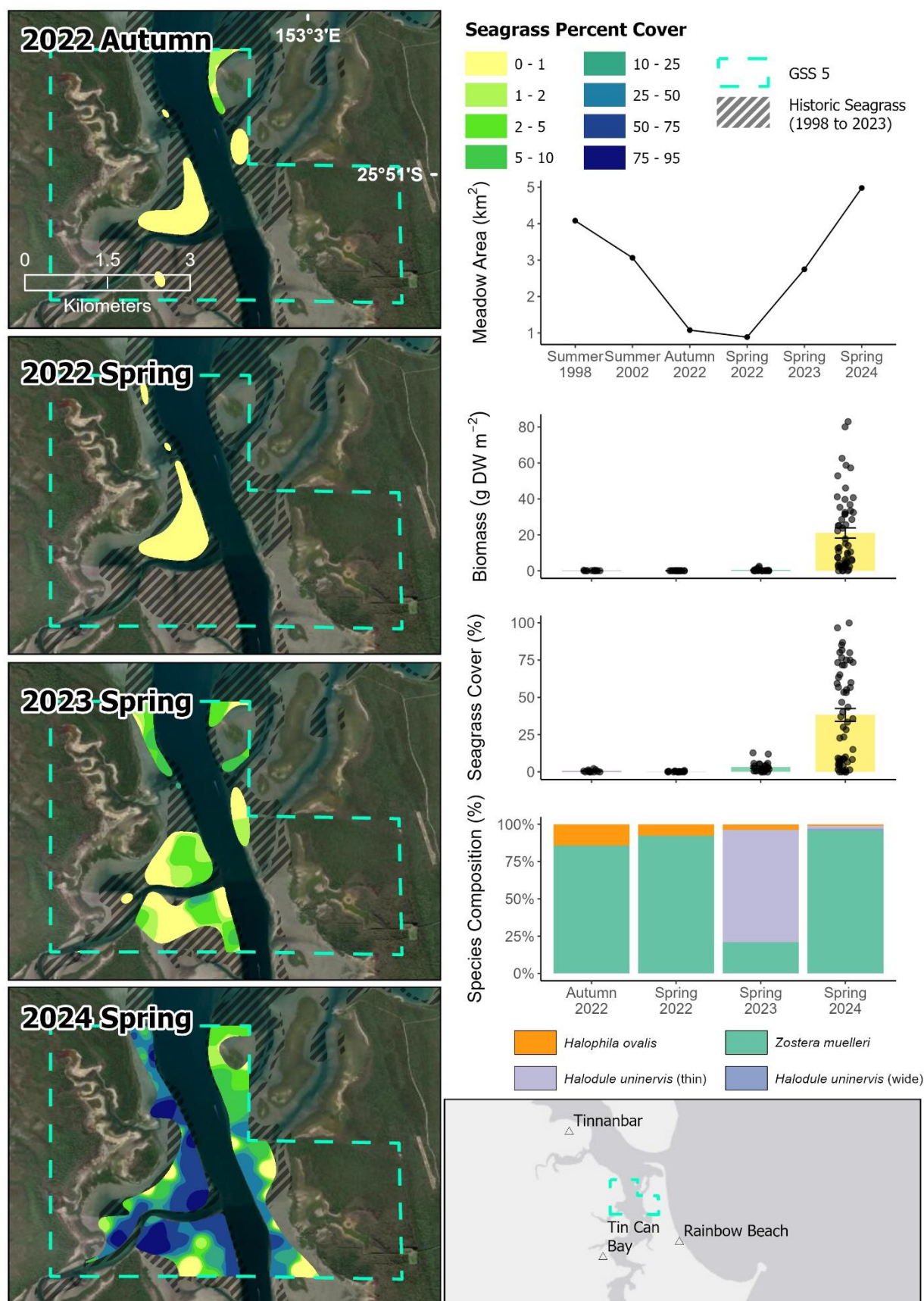


Figure 37. Seagrass area and percent cover in monitoring block GSS 5 in each survey (left side) and total meadow area, seagrass mean ($\pm$ SE) biomass and percent cover, and species composition in GSS 5 each survey (right side). Block location is at the bottom right.

Table 3. Total area (km²), of seagrass at survey blocks mapped in Hervey Bay and the Great Sandy Strait in December 1998, February 2002, May, October/November 2022 and August to November 2023 and October 2024. NS = not surveyed, NC = not calculated.

Total area (km ²)						
Block	Dec 1998	Feb 2002	May 2022	Oct/ Nov 2022	Aug to Nov 2023	Oct 2024
GSMP	315.42	69.82	136.79	224.86	269.38	248.91
GSS	20.75	19.56	5.55	4.62	20.33	24.38
GSS 1	7.79	7.53	1.86	2.98	8.12	6.48
GSS 2	3.78	4.08	1.41	0.76	5.26	5.07
GSS 3	0.89	1.65	0.243	NS	0.265	4.46
GSS 4	4.20	3.23	0.96	NS	3.94	3.39
GSS 5	4.08	3.06	1.08	0.898	2.75	49.80
HB	294.67	50.26	131.25	220.23	249.05	224.53
HB 1	NS	NS	NS	NS	NS	51.87
HB 2	50.26	50.26	50.265	50.26	50.26	45.15
HB 3	50.26	NS	23.66	50.26	50.26	50.46
HB 4	47.56	NS	46.85	37.53	49.15	32.79
HB 5	50.24	NS	NS	39.72	43.27	47.88
HB 6	50.24	NS	0	29.42.	39.36	34.40
HB deep	248.56	50.26	120.77	207.19	232.30	262.54*
HB 7	39.37	NS	9.40	9.29	13.36	10.95
HB 8	6.74	NS	1.08	3.76	3.39	2.91
HB shallow	46.11	0	10.48	13.05	16.76	13.86

*2024 total area for HB deep includes the new HB1 block that was not part of any previous survey

Table 4. Mean biomass (g DW m⁻²) of seagrass at survey blocks mapped in Hervey Bay and the Great Sandy Strait in December 1998, February 2002, May, October/November 2022 and August to November 2023 and October 2024. NS = not surveyed, NC = not calculated. Means are based on all blocks surveyed each year.

Mean biomass (g DW m ⁻²)						
Block	Dec 1998	Feb 2002	May 2022	Oct/ Nov 2022	Aug to Nov 2023	Oct 2024
GSMP	NC	NC	0.21 ± 0.06	1.0 ± 0.3	1.5 ± 0.2	10.0 ± 0.8
GSS	NC	NC	0.13 ± 0.05	0.05 ± 0.01	1.32 ± 0.2	14.5 ± 1.3
GSS 1	NC	NC	0.011 ± 0.002	0.10 ± 0.03	3.2 ± 0.6	13.0 ± 2.1
GSS 2	NC	NC	0.06 ± 0.03	0.03 ± 0.01	1.1 ± 0.3	24.9 ± 3.4
GSS 3	NC	NC	0.7 ± 0.3	NS	0.02 ± 0.01	1.9 ± 0.2
GSS 4	NC	NC	0.02 ± 0.01	NS	0.4 ± 0.2	7.0 ± 1.1
GSS 5	NC	NC	0.07 ± 0.03	0.02 ± 0.004	0.4 ± 0.1	21.1 ± 2.8
HB 1	NS	NS	NS	NS	NS	2.8 ± 0.7
HB 2	NC	NC	1.9 ± 0.7	11.7 ± 0.9	10.9 ± 1.8	8.9 ± 0.9
HB 3	NC	NC	0.3 ± 0.1	9.0 ± 1.4	2.1 ± 0.8	7.8 ± 0.9
HB 4	NC	NC	0.04 ± 0.01	2.2 ± 1.4	3.7 ± 1.3	1.3 ± 0.5
HB 5	NC	NC	0	0.3 ± 0.3	1.3 ± 1.2	1.9 ± 0.5
HB 6	NC	NC	0	0.3 ± 0.3	1.1 ± 0.9	2.5 ± 0.7
HB deep	NC	NC	0.8 ± 0.4	5.2 ± 1.3	4.3 ± 1.1	4.4 ± 0.4
HB 7	NC	NC	0.04 ± 0.04	0.4 ± 0.2	0.9 ± 0.3	3.5 ± 0.7
HB 8	NC	NC	<0.001	0.2 ± 0.1	0.2 ± 0.2	1.7 ± 0.5
HB shallow	NC	NC	0.04 ± 0.04	0.4 ± 0.1	0.7 ± 0.2	2.9 ± 0.5

Table 5. Mean percent cover of seagrass at survey blocks mapped in Hervey Bay and the Great Sandy Strait in December 1998, February 2002, May, October/November 2022 and August to November 2023 and October 2024. NS = not surveyed, NC = not calculated. Means are based on all blocks surveyed each year.

Mean Percent Cover						
Block	Dec 1998	Feb 2002	May 2022	Oct/ Nov 2022	Aug to Nov 2023	Oct 2024
GSMP	NC	NC	1.5 ± 0.4	3.9 ± 1.1	6.8 ± 0.9	16.9 ± 1.1
GSS	NC	NC	1.1 ± 0.3	0.6 ± 0.1	7.4 ± 1.2	22.7 ± 1.7
GSS 1	NC	NC	0.6 ± 0.1	0.9 ± 0.2	7.4 ± 1.3	22.7 ± 2.2
GSS 2	NC	NC	0.8 ± 0.2	0.4 ± 0.1	16.4 ± 4.3	24.9 ± 2.7
GSS 3	NC	NC	4.2 ± 1.4	NS	0.5 ± 0.3	3.8 ± 0.5
GSS 4	NC	NC	0.4 ± 0.1	NS	3.7 ± 0.8	15.6 ± 2.2
GSS 5	NC	NC	0.5 ± 0.2	0.2 ± 0.07	3.2 ± 0.7	38.2 ± 4.3
HB 1	NS	NS	NS	NS	NS	8.6 ± 1.4
HB 2	NC	NC	12.0 ± 4.1	43.8 ± 9.6	23.6 ± 3.2	15.4 ± 1.5
HB 3	NC	NC	2.0 ± 0.3	29.4 ± 2.8	9.4 ± 0.5	12.8 ± 1.2
HB 4	NC	NC	0.2 ± 0.08	7.6 ± 4.2	18.6 ± 7.7	4.2 ± 1.4
HB 5	NC	NC	0	1.6 ± 0.5	3.6 ± 2.6	5.8 ± 1.0
HB 6	NC	NC	0	1.1 ± 0.4	11.3 ± 10.3	8.4 ± 2.1
HB deep	NC	NC	5.3 ± 2.4	18.4 ± 5.1	14.1 ± 2.7	9.5 ± 0.7
HB 7	NC	NC	0.2 ± 0.08	1.5 ± 0.4	3.3 ± 0.6	9.6 ± 2.3
HB 8	NC	NC	0.1 ± 0.1	1.6 ± 0.7	0.8 ± 0.4	4.2 ± 1.2
HB shallow	NC	NC	0.2 ± 0.08	1.5 ± 0.4	2.5 ± 0.4	7.9 ± 1.7

PAR and Temperature

Data collected at the Toogoom and Woodgate sites showed that the 14 day rolling average total daily PAR continued to increase into 2024 showing higher lows and higher highs (Figure 38). Toogoom however appears to have a decline in light towards the end of the year, while the Woodgate site continued in an uptrend (Figure 38). Tobruk maintained a consistent range with peaks of around $2 \text{ mol m}^{-2} \text{ day}^{-1}$. All three locations, despite dipping below the $2 \text{ mol m}^{-2} \text{ day}^{-1}$ minimum light requirements for *Halophila* species, maintained seagrass communities.

Late November 2023 saw the introduction of two new shallow water quality sites to the monitoring program. These were at Moon Point and Kauri Creek and incorporate the Great Sandy Strait into the ongoing ambient water quality monitoring (Figure 36). These two sites show significantly higher light readings (Figure 39) to their deeper water counterparts in Hervey Bay (Figure 38). This is expected in intertidal waters when compared to subtidal waters.

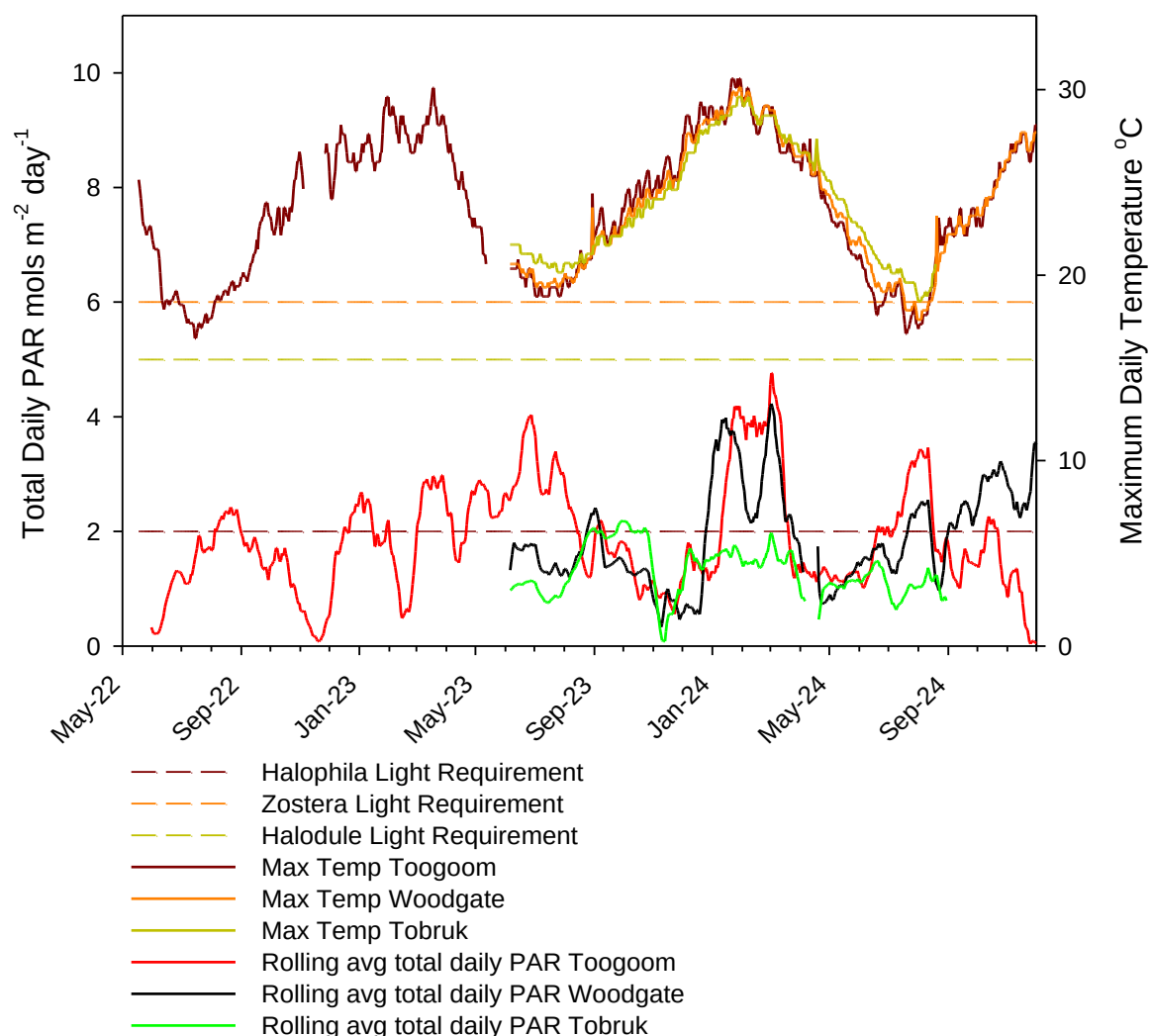


Figure 38. Total Daily PAR (mol m⁻² day⁻¹) and maximum daily temperature (°C) readings from light logging stations at Toogoom, Woodgate and Tobruk from May 2022 to December 2024. Light requirements (LR) for three different seagrass genera (*Halophila*, *Zostera*, *Halodule*) are also shown.

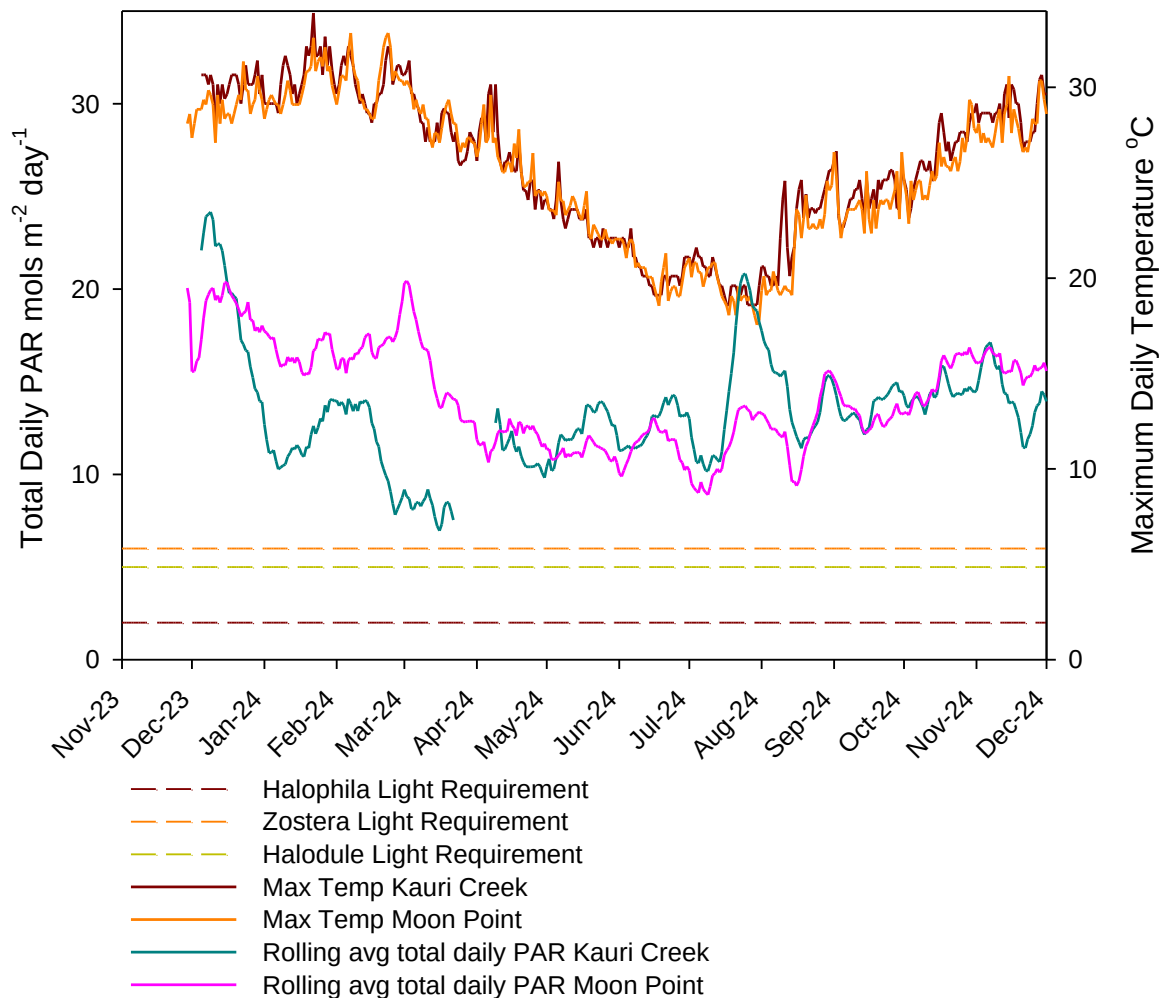


Figure 39. Total Daily PAR ($\text{mol m}^{-2} \text{day}^{-1}$) and maximum daily temperature ($^{\circ}\text{C}$) readings from light logging stations at Moon Point and Kauri Creek from mid November 2023 to December 2024. Light requirements (LR) for three different seagrass genera (*Halophila*, *Zostera*, *Halodule*) are also shown.

Following the large-scale flooding in early 2022, there had not been other major events that have impacted river flow in the Mary River leading to the large and prolonged plumes that severely impact seagrass health in the region. River flow was fairly steady through 2023 and 2024 (Figure 37). However, after the survey at the end of 2024, the region was impacted by Tropical Cyclone Alfred in March 2025 which resulted in local flash flooding around Hervey Bay. This event brought local heavy rainfall to the region over several days but was not as prolonged and widespread through the major Mary River catchment as previous flooding events in 1992, 1999, 2011, 2013 and 2022 (Figure 40).

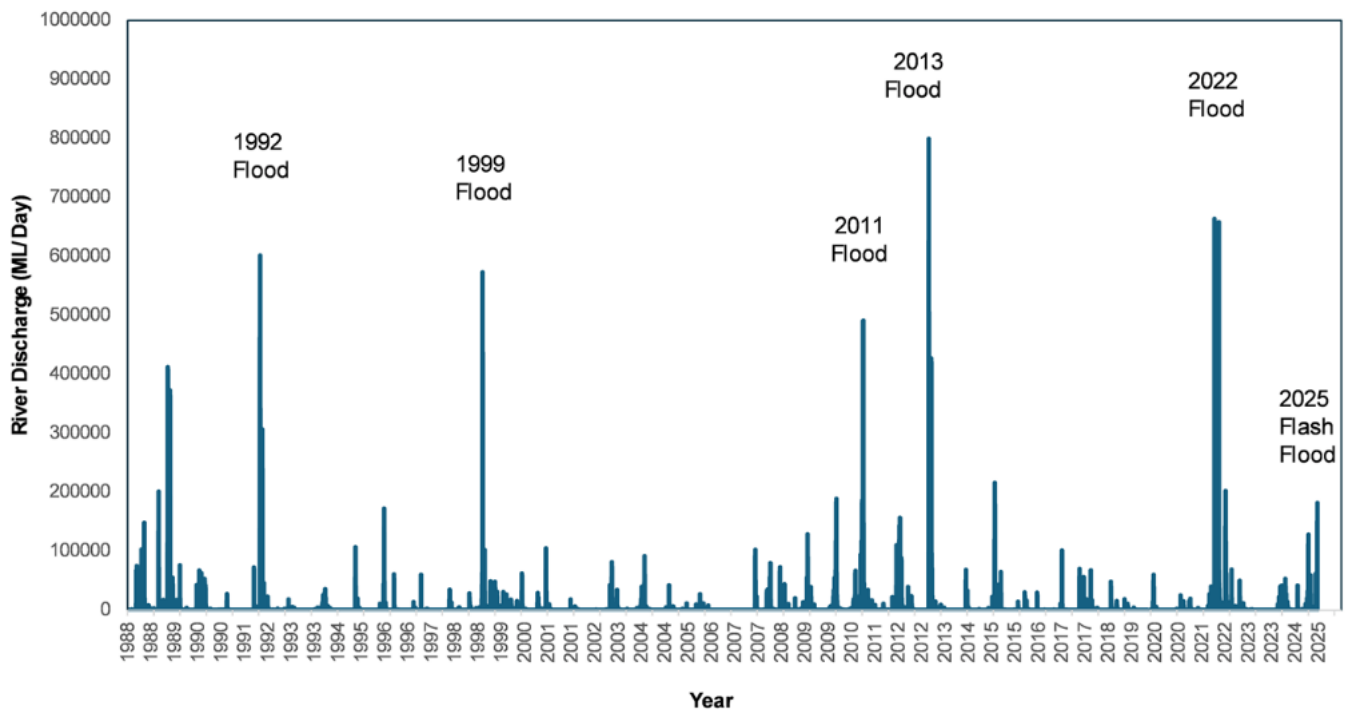


Figure 40. Daily discharge at Home Park gauge (138014A) in the Mary River from 1988 to March 2025. Data sourced from the Queensland Government (<https://water-monitoring.information.qld.gov.au/>)

DISCUSSION

Seagrass surveys were conducted in October–November 2024 in the Great Sandy Marine Park (GSMP), approximately 2.5 years following extensive flooding with persistent flood plumes that lead to widespread declines of seagrass in early 2022. The 2024 survey sampled newly established monitoring blocks in deep-water and shallow subtidal habitats in Hervey Bay, which included previously surveyed intertidal meadows in both Hervey Bay and the Great Sandy Strait. This survey is the fourth assessment of the seagrass distribution and abundance to monitor seagrass change post-flood. Previous surveys included a broadscale survey of Hervey Bay and intertidal meadows in the Great Sandy Strait in May 2022 (York et al. 2022), a broadscale survey of Hervey Bay and newly established monitoring blocks in the Great Sandy Strait intertidal meadows in October/November 2022 (Bryant et al. 2023) and a broadscale survey across all of Hervey Bay and Great Sandy Strait subtidal and intertidal habitats in August–October 2023 (Bryant et al. 2024).

In 2024, overall mean seagrass abundance measured increased significantly across the GSMP compared to previous years. Seagrass biomass across combined Hervey Bay and Great Sandy Strait monitoring areas is 7 times higher than the previous year (Bryant et al. 2024) and almost 50 times higher than post-flood levels two and a half years prior (York et al. 2022). The mean seagrass percent cover has also increased across all monitoring areas in the GSMP and is 2.5 times higher than the previous year (Bryant et al. 2024) and almost 11.5 times higher than post-flood levels two and a half years prior (York et al. 2022). The total area of seagrass meadows in the GSMP monitoring areas has remained steady overall in the last 12 months with only an 8 percent increase, however, seagrass area has increased by 80 percent in the monitoring areas since the initial post-flood survey in May 2022. Changes in seagrass abundance and area, however, have not been consistent across the region with the greatest increases occurring in the Great Sandy Strait intertidal areas and substantial increases also incurring in intertidal meadows in Hervey Bay, while the deep-water seagrasses in Hervey Bay have generally remained relatively steady. Deep-water blocks closer to the mainland showed increases in biomass and cover and blocks in central Hervey Bay showing slight decreases over the previous 12 months.

The greatest recovery in seagrass abundance over the last year has occurred in intertidal meadows particularly in the Great Sandy Strait dominated by *Zostera muelleri* and mixed with *Halodule uninervis* and *Halophila ovalis*. The aerial footprint of seagrass in monitoring blocks at the northern end of the Great Sandy Strait around Moon Point and Urangan declined moderately over the previous year. However, the average abundance of seagrass at Urangan (GSS1) increased to 24.9 g DW m² in 2024, approaching levels last recorded prior to the 1999 floods of 29.2 g DW m² (McKenzie et al. 2000), and approximately half the biomass at Moon Point (GSS2) in the current survey. The greatest expansion in meadow area occurred in the central Great Sandy Strait, south of the Mary River mouth around Booker, Walsh and Turkey Islands (GSS3). Seagrass in this monitoring area increased in size over 17-fold from 0.26 km² in 2023 to 4.46 km² in 2024. Seagrass biomass in the area also increases almost two orders of magnitude from very low levels to 1.9 g DW m², however, it remains well below the 1998 pre-flood levels of 31.8 g DW m² at nearby Wanggoolba Creek (McKenzie et al. 2000). In the southern end of the Great Sandy Strait less seagrass was mapped around the mouth of Kauri Creek than in 2023, however the survey was limited by tides and the outer extent of the meadow, particularly south of Kauri Creek could not be validated on the survey. Seagrass mean biomass increased substantially here over the previous 12 months to 7.0 g DW m², similar to levels observed prior to the 1999 flood (10.46 ± 8.10 g DW m² - McKenzie et al. 2000). Mean seagrass cover showed a similar pattern increasing to 15.6%, more than four times the mean cover in 2023 (3.7%). In Tin Can Bay, the area of seagrass mapped increased over the previous 12 months, however, this was

predominately due to the expansion of the bottom of the monitoring area to include the eastern side of the inlet for the first time. Seagrass biomass increased in this area by a factor of 50 to reach 21.1 g DW m² and cover increased by a factor of 10 to be 38.2%.

The intertidal seagrass in Hervey Bay showed the same increasing trend in abundance as those in the Great Sandy Strait, despite small declines in the seagrass area of each monitoring block. The intertidal seagrass between Burrum Heads and Toogoom (HB7) and to the west of Point Vernon (HB8) increased in biomass by a factor of 4 and 8.5 to means to 3.5 g DW m² and 1.7 g DW m² respectively. Seagrass abundances at these locations still remain below historical levels, with percent cover of seagrass around Burrum Heads currently just under 10% compared to 10-50% in 1998 (Lee Long et al. 1992; Preen et al. 1995) and fluctuating up to 30-40 percent over the last 20 years (Seagrass Watch 2024). On a regional scale, intertidal seagrass to the north of Hervey Bay in Gladstone and Rodds Bay also exhibited large increases in biomass over the period from late 2023 to late 2024 (Reason et al. 2025). The subtidal *H. uninervis* meadow adjacent to Burrum Heads in HB7 reduced in area by 27 percent over the last year and underwent a large reduction in mean biomass from 9.4 g DW m² in 2023 to 0.5 g DW m² in 2024. This area was once much larger and contained dense areas of subtidal seagrass that were important feeding grounds for dugong (Shepperd et al. 2007).

Deep-water seagrasses in Hervey Bay had fared much better than intertidal meadows following the floods. Large areas of relatively abundant meadows consisting of *Halophila* species remained in the centre of the bay immediately after the 2022 flood (York et al. 2022) and expanded in distribution and increased in mean biomass particularly by the growing season of 2022 (Bryant et al. 2023). Over the last 12 to 24 months these deepwater seagrass meadows have remained relatively stable with mean biomass barely changing since the previous survey (4.3 g DW m² in 2023 and 4.4 g DW m² in 2024). Across the bay in 2024 there has been variability among monitoring blocks with some areas increasing in biomass and percent cover over the previous twelve months while others decreased. The new monitoring block HB1 was surveyed for the first time and demonstrated that the meadow extent extends to the north of the traditional survey area with the location of the meadow edge still unknown. The *Halophila* species that are found in these meadows are considered colonisers and are known to be highly variable in abundance and distribution. Such natural variability may explain decreases in biomass and cover in the central blocks of Hervey Bay (HB 2-4). The life cycle of *Halophila* species is characterised by rapid colonisation of suitable habitat following disturbance, relying on short reproductive cycles and maintenance of large seed banks (Kilminster et al. 2015). They are also more susceptible to unfavourable light conditions and can decline rapidly in these environments (Kilminster et al. 2015). While abundances of Hervey Bay deepwater meadows are relatively high compared to the Great Barrier Reef lagoon (Coles et al. 2009), they are well below historical comparisons with estimates of over 50 percent cover in 1988 (Lee Long et al. 1992; Preen et al. 1995) and mean biomass for deep-water meadows in 1998 of 20 - 35 g DW m⁻² (McKenzie et al. 2000).

The main reason for the variable trends in seagrass abundance across habitats in the GSMP is likely to be the benthic light environment over the period since the previous survey. Monitoring of benthic light (Photosynthetically Active Radiation - PAR) now occurs at stations ranging from intertidal meadows through to the offshore deep-water seagrass areas. Benthic light levels remained well above growth requirements for key shallow water species (*H. uninervis* and *Z. muelleri*) (Collier et al. 2016) in the intertidal meadows in the northern (Moon Point) and southern (Kauri Creek) Great Sandy Strait where PAR was measured from late 2023 to the end of 2024. These high light conditions are very favourable to seagrass growth and created the environment for the large increases in seagrass abundance in the intertidal meadows (Ralph et al. 2007). Light conditions at shallow subtidal (Toogoom) and deeper sites (HMAS Toobruk and Woodgate) in Hervey Bay were lower due to the light

attenuation with water depth. While benthic PAR levels remained above the minimum light requirements for *Halophila* species (Collier et al. 2016) for large parts of the 2024 seagrass growing season, there were also periods when they fell below these limits. These variable light conditions may have led to the relatively poorer seagrass recovery compared to the intertidal seagrass.

There have been no prolonged and large-scale flood events since early 2022, allowing for several years of relatively favourable conditions for seagrass recovery. Following the 2024 survey, however, Tropical Cyclone Alfred passed through the region in early March and the aftermath saw local heavy rainfall events and flash flooding around Hervey Bay. While river flows and therefore plumes from the Mary River did not reach levels of the 2022 event, further monitoring in 2025 will be vital to understanding the continuing seagrass recovery processes in the region.

The rapid recovery of seagrass over the last twelve months, particularly in the intertidal meadows in the Great Sandy Strait and Hervey Bay, is likely due to a combination of meadows reproducing sexually and dispersing seeds, and favourable conditions for seagrass growth and rhizome extension. Recovery of intertidal *Zostera muelleri* meadows in the Great Sandy Strait in 1999 took a similar time frame (3 years - Campbell and McKenzie 2004) and in intertidal and subtidal meadows near Burrum Heads abundant and continuous seagrass had returned within five years of the flood events (Sheppard et al. 2007). Seed banks containing low abundances of *Halodule uninervis* at Poona and Tin Can Bay and *Zostera muelleri* in Burrum Heads were surveyed in 2023 (Bryant et al. 2024). Flowering shoots on *Zostera muelleri* were observed during the 2024 surveys at Tin Can Bay and other intertidal sites during the 2024 survey. Flowering shoots of *Halophila spinulosa* were also observed at multiple sites in deepwater meadows within Hervey Bay in 2024 highlighting the important role of sexual reproduction in maintaining *Halophila* meadows.

The continued improvement in seagrass abundance throughout the region is good news for dugong and turtle populations. Dugongs and turtles have historically been observed throughout Hervey Bay and the Great Sandy Strait in densities ranging from low to very high during quantitative aerial surveys (2005, 2011, 2016 - Cleguer et al. 2023; Rasheed et al. 2023). Following the floods in early 2022 no dugongs were observed in aerial surveys throughout the Great Sandy Strait (Cleguer et al. 2023; Rasheed et al. 2023). The population of dugong in Hervey Bay had also shifted from their usual distribution of higher densities on the western side of the bay to be concentrated in the centre of the bay where the vast majority of seagrass resources remained (Cleguer et al. 2023; Rasheed et al. 2023). Turtle observations following the floods continued across the whole of the Bay and the Great Sandy Strait, however, loss of seagrass foraging grounds through much of that area led to sharp increases in turtle strandings in the Great Sandy Bioregion in 2022 and 2023 (Rasheed et al. 2023). The current (2024) survey coincided with a dugong aerial survey that is still being analysed, however, observers from the survey reported that dugong feeding herds had returned to the Great Sandy Strait and the population of dugong in Hervey Bay were more widely distributed across the bay compared to post-flood (pers. comms. Chrisophe Cleguer, James Cook University). Dugong feeding trails were also observed throughout the helicopter surveys of the Great Sandy Strait and the number of turtle strandings in 2024 in the Great Sandy bioregion had reduced to approximately half that of the previous 2 years (Figure 41).

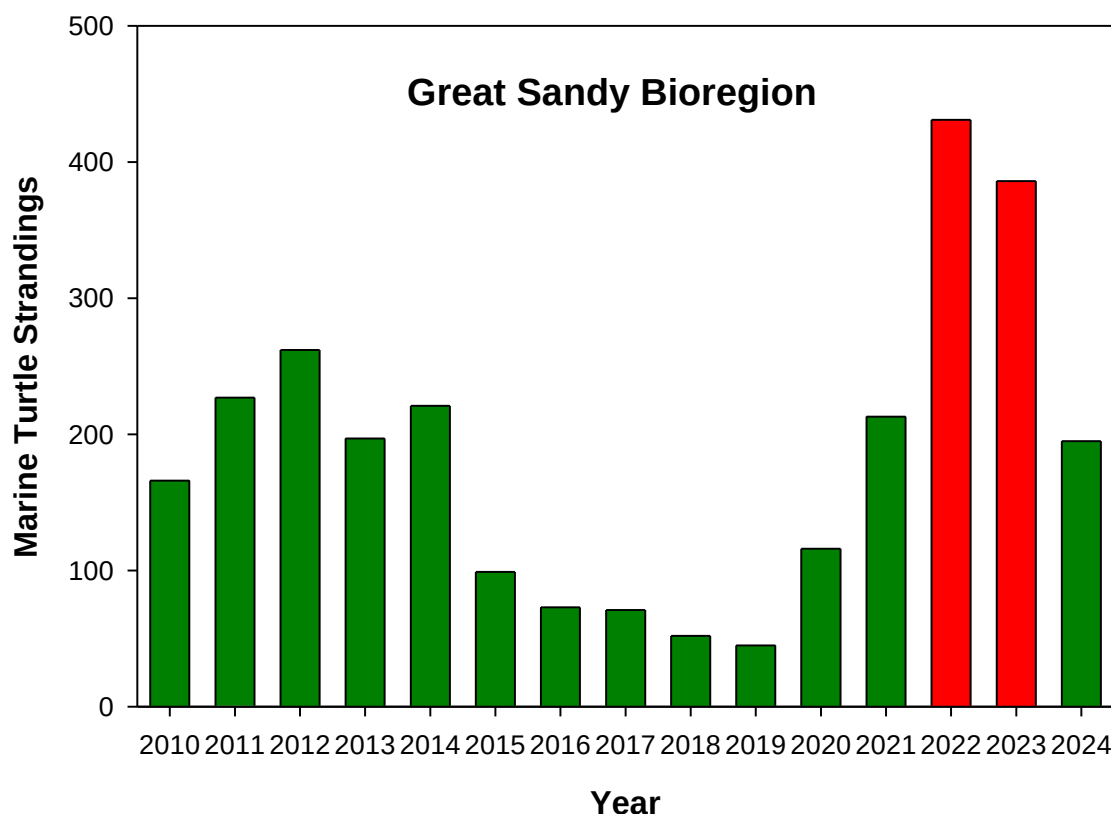


Figure 41. Historical stranding data of sea turtles for the Great Sandy Marine Park region from 2010 to 2024 highlighting the spike in strandings following the extensive floods in 2022.

Long-term Monitoring Strategy

The long-term monitoring strategy, employed for the first time in 2024, includes monitoring areas spread through the major seagrass communities in deep-water, subtidal and intertidal meadows throughout the GSMP. The design of the program also incorporates key management zones within the Great Sandy Marine Park. Based on the results of this year's survey this strategy provided good coverage of the major representative seagrass community types and captured a range of recovery outcomes highlighting spatial variability within the region. If this strategy is continued on an annual basis combined with broadscale surveys every 5 years it would provide an informative timeline of seagrass condition in the area and provide baseline data for which to benchmark major changes to seagrass ecosystems following major events such as storms or floods. This strategy is comparatively affordable and logistically feasible compared to annual broadscale surveys. If data collection continues beyond 5 years, the information can be utilised in a seagrass scoring methodology that would be consistent with approaches for other nearby regional seagrass report cards including in the Gladstone Healthy Harbour Partnership (Carter et al. 2023) and the other regional partnerships for waterway health along the Great Barrier Reef Catchments. Given the importance of seagrass resources to turtle and dugong populations and their close association with the habitat for foraging it is recommended to synchronise baseline surveys to coincide with the 5-yearly quantitative dugong aerial surveys in the region. In the event of a major disturbance such as a flood, additional broadscale surveys could be undertaken to monitor seagrass more broadly.

Other measures that would provide extra valuable information to the seagrass recovery include the continued collection of benthic light associated with seagrass meadows at the network of monitoring stations now set up through intertidal and subtidal locations in Hervey Bay and the Great Sandy Strait. As detailed over the previous year in this report, this data gives insight into the spatial variability of seagrass condition across the GSMP. Further assessments of seed-banks in intertidal meadows conducted in late 2023 would also build on our understanding of seed bank dynamics in the region and their contribution to the recovery and resilience of seagrass resources.

Conclusions and recommendations

Overall, the seagrass condition in Hervey Bay and the Great Sandy Strait has improved greatly since the previous survey conducted in late 2023 (Bryant et al. 2024). This is particularly the case for the intertidal meadows throughout the region which have improved in biomass across all monitoring areas and increased in area particularly in the central Great Sandy Strait. In contrast, deep-water seagrasses in Hervey Bay remained more stable with some areas undergoing either slight increases or declines in abundance over the last year and the largest decline in abundance occurring in the shallow subtidal meadow offshore from Burrum Heads. These deep meadows have generally been in better condition than intertidal meadows following the 2022 floods and are characteristically more variable in distribution and biomass so changes in these meadows are not of great concern given natural annual variability. The return of dugong feeding herds to the Great Sandy Strait and the large reduction in turtle strandings throughout the bioregion suggest that key ecological functions are also returning with the increased abundance of seagrass in the region. While the results of the current survey are overall positive for seagrass in the GSMP following the large-scale floods in early 2022, continued annual monitoring is recommended, particularly following local flash flooding around Hervey Bay following Tropical Cyclone Alfred in March 2025. We have recommended a continuation of the seagrass monitoring approach adopted in the current survey in 2025 and, ideally, on an annual basis into the future. We have also suggested a range of other measures that could be implemented to improve the understanding of seagrass dynamics and recovery in the region and ensure that management of seagrasses and associated fauna are well informed in the future.

APPENDICES

Appendix 1. Coastal benthic survey data sheet

COASTAL BENTHIC SURVEY

Recorder:

Vessel:

Date:

Site #:.....Location:.....
 Time:.....hrs Depth:.....m Observer:.....
 Sed/Substrate:.....% Consolidated
Beach / Coffee Rk (Cons)

☐ Helicopter ☐ Camera ☐ Grab ☐ Diver
☐ Dugong ☐ Turtle ☐ Dolphin ☐ DFT

ALGAE Total % cover:.....

Algal category	% of total algae	% Consolidated
Erect macros		
Erect calcareous		
Filamentous		
Turf Mat		
Encrusting		

COMMENTS:

SEAGRASS Total % cover:.....

Rank	Species / % composition	% Cover

Epiphyte Cover: None L M H

☐ Exclude from Biomass

BENTHOS

Benthic category	% of total cover
Open Substrate	
Hard Coral	
Soft Coral	
Sponges	
Other BMI	

Site #:.....Location:.....
 Time:.....hrs Depth:.....m Observer:.....
 Sed/Substrate:.....% Consolidated
Beach / Coffee Rk (Cons)

☐ Helicopter ☐ Camera ☐ Grab ☐ Diver
☐ Dugong ☐ Turtle ☐ Dolphin ☐ DFT

ALGAE Total % cover:.....

Algal category	% of total algae	% Consolidated
Erect macros		
Erect calcareous		
Filamentous		
Turf Mat		
Encrusting		

COMMENTS:

SEAGRASS Total % cover:.....

Rank	Species / % composition	% Cover

Epiphyte Cover: None L M H

☐ Exclude from Biomass

BENTHOS

Benthic category	% of total cover
Open Substrate	
Hard Coral	
Soft Coral	
Sponges	
Other BMI	

Site #:.....Location:.....
 Time:.....hrs Depth:.....m Observer:.....
 Sed/Substrate:.....% Consolidated
Beach / Coffee Rk (Cons)

☐ Helicopter ☐ Camera ☐ Grab ☐ Diver
☐ Dugong ☐ Turtle ☐ Dolphin ☐ DFT

ALGAE Total % cover:.....

Algal category	% of total algae	% Consolidated
Erect macros		
Erect calcareous		
Filamentous		
Turf Mat		
Encrusting		

COMMENTS:

SEAGRASS Total % cover:.....

Rank	Species / % composition	% Cover

Epiphyte Cover: None L M H

☐ Exclude from Biomass

BENTHOS

Benthic category	% of total cover
Open Substrate	
Hard Coral	
Soft Coral	
Sponges	
Other BMI	

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