2023 Dugong Aerial Survey: Mission Beach to Cape York

July 2024 | Report No. 24/43

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The report may be cited as

Cleguer C, Hamel MA, Rankin RW, Langlois L, Edwards C, Marsh H (2024) '2023 Dugong Aerial Survey: Mission Beach to Cape York', JCU Centre for Tropical Water & Aquatic Ecosystem Research Publication 24/43, Townsville. 61pp. https//doi.org/10.25903/jz1s-xq74

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Acknowledgments

Our James Cook University (JCU)-TropWATER team extends its deepest respect and recognition to all Traditional Owners of the Great Barrier Reef, as First Nations Peoples holding the hopes, dreams, traditions, and cultures of the Reef.

We express our gratitude to the Great Barrier Reef Foundation, the Department of Climate Change, Energy, the Environment, and the Australian Government's National Environmental Science Program (NESP) for generously funding this research. We extend our appreciation to the Project Steering Committee (including Professor Damien Burrows, and representatives of the Great Barrier Reef Marine Park Authority (GBRMPA), Queensland and federal Governments) for their valuable support and feedback throughout the project. We are grateful for the support of Shane Forester and Leon Jackson (GBRMPA), who have greatly facilitated our engagement with Traditional Owners across the Great Barrier Reef World Heritage Area. We would like to thank Takahiro Shimada (Queensland's Department of Environment, Science and Innovation) for granting us access to the Queensland dugong and sea turtle stranding data. Our sincere appreciation goes to Josh and Renee Liddle (Liddle Air Services) for their technical support, as well as pilots Mitch Mcquire and Gail Neylan for ensuring our safety throughout the survey. Lastly, we extend our heartfelt thanks to the dedicated members of the aerial survey team: Kym Reeve, Lily Donnelly, Daniel Gonzalez-Paredes and Jay Harris for their tireless efforts in the field. The unwavering dedication and assistance provided by the JCU-TropWATER staff, including Susan Lesley, Karen Woods, and Molly McShane, in their round-the-clock administrative support before, during, and after the survey, is sincerely acknowledged.

Research was conducted under JCU Animal Ethics A2798 and GBRMPA Approval CSE148.

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4 EXECUTIVE SUMMARY

Project objectives

- The objectives of our study were to:
  1. Continue the time series of surveys for dugongs across the inshore waters of the northern section of the Great Barrier Reef World Heritage Area
  2. Continue to explore the reduction uncertainty in the results for the surveys
  3. Provide advice to relevant management partners (GBRMPA, DCCEEW, and the Queensland Government) and Traditional Owners about the implications of the findings for the conservation, management, and monitoring of dugongs in the northern Great Barrier Reef.

Methods

- We surveyed the inshore waters of the Great Barrier Reef (GBR) between Mission Beach and Cape York in October-November 2023.
- The survey design was based on the aerial surveys conducted by researchers at James Cook University since the 1980s as optimised during the RIMReP process.
- The aerial survey methodology followed the strip transect aerial survey technique used in earlier surveys along the Queensland coast.
- Imagery experiments were undertaken as part of this survey but will be synthesised in a separate report.
- Dugong abundance was estimated using the Hagihara method, which corrects for detection biases.
- N-mixture Bayesian models were used to assess trends in the dugong population across the surveyed region between 2006 and 2023.
- We developed spatially explicit models of dugong density distribution for survey years 2006, 2013, 2018-19, and 2023 using the Inverse Distance Weighting (IDW) technique.

Key findings

- The dugong population in the northern Great Barrier Reef (**nGBR**) in late 2023 was estimated at 6,838 dugongs (±se 968) using the Hagihara method. This compares with the (revised) population estimate of 6942 (±se 1618) in 2018-19.
- 9.1% of dugong sightings in the **nGBR** were calves (43 calves out of 471 dugongs), the highest percentage recorded since 2006 and within the 'normal' range for dugong surveys.
- Over 17 years, the population has grown at approximately 2% per year, indicating that the dugongs in the **nGBR** are in good condition.
- The population density in 2023 was the highest among all survey years (2006, 2013, 2018-19, 2023).
- Most population growth occurred between 2006 and 2019, with no statistical difference between 2019 and 2023.
- This population trend confirms the status of the dugong in the **nGBR**, an attribute of the Outstanding Universal Value of the region's Outstanding Universal Value.
- The increasing population in the **nGBR** contrasts with a significant population decline in the southern Great Barrier Reef (**sGBR**), and concerns about their status in Hervey Bay and Moreton Bay.
- From 2006 to 2023, high and very high dugong densities were consistently found inshore and offshore between north of Cape Flattery (14° 53' S) and Cape Melville (14° 10' S), and in sheltered bays like Lloyd Bay(12° 51' S), Temple Bay (12° 20' S), and Shelburne Bay (11° 55' S).

- Consistently low dugong densities were found inshore between north of Shelburne Bay and the northern boundary of the survey region.
- Spatial models indicate spatial variations in dugong density 'hotspots', likely reflecting temporary emigration of dugongs within and possibly out of the survey area between survey events.
- Spatial models from the 2018 and 2023 surveys in the northern Central GBR (Mission Beach to Cape Bedford, north of Cooktown) show overall low dugong densities, but an increase in dugong density around Innisfail and fewer dugongs in the Cape Tribulation area in 2023 compared to 2018. These differences may be due to temporary emigration.
- We repeated two survey transects where a high number of dugongs were present to test the increase in the precision of estimates and decrease the statistical variance of transect densities. Our analysis also revealed that the gains in repeat surveys was only slightly better than the gains from expanding the overall number of transects. Therefore, it is an open question whether resources would be better spent on surveying more transects, or whether it is better to do repeat surveys on the same transects where high number of animals are observed. This conclusion is tentative given that only two transects were repeated but suggest an area for further research to reduce the uncertainty surrounding dugong population estimates.

Key findings for policy makers

- The status of the dugong population in the remote coast of the **nGBR** is good and in much better condition than the populations along the more urbanised coast of the **sGBR**.
- The first priority of the survey team/dugong scientists must be to consult with the Traditional Owners of the Indigenous communities in the nGBR about the results of this survey and how they would like to share these results with their communities.
- Despite considerable attempts to reduce impacts in the GBRWHA, threats to dugongs and their habitats remain. An important next step might be to work with key Traditional Owners of: 1) the Sea Country bordering the dugong 'hotspots' in the **sGBR** (e.g., Hinchinbrook, Townsville and Shoalwater Bay), and 2) in the Sea Country of the major communities in the **nGBR**: to consider the risks, including the climate risks, to dugongs and their habitats in their region.
- This consultation could be a key first step in developing a Wildlife Conservation Plan for Dugongs (or Coastal Megafauna more generically) in the coastal waters of the GBRWHA.
- The development of such a Plan would provide a vehicle for exploring opportunities for increased Traditional Owners participation in the research and management of dugongs in the GBRWHA.
- The 5-yearly aerial surveys of dugongs across the GBRWHA are clearly an effective method of monitoring the status of dugongs in the region.

5 INTRODUCTION

Significance of the dugong and sea turtles in the Great Barrier Reef and neighbouring regions

In Australia, the dugong (*Dugong dugon*) is a *Matter of National Environmental Significance* because it is listed as a listed migratory species under the Environment Protection and Biodiversity Conservation Act 1999. The dugong is also listed as Vulnerable under the Nature Conservation Act 1992 (Qld) and at a global scale (Marsh and Sobtzick, 2019).

Australia is a signatory to several international agreements that define its obligations to protect dugongs including the Convention on Migratory Species of wild Animals and the associated *Memorandum of Understanding on the Conservation and Management of Dugongs and their Habitats throughout their Range* (Dugong MOU). Signatories to the Dugong MOU agree to cooperate to restore or maintain a favourable dugong conservation status. The dugong is also explicitly mentioned as an attribute of the *Outstanding Universal Value* of the Great Barrier Reef World Heritage Area (hereafter GBRWHA, Criterion (x)) in the Statement of Outstanding Universal Value.

As the only surviving member of the family Dugongidae (Marsh et al. 2011), the dugong is a species of high biodiversity value. Anecdotal evidence suggests that dugong numbers have decreased throughout most of their range (Marsh and Sobtzick, 2019), which is the basis for their global listing. Significant populations persist in Australian waters, which are now believed to support most of the world's dugongs. The dugong is of high cultural value to the Traditional Custodians of the GBRWHA. The status of the dugong is reported in the Great Barrier Reef Outlook Reports (e.g., GBRMPA 2019) and State Party Reports on the state of conservation for Australia's Great Barrier Reef (e.g., DCCEEW 2022) and in the national State of Environment Report (Trebilco et al. 2021).

Aerial surveys of dugongs on the eastern coast of Queensland

Since the late 1980s, it has been established practice to monitor the GBRWHA for dugongs every five years using trained human observers in light aircraft (henceforth observer surveys) with empirically derived corrections for detection bias (see Cleguer and Marsh (2023) for an inventory and the Dugong Aerial Survey Database). The surveys have been carried out in two stages in separate years for logistical reasons:

(1) the **urban coast of the Great Barrier Reef** (from near the southern boundary of the Great Barrier Reef Marine Park (15° 20'S)) to near Cape Bedford just north of Cooktown (14° 10'S)), which includes: a central section ('**Central Great Barrier Reef**' or 'cGBR', from the northern survey boundary to Midge Point (20° 38'S)) and a southern section ('**Southern Great Barrier Reef**' or 'sGBR', from Midge Point to the southern survey boundary, see Figure 1);

(2) the **Northern Great Barrier Reef** ('nGBR') from near Cape Bedford to 14°10'S just south of Newcastle Bay (Figure 1). The Cape York region from Newcastle Bay north has been surveyed as part of the Torres Strait survey region.

These survey regions as are based on GBRMP zoning and logistical considerations, rather than reasons related to dugong biology.

The aerial surveys of sGBR have historically included the Hervey Bay-Great Sandy Strait region (hereafter '**Hervey Bay**') and **Moreton Bay** because dugong movements were suspected and subsequently documented between the GBR and these regions in South-East Queensland (Cope et al. 2015; Zeh et al. 2016).

The efficacy of the 5-yearly survey schedule was confirmed by prospective power analysis as part of the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP) (Marsh et al. 2019). This schedule is also consistent with the statutory five-year reporting period required by the GBRMPA Act 1975 for the Great Barrier Reef Outlook Report.

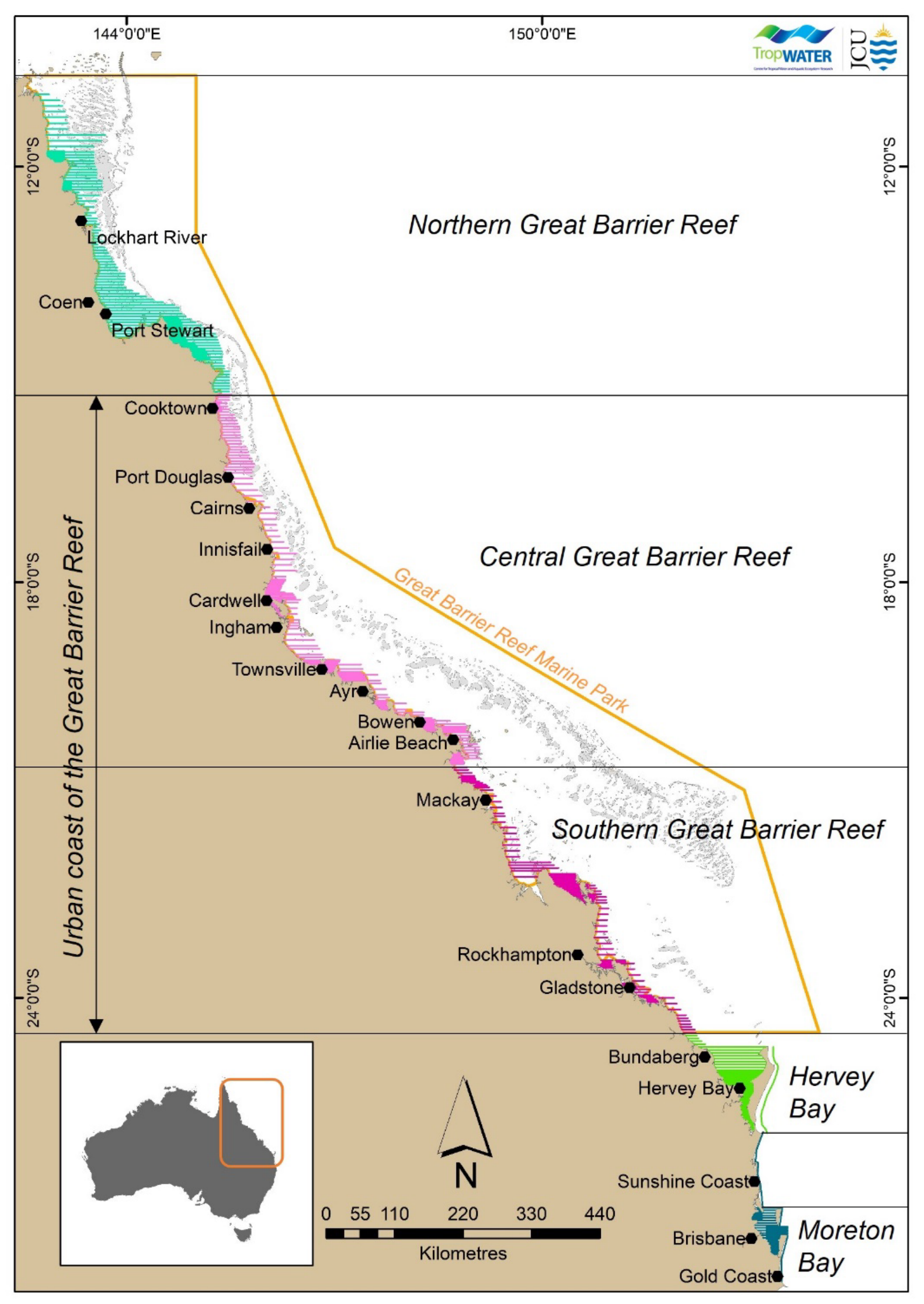

Figure 1. Regions covered by dugong aerial surveys on the eastern coast of Queensland across the Great Barrier Reef World Heritage Area: Moreton Bay, Hervey Bay, Southern Great Barrier Reef (sGBR), Central Great Barrier Reef (cGBR), and Northern Great Barrier Reef (nGBR).

Summary of previous findings

An observer survey of the urban coast of the GBR (including a section of the central GBR and the entire southern GBR) was last conducted in 2022 (Cleguer et al. 2023) and produced an estimated dugong population of 2,124 dugongs (± se 476). The dugong density trend analysis conducted for surveys between 2005 and 2022 presented evidence of decline in dugong populations along the urban coast of the GBR. The urban coast of the GBR had the lowest dugong population density of all surveyed regions in 2022, as well as very high inter-survey density variation. Results from the 2022 survey increased the longevity of the trend of long-term decline in the dugong population off the urban coast detected by Marsh et al. (2019). The estimated decline was approximately -2.3% per year between 2005 and 2023 compared with -4% per year from 2005 to 2016. The probability of long-term decline of the dugong population continued to be very high (0.97 based on survey data from 2005 to 2016 and 0.94 from 2005 to 2022). While there is large inter-annual variation and uncertainty with the statistical outputs, the overall results are of great concern.

The dugong population along much of the **urban coast of the GBR** has a low density, with higher densities in the Hinchinbrook Island and Townsville areas, and Shoalwater Bay, a spatial pattern evident since systematic surveys began in the 1980s (Marsh and Saalfeld 1990) In its section on dugongs, the Australian State of Environment Report (SoE) 2021 states that the condition of the dugong along the urban coast of the GBR is 'poor' and its trend is 'deteriorating' (Trebilco et al. 2021), the report from Cleguer et al. (2023) corroborates this statement.

In addition, Cleguer et al. (2023) found recent evidence of dugong population declines in Hervey Bay and Moreton Bay, south of the GBRWHA. These results were likely confounded by the impact of the 2022 floods in south-east Queensland and need to be reassessed after another survey.

The **nGBR** dugong population was last surveyed in 2018-2019 and reported by Marsh et al. (2020), was assessed as being stable or slightly increasing, with a (revised) estimate of 6942 (±se 1618) animals. The ***Australian State of Environment Report*** ***(SoE)*** 2021 states that the condition of the dugong population in this region is 'very good' based on Marsh et al. (2020). The next survey of the **nGBR** was due in 2023.

This study addresses the requirements of the Reef 2050 Pllamaan (Commonwealth of Australia 2018) by continuing the time series of surveys for dugongs using the latest advances in distribution and abundance analysis.

Two past reports of previous surveys conducted in the GBR for dugongs (Sobtzick et al. 2017, Marsh et al. 2020) have also provided estimates and spatial distribution models for sea turtles (Cleguer et al. 2023). This analysis was not conducted for this survey and is awaiting a more error-free and streamlined workflow for such analyses. This protocol is currently being developed (see section 2.4.1 in Cleguer et al. 2023, for additional technical details).

6 METHODS

6.1 STUDY LOCATION

The design for the 2023 aerial surveys was based on historical aerial surveys conducted by researchers at James Cook University as optimised during the RIMReP process (Marsh et al. 2019). Figure 2 shows the location of the survey blocks and the orientation and spacing of transects used in the 2023 survey.

Unlike some previous observer surveys across the GBR that used two aircraft, we opted for one team and one aircraft only for the 2023 survey. This decision was made to: 1) ensure effective management of the experimental imagery work also conducted during this survey (Cleguer et al. unpublished), and 2) minimize the financial impact in case of a long-term grounding of our survey team, aircraft, and pilot, which typically occurs when the weather is inadequate for a long period. Our survey covered the area from Mission Beach (17° 52' S) to the tip of Cape York (10° 41' S). This included the northern part of the **cGBR** from Mission Beach to Cooktown, and the entire **nGBR**, from Cooktown to the northern boundary of the GBRWHA.

The inshore-offshore parallel transect survey design stops north of block N15 (north of Turtle Head island). Thus, we also ran a shoreline exploration survey, through Jackey Jackey creek and up to the tip of Cape York because of requests from the local community and the Queensland Department of Environment, Science and Innovation (DESI).

6.2 AERIAL SURVEY METHODOLOGY

This section details the aerial survey methods used in 2023. General changes in the dugong aerial survey design are described in 6.2.1. The 2023 survey was novel because two survey techniques were applied simultaneously: 1) an observer survey and 2) an experimental imagery survey. The methodology used in the observer survey, the subject of this report, is detailed in Cleguer et al. (2023). The experimental imagery survey will be the subject of a separate report.

6.2.1 CHANGES IN AERIAL SURVEY DESIGN

There have been some changes in the design of dugong aerial surveys over the past 35 years, largely driven by adaptive monitoring and advances in technology as well as changes in the logistical and financial constraints. As part of the RIMReP process, Marsh et al. (2019) analysed the design and results from dugong surveys conducted within the GBRWHA to optimise the survey design for the GBR surveys of dugongs (as well as large juvenile and adult turtles).

The optimised design of the GBR surveys resulted in a reduction in required flight time compared to the original survey design, thus decreasing the number of survey days and overall cost for the two regions. For this project (as in the 2018-19 survey), we followed advice from Marsh et al. (2019) and used the optimised design to conduct the surveys (Figure 2).

The survey team included:

- A pilot with hundreds of hours experience in flying with the survey aircraft (P68C). A backup pilot was also available if required.
- An experienced survey leader.
- Three experienced marine mammal observers, including one highly experienced dugong aerial survey observer.
- One inexperienced marine mammal observer.
- One backup observer.
- One team driver to transfer equipment between airports.

Four different team configurations were used to complete the survey as a result of observer availability and/or health conditions during the survey. All participants were provided with thorough theoretical and practical training. The practical component of the training involved practice surveys north of Hinchinbrook Island, a well-known dugong hotspot.

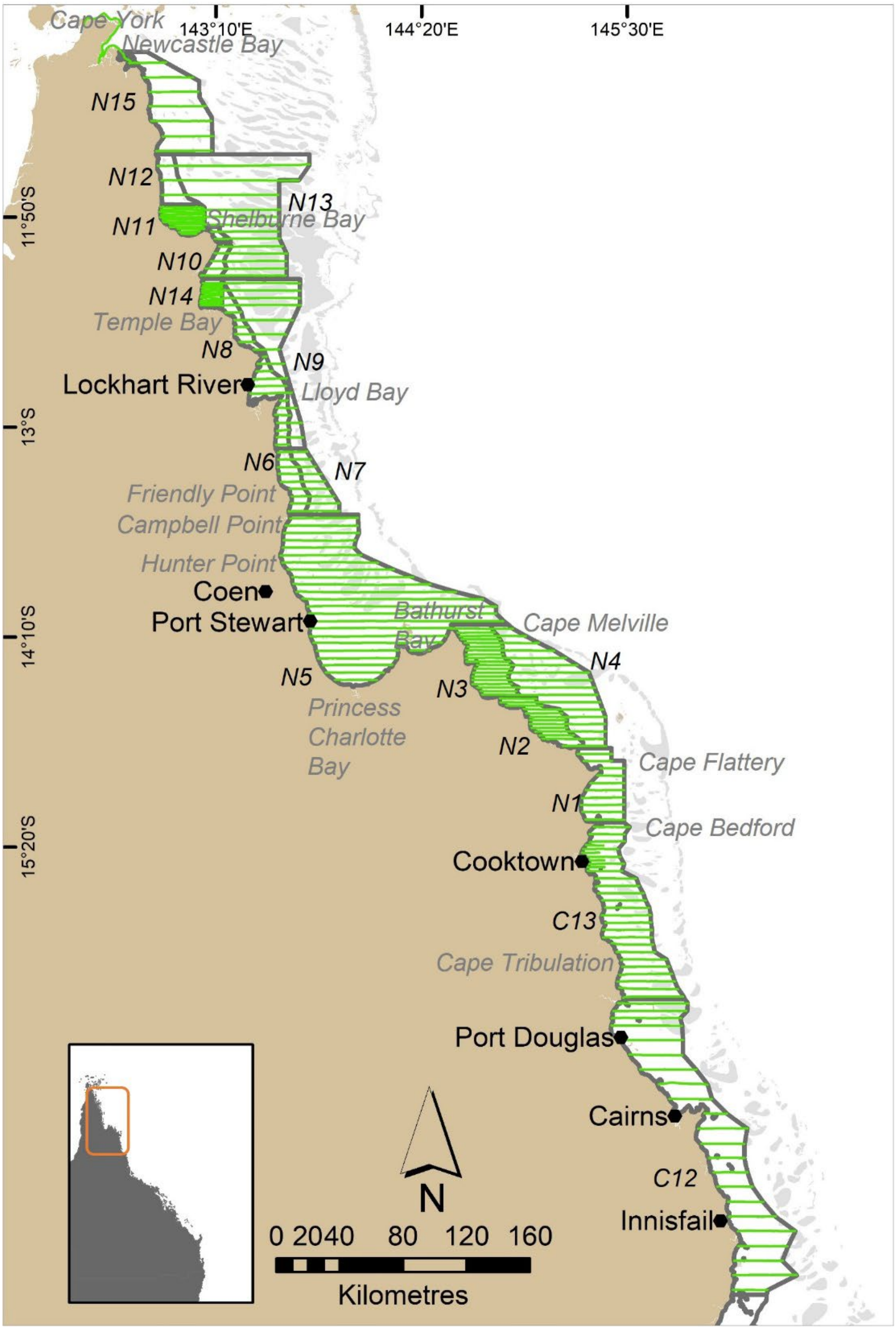

Figure 2. Area covered by the 2023 dugong aerial survey in the nGBR and northern section of the cGBR, with transects (green lines) and blocks (grey polygons; the first letter in the block name corresponds to the broader survey region, e.g., N{1-15} for nGBR). The apparently solid colouring of blocks N11 and N14 reflect high survey intensity. A shoreline exploratory survey was conducted between the northern limit of block N15 and the tip

of Cape York, to rule out any doubt in missing areas with high dugong densities.

6.2.2 Survey protocol

The aerial survey methodology followed the strip transect aerial survey technique detailed in Marsh and Sinclair (1989) and used in subsequent surveys along the Queensland coast (see Cleguer and Marsh, 2023 for an inventory of all surveys conducted in Queensland and their associated methodologies).

Strip transect sampling uses the same fundamental principles as distance sampling, with the additional assumption that the detectability of the target animals is constant across the designated survey strip. Observers record all observed sightings occurring within a strip of predefined width on either side of the transect line. This method has been extensively applied to dugong surveys (see Pollock et al. 2006) and (Hagihara et al. 2014; 2018). The method is particularly suitable for dugongs and large marine turtles as a result of their relatively brief and cryptic surfacing behaviour, which prevents reliable recording of distance of individuals from the transect line from a passing aircraft.

A 6-seat, high-wing, twin-engine Partenavia 68C was flown along predetermined transects as close as possible to a ground speed of 100 knots (Figure 3). To comply with the requirements of the Civil Aviation Safety Authority and to calibrate observer and experimental imagery survey, the survey was conducted at a height of 500 feet (150 m) above sea level.

Transects 200 m wide on the water surface on each side of the aircraft were demarcated using fiberglass rods attached to artificial wing struts on the aircraft (Figure 3). Distance categories (50, 100, and 150 m) within the strip were marked by colour bands on the artificial wing struts. Two trained tandem teams of observers on each side of the aircraft scanned their respective transects and recorded their sightings onto separate tracks of an audio recorder (Zoom H4n, Zoom Corporation). The two members of each tandem team operated independently and could neither see nor hear each other when on transect. The location of the sightings in the distance categories within the survey strip enabled the survey team to decide if simultaneous sightings by tandem team members were of the same group of animals when reviewing the recordings. The sightings of the tandem observers were also used to calculate survey specific corrections for perception bias (i.e., for animals visible in the survey transect but missed by observers) for each side of the aircraft as outlined below (Marsh and Sinclair 1989, Pollock et al. 2006).

The surveys were conducted in passing mode with dugongs (and large marine turtles) as the focal species (i.e., in situations where animals other than dugongs and sea turtles were present within the observers' field of view simultaneously with dugongs/sea turtles, priority was assigned to the collection of information on the dugongs/sea turtles). For each animal sighting, observers recorded the type of animal (e.g., dugong or sea turtle), total number of animals seen, position in the transect (e.g., low, or medium), and a composite index of environmental conditions (see Appendix 1). In addition, the number of calves was recorded for each dugong sighting as an index of population health (Marsh et al. 2019; Marsh 2022). Calves were defined as being less than 2/3 of the size of the accompanying cow and swimming near her. When groups of dugongs were too large to accurately count in passing mode (generally more than 10 animals), the aircraft abandoned the transect and went into circling mode to obtain a total count of the group before resuming the transect.

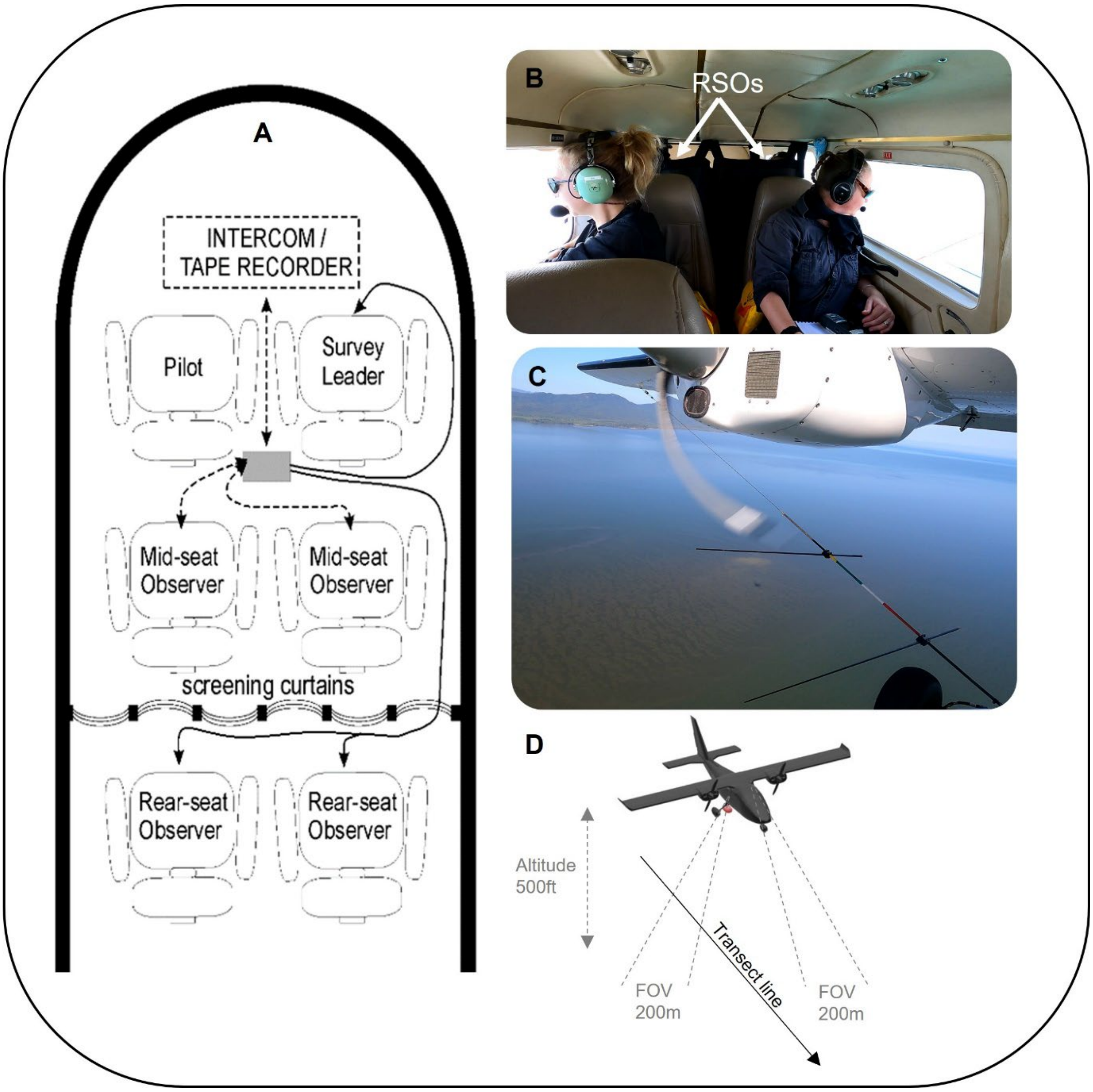

Figure 3. (A) survey aircraft setup, (b) view of the mid-seat observers, separated with the rear-seat observers (RSOs) using a black curtain, (c) view of the transect markers from the inside of the aircraft, (D) schematic representation of survey line, field of view (FOV) and altitude.

The survey leader collected data on environmental conditions at the beginning of each flight (cloud cover, cloud height, wind speed and direction, and air visibility) and each transect (e.g., transect direction). Every few minutes during each transect, and whenever conditions changed, the survey leader recorded sea state (assessed by the survey leader), water visibility, and glare (assessed by the mid-seat observers) (see Appendix 1). An example of the spatial distribution of recordings of water visibility is provided in Figure 4.

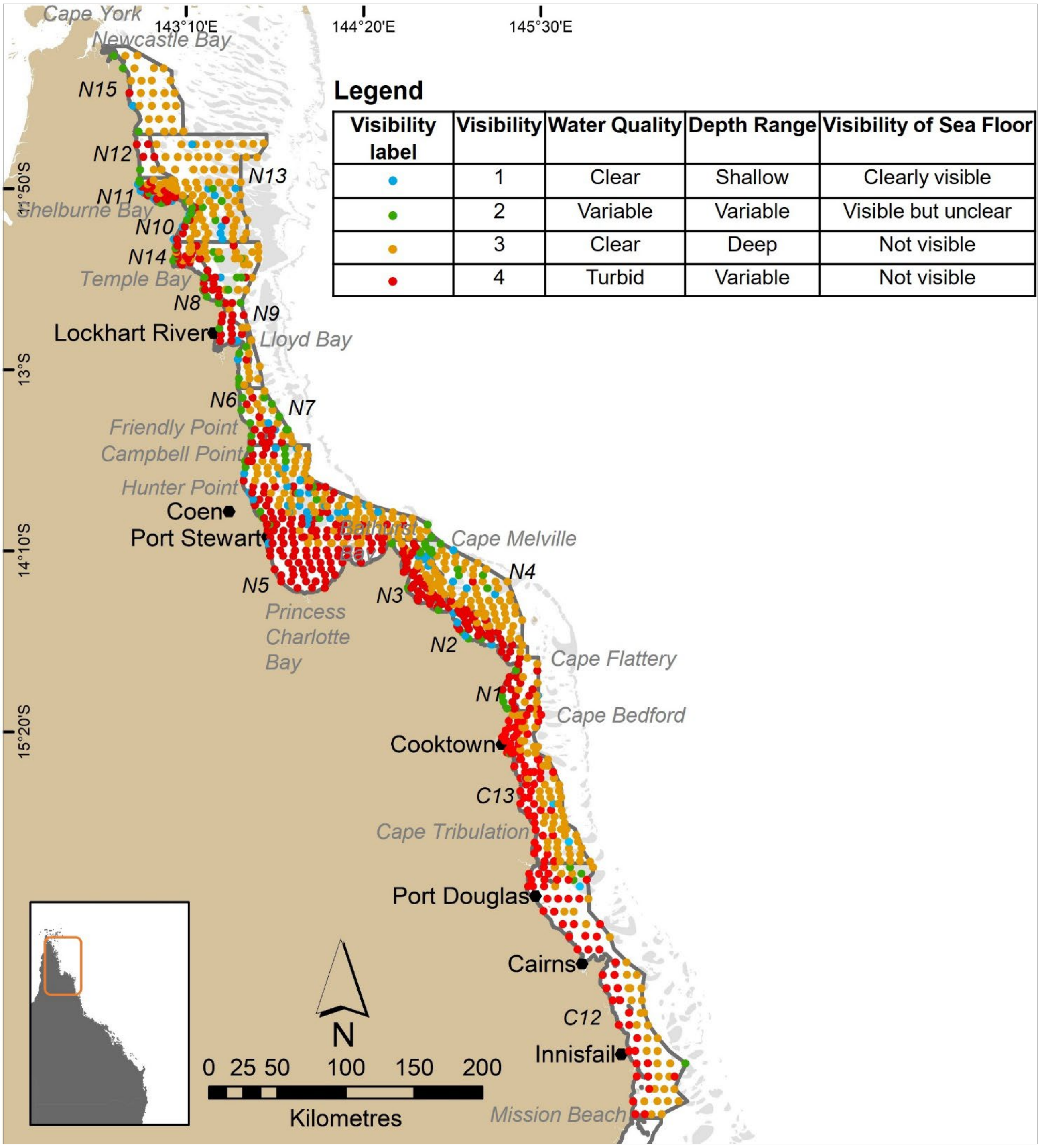

Figure 4. Environmental data (here water visibility) recorded along transect lines during the 2023 dugong aerial survey in the nGBR and northern section of the cGBR. The legend details criteria used to inform the 'water visibility' index (from 1 to 4).

6.3 DUGONG POPULATION ANALYSIS

6.3.1 POPULATION SIZE ESTIMATES

We used the method developed by Hagihara et al. (2014; 2018), henceforth 'the Hagihara method', to estimate dugong relative abundance and density. The analysis was conducted in R (R Core Team 2020, version 4.2.3) with a script bundle specifically developed for this purpose (see Cleguer et al. 2023; Hamel and Cleguer 2024 for description of the development of the script bundle). The method attempts to correct for availability bias (animals not available to observers because of environmental conditions and animal diving behaviour) and perception bias (animals visible in the survey transect but missed by observers due to imperfect detection). We followed recommendations from Marsh et al. (2019) who considered that the way the Hagihara method corrects for availability bias to be superior to previous methods (Marsh and Sinclair, 1989; Pollock et al. 2006) for correcting availability bias because it makes fewer assumptions. Using the Hagihara method also aligns with recommendations from Cleguer and Marsh (2023) to increase effort to standardise survey and data analysis approaches across surveyed areas of the dugong Australian range. The additional data required to implement the Hagihara method has been collected since 2006 in the **cGBR** and **nGBR**; hence the results from 2006 (refer to Marsh et al. 2007), 2013 (refer to Sobtzick et al. 2014) and 2018-19 (refer to Marsh et al. 2020) are included in this report for comparative purposes.

The data reported here for the 2018-19 survey of the **nGBR** is a re-analysis performed in 2024. Consequently, estimates and other results for this survey differ slightly from that previously reported in Marsh et al. (2020). An amendment to Marsh et al. (2020) is being prepared by the lead author. The corrected data for the 2018-19 survey can be accessed from the JCU Dugong Aerial Survey database.

To estimate the perception bias, a mark-recapture model was used to calculate the proportion of the 'available' dugongs that are counted during each survey (Marsh and Sinclair, 1989; Pollock et al. 2006). Each primary observer sighted (marked) a group of dugongs that may or may not have been seen (recaptured) by the corresponding secondary observer, and thus each dugong sighting was categorised as being recorded by one or both observers. These categories were then fitted into a mark recapture framework to calculate the probability of a dugong group being seen (captured) by a tandem team. Pollock et al. (2006) describe how to fit generalised Lincoln-Petersen models to determine perception probability (conditional on dugongs being available) and whether this varied according to observer, experience (primary or secondary observers), or side (port or starboard) using program MARK (White and Burnham, 1999). The perception probabilities used for each observer were provided by the model that best fits the data according to Akaike's Information Criterion (AIC), which corrects for small sample bias. Following the Hagihara method, the standard error for the population estimate for each block were simulated using the program Python using 5000 iterations. The analyses assumed that there was no directional movement of animals between each day of survey across the surveyed area.

6.3.2 POPULATION TRENDS

An analysis of population trends was performed using a hierarchical Bayesian N-Mixture model to estimate changes in adjusted-counts over time. The method integrated various sources of statistical uncertainty and variation, such as stochastically imputing undetected dugongs due to the availability biases and capture-recapture uncertainties described above.

The N-Mixture method was developed and evaluated by Rankin and Marsh (2020), who concluded that it had higher statistical "power" (i.e., reliability in detecting trend) and lower estimation-bias than earlier estimators which estimated dugong population trends from adjusted counts (e.g., Horvitz-Thompson estimator).

The present study continued with that approach, using data collected in the **nGBR** from 2006 to 2023 to estimate population trends as well as the statistical probability that different regions were in decline. Specifically, the study aimed to:

(1) Estimate dugong population densities in the **nGBR**;

(2) Estimate the annual percent change in dugong population density, as well as a retrospective probability of a decline; and

(3) Calculate the probability that the dugong density in the year 2023 was greater than the population density in previous survey years.

At the core of the N-Mixure trend-analysis was a Negative Binomial distribution to model counts of dugongs $N_{t,s}$ at transect *s* in year *t, and how they* changed across years and different regions.

The primary focus of estimation was the regression coefficients $\beta_0 + \beta_{t,l}$ which sum to the (log) density of dugongs in year *t* at location *l*. We used the posterior samples of $\boldsymbol{\beta}$ to make conclusions about the dugongs' population densities and trends over time.

The Negative Binomial regression equation is as follows:

$$
\begin{aligned}
p(N_{t,s}|\lambda_{t,l},\theta) &= \mathrm{NB}(N;\mathbb{E}[N_{t,s}],\theta)\\
\mathbb{E}[N_{t,s}] &= \lambda_{t,l}A_s\\
\log(\lambda_{t,l}) &= \beta_0 + \beta_{t,l} \qquad (1)
\end{aligned}
$$

where *NB* is the Negative Binomial count distribution with overdispersion parameter θ; $\mathbb{E}[N_{t,s}]$ is the expected (or average) number of dugongs in year *t* at transect *s.* Line 2 states that the expected number of dugongs at (*s,t*) is equal to the density of dugongs ($\lambda_{t,l}$) in year *t* at location *l* (conditional on transect *s* being in location *l*) multiplied by transect length A_s, which is a fixed measurement per transect, also known as an 'offset'. Line 3 states that the log-density of dugongs is a linear model of intercept β_0 and marginal density $\beta_{t,l}$ for year *t* at location *l*. Notice that all *S* transects in location *l* have the same expected density.

Use of priors

To complete regression Equation (1) and sample from the posterior distributions of the regression coefficients ($\boldsymbol{\beta}$), we used independent Normal priors on the Negative Binomial regression coefficients, using the same prior-parameters for all priors, including the intercept β_0 and the per-year/per-location marginal densities $\beta_{t,l}$ for years 2006, 2013, 2018-19, 2023 in the **nGBR**. We used a uniform prior on the overdispersion parameter.

Inference

We used Markov Chain Monte Carlo (MCMC) analysis to sample from the posteriors of model parameters. Although the regression coefficients $\boldsymbol{\beta}$ and densities $\boldsymbol{\lambda}$ where the primary focus of estimation, we calculated other quantities to help understand the magnitude and confidence of population trends, including:

- The log-linear trend of dugong populations at each location over 17 years, as the annualised percent change, including 95%Cis, (i.e., the population trend).
- The posterior probability of a decline at each location.
- The posterior probability that dugong densities in year 2023 are higher than densities in prior years (2006, 2013, and 2018-19); and

- Indices of excess variation and uncertainty, at sub-region levels, such as survey 'blocks'.

The above statistics helped us to understand the *magnitude* and *significance* of dugong population declines. For instance, the magnitude of the trend may be large or small, whereas the probability of decline quantified how *certain* we are of a decline, regardless of its magnitude. The index of excess variation can help prioritise regions of the survey-area that deserve additional survey effort.

6.3.3 CALF PROPORTION

The proportion of dugong calves is an indicator of dugong population health (Fuentes et al. 2015; Marsh et al. 2019, Marsh, 2022). We plotted the percentage of dugong calf sightings from 1984 to 2023 and the distribution of calf sightings from the 2023 survey to explicitly report these findings on a single graph for visual examination. Statistical analyses were not undertaken for this dataset.

6.4 SPATIAL DISTRIBUTION OF DUGONG DENSITY

We developed spatially explicit models of dugong distribution for survey years 2006, 2013, 2018-19, and 2023 using the Inverse Distance Weighting (IDW) technique with the 'terra' package in R (Hijmans, 2023), with an output grid size of 1 km^2.

Input data were dugong counts corrected for perception and depth-specific probabilities as per the Hagihara method. To account for the positional error of the sighting GPS location due to the time delay caused during the recording of a sighting in a moving plane, each sighting point was converted to a polygon buffer. First, the point was matched to the closest location on the transect flight track. A backward lag of 140 to 300 m was applied as well as 350m buffer on either side of the track line to account for the observational distance on both sides of the plane. The backward lag values were estimated from average plane speed and using spatially highly accurate aerial images for position comparison (Cleguer et al. ongoing). The resulting time-delay buffers (160 m x 700 m polygons) were converted to a centroid point and summed into a 1 km^2 raster grid. The raw density raster was converted to points (taking the centroid point for each with summed corrected count values) and used as the input to interpolate.

The IDW analysis parameters used were search radius of 5500 m (equivalent to the 5000 m search neighbourhood radius used in the Empirical Bayesian Kriging (EBK) models developed by (Grech and Marsh, 2007) and (Grech et al. 2011); the default weighting power of 2; smoothing parameter of 5; minimum points to use of 1; maximum points to use of 20. Due to the change in method compared to the previous reports the dugong density classes were changed to the closest rounded quantiles (minimum, 33^{th}, 66^{th}, maximum) which best capture the natural variability in the aerial surveys since 2006:

- Very High (>3 dugongs per km^2),
- High (3 – 1.5 dugongs per km^2),
- Medium (1.5 – 1 dugongs per km^2) and
- Low (<1 dugongs per km^2).

6.5 EXPLORING THE USE OF REPEAT TRANSECT SURVEY DATA TO REDUCE VARIANCE IN DUGONG ESTIMATES

In the previous report on the 2022 survey of the southern section of **cGBR** (i.e., southward from Mission Beach) and the **sGBR** (Cleguer et al. 2023), it was recommended to experiment with survey designs that include repeat surveys in quick succession on certain transects to reduce the variance in dugong estimates. By repeatedly surveying the same transects, we can average out random fluctuations and anomalies that might occur in a single survey. The underlying assumption for repeat surveys is the concept of 'population closure', whereby one assumes that the population is unchanged between repeats. Such techniques are routinely employed in capture-recapture methods to increase effective detections and increase precious of estimates.

During the 2023 survey of **nGBR** and the northern section of **cGBR** (i.e., northward from Mission Beach), two transects were subject to repeat aerial surveys in quick succession: transect 3328 (surveyed three times) and transect 4170 (surveyed twice).

We used bootstrap estimation (Efron, 1992) to compare the difference in estimated densities of dugongs and, most importantly, the variance in estimates. We compared three bootstrap methods, two of which serve as benchmarks, and a third that serves as the experiment treatment in which we assume 'population closure'.

The goal is to reduce the variance of estimates, while maintaining an unbiased estimate of population density. Reduction of variance is important, as this proportionally leads to increases in statistical power and detectability of trends.

<u>Bootstrap Method 1 – Benchmark Single Survey:</u> this method served as a benchmark, in which there were no repeat surveys. For each bootstrap iteration, we sampled one transect (from the 2/3 repeats) and estimated the density of dugongs. This method was expected to have the highest variance and be unbiased. It also best corresponds to the current survey regime where there are no repeat surveys.

<u>Bootstrap Method 2 – Benchmark I.I.D. Surveys:</u> this method served as a second benchmark, whereby repeat-surveys were treated as independent and identically distributed samples (i.e., no assumption of population closure). Because "n" was larger than Method 1, the variance was expected to be lower compared to Method 1, and the estimates should be unbiased. For each bootstrap iteration, we sampled with replacement from all repeats, and estimated population density across all surveys. This method serves as an important benchmark because it asks the question "what if, instead of conducting repeat surveys at the same transects, we merely increase the number of surveys elsewhere, with no assumption of closure"? When compared to Method 3, this benchmark challenges the utility of the assumption of closure, and whether we are better to just conduct more surveys, in general.

<u>Boostrap Method 3 – Repeats Under Closure:</u> this final method bootstraps with replacement from the 2/3 repeat surveys. However, the number of dugongs at each transect is taken as the maximum across (bootstrapped) repeats, and the detectability is adjusted for multiple passes (2 passes in the case of 4170, and 3 passes in the case of 3328). The adjusted detectabilities are much higher, due to multiple passes under population closure, such that the estimated Nadj, may not be higher. This method should have the lowest variance (because the max operator is reducing the variance of the total number of seen dugongs), but it is unknown whether the adjustment will cause an increase in bias.

By comparing the three methods, we can test i) if we can increase statistical power with repeat surveys under the assumption of population closure (i.e., is the variance of Method 3 lower than the variance of Methods 1 and 2?); and ii) if we can maintain unbiased estimates while doing so, or iii) is it better to just use the extra survey-effort to survey more I.I.D transects (i.e., is the variance of Method 2 similar to or equal to Method 3?).

6.6 EXPLORATION OF DUGONG STRANDING DATA

We extracted data on the number of dugong strandings reported to Queensland's marine wildlife stranding program, StrandNet, during the period from 2011 to 2024 (https://www.qld.gov.au/environment/plants-animals/wildlife/marine-strandings/stranding-data), primarily to determine how many dugongs had been reported stranded in the c-nGBR between the last survey (2018-19).

7 RESULTS

7.1 AERIAL SURVEY SUMMARIES

7.1.1 FLIGHT SUMMARY AND SAMPLING INTENSITY

The 2023 dugong aerial survey of the **cGBR** (northern section, from Mission Beach to Cooktown) and **nGBR** **(**from Cooktown to the northern boundary of the GBRWHA), was conducted from 14th October to 18th November 2023. It took 37 days to complete the survey (Table 1). Appendix 2 summarises the details of the daily activities and survey flights.

Table 1. Number of days required to survey the central and northern inshore waters of the GBR in 2023

Survey region	Start and end date (year 2022)	Total number of days	Total number of flying days	Total number of down days
cGBR (Mission Beach to Cooktown)	14th Oct – 17th Oct	4	4	0
nGBR (Cooktown to northern boundary of GBRWHA)	17th Oct – 18th Nov	33	11	22

Survey block N14 was surveyed twice (on the 14th and 18th November) because: 1) the cameras used as part of our imagery experiment did not work during the first pass; 2) conditions during the first pass were marginal (i.e. sea-state 3 leaning towards 4).

The team had the opportunity to conduct same-day, same-time repeats of transect 3328 (survey block C13, repeats conducted on 14th October 2023) and transect 4170 (survey block N11, conducted on 17th November 2023). The objective for these repeats was to help evaluate the variation in dugong sightings from one transect pass to the next, as a way to help further reduce uncertainty in our survey data (see 6.5).

The decision to repeat the pass of these transects was made as we had run the first pass and realised there was a relatively high number of dugong sightings on the transect (dugongs spread out across the transect and observation strip, so not referring to herds here). The aircraft turned back on the same transect immediately after finishing the first pass to limit time lag and animal horizontal movement. TR 3328 was surveyed on three consecutive passes (heading EAST, then WEST, then EAST again), while TR 4170 was surveyed on two consecutive passes (heading WEST and then EAST). Results are presented in section 7.7.

Sampling intensities in the cGBR varied between 4.8% (survey block C12) and 9.4% (survey block C13). In the northern GBR, sampling intensity varied between 3.8% (survey block N12) and 23.8% (survey block N 11) (Appendix 3).

7.1.2 OVERALL CONDITIONS DURING THE AERIAL SURVEY

Overall weather conditions were satisfactory and significantly improved compared to those encountered by the 2018-19 survey team (Appendix 4). This was mainly the result of consecutive tropical low systems developing in the Pacific Island region, leaving the **nGBR** region in a 'pocket' of low wind. Despite more favourable conditions overall, unsuitable weather forced the team to stay grounded in Cairns for five consecutive days between 18th Oct and 22nd Oct 2023 and a further 17 consecutive days between 28th Oct and 13th Nov 2023. Extended periods of unsuitable weather are logistically and financially easier to manage compared to marginal weather conditions, when the potential for conducting a survey flight remains uncertain until the last minute.

7.2 DUGONG SIGHTINGS

We recorded 364 sightings of 471 dugongs across the **nGBR** and 16 groups of 28 dugongs in the surveyed section of the **cGBR** (northward from Mission Beach, Table 2 and Figure 5). These records are within the range of dugong numbers reported since 2005, with a slight increase in numbers from the most recent survey (2018-19). Similarly, the number of dugong herds and cumulative number of individuals (n=70) is within the expected number of large groups to be reported in this area. The distribution of dugong sightings across the surveyed area is presented in Figure 5, and all other marine megafauna species in Appendix 5. No dugongs were sighted during our shoreline exploration survey, through Jackey Jackey creek and up to the tip of Cape York. When this region has been surveyed more rigorously using transect surveys of Torres Strait (e.g., Sobtzick et al. 2014) the number of dugongs sighted on transect has been zero or too small to calculate a population estimate (Sobtzick et al. 2014).

Table 2. Number (including herds) of dugongs and calves encountered and group size (mode, mean and range) during the 2023 dugong survey in the nGBR and a section of the cGBR (northward from Mission Beach). Data from the 2005, 2006, 2013 and 2018-19 surveys are also provided for comparative purposes.

Survey region	Number of dugong group sightings (number of dugongs)			
	2006	**2013**	**2018-19**	**2023**
Central GBR[1]	ns	ns	25 (34)	16 (28)
Northern GBR	321 (532)	270 (381)	324 (438)	364 (471)
Survey region	**Number of calves sighted (percentage of calves)2**			
	2006	**2013**	**2018-19**	**2023**
Central GBR	ns	ns	1 (2.9)	2 (7.1)
Northern GBR	38 (8.7)	25 (6.0)	34 (7.7)	43 (9.1)
Survey region	**Group size mode | mean | range**			
	2006	**2013**	**2018-19**	**2023**
Central GBR	ns	ns	1 | 1.4 |1-3	1 | 1.5 | 1-10
Northern GBR	1|1.6|1-8	1 | 1.4 | 1-9	1 | 1.4 |1-6	1 | 1.5 | 1-8
Survey region	**Number of dugong herds (Number of dugongs in each herd)**			
	2006	**2013**	**2018-19**	**2023**
Central GBR	ns	ns	No herd sighted	No herd sighted
Northern GBR	5 (20+20+15+27+10=92)	1 (49)	5 (20+32+22+18+12=104)	5 (22+10+10+15+13=70)

[1] Northern section of the cGBR

[2] Includes counts from herds (group of > 10 individuals)

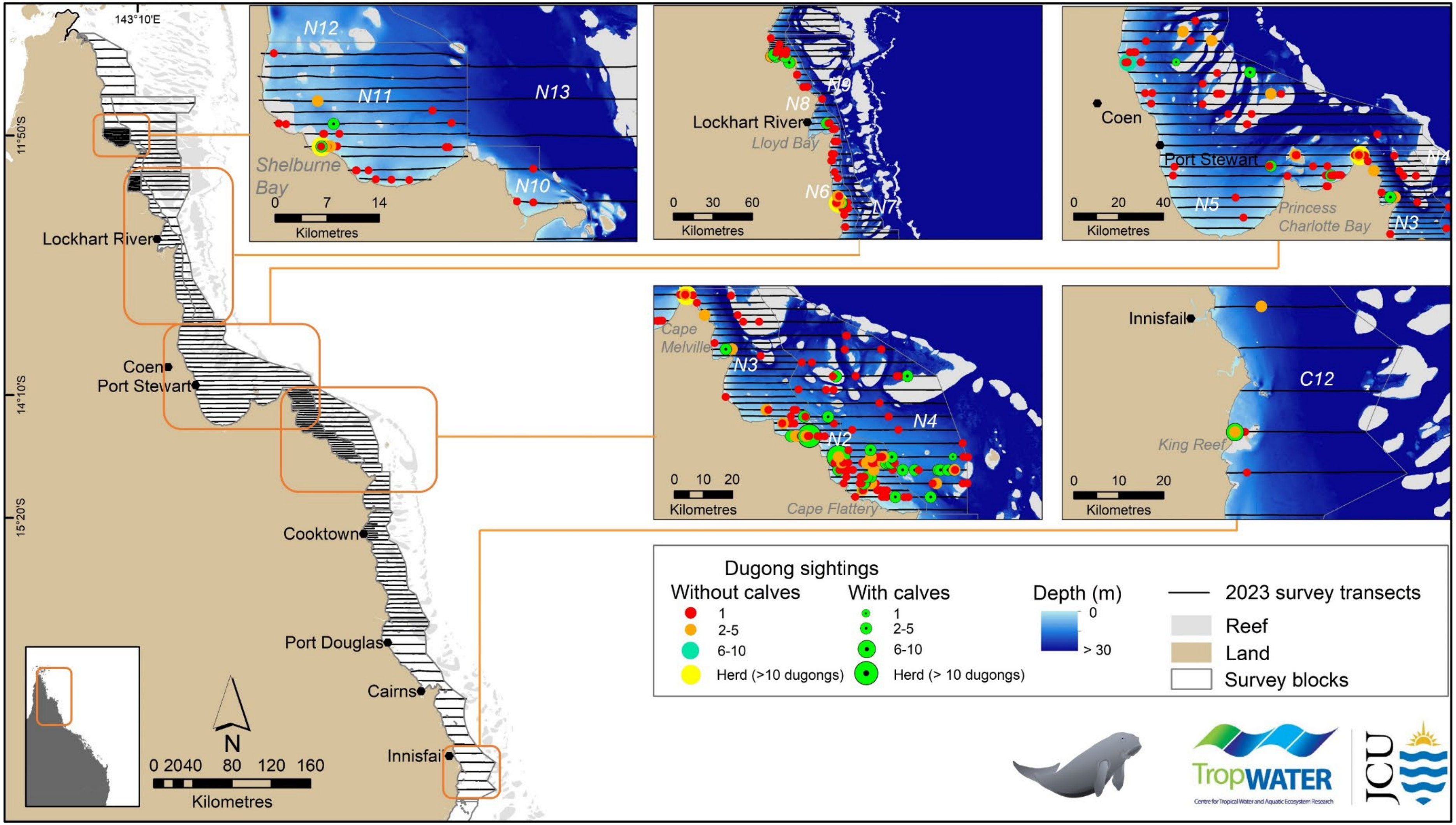

Figure 5. Distribution of dugong sightings in the Central and Northern GBR regions surveyed in 2023. Distribution of other marine megafauna is presented in

Appendix 5.

7.3 POPULATION SIZE ESTIMATES

7.3.1 PERCEPTION PROBABILITIES

The probability that observers sighted dugongs that were available for detection was high for all surveys. The perception probability estimates suggest that the double-observer teams sighted 94–99 per cent of the dugongs that were available across all survey team configurations (Table 3). Details of the different team compositions are presented in Appendix 6.

Table 3. Survey teams, blocks surveyed by each team, and models used to estimate the perception bias and the perception probabilities for dugongs for each survey team.

Team	Survey block	Model	Probability estimates (±se)	Perception probability for each tandem team
1	C11, C12, C13, N1, N2, N4, N5, N6, N7, N8, N9, N11, N12, N13	All observers different	Port primary 0.82 (± 0.03) Port secondary 0.68 (± 0.03) Starboard primary 0.91 (± 0.02) Starboard secondary 0.81 (± 0.03)	Port = 0.94 Starboard = 0.98
2	C13, N1	All observers same	All observers 0.86 (± 0.09)	Port = 0.98 Starboard = 0.98
3	N5	Front observers different to back observers	Primary 0.87 (± 0.07) Secondary 0.68 (± 0.08)	Port = 0.96 Starboard = 0.96
4	N10, N13, N14, N15	All observers same	All observers 0.93 (± 0.05)	Port = 0.99 Starboard = 0.99

7.3.2 POPULATION ESTIMATES

We estimated the dugong population in the nGBR in late 2023 to be 6,838 dugongs (±se 968; using the Hagihara method) (Table 4, Figure 6). This estimate is very similar to that of the estimates from the 2018-19 survey with 6942 dugongs (±se 1618)[1].

Across the northern section of the GBR (blocks N1-N15) dugongs were most abundant in the region between Cape Flattery and Bathurst Bay (blocks N2, 3 and 4), Princess Charlotte Bay (block N5), the Friendly Point/Lockhart River area (blocks N6 and 8), Temple Bay (block N14), and Shelburne Bay (block N11).

[1] The data reported here for the 2018-19 survey of the **nGBR** are from a re-analysis performed in 2024. Consequently, estimates and other results for this survey differ slightly from those previously reported in Marsh et al. 2020. Overall, the differences are not substantive.

It is interesting to note the increase in dugong numbers present between Friendly Point (block N6) and Lockhart River (N8). The estimated dugong abundance of 823 dugongs (±se 588) in the Friendly Point area is the highest for the four surveys reported here. A similar upward trajectory in dugong abundance estimates is noticeable in the Temple Bay area (block N14) where numbers have grown from 89 dugongs (±se 57) in 2006 to 426 dugongs (±se 184) in 2023, (Table 4, Figure 6). Fluctuations in dugong numbers across other survey blocks, a likely result of temporary emigration of dugongs as a result of changes in the status of seagrass communities on which they depend for food (e.g., Sobtzick et al. 2014, Marsh et al. 2020, Cleguer et al. 2023), are explicitly shown in Figure 6.

Four dugong herds were detected in our late 2023 survey: in the inshore waters immediately north of Cape Flattery (two herds of 22 and 10 dugongs in block N2), south of Bathurst Bay (one herd of 10 dugongs in block N3), near Friendly Point (one herd of 15 dugongs in block N6, first time recorded from aerial surveys during the 2006-2023 time series), and in Shelburne Bay (one herd of 13 dugongs in block N11, first time recorded from aerial surveys during the 2006-2023 time series). The time series of sightings dugong herds across the northern GBR is explicitly shown in Table 4.

Table 4. Dugong population estimates (using the Hagihara method) in the nGBR between 2006 and 2023. nc: Survey design not comparable, ns: not surveyed, tfs: too few dugongs seen to estimate population size, nds: no dugongs sighted. Herd sightings are colour coded by survey year and explained in the footnotes.

Survey region	Block	Survey year 2005	2006	2013	2018-19	2023
Central Great Barrier Reef	C12	nc	ns	ns	tfs	1303 (110)
Central Great Barrier Reef	C13	ns	ns	ns	112 (97)	111 (49)
TOTAL (±se) for **cGBR** (surveyed blocks only)					112 (97)	1414 (120)
Northern Great Barrier Reef	N1	ns	tfs	tfs	ns	tfs
Northern Great Barrier Reef	N2	ns	1293 (466)	820 (278)[1]	1379 (535)[2]	1353 (333)[6]
Northern Great Barrier Reef	N3	ns	498 (249)	1077 (612)	1371 (714)[3]	387 (118)[7]
Northern Great Barrier Reef	N4	ns	1619 (802)	597 (200)	870 (477)[4]	1059 (460)
Northern Great Barrier Reef	N5	ns	3061 (1333)	1990 (675)	2381 (1231)[5]	1786 (399)
Northern Great Barrier Reef	N6	ns	tfs	504 (306)	193 (143)	823 (588)[8]
Northern Great Barrier Reef	N7	ns	tfs	tfs	nds	nds
Northern Great Barrier Reef	N8	ns	1407 (725)	979 (394)	127 (92)	714 (205)
Northern Great Barrier Reef	N9	ns	tfs	tfs	tfs	nds
Northern Great Barrier Reef	N10	ns	tfs	tfs	tfs	tfs
Northern Great Barrier Reef	N11	ns	293 (116)	108 (71)	196 (95)	290 (144)[9]
Northern Great Barrier Reef	N12	ns	tfs	tfs	tfs	nds
Northern Great Barrier Reef	N13	ns	189 (105)	nds	214 (151)	nds
Northern Great Barrier Reef	N14	ns	89 (57)	58 (40)	211 (133)	426 (184)
Northern Great Barrier Reef	N15	ns	nc	nc	tfs	nds
TOTAL (±se) for **nGBR** (surveyed blocks only)			8449 (1803)	6133 (1097)	6942 (1618)	6838 (968)

[1] Includes one herd of 49 dugongs

[2] Includes one herd of 20 dugongs

[3] Includes one herd of 32 dugongs

[4] Includes one herd of 22 dugongs

[5] Includes two herds of 18 and 12 dugongs

[6] Includes two herds of 22 and 10 dugongs

[7] Includes one herd of 10 dugongs

[8] Includes one herd of 15 dugongs

[9] Includes one herd of 13 dugongs

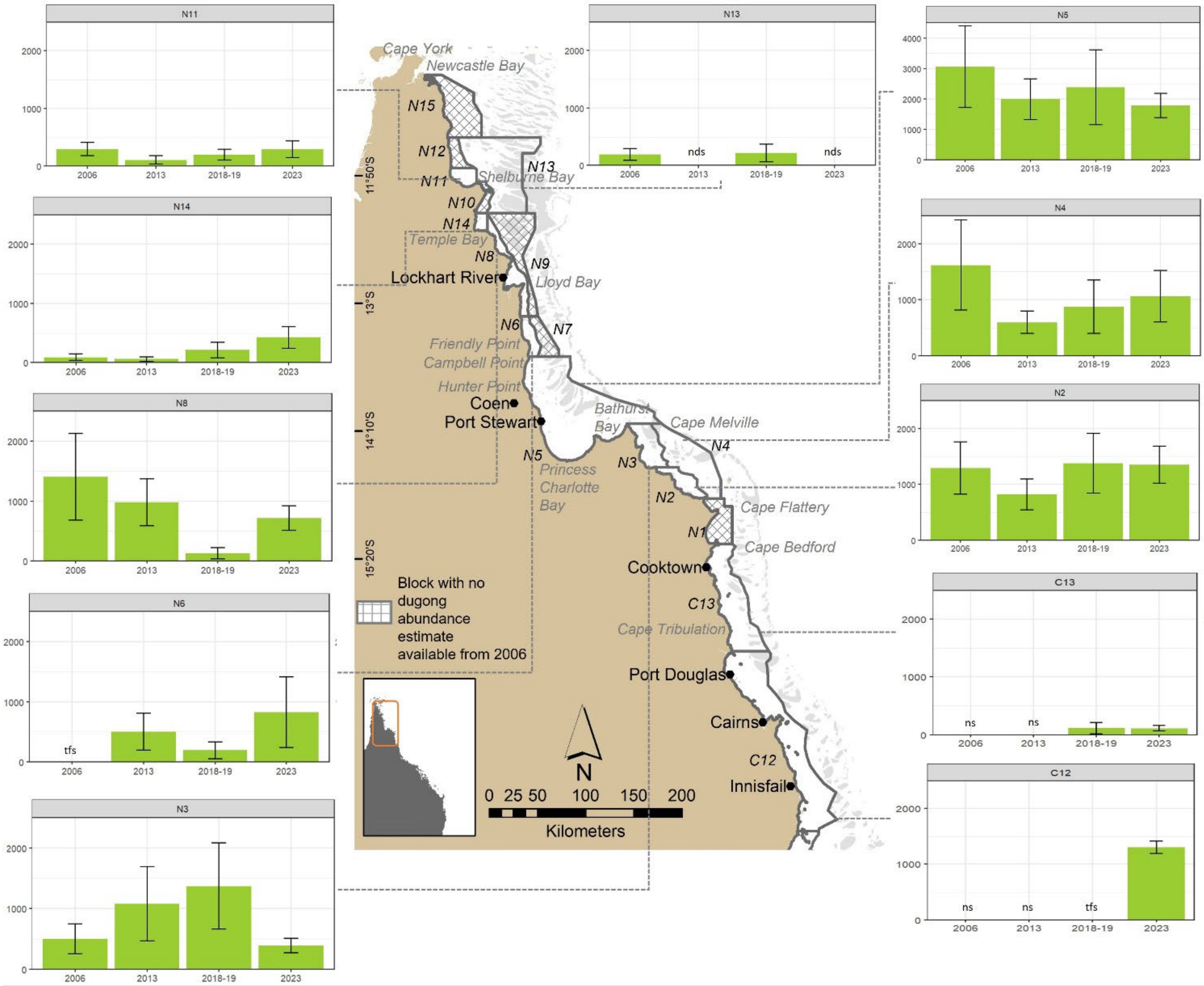

Figure 6. Estimated dugong abundance for the central and northern sections of the GBR region between 2006 and 2023. Y axes show the estimated dugong population size for the block (these can also be found in Table 4). Whiskers represent standard errors. For some year, estimates are not available because there were too few sightings (tfs) or no sightings (ns) to estimate population size. Survey blocks for which no estimates are available across all survey years are hashed.

7.4 DUGONG POPULATION DENSITY AND TRENDS

The estimated population density of dugongs in the **nGBR** in 2023 was 0.250 dugongs/km (±se 0.048; 95% CI 0.17 - 0.36) (Figure 7 and Appendix 7). This value was in line with the 2019 estimate of 0.249 dugongs/km (±se 0.050, 95% CI 0.167 - 0.364), 51% higher than the 2013 estimate (0.165 dugongs/km; ±se 0.031, 95% CI 0.115 - 0.236), and 23% higher than the 2006 estimate (0.203 dugongs/km; ±se 0.039, 95% CI 0.142 - 0.292). There was strong overlap between all years' 95% CIs.

Compared to other regions surveyed in 2022 (see Cleguer et al. 2023), the 2023 **nGBR** dugong population density was slightly lower than the estimate for **Moreton Bay** (0.274 dugongs/km), and much higher than the

2022 estimates for **Hervey Bay** (0.094 dugongs/km) and **sGBR** (0.086 dugongs/km).

The **nGBR** was the only region to exhibit a positive trend over the study period (1.8%/year increase). However, the 95%CI strongly overlapped with 0, suggesting that we cannot definitively rule-out a zero-trend for this region. In contrast, all regions surveyed in 2022 (Cleguer et al. 2023) had negative trends: **Hervey Bay** (-5.7%/year), **sGBR** (-2.3%/year), and **Moreton Bay** (-1.2%/year). Annualised log-linear change in dugong population densities since 2005 across the eastern Queensland coast are presented in Appendix 8.

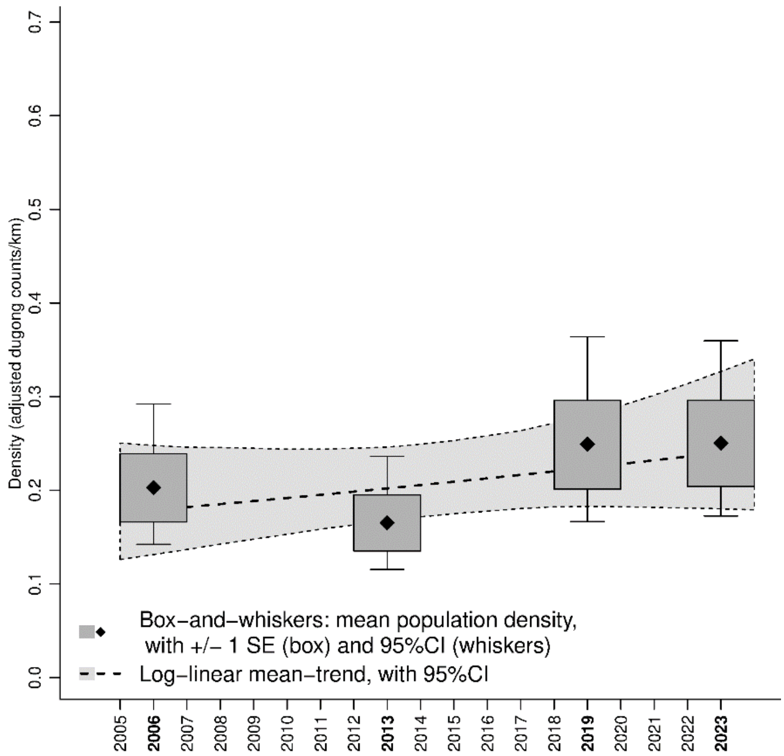

Figure 7. Mean dugong density estimates across the nGBR between 2006 and 2023. Survey years are indicated in bold font.

7.5 DUGONG CALF PROPORTIONS

Two calves were sighted in the northern section of the **cGBR** (northward from Mission Beach, blocks C12, C13) (Table 2 and Figure 8), representing 7.1% of the total number of dugongs detected in this region. In 2018-19, one calf was sighted across the same area. The percentage of calf sightings in the **nGBR** in 2023 was 9.1% (43 calves out of 471 dugong sightings, Table 2). This is the highest percentage of calves reported in the 2006-2023 time series of surveys conducted between Cape Bedford and New Castle Bay (Figure 8A, B). The percentages of dugong calves sighted in the region go back from 1984 but correspond to surveys conducted in portions of the region surveyed in 2006-2023, thus caution must be taken in interpreting these numbers (Figure 8A, B).

Across **nGBR** survey blocks where dugongs were sighted, the percentage of dugong calves was highest in block N4 (21.7% based on 60 dugongs sighted, Figure 9). In other **nGBR** blocks, the percentage of calves ranged between 0% (survey blocks N1 and N10) and 11.4% (survey block N14). The seemingly high percentage of calves in block C13 (16.7%) in the **cGBR** is insignificant as it was calculated based on a total number of sightings of one calf and 6 adults. These percentages need to be interpreted with caution as the number of dugongs sighted was much less for some survey blocks than others (Figure 9). Besides, the spatial distribution of percentage calves has not been formally investigated.

We also note the sighting of an adult dugong accompanied by two calves (Figure 8A), though it is unknown whether both calves were born to the same animal or if one was adopted. Adoption has not been confirmed in dugongs but twin foetuses have been reported occasionally (Marsh et al. 2011).

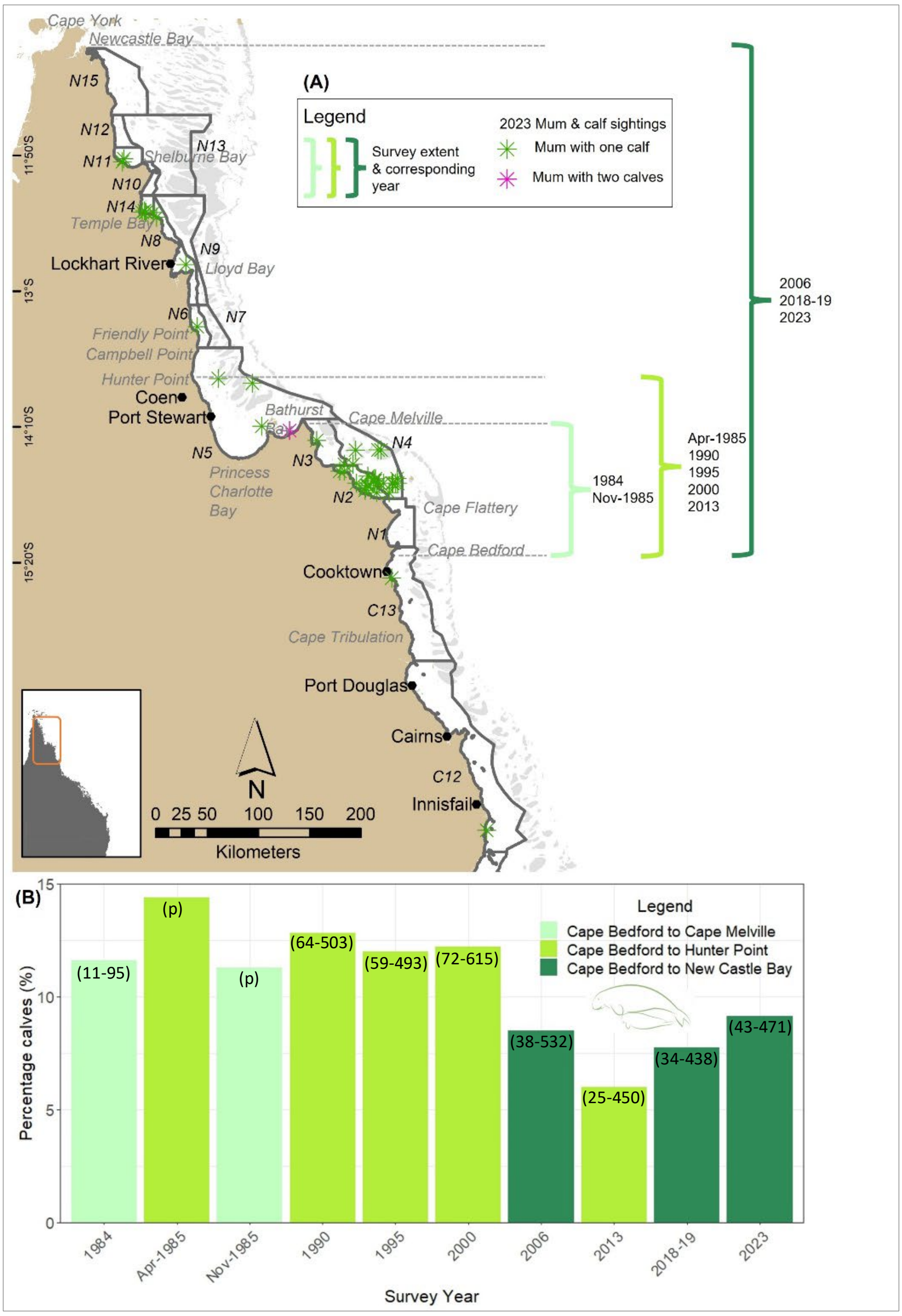

Figure 8. (A) Distribution of dugong 'mum and calf pair' sightings in 2023 and survey extents from 1984 to 2023; (B) Percentage of dugong 'mum and calf pairs' for each survey event. Number in the bars indicate '(number of calves-number of animals)', while '(p)' indicates that only percentage values could be found in records. Bars with the same colour indicate comparable surveys and correspond to geographic extents indicated in curly brackets in (A).

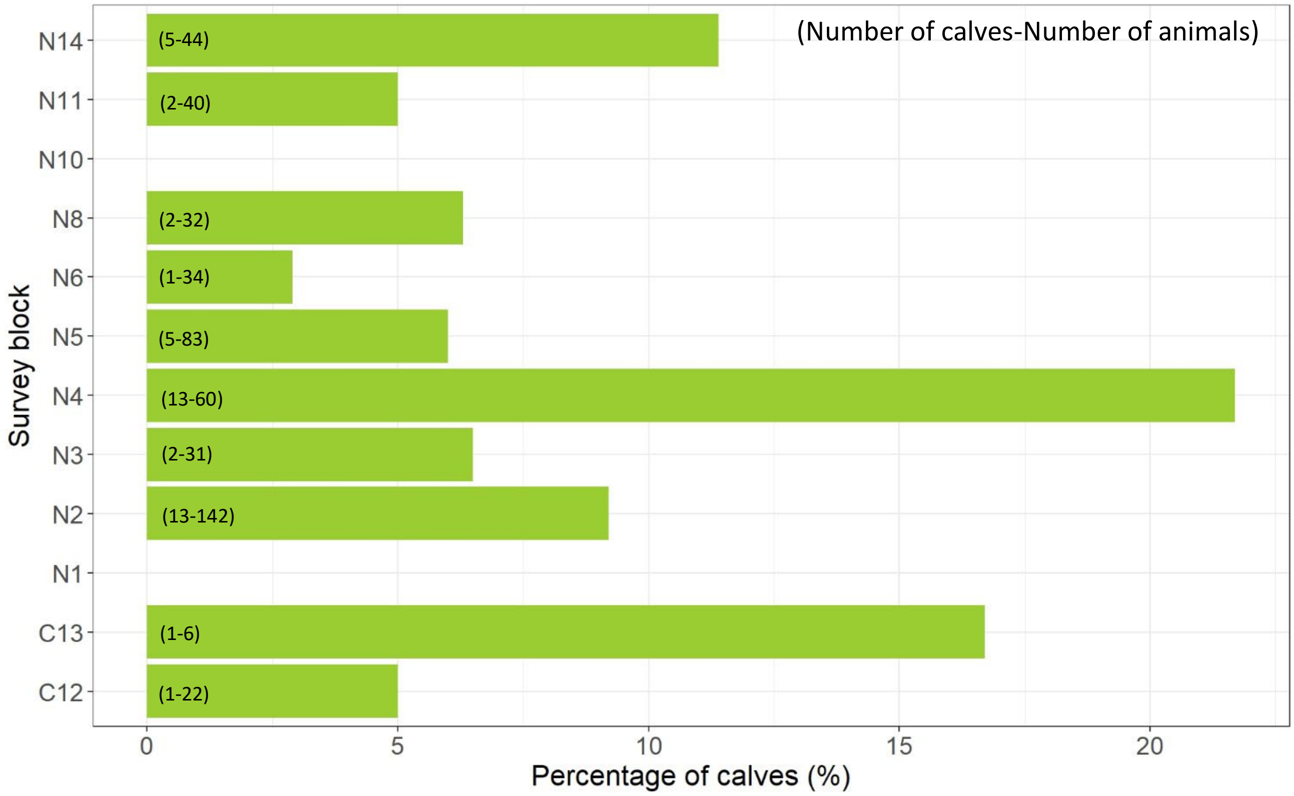

Figure 9. Percentage of dugong calves per survey block for the 2023 survey. Block names surveyed in the nGBR start with 'N'. Block names surveyed in the cGBR start with 'C'. Survey blocks N1 and N10 had dugong sightings but no calves. Survey blocks N7, N9, N12, N13, and N15 had no dugong sightings and thus are not plotted in this figure. This figure must be interpreted with caution. The spatial distribution of percentage calves has not been formally investigated and the number of dugongs sighted in some blocks is small.

7.6 SPATIAL DISTRIBUTION OF DUGONG DENSITY

For the northern section of the **cGBR** region (Mission Beach to north of Cooktown), we examined changes in dugong density classes yielded by the spatially explicit models developed using the results of the 2018 and 2023 surveys. Although very low (0 – 1 dugong / km^2) densities occurred throughout the region overall, an increase in dugong density was detected around Innisfail (Figure 10). In contrast, a lower dugong density was detected in the Cape Tribulation area in 2023 compared to 2018.

For the **nGBR** region, we examined changes in dugong density classes yielded by the spatially explicit models developed using the results of the 2006-2023 period. Much of the inshore as well as offshore reef area between north of Cape Flattery and Bathurst Bay showed consistent high (1.5 – 3 dugongs / km^2) and very high (>3 dugongs / km^2) densities throughout (Figure 10). A similar pattern was observed in sheltered bays to the north such as Lloyd Bay, Temple Bay, Shelburne Bay. Dugongs were also seen at medium (1 – 1.5 dugong / km^2) densities in some bays and associated with many reefs in the NGBR survey region. In contrast, dugong density was consistently low in the inshore waters between north of Shelburne Bay and northern boundary of the survey area.

Latitudinal (north-south) and longitudinal (~inshore-offshore) variations in dugong density hotspots can be observed in the model outputs (Figure 11). For example, in the region located northeast of Shelburne Bay (northern section of **nGBR**), the use of offshore reefs to appears to be fluctuating across survey events (medium, high and very high dugong densities were detected in 2006 and 2018 but not in 2013 and 2023). Similarly, an increase in dugong density is observed in 2023 in the inshore water area between Hunter Point and Temple Bay and across the offshore reefs in the Cape Flattery - Cape Melville region (Figure 11).

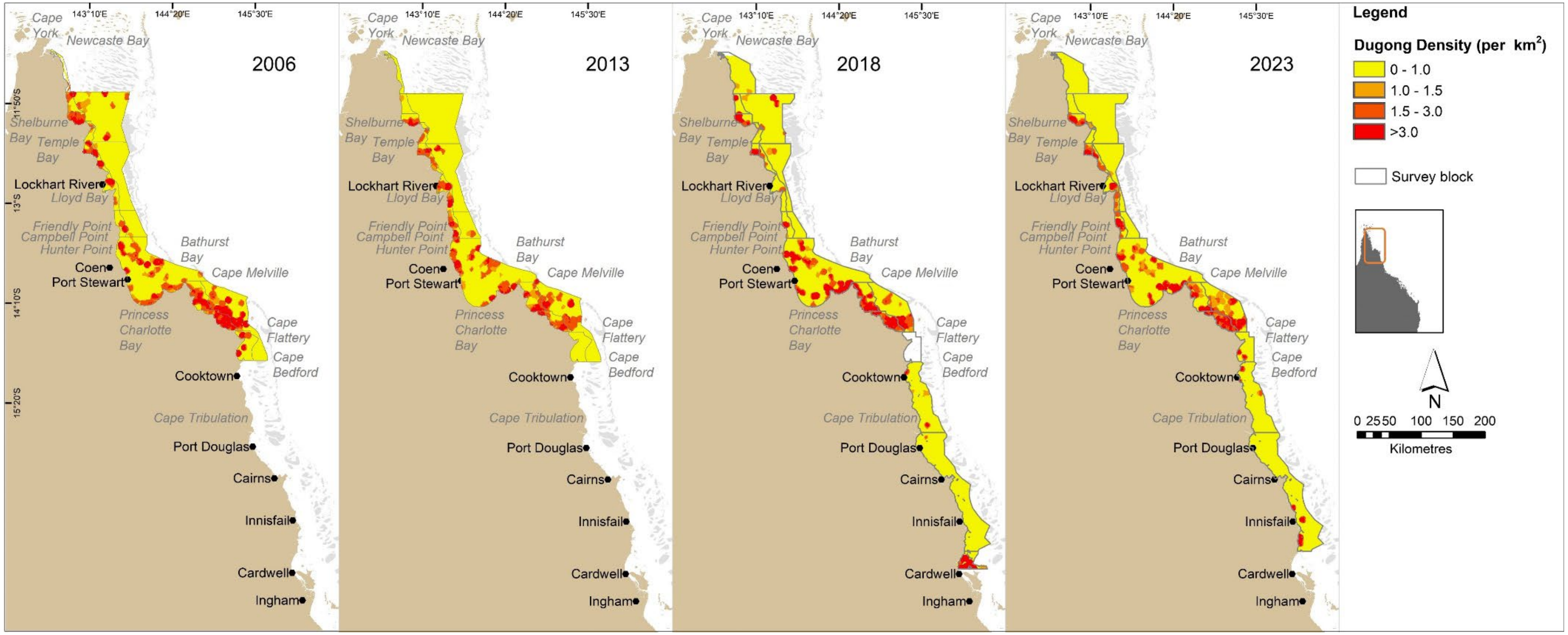

Figure 10. Spatially explicit models of dugong density in the central and northern section of the GBR using data from aerial surveys conducted in 2006, 2013, 2018-19, and 2023. Dugong density estimations were based on the Hagihara method. Dugong densities were classified as Low (<1 dugongs per km^2), Medium (1.5 – 1 dugongs per km^2), High (3 – 1.5 dugongs per km^2), and Very High (>3 dugongs per km^2).

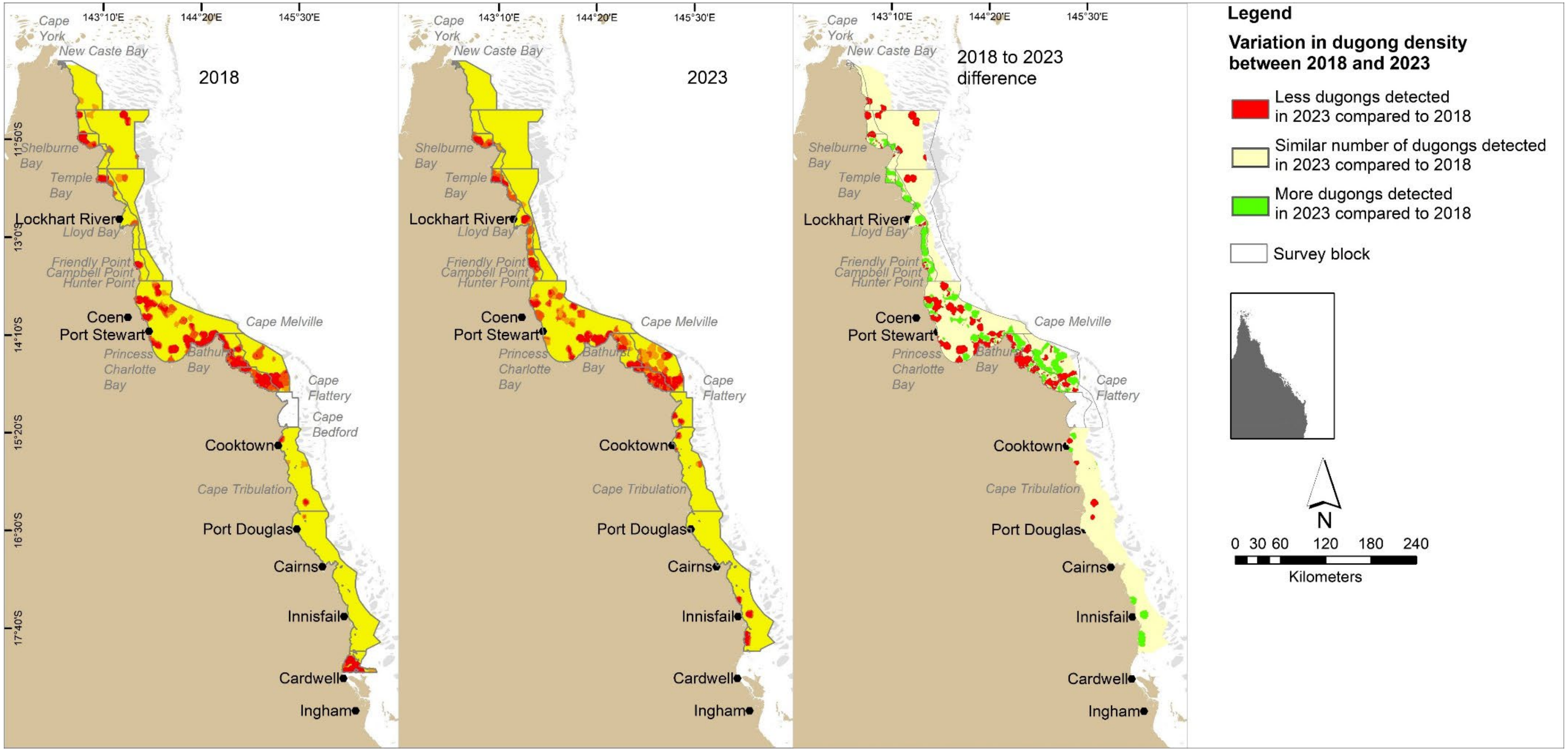

Figure 11. The left and centre panels depict spatially explicit models of dugong density in the central and northern sections of the GBR, using data from aerial surveys conducted in 2018-19 and 2023. The right panel shows the changes in dugong densities from 2018 to 2023, illustrating the local spatial shifts in dugong distribution as a result of their movements within the surveyed areas between the survey years.

7.7 REPEAT SURVEY – AUXILARY STUDY

In this experiment, Method 1 ('Benchmark single survey') approximates the 'nowadays' survey design, with no repeat surveys and no population closure. Method 2 ('Benchmark IID surveys') uses the additional surveys and treats them as independent and identically distributed (IID) samples, gaining increased precision of estimates through more survey effort and no assumption of population closure. Method 3 ('Repeat under closure') uses a max operator and adjusted detections for multiple repeat surveys under the assumption of closure.

The results reveal that the lowest variance and best bias is obtained by Method 3 (Table 5), lending credibility to the idea of using repeat surveys under the assumption of population closure. However, the variance is nearly identical to that of Method 2, which suggests that merely allocating the additional survey effort to more surveys is what is driving the improved performance. In other words, we will gain additional precision from repeat surveys, but it may not be a lot more than had we merely increased the number of transects surveyed, in general. The additional statistical complexity may not be worth the small marginal gains in variance-reduction.

These results need to be treated with caution as only two transects were repeated but suggest an area for further study.

Table 5. Comparison of variance of repeat surveys under different assumptions

	Method 1 – Benchmark single survey	Method 2 – Benchmark IID surveys	Method 3 – Repeat under closure
Mean Density	1.0715	1.0664	1.0662
Bias	-0.0715	-0.0664	-0.0662
SE	0.0821	0.0803	0.0803
Variance	0.0067	0.0065	0.0064

7.8 REPORTED DUGONG STRANDINGS ACROSS THE SURVEYED AREA

Overall, the number of reported dugong strandings in the **nGBR** between 2011 and 2023 accounts for 0.7% (4 out of 583 strandings) of all reported strandings in Queensland (Table 6). The **cGBR** reported the highest number of dugong strandings during this period, accounting for 34% of the total. This is followed by the **sGBR**, **Hervey Bay**, and **Moreton Bay**, each contributing approximately 21% of the strandings. There was no dugong stranding reported for 2024 at the time of writing of this report (June 2024).

When examining the data temporally and comparing the four-year period from 2018-2019 to 2023 (the period between the last two surveys of the **nGBR**, Table 7) with the period from 2014 to 2018 (four years prior to the 2018 survey), we find that **Hervey Bay** and **Moreton Bay** are the two areas in Queensland where reported dugong sightings have increased. In contrast, the **cGBR** and **sGBR** have experienced slight declines in the number of reported sightings (Table 7).

It is important to acknowledge that stranding reports are strongly biased towards areas with higher human density. Thus, the number of strandings reported north of Cooktown are underestimated to an unknown amount.

Table 6. Reports of dugong strandings across the Queensland coast 2011-2024 (extracted from https://www.qld.gov.au/environment/plants-animals/wildlife/marine-strandings/stranding-data). These data need to be interpreted with caution as strandings in the northern GBR are likely underestimated.

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Grand Total
Gulf of Carpentaria								1						1
Northern GBR	1	1	1						1					4
Central GBR	111	18	11	8	3	6	7	11	11	7	1	3	2	199
Southern GBR	43	25	13	8	6	4	4	3	4	1	3	7	3	124
Hervey Bay	21	4	8	5	7	4	4	7	4	17	18	22	2	123
Sunshine Coast	3									1	1	1		6
Moreton Bay	22	11	10	9	5	10	3	5	6	8	11	23	3	126
Grand Total	201	59	43	30	21	24	18	27	26	34	34	56	10	583

Table 7. Comparison of the cumulative number of dugong stranding reports in the periods 2014-2018 and 2019-2024

Region	2014 to 2018	2019 to 2023
Gulf of Carpentaria	1	0
Northern GBR	0	1
Central GBR	35	24
Southern GBR	25	18
Hervey Bay	27	63
Sunshine Coast	0	3
Moreton Bay	32	51

8 DISCUSSION

8.1 THE 2023 DUGONG AERIAL SURVEY

8.1.1 STATUS OF DUGONGS IN THE SURVEYED AREA

The findings from the present survey (**nGBR** and northern section of the **cGBR**, 2023) add to the evidence that the dugong population in these areas is in good condition, in contrast to their decline in the southern section of the Reef (**sGBR**) and the concerns about dugongs in Hervey Bay and Moreton Bay after the 2023 floods (Cleguer et al. 2023).

The dugong population of the **nGBR,** in October- November 2023, was estimated to be 6,838 dugongs (±se 968) using the Hagihara method (Table 4 in section 7.3.2). This population has grown at an estimated ~2% per year (section 7.4) since 2006. The dugong population density in 2023 was the highest among the four surveys analysed here (2006, 2013, 2018-19, 2023) (in section 7.3.2). Most of the growth appears to have occurred between 2006 to 2019, there was no statistical difference between years 2019 and 2023. Bayesian statistics indicate that the probability of an increase in the nGBR was ~89%, enabling us to place higher confidence in a population increase, even if it is not significant in the conventional sense.

The dugong population in the **cGBR** north of Mission Beach was estimated to be 1,414 dugongs (±se 120) using the Hagihara method on the basis of our 2023 survey (Table 4 in section 7.3.2). Population trends were not estimated for this region because most of it was not surveyed in 2006 or 2016 using the standard technique for dugong aerial surveys, a situation that precludes analysis of trends in abundance across the surveys conducted during this century (section 7.3). Nonetheless, the estimates of dugong numbers for this section of the **cGBR** suggest an increase compared to previous surveys, likely primarily due to a rise in sightings around the Innisfail region (survey block C12). Nonetheless, overall, blocks C12 and C13 (Mission Beach to Cape Bedford) continue to represent a large area with relatively low dugong densities.

Marsh et al. (2019) suggested using the percentage of dugong calves as an indicator of the health status of dugongs in the GBRWHA. The proportion of calves, which reflects population health with a 2-3 year delay, depends mainly on the condition of the seagrass that serves as the dugongs' primary food source (Marsh et al. 2011). In 2023, the proportion of calves in the **nGBR** was 9.1% (Figure 8, section 7.5), the highest percentage recorded since the 2000 survey. This continues an upward trend in calf proportions in the region since 2013, further suggesting a positive health status for the **nGBR** dugong population. The densities of dugongs found in the surveyed sections of the **cGBR** are too low to make any inference on calf proportions in that area.

8.1.2 DISTRIBUTION AND INFERRED DUGONG MOVEMENTS

As demonstrated with our spatially explicit dugong density models (Figures 10 and 11), the distribution of dugongs has remained relatively stable across the **nGBR** since 2006. Comparison with the data from Marsh and Saalfeld (1989) suggest that this overall pattern was similar to that November 1984 and 1985. The spatial shifts in dugong hotspot areas (Figure 11), are likely due to dugong movements within their dynamic seagrass habitats, as documented in numerous past reports (e.g., Marsh et al. 2020; Cleguer et al. 2023 for the most recent aerial survey reports). Deutsch et al. (2022a) concluded that periodic seagrass loss driven by extreme weather events is likely to be the most important driver of larger-scale movements in dugongs, while local movements may be driven by the accessibility of intertidal seagrass meadows at the time of the survey in some areas. While we endeavoured to survey areas of expected high dugong density at high tide, this was not always possible for logistical reasons.

Scientific data and information on the distribution and status of seagrasses in the **nGBR** are for the most part outdated (Table 1 in Carter et al. 2021; https://eatlas.org.au/map/gbr-seagrass); preventing meaningful linking of our survey results with the current state of seagrass in the region. However, the lack of significant changes in the numbers and distribution of dugongs across the region in our time-series of dugong surveys suggest that seagrasses in the **nGBR** are likely in good condition overall, at least those in the generally shallow waters used as a food source by dugongs. Outputs from our spatially-explicit models, particularly the areas of consistently high dugong densities, could be used to help prioritise future seagrass mapping in the region.

Individual dugongs can be highly mobile (Deutsch et al. 2022a; b) and travel large distances (hundreds of kilometres) in relatively short periods of time (days). Thus, movements of dugongs into and out of the surveyed area across survey events are likely, particularly inshore north or southward movements at the northern boundary around the Torres Strait, and the southern boundary around Hinchinbrook Island. Sheppard et al. (2006) reported an adult female dugong with a satellite-tag deployed in 1997 by Preen (2001) and local Girringun Traditional Owners near Hinchinbrook Island, later transmitting in Princess Charlotte Bay, approximately 560 km from the initial tagging location. To date, only Marsh and Rathbun (1990) have conducted a dugong movement study in the **nGBR** region, tracking four male dugongs around the Starcke River area. None of them moved far from their capture site; one animal made repeated movement to tidal pools about 10 km upstream from the mouth of Dead Dog Creek. There is a need for increased tracking efforts in this region to better understand dugong dynamics and habitat use and e-DNA studies to understand dugong usage of rivers and creeks. Such studies would provide critical insights into the movement patterns, habitat preferences, and overall ecology of dugongs in the **nGBR**, facilitating more effective conservation and management strategies.

<u>Explanation of differences in dugong status across the eastern coast of Queensland</u>

The stable condition of the dugong population in the **nGBR** (overlaying with the Cape York National Resource Management-NRM as reported in the Reef Report Cards) contrasts with the declining population in the **sGBR** (particularly the Mackay-Whitsunday to Burnett Mary NRM region; Cleguer et al. 2023). This disparity is likely due to higher cumulative pressures impacting dugong habitats in the more urbanised **sGBR** compared to the north, In the **sGBR**, where the coastline is more heavily populated (Sanderson et al. 2022), direct impacts on dugong population mortality such as from gill netting and vessels collisions are also likely more of a concern than in the remote **nGBR** and the seagrass habitats are under pressure from terrestrial runoff. Accurately comparing the current cumulative pressures on coastal habitats between the **sGBR** and the **nGBR** is challenging due to the uneven availability of scientific data from environmental monitoring activities across the region. For example, dugong stranding records (section 7.8) are based on opportunistic reports and thus biased towards populated areas, a bias that is likely to be very difficult to overcome. Thus, the causes of these spatial differences remain speculative and are likely to remain so for the foreseeable future.

Threats to dugongs can be categorised into two types: those that cause direct dugong mortality, and indirect threats that result in dugong habitat loss or degradation, which in turn, negatively affect dugong fecundity. As dugongs are long-lived, slow breeding mammals, threats to mortality are generally more serious than threats to fecundity (Marsh et al. 2011).

As identified by Marsh and Sobtzick et al. (2019) in their global assessment of the status of the dugong, the primary threats to dugongs are:

- Incidental capture in fishing gear, largely in small-scale fisheries, especially gillnet fisheries; illegal, unreported, and unregulated (IUU) fishing; entanglement in marine debris including discarded fishing gear and plastic litter.

- Unsustainable hunting
- Vessel strikes.

Threats to dugong fecundity due to habitat loss, fragmentation, and modification include:

- Habitat damage caused by development in the coastal zone, shipping, destructive fishing (netting and trawling).
- Degradation of seagrass habitat, coastal dredging and reclamation, commercial trawling in seagrass areas, declining water quality due to land clearing and resultant erosion.
- Extreme weather and climate change impacts on seagrass communities (e.g., extreme tropical storms, marine heatwaves).

The relative importance of these threats must vary across the GBRWHA. Because of the region's World Heritage Status a great deal has been and is being done to protect dugongs in the GBRWHA, e.g., spatial closures to fishing and habitat protection under both Queensland Fisheries and GBRMP zoning; restrictions on port development; measures to address terrestrial runoff and agreements with some Traditional Owners (Traditional Use of Marine Resources Agreements, hereafter TUMRAs; and Indigenous Land Use Agreement to manage hunting, hereafter ILUAs (see Marsh et al. in press for a full account). The latest very significant initiative is the Queensland Government ban on commercial gillnets from the northern third of the GBR and all Dugong Protection Areas, with the exception of the rivers and creeks in Dugong Protection Areas Bs; accelerated implementation of the Queensland Sustainable Fisheries Strategy 2017-27, agreement to phase out gillnet fishing in the GBRWHA by mid-2027, and to introduce Independent Data Validation in Queensland's commercial fisheries, so that the incidental capture of protected species such as dugongs is more likely to be reported.

Nonetheless, threats to dugongs and their habitats remain. Threat risk assessment is a tool that can be used to compare the levels of relative risk to dugongs and their habitats caused by various direct or indirect threats or hazards with the aim of helping stakeholders prioritise conservation responses within and between localities. Although there has been an assessment of the risks to dugongs and their habitats from climate change (Marsh et al. 2022), and an assessment of the risk to the dugong from climate change relative to other marine mammals (Albouy et al. 2020), we know of no contemporary, comparative assessment of risk to dugongs across their 'hotspots' in the GBRWHA.

An important next step might be to work with key Traditional Owners of: (1) the Sea Country bordering the dugong 'hotspots' in the **sGBR** (e.g., Hinchinbrook, Townsville and Shoalwater Bay (Cleguer et al. 2023), and (2) in the Sea Country of the major communities in the **nGBR** (Cooktown and Hopevale, Coen and Port Stewart, Lockhart River and Portland Roads, Princess Charlotte Bay) to consider the risks, including the climate risks, to dugongs and their habitats in their region, as a key first step to developing a Wildlife Conservation Plan for Dugongs (or Coastal Megafauna more generically) in the coastal waters of the GBRWHA. The development of such a Plan would also provide a vehicle for exploring opportunities for increased Traditional Owners participation in the research and management of dugongs in the GBRWHA.

8.1.3 Engagement with Traditional Owners

With some exceptions (e.g., presenting survey results at the Lama Lama TUMRA meeting in Cairns in November 2023), the current project engagement activities have mostly been conducted remotely through online webinars, development of a dugong survey website, blogs, digital flyers, and phone conversations. The project's primary goal was to complete the aerial survey and imagery development work. Logistical and cultural considerations have long hampered active participation from Traditional Owners in dugong population aerial surveys. Transitioning to the use of imagery and AI is unlikely to solve this problem for large-scale surveys because this approach will require less human input into data collection and analysis.

Following this survey, Traditional Owners from each of the major communities in the **nGBR** need to be consulted about: 1) how they would like the results of this survey to be shared with their community[2], an immediate priority, and 2) what types of research and monitoring on dugongs and their habitats, they would like to co-design, lead and collaborate in, as discussed below.

8.1.4 Increasing Traditional Owners participation in dugong research and monitoring

Consultation undertaken with Traditional Owners across the Reef during this project confirmed findings from the Indigenous Participation Team in the RIMReP Megafauna Expert Group (Bayliss and Fischer, 2020): much more engagement is necessary between Traditional Owners across the Reef and dugong scientists. This would help to foster meaningful dialogue and collaboration between Indigenous communities, scientists, and managers on dugong ecology, population status, threatening processes, and sustainable management. Extending and enhancing these dialogues and collaborations is fundamental to transforming dugong research, monitoring, and management into a much more proactive approach approved and supported by Indigenous communities of the Reef, thereby enhancing conservation impacts.

In this section, we discuss ways in which increasing Indigenous participation could improve dugong research and monitoring in the Great Barrier Reef.

8.1.4.1 IMPORTANCE OF INDIGENOUS PARTICIPATION IN THE MONITORING OF DUGONGS

A literature search conducted as part of the report of the Indigenous Participation Team in the Megafauna Expert Group (RIMReP, Bayliss and Fischer 2020) found that ~20% (9 out of 44) of Traditional Owner groups in the GBR were identified as being involved in marine megafauna monitoring activities through existing ranger programs. However, the desktop study found monitoring reports only for inshore dolphins by JCU (Beasley et al., 2013; 2014a and b; 2016a-c; 2017a and b) in partnership with five north Queensland Traditional Owner groups (Girringun Aboriginal Corporation, Mandubarra Aboriginal land and Sea Inc., Dawul Wuru Aboriginal Corporation, Jabalbina Yalanji Aboriginal Corporation and the Yintjingga Aboriginal Corporation/Lama Lama rangers). The researchers found no other documentation detailing the nature of any collaborative partnerships, funding sources, monitoring methods, selected species, spatial locations of survey sites, data availability and custodianship, nor any analysis reporting abundance or trends. Importantly, Jarvis et al. (2018) reported that all Traditional Owner groups in the Reef have expressed a strong aspiration to become involved at some level in RIMReP.

<u>Satellite Tracking</u>

Traditional Owners have enthusiastically used their expertise and Traditional Knowledge to help scientists catch dugongs for satellite tracking since the technique was first used in the 1980s (Marsh and Rathbun 1980; see Deutsch et al. 2022a for details of dugong satellite tracking until 2022). The movements of dugongs are individualistic, and it would be desirable to catch a large number of animals (e.g., 20) from one location in the

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[2] Traditional Owners of the major communities in the **nGBR** were adamant that they wished to control the dissemination of information about the results of the 2018-19 dugong aerial survey to their community (Marsh personal communication 2024)

nGBR to obtain meaningful new results. However, these types of studies with a large number of tags to be deployed are expensive, require substantial funding and are logistically challenging, especially in remote areas such as the nGBR, where tag retrieval can be very difficult.

Addressing local-scale knowledge gaps

During the International Year of the Reef in 2018 (International Coral Reef Initiative), following back-to-back coral bleaching events in 2016 and 2017, the Australian Government announced investment of $443.3 million in a Reef Trust Partnership with the Great Barrier Reef Foundation (hereafter 'the Foundation'). The partnership has boosted the number of opportunities to assist Traditional Owners to lead and collaborate on activities that reflect their aspirations and traditional obligations to connect, care for, heal and maintain the condition of the Great Barrier Reef. Grant opportunities such as the Healing and Helping grants have enabled the inception of new projects led by Traditional Owners to conduct research and monitoring activities on dugongs and their seagrass environments at relevant spatial scales being existing Traditional Use of Marine Resources Agreements (TUMRAs) or specific Sea Countries. For example, Pryor et al. (2024) documents a new collaboration between the Girringun Aboriginal Corporation, the land and sea ranger team, our research group (TropWATER at JCU) and scientists from Charles Darwin University. This partnership aimed to address knowledge gaps around dugong and seagrass, which are fundamental to the Traditional Owners that Girringun represent. This research was critical to the cultural, natural, socio-economic values of the Girringun TUMRA and IPA, the GBRWHA and the Hinchinbrook Island Dugong Protection Area. In this project, research partners pioneered the use of off-the-shelf, user-friendly small drones to monitor dugongs and other marine megafauna species at a local scale within the Great Barrier Reef World Heritage Area. This approach adapts the recently developed drone survey method by Cleguer et al. (2021). The Girringun rangers were trained to conduct intertidal and subtidal seagrass surveys and drone surveys to explore the distribution of dugongs and other marine megafauna within Girringun Sea Country. The entire project was co-designed by all partners from the proposal writing stage through the design of research questions, survey areas of interest, and training approaches. Initial surveys provided insights into the use of Missionary Bay by dugongs and other marine megafauna, as well as their habitat use (Pryor et al. 2024). The success of this project has led to funds being secured for similar programs starting and led by Traditional Owners in the Cairns (Gunggandji-Mandingalbay Yidinji rangers), Innisfail (Mandaburra rangers) and Townsville region (Wulgurukaba) in the GBR and by the Indigenous Salt Water Advisory Group in the Kimberley (https://www.nespmarinecoastal.edu.au/project/4-6/). In the future, we hope to explore how these local-scale drone surveys of marine megafauna across multiple locations in the GBR can be integrated into broad-scale assessments of marine megafauna populations.

Integrating Indigenous knowledge and scientific information

Although studies highlighting the importance of Indigenous knowledge of marine megafauna in the GBRWHA and its potential role in integrated assessments exist (Marsh et al. 2022), dedicated marine megafauna studies that attempt to combine both knowledge systems are scant. This represents a significant knowledge gap, given the increasing interest and necessity. Bayesian statistical methods, which acknowledge both the intrinsic value of expert knowledge and quantitative data, have been widely used to integrate knowledge from various sources. For example, Bayliss et al. (2015) used a Bayesian probability approach to integrate Indigenous and scientific knowledge of dugongs in the north Kimberley region, mapping important dugong areas. Bayesian Belief Networks, which graphically and transparently display the contributions of all knowledge sources, are powerful tools for enhancing stakeholder engagement and communication in natural and cultural resource management (e.g., van Putten et al. 2013; Bayliss and Hutton 2017). This Bayesian approach has demonstrated versatility across nearly all ecological fields, particularly those involving decision-making amidst risk, uncertainty, and variability in scientific data and complex social and biophysical systems. This method has potential to integrate Indigenous and scientific knowledge of dugongs across the GBRWHA, if it is a priority for Traditional Owners.

8.2 OPPORTUNITIES FOR IMPROVING THE DESIGN OF LARGE-SCALE DUGONG MONITORING ACROSS THE GREAT BARRIER REEF

8.2.1 ADAPTING THE DUGONG AERIAL SURVEY DESIGN

Both Marsh et al. (2019) and Cleguer et al. (2023) recommended experimenting with repeat-surveys to increase the precision of estimates and decrease the statistical variance of transect densities, especially under the assumption of 'population closure', a technique routinely used in ecological capture-recapture surveys. In the present survey (**nGBR** and northern section of the **cGBR**, 2023), two high density transects were repeated. Our analysis confirmed the statistical benefits of conducting repeat surveys, both in terms of reduction in variance and maintaining little-to-no bias (section 7.7). However, our analysis also revealed that the gains in repeat surveys was only slightly better than the gains from expanding the overall number of transects (i.e., a larger sample-size will always reduce the variance, regardless of the assumptions of population closure or not). Therefore, it remained an open question whether resources would be better allocated to surveying additional transects, or to conducting repeat surveys on the same transects. A compromise between increasing the precision of estimates/reducing statistical variance and considering the cost and logistical constraints of resurveying entire survey blocks could be achieved by either: 1) conducting repeat surveys only on transects with high numbers of sightings, or 2) focusing on transects with significant variability. The experiment undertaken as part of our **nGBR** survey was based only two transects. It would be worth expanding this research to explore systematically selected types of transects.

As part of RIMReP, Rankin (Appendix 1 in Marsh et al. 2019) conducted a Bayesian prospective 'power' analysis to estimate the ability of the observer survey program to detect trends according to several different scenarios. Rankin estimated that the current five-year survey regime had a reasonable ability to detect declines of at least three per cent, per annum with a 0.8 probability at mid- to long-term time horizons (such as eight years or greater). The ability to detect trends within shorter periods of time, such as five years, was much less reliable (<0.7 power), and may not improve significantly with more frequent surveying or other modifications to the survey protocol. Shallower trends would be much more difficult to detect due to the high amount of heterogeneity in the system. Rankin concluded that additional types of survey protocol enhancements (such as increasing sampling frequency or increasing detection) would have little impact on improving power but suggested other modifications (such as the repeat sampling of transects described above) would be worth exploring. However, such modifications may not be backwards compatible with the existing time-series of counts, which is why Rankin recommended using a lines of evidence approach. The transition to the use of imagery surveys and AI provides an opportunity to systematically explore such modifications.

8.3 KEY FINDINGS FOR POLICY MAKERS

- The status of the dugong population in the remote coast of the nGBR is good and in much better condition than the populations along the more urbanised coast of the **sGBR**.
- The first priority of the survey team/dugong scientists must be to consult with the Traditional Owners of the Indigenous communities in the nGBR about the results of this survey and how they would like to share these results with their communities.
- Despite considerable attempts to reduce impacts in the GBRWHA, threats to dugongs and their

habitats remain. An important next step might be to work with key Traditional Owners of: 1) the Sea Country bordering the dugong 'hotspots' in the **sGBR** (e.g., Hinchinbrook, Townsville and Shoalwater Bay), and 2) in the Sea Country of the major communities in the **nGBR**: to consider the risks, including the climate risks, to dugongs and their habitats in their region.

- This consultation could be a key first step in developing a Wildlife Conservation Plan for Dugongs (or Coastal Megafauna more generically) in the coastal waters of the GBRWHA.
- The development of such a Plan would provide a vehicle for exploring opportunities for increased Traditional Owners participation in the research and management of dugongs in the GBRWHA.
- The 5-yearly aerial surveys of dugongs across the GBRWHA are clearly an effective method of monitoring the status of dugongs in the region.
- The transition to imagery surveys and AI should a be significant improvement in both: 1) the accuracy of: a) species recognition, and b) mapping the spatial positions of sightings; and 2) human safety. Quantifying the differences between the results of the observer and imagery surveys conducted together in 2023 and 2024 should enable the integrity of the time series to be maintained.
- Modifications to the survey protocol to improve the power of the surveys to detect trends would be desirable and should be explored as part of the transition to imagery surveys and AI.

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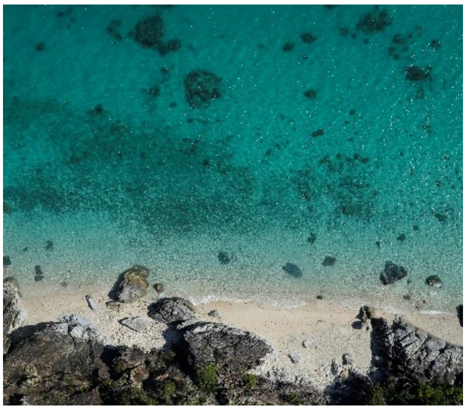
10 APPENDICES

10.1 APPENDIX 1: SCALES USED TO DESCRIBE THE ENVIRONMENTAL CONDITIONS ENCOUNTERED DURING THE AERIAL SURVEYS.

Table 1.1. Water visibility Scale

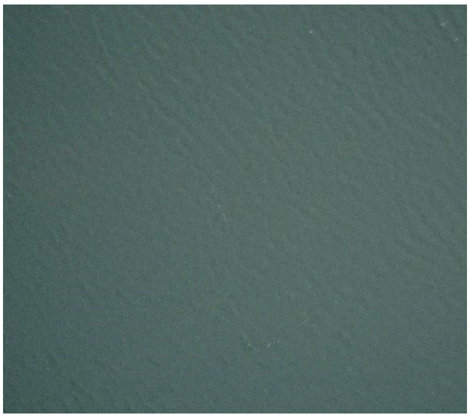
Visibility	Water Quality	Depth Range	Visibility of Sea Floor
1	Clear	Shallow	Clearly visible
2	Variable	Variable	Visible but unclear
3	Clear	Deep	Not visible
4	Turbid	Variable	Not visible



Visibility 1

Visibility 2

Visibility 3



Visibility 4

Table 1.2. Glare Scale

Glare	Proportion of view affected
0	No glare
1	< 25% of view affected
2	25-50% of view affected
3	> 50% of view affected

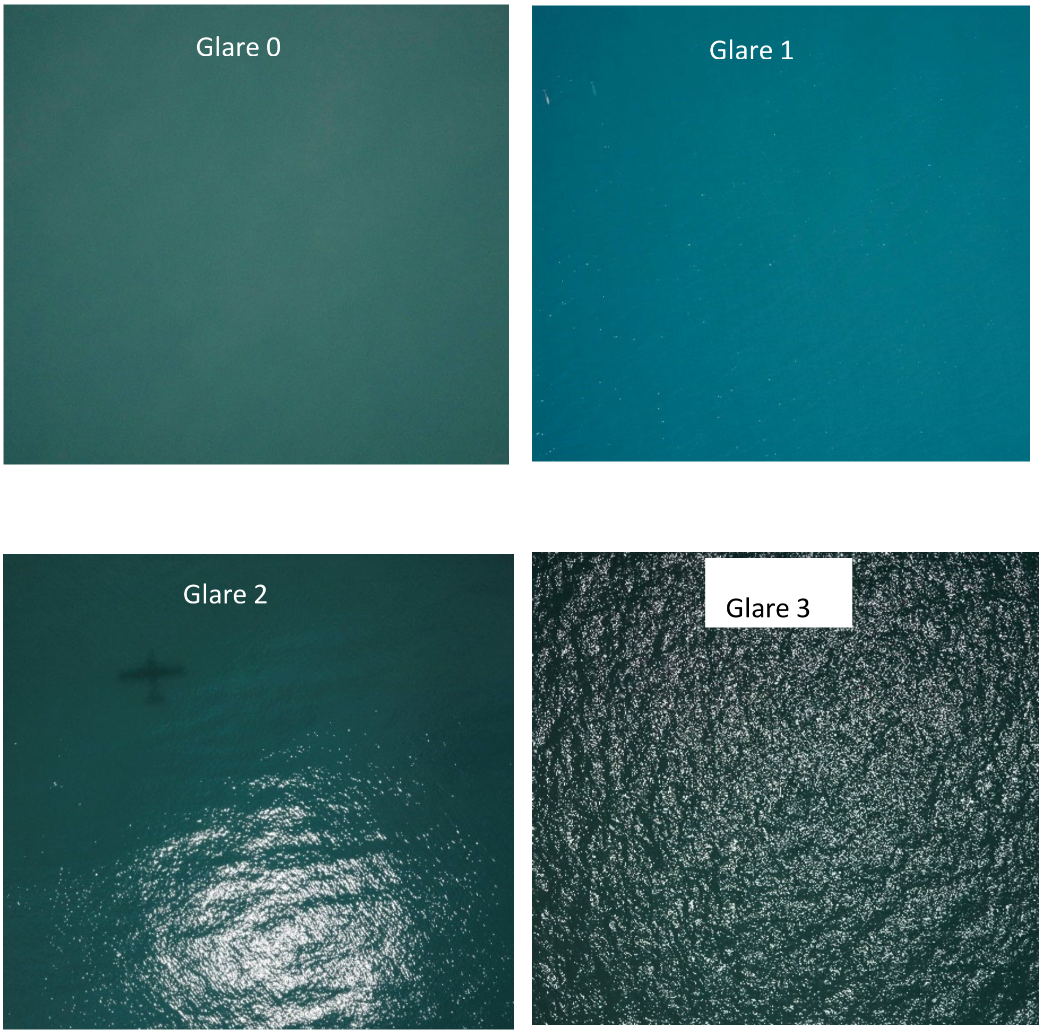
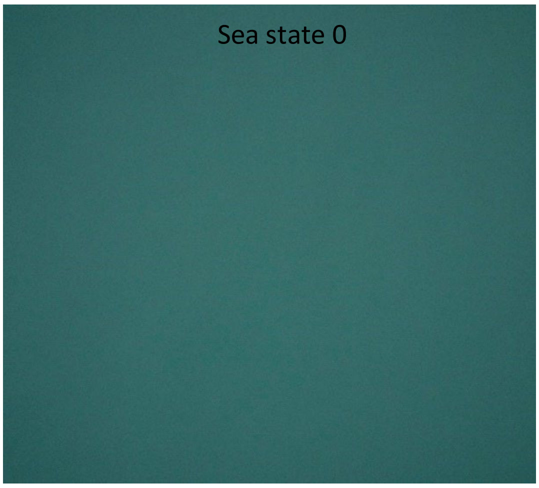
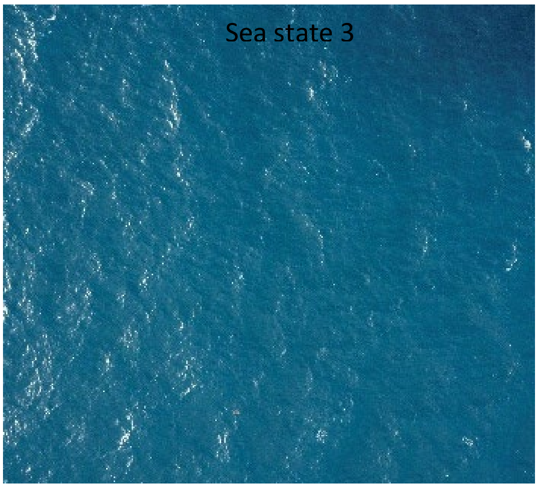


Table 1.3. Sea state Scale

Beaufort Sea state	Description
0	Calm; like a mirror
1	Light air; ripples, no foam
2	Light breeze; small wavelets, smooth crests with glassy appearance
3	Gentle breeze; large wavelets, some crest breaks, some white caps
4	Moderate breeze; small waves, frequent white caps – Abort survey





10.2 APPENDIX 2: DAILY ACTIVITIES DURING THE 2023 DUGONG SURVEY IN THE CENTRAL AND NORTHERN GBR.

Date	Activity	Block surveyed	Survey flight hours (hh:mm), excluding transit hours	Notes
13/10/2023	Team drive up to Ingham to setup the survey aircraft, test cameras, and conduct observer training flight	C11	1:41:00	
14/10/2023 AM1	Survey, start Ingham-land Innisfail	C12	2:50:00	
14/10/2023 AM2	Survey, start Innisfail-land Cairns	C12	2:12:00	
15/10/2023	Survey, start Cairns-land Cairns	C12, C13	3:20:00	
16/10/2023	Survey, start Cairns-land Cooktown	C13	3:28:00	
17/10/2023	Survey, start Cooktown-land Cooktown. Transit back to Cairns. Plane ferries back to Ingham.	C13, N1	5:05:00	Missing ferry time
18/10/2023	No flight	-	-	Unsuitable weather
19/10/2023	No flight	-	-	Unsuitable weather
20/10/2023	No flight	-	-	Unsuitable weather
21/10/2023	No flight	-	-	Unsuitable weather

22/10/2023	No flight	-	-	Unsuitable weather
23/10/2023	Survey, start Cairns-land Cooktown	N1, N2, N4	8:23:00	
24/10/2023	Survey, start Cooktown-land Cooktown	N2, N4	6:59:00	
25/10/2023	Survey, start Cooktown-land Coen	N5	7:07:00	
26/10/2023	Survey, start Coen-land Coen	N5	6:42:00	
27/10/2023	Survey, start Coen-land Lockhart, then transit back to Cooktown	N5, N6, N7, N8, N9	5:27:00	
28/10/2023	No flight	-	-	Unsuitable weather
29/10/2023	No flight	-	-	Unsuitable weather
30/10/2023	No flight	-	-	Unsuitable weather
31/10/2023	No flight	-	-	Unsuitable weather
1/11/2023	No flight	-	-	Unsuitable weather
2/11/2023	No flight	-	-	Unsuitable weather
3/11/2023	No flight	-	-	Unsuitable weather
4/11/2023	No flight	-	-	Unsuitable weather
5/11/2023	No flight, team relocated to Townsville	-	-	Unsuitable weather

6/11/2023	No flight	-	-	Unsuitable weather
7/11/2023	No flight	-	-	Unsuitable weather
8/11/2023	No flight	-	-	Unsuitable weather
9/11/2023	No flight	-	-	Unsuitable weather
10/11/2023	No flight	-	-	Unsuitable weather
11/11/2023	No flight	-	-	Unsuitable weather
12/11/2023	No flight	-	-	Unsuitable weather
13/11/2023	Team relocate to Lockhart River	N9, N8	-	Unsuitable weather
14/11/2023	Survey, start Lockhart River-land Bamaga	N14, N10	5:55:00	No camera
15/11/2023	Survey, start Bamaga-land Bamaga	N13, N15	3:38:00	
16/11/2023	Survey, start Bamaga-land Bamaga	N13	3:30:00	No camera
17/11/2023	Survey, start Bamaga-land Bamaga	N11, N12, N13	6:32:00	
18/11/2023	Survey, start Bamaga-land Bamaga	N14	2:40:00	Repeat of N14 due to camera problem during first flight

10.3 APPENDIX 3: SAMPLING INTENSITIES FOR INDIVIDUAL SURVEY BLOCKS SINCE 2006 IN THE CENTRAL AND NORTHERN GBR.

Block	Most recent survey prior to 2018-19 (see footnotes)		2018-2019		2023	
	Block Size (km^2)	Sampling Intensity (%)	Block Size (km^2)	Sampling Intensity (%)	Block Size (km^2)	Sampling Intensity (%)
C11	3511	18.1	675	17.9	ns	ns
C12	55112	9.5	5483	4.9	5485	4.8
C13	ns[3]	ns[3]	2955	9.5	2955	9.4
N2	6744	19.4	677	17.2	674	17.5
N3	10524	19.8	1055	17.3	1051	17.0
N4	23834	10.1	2392	8.6	2383	8.9
N5	72764	10.1	7276	8.9	7263	8.8
N6	4644	10	464	9.1	463	8.5
N7	6014	10.1	600	9.3	600	8.8
N8	9814	9.8	979	8.5	978	8.6
N9	18374	6.8	1833	6	1831	6.3
N10	2784	10.4	278	9.2	277	9.7
N11	4304	28.6	429	24.1	428	23.8
N12	4154	4.2	413	3.8	413	3.8
N13	40124	7	4003	6.1	3999	6.0
N14	2264	22.9	225	22.8	225	22.8
N15	ns[3]	ns	1960	4.9	1960	4.7

[1] Last surveyed in 2005
[2] Last surveyed in 2011
[3] Not surveyed
[4] Last surveyed in 2013

10.4 APPENDIX 4: WEATHER CONDITIONS ENCOUNTERED DURING THE 2023 DUGONG SURVEY IN THE CENTRAL AND NORTHERN GBR IN COMPARISON TO THE MOST RECENT PREVIOUS SURVEYS.

Weather conditions	Central and northern GBR[1]			Central GBR	Northern GBR
	Nov-2018	Jun-2019	Nov/Dec 2019	Oct/Nov 2023	Oct/Nov 2023
Max wind speed (Kts)	<10	<15	<15	7.0	<15
Cloud cover (Oktas)	1.2[2]	2.7	3.7	(0-2)[3]	(0-4)
Min cloud height (Ft)	2000	3333	1300	1000.0	1000.0
Beaufort Sea State Mean (Range)	1.7 (0–3)	2.6 (1–4)	2.3 (1-3)	2.2 (1-3)	2.15 (1-3)
Glare North[4]	na	na	na	2.6	2.4
Glare South[4]	na	na	na	2.6	2.6
Glare overall	1.8 (0-3)	3.0 (0-3)	2.0 (0-3)	2.6	2.5
Air visibility (Km)	10+	10+	10+	10+	10+

[1] Taken from Marsh et al. (2020)
[2] Mean value
[3] Range value
[4] Means of modes for each transect
[Na] Not available in Marsh et al. (2020)

10.5 APPENDIX 5: DISTRIBUTION OF MARINE MEGAFAUNA SIGHTINGS OTHER THAN DUGONGS FROM THE 2023 SURVEY OF THE NORTHERN SECTION OF THE CENTRAL AND THE NORTHERN GBR

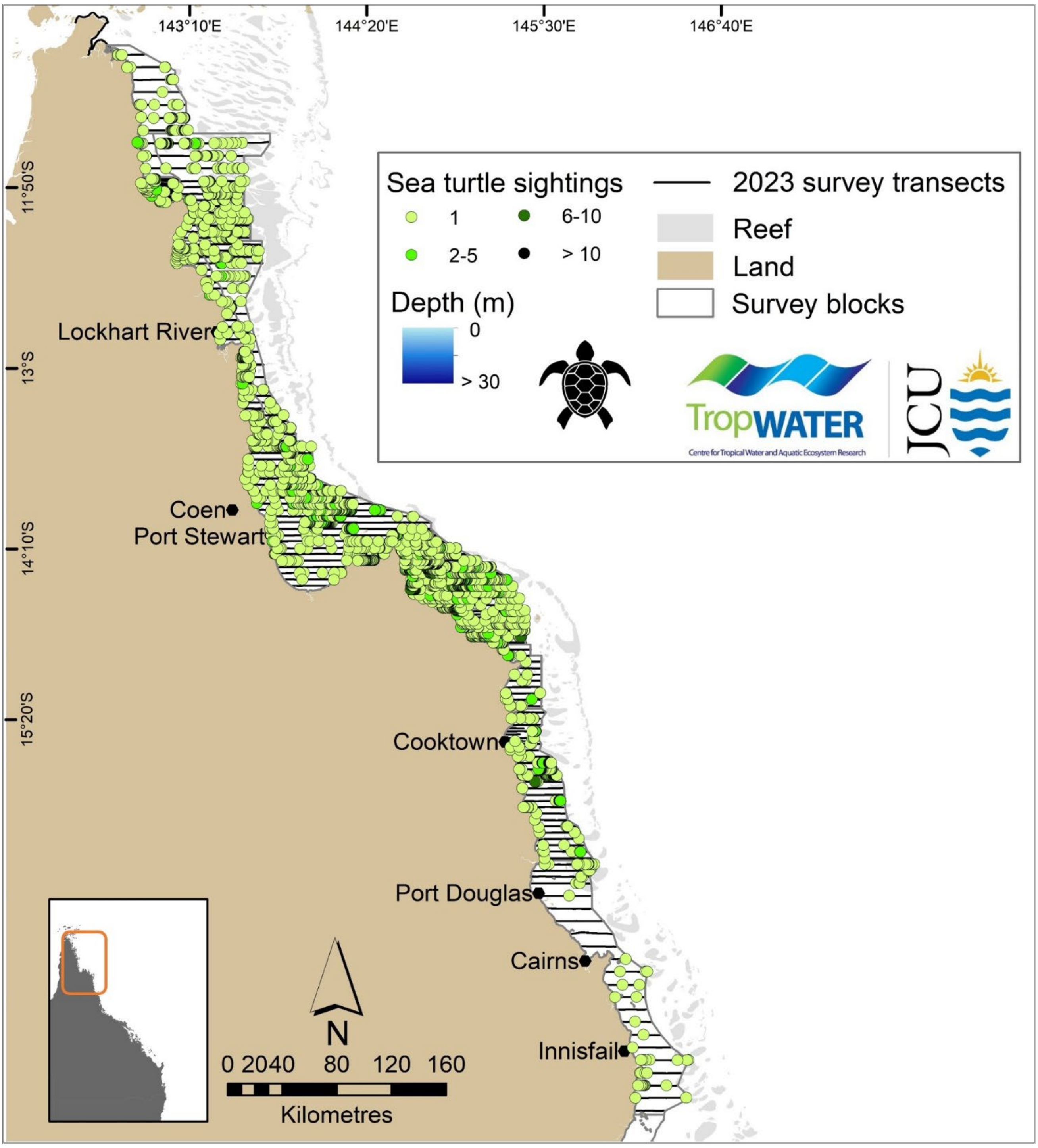


Figure 5.1. Distribution of sea turtle sightings in the -northern section of- the Central and Northern GBR in late 2023.

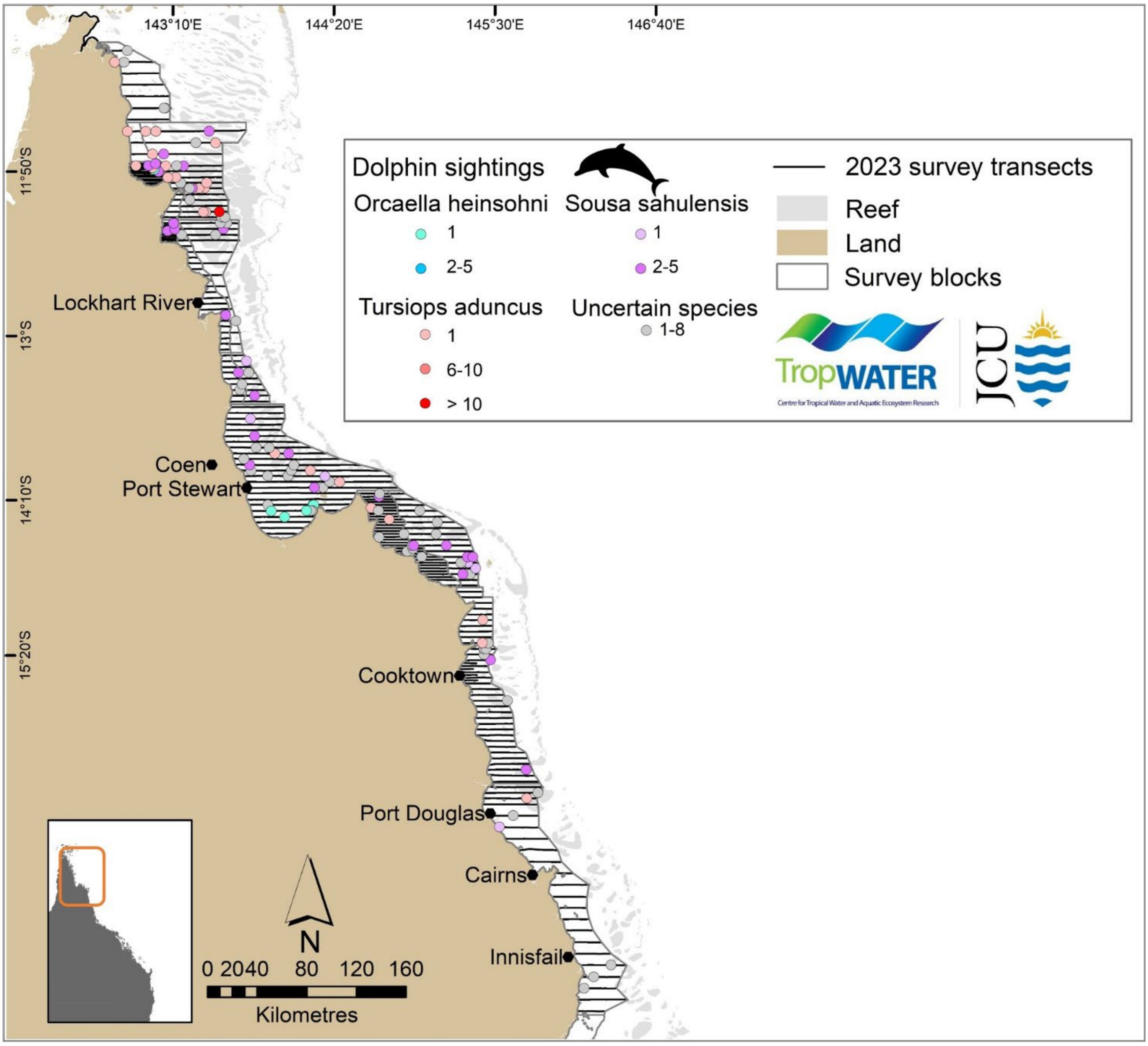


Figure 5.2. Distribution of dolphin sightings in the -northern section of- the Central and Northern GBR in late 2023.

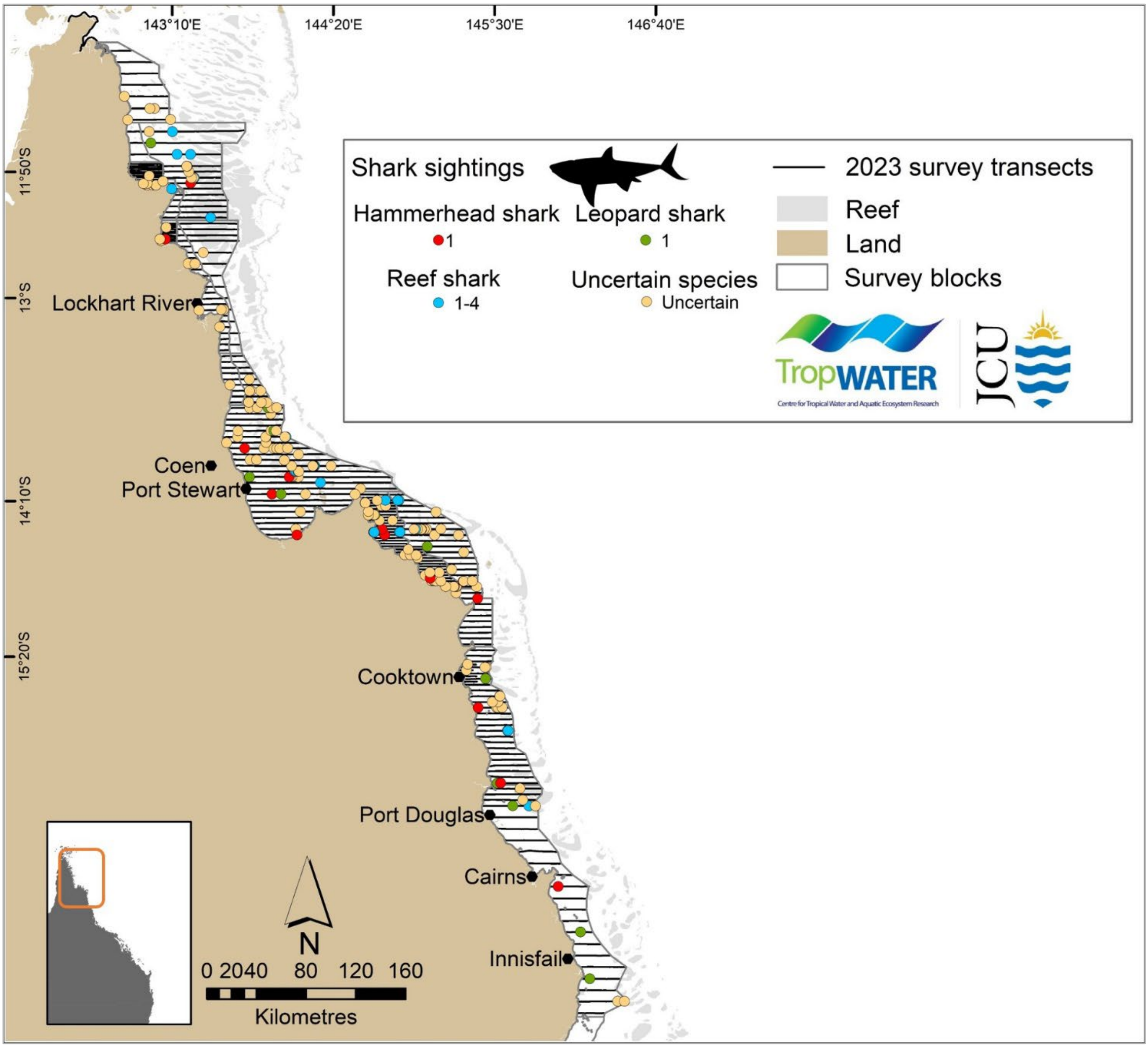


Figure 5.3. Distribution of shark sightings in the -northern section of- the Central and Northern GBR in late 2023.

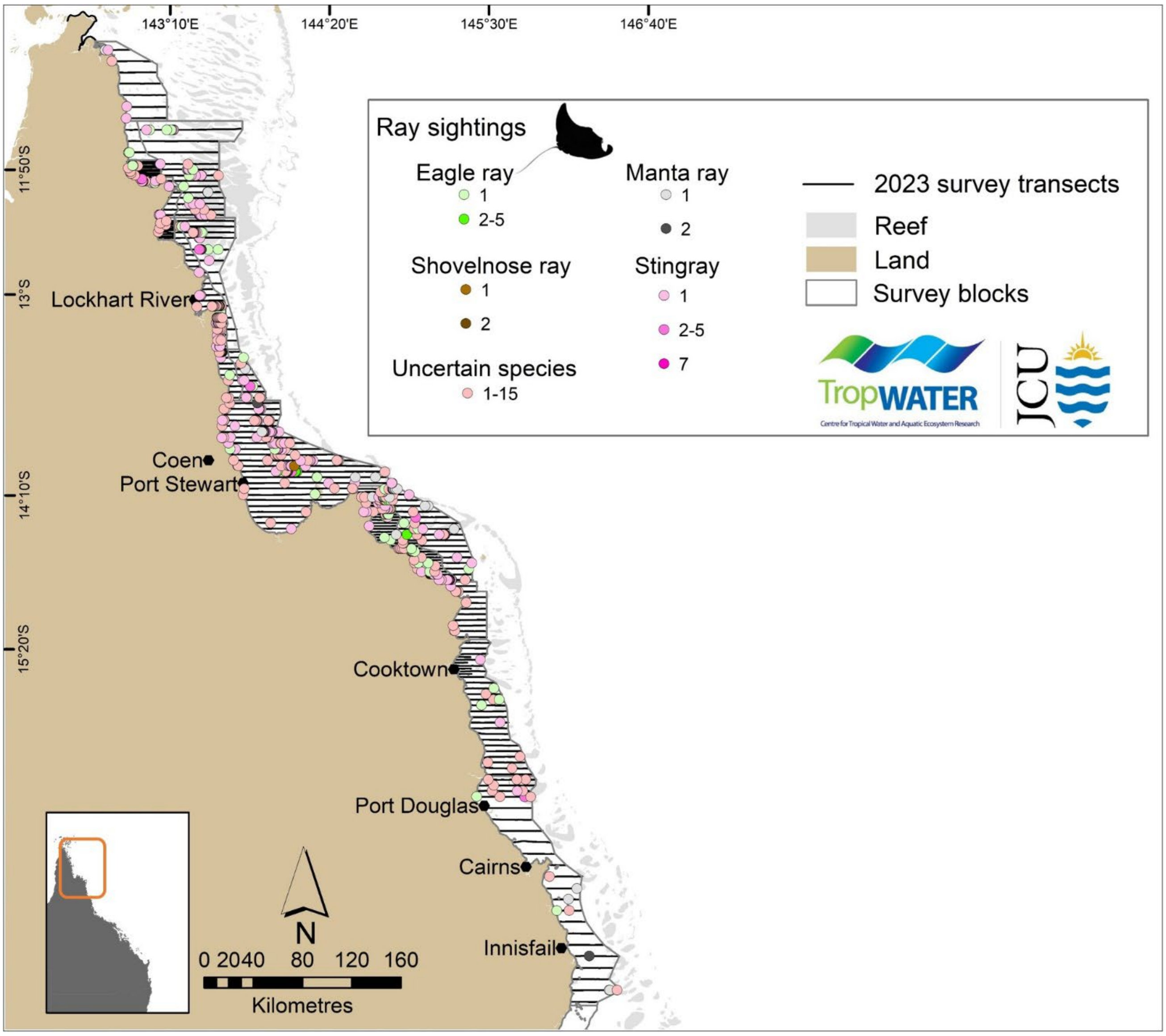


Figure 5.4. Distribution of ray sightings in the -northern section of- the Central and Northern GBR in late 2023.

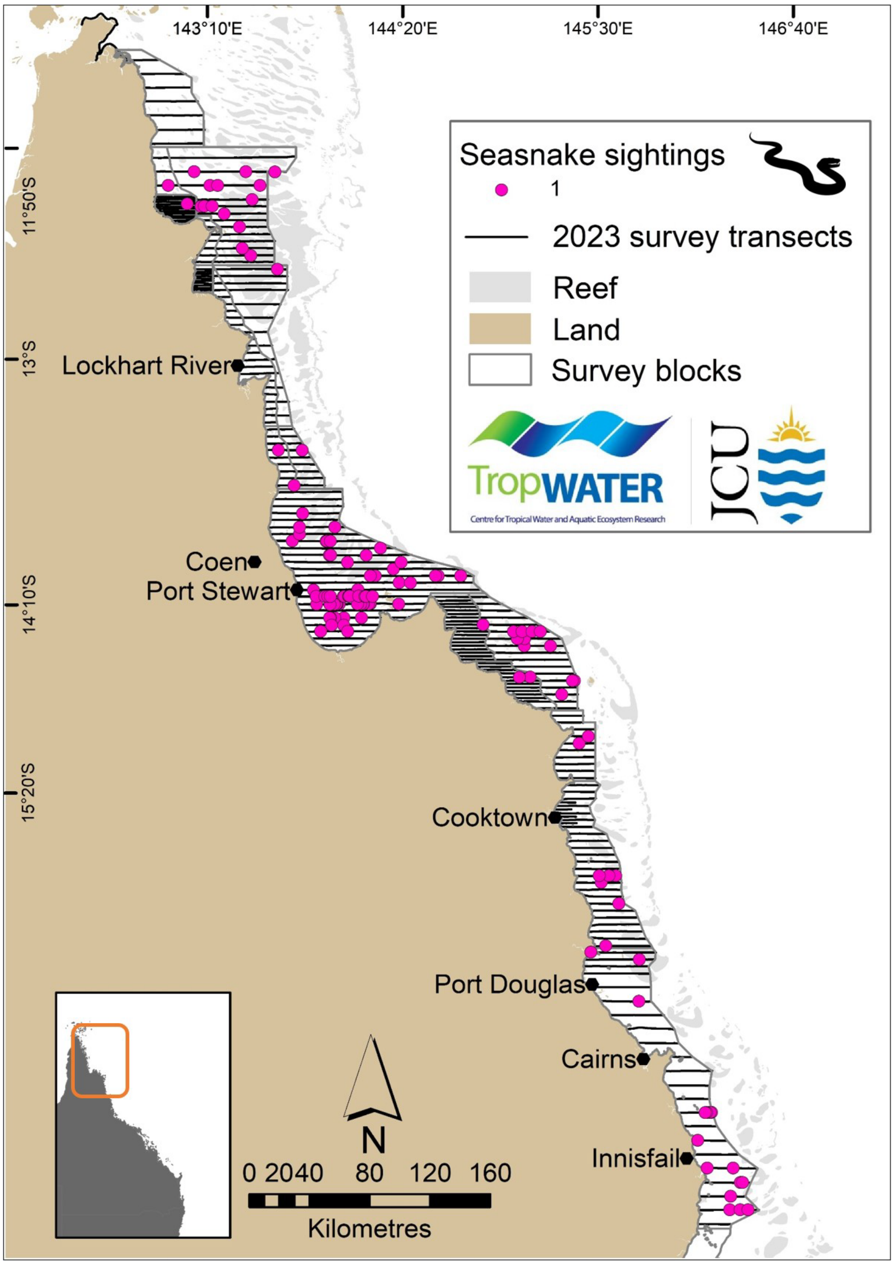


Figure 5.5. Distribution of seasnake sightings in the -northern section of- the Central and Northern GBR in late 2023.

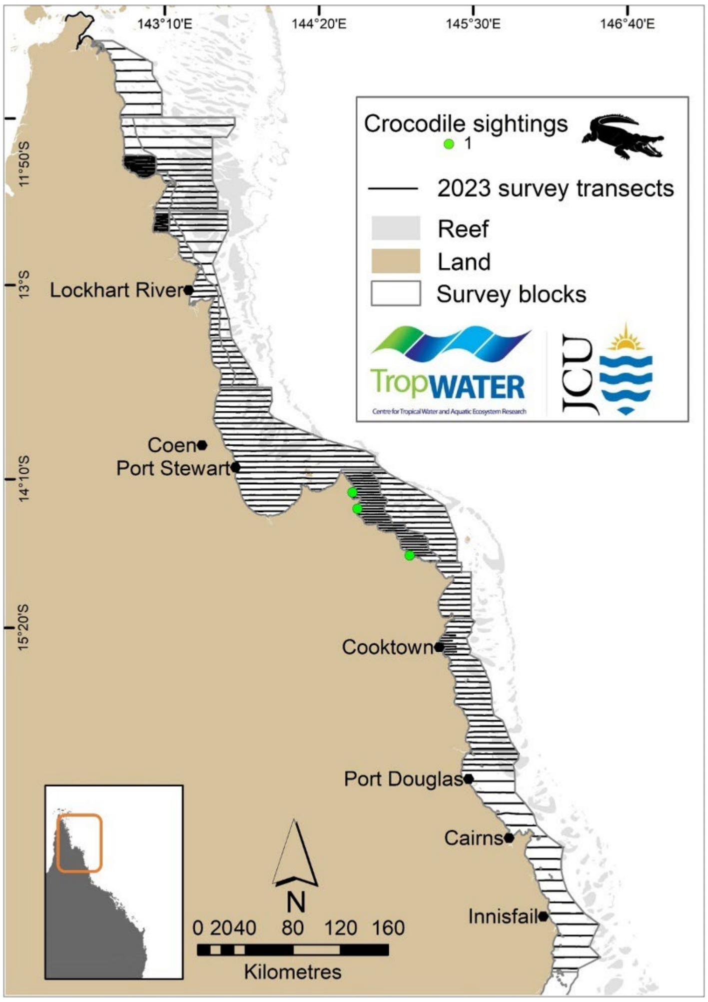


Figure 5.6. Distribution of crocodile sightings in the -northern section of- the Central and Northern GBR in late 2023.

10.6 APPENDIX 6: COMPOSITION OF THE DIFFERENT TEAMS INVOVLED IN THE 2023 DUGONG SURVEY IN THE CENTRAL AND NORTHERN GBR.

Team	Observers' position and name	Survey block
1	SL: Chris Cleguer, PF: Chloe Edwards, SF: Kym Collins, PR: Lilly Donnelly, SR: Daniel Gonzales-Parades	C11, C12, C13, N1, N2, N4, N5, N6, N7, N8, N9, N11, N12, N13
2	SL: Chris Cleguer, PF: Chris Cleguer, SF: Kym Collins, PR: Chloe Edwards, SR: Daniel Gonzales-Parades	C13, N1
3	SL: Kym Collins, PF: Chloe Edwards, SF: Daniel Gonzales-Parades, PR: Lilly Donnelly, SR: Jay Harris	N5
4	SL: Chris Cleguer, PF: Chris Cleguer, SF: Kym Collins, PR: Lilly Donnelly, SR: Chloe Edwards	N10, N13, N14, N15

10.7 APPENDIX 7: DUGONG POPULATION DENSITIES ACROSS THE EASTERN COAST OF QUEENSLAND BETWEEN 2005 AND 2023

Region	Year	Posterior Mean Density (Dugongs/km)	SE	95%CI
Northern Great Barrier Reef	2006	0.203	0.039	0.142 - 0.292
Northern Great Barrier Reef	2013	0.165	0.031	0.115 - 0.236
Northern Great Barrier Reef	2019	0.249	0.050	0.167 - 0.364
Northern Great Barrier Reef	2023	0.250	0.048	0.173 - 0.360
Southern Great Barrier Reef	2005	0.230	0.044	0.159 - 0.332
Southern Great Barrier Reef	2011	0.022	0.004	0.015 - 0.031
Southern Great Barrier Reef	2016	0.144	0.033	0.093 - 0.224
Southern Great Barrier Reef	2022	0.086	0.017	0.058 - 0.125
Hervey Bay	2005	0.309	0.084	0.184 - 0.504
Hervey Bay	2011	0.215	0.062	0.123 - 0.359
Hervey Bay	2016	0.304	0.088	0.173 - 0.514
Hervey Bay	2022	0.094	0.030	0.052 - 0.166
Moreton Bay	2005	0.330	0.090	0.201 - 0.540
Moreton Bay	2011	0.444	0.106	0.279 - 0.695
Moreton Bay	2016	0.393	0.102	0.244 - 0.644

Moreton Bay	2022	0.274	0.078	0.160 - 0.458

10.8 APPENDIX 8: ANNUALISED LOG-LINEAR CHANGE IN DUGONG POPULATION DENSITIES SINCE 2005 ACROSS THE EASTERN QUEENSLAND COAST

Region	Posterior Annualised Trend in Density	SE	95%CI	Probability of Decline
Northern Great Barrier Reef	0.018	0.015	-0.012 - 0.047	0.119
Southern Great Barrier Reef	-0.023	0.015	-0.052 - 0.006	0.938
Hervey Bay	-0.057	0.021	-0.098 - -0.014	0.995
Moreton Bay	-0.012	0.021	-0.051 - 0.028	0.720