Garig Gunak Barlu National Park Green Sawfish (*Pristis zijsron*) aggregation surveys

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Project A12 - Australia’s Northern Seascape: assessing status of threatened and migratory marine species

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This research was prompted by drone footage captured by Garig Gunak Barlu Senior District Ranger Alan Withers; we thank Alan for sharing his knowledge of the area, accumulated over more than 2 decades working in the region. We also thank Traditional Owners and other residents for their knowledge in the form of sawfish sightings. Fieldwork would not have been possible without the on-ground support of rangers Alan Withers and Robbie Risk, who assisted us in every way imaginable. We extend our sincere thanks to Naima Rodriguez Lopez, Greg Williams, and Fredrick Baird for assistance in the field. Finally, we thank the Traditional Owners and the Cobourg Peninsula Sanctuary and Marine Park Board for granting us permission to visit and work on their country.

Important Disclaimer

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EXECUTIVE SUMMARY

Sawfishes are one of the most threatened families of vertebrates with Australia now widely recognised as a global 'lifeboat' for the group. Despite this, significant knowledge gaps remain and the local distribution and areas of critical importance for sawfish are poorly defined. Drone footage captured in late 2018 showed an aggregation of sawfish in the shallow waters of Garig Gunak Barlu National Park in the Northern Territory. This project aimed to characterise this sawfish aggregation and determine if it represented a nursery area by deploying baited remote underwater video (BRUV) stations and unmanned aerial vehicles (drones).

A number of survey sites were identified within the National Park and two survey trips were undertaken. Prevailing weather conditions and limited water clarity restricted usable video footage to that captured by drones at one site (Lidarnardi) during Survey Trip 2. The deployment of BRUVs proved to be unsuccessful during this project.

Drone surveys recorded Green Sawfish on seven out of eight survey days (88%) and on eight of 26 transect flights (31%). Recorded sawfish numbers ranged 1–8 individuals per transect and sawfish density ranged 3.8–30.5 sawfish per hectare. The size of individual sawfish was 57–167 cm total length (TL) with most in the size range 60–100 cm TL.

Despite the challenging field conditions and failure of BRUVs to obtain usable video footage, the drone surveys confirmed the occurrence of juvenile Green Sawfish in the shallow intertidal waters of Garig Gunak Barlu National Park. Given the number of small individuals recorded, this area likely represents a nursery area for the species although this could not be validated with widely-used criteria for defining elasmobranch nursery areas. Despite this, park waters clearly represent critical habitat for the species. The Green Sawfish aggregation is within a protected area affording it some refuge from major threatening processes. However, similar inshore intertidal habitat is not well represented in northern Australian protected areas.

1. INTRODUCTION

1.1 Shark & Ray Fauna of Northern Australia

Australian territorial waters are home to 328 species of chondrichthyan fishes (sharks, rays, and ghost sharks) (Kyne *et al.* 2021) which represents over a quarter of the global fauna and is the highest diversity of any single country. The fauna differs considerably between southern temperate regions and the tropical north. The latter is characterised by inshore, coastal, and continental shelf species with the dominant families being the whaler sharks (family Carcharhinidae) and stingrays (Dasyatidae). In general, northern Australian species are more poorly-known than southern species, with considerable knowledge gaps for even some of the most common species (Kyne *et al.* 2018, 2021). Northern Australia is a stronghold for several nationally and globally threatened species, including species of wedgefish (Rhinidae), giant guitarfishes (Glaucostegidae), hammerhead sharks (Sphyrnidae); and in particular, the sawfishes (Pristidae) (Kyne *et al.* 2021).

1.2 Sawfishes

Sawfishes are one of the most threatened families of vertebrates, with all five species assessed as either Critically Endangered or Endangered on the IUCN Red List of Threatened Species (IUCN 2022). Sawfishes have undergone significant global range contraction (Yan *et al.* 2021) with Australia now widely recognised as a global 'lifeboat' for the group (Fordham *et al.* 2018). Despite this, significant knowledge gaps remain and the local distribution and areas of critical importance for sawfish are poorly defined.

The Green Sawfish (*Pristis zijsron*) was identified as one of the two most poorly known northern Australian threatened species in a gap analysis undertaken in Phase 1 of the NESP Marine Biodiversity Hub Project A12 (see Tables 4 & 13 in Kyne *et al.* 2018). The species is listed as Vulnerable on the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* although *The Action Plan for Australian Sharks and Rays 2021* recommends uplisting to Critically Endangered (Kyne et al. 2021). It is globally Critically Endangered (IUCN 2022). There are no documented breeding areas for Green Sawfish and no designated Biologically Important Areas in the North Marine Bioregion (DAWE 2022).

Drone footage captured by Senior District Ranger Alan Withers in late 2018 showed an aggregation of sawfish in the shallow waters of Garig Gunak Barlu National Park which were identified as Green Sawfish (Figure 1). To the best of our knowledge, this footage was unprecedented anywhere in the formally global range of sawfishes and suggested that this site may not only be nationally, but also internationally significant for this highly threatened group.

Figure 1. Still capture from drone footage showing at least nine Green Sawfish (*Pristis zijsron*) aggregating in the shallow water off Lidarnardi (Record Point), Cobourg in January 2018 (Credit: Alan Withers).

1.3 Garig Gunak Barlu National Park

The Cobourg Peninsula is located approximately 220 km northeast of Darwin (~570 km by road via Kakadu National Park; Figure 2). Garig Gunak Barlu National Park (GGBNP; previously Gurig National Park and Cobourg Marine Park) includes the entire peninsula, encompassing both land and sea country (*gunak* and *lala*, respectively in the local language Iwaidja). It incorporates the surrounding waters of the Arafura Sea and Van Diemen Gulf, and some of the neighbouring islands. The park is Aboriginal-owned land that is jointly managed by the Cobourg Peninsula Sanctuary and Marine Park Board, which includes representatives from local Traditional Owner groups and the Northern Territory Government.

The park zoning scheme, detailed in the management plan (CPSMPB & PWS 2011), provides for a broad spectrum of activities from intensive commercial fishing in Multiple Use A, an extensive Conservation Zone to the south of the peninsula where no commercial or recreational fishing is permitted, and a Scientific Reference Zone with tightly restricted (permit only) access with the intention of protecting areas of outstanding scientific and conservation value. The Port Essington Zone is an area of relatively high visitation and the zoning is intended to provide a higher level of protection of marine biodiversity and habitats, and cultural sites whilst permitting recreational fishing (with some gear restrictions).

The high diversity of marine life in the waters of GGBNP is well renowned and valued by Traditional Owners, Rangers, recreational fishers, and other visitors. The waters of Port Essington (with a maximum depth of ~15 m) are frequented by a variety of large marine vertebrates. Cetaceans including Australian Humpback Dolphins (*Sousa sahulensis*), Indian Ocean Bottlenose Dolphins (*Tursiops aduncus*), Australian Snubfin Dolphins (*Orcaella heinsohni*), and False Killer Whales (*Pseudorca crassidens*) are known to frequent Port Essington. Dugong (*Dugong dugon*) and six species of marine turtle are known to occur in the waters of the park, with Green (*Chelonia mydas*) and Flatback (*Nantator depressus*) turtles regularly nesting on the beaches of the peninsula (CPSMPB & PWS 2011).

A preliminary fauna list provided in Appendix 2 of the Cobourg Management Plan (CPSMPB & PWS 2011) was based on specimens held at the Museum and Art Gallery of the Northern Territory, and on all available published scientific literature as of 1988. Only 18 species of sharks and rays appear on this list which did not include any sawfishes (four sawfish species occur across northern Australia). This species list is considerably lower than would be expected given the diversity of sharks and rays that occur in northern Australian waters (Kyne *et al.* 2021).

Coastal waters across much of the Northern Territory (NT) are highly turbid due to high input of numerous large rivers and large tidal ranges; however, on the northern side of Cobourg Peninsula turbidity is lower than other NT coastal regions due to meso and micro tidal conditions and lack of significant stream inputs (CPSMPB & P&W 2011). This relatively good water clarity provides an opportunity to apply visual sampling techniques – Unmanned Aerial Vehicles (UAVs, commonly referred to as drones) and Baited Remote Underwater Video (BRUVs) – that are difficult to utilise in much of the NT. Yon *et al.* (2020) used BRUVs to examine the shark and ray community structure of nearshore coral reefs in the park in 2016 and found the relative abundance of elasmobranchs was comparable to, or higher than, other locations across northern Australia. Yon *et al.* (2020) did not record any sawfish during their study.

2. PROJECT AIMS

This project was undertaken as a component of the National Environmental Science Program (NESP) Marine Biodiversity Hub Project A12 *Threatened and Migratory Marine Species in Australia's Northern Seascape*.

The aim of the project was to deploy both UAVs and BRUVs to characterise sawfish aggregations within Garig Gunak Barlu National Park and to determine if this area constituted a nursery area for the species.

The project also originally aimed to use the information derived from field sampling to model animal presence/counts based on habitat variables (e.g., water temperature, salinity, turbidity, water depth, substrate type, fringing vegetation). Alternatively, if data were too limited for modelling, the aim was to identify similar habitat across the North Marine Bioregion using Landsat imagery. By extrapolating habitat type from the fine-scale of the survey area to the broad-scale of the seascape, it may be possible to map 'likely breeding' areas for the species. However, insufficient data were obtained for either of these approaches.

3. METHODS

3.1 Field Surveys

Fieldwork for this project comprised three trips undertaken throughout 2019. A scoping trip during 15–22 March aimed to identify potential sampling sites and assess logistics involved in sampling this remote location (see Davies *et al.* 2019). Surveys were carried out during two trips; Survey Trip 1 occurred 20 August–02 September and Survey Trip 2 occurred 17–26 October.

The sampling team for Survey Trip 1 comprised Christy Davies (Research Institute for the Environment and Livelihoods, CDU), Naima Rodriguez Lopez and Thomas Tothill (Marine Futures Lab, UWA), Greg Williams (Traditional Owner), and Fredrick Baird (Cobourg Peninsula Sanctuary and Marine Park Board Member). The sampling team for Survey Trip 2 comprised Christy Davies and Thomas Tothill. Although they did not participate directly in the surveys, the support of Garig Gunak Barlu National Park Rangers Alan Withers and Robbie Risk was critical to the success of the fieldwork.

3.1.1 Survey Trip 1

This trip attempted to explore a range of sites to select survey locations. To inform site selection, recent and historical sawfish sightings from Rangers and other local residents, sites identified during the scoping trip, and additional sites identified during this trip itself were considered.

Prevailing environmental conditions impacted the success of this trip. Very high winds (gusts to over 40 km/hr) completely precluded sampling for two days out of a possible 11 sampling days. High winds prevailed for the duration of the trip, preventing safe travel outside Port Essington, and as a result the sites Gul and Nudaway (Danger Point) were unable to be surveyed (these sites were identified during the scoping trip; Davies *et al.* 2019). Of the sites surveyed, the high winds limited the ability to deploy and utilise drones and impacted water clarity, which resulted in no useful data collection.

3.1.2 Survey Trip 2

Taking onboard the learnings from Survey Trip 1, the second trip applied a structured sampling design at fewer accessible sites. The sites Lidarnardi and Kennedy Bay were initially selected as the survey sites (Figure 2). Kennedy Bay was later abandoned as a survey site and all results are derived from surveys at Lidarnardi.

Surveys consisted of a combination of drone flights and BRUV sets. Scoping drone flights were used where needed to assess conditions and plan daily deployments. Any Green Sawfish recorded on these flights were noted. Formal site surveys consisted of:

1. One or more 200 m drone transect flights; and,
2. Two BRUV sets (each of 5 x BRUVs along ~1 km transect).

3.2 Survey Locations

Surveys were focussed on Port Essington (Figure 2). The base of operations was at Algarlalgarl (Black Point) where the ranger base for the national park is located. The only public boat ramp for the park is situated nearby.

Four key sites within Port Essington were investigated for surveys: Lidarnardi, Kennedy Bay, Knocker Bay, and Gumeragi (Figure 2). The results reported here are derived from surveys undertaken at Lidarnardi which was the prime focus of Survey Trip 2. This site is detailed here; other sites are detailed in Appendix A.

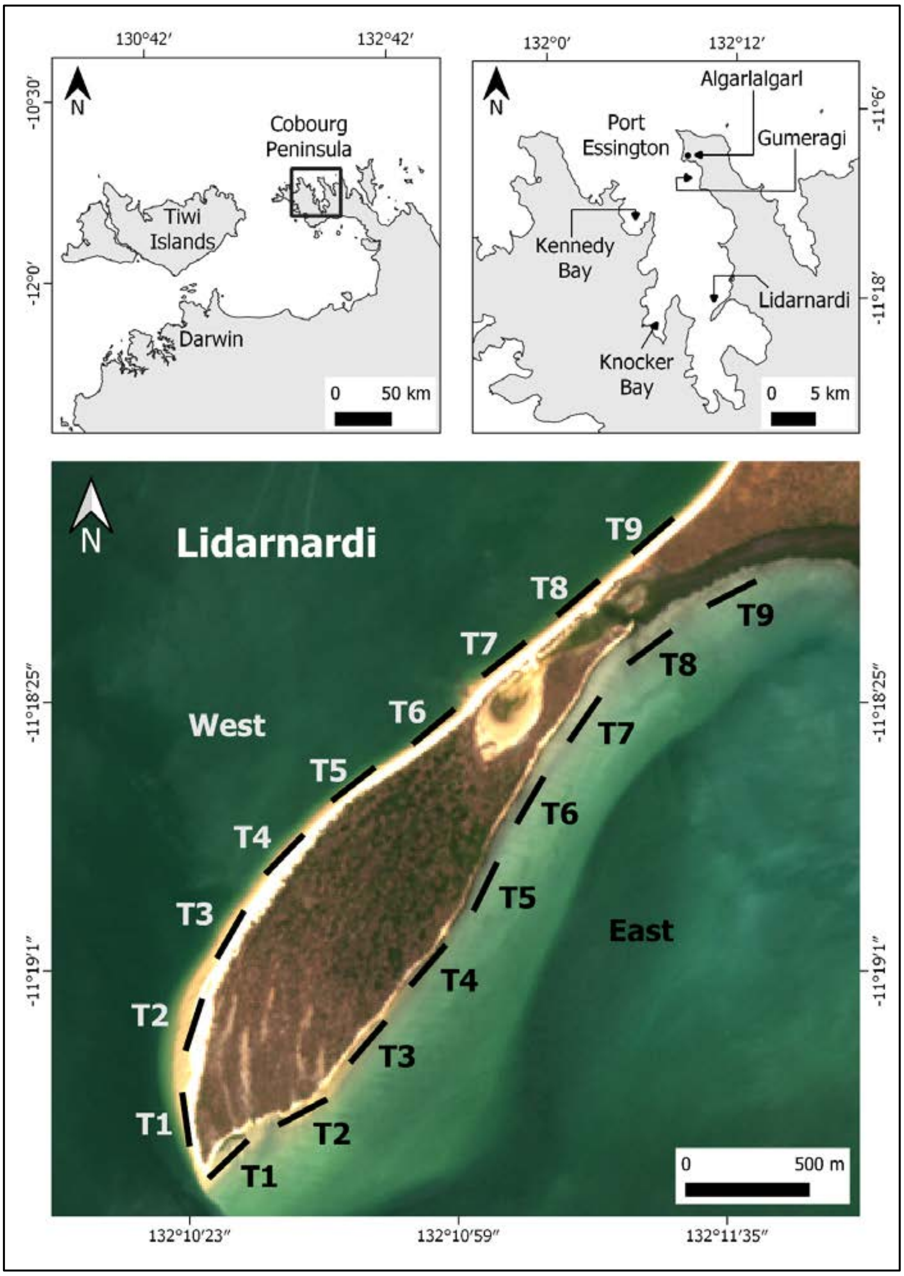

Figure 2. Cobourg Peninsula, Northern Territory (top left) showing Port Essington (top right) and Lidarnardi (Record Point; bottom), the study area of the project. Transects (T) are numbered sequentially from T1 to T9 on both the East and West sides of the point (not all transects were surveyed due to operational conditions).

3.2.1 Lidarnardi (Record Point/Ngi-lad-pa)

Lidarnardi is the site where the original drone footage of the sawfish aggregation was captured (Figure 1). As a result of a number of environmental factors and access, Lidarnardi proved to be the focal site of surveys during Survey Trip 2. Lidarnardi is a narrow south-southwest pointing spit in Port Essington, 15–20 minutes south of Algarlalgarl by boat at -11.3242278°, 132.1735278° (Figure 2). This site is comprised of two distinct sections (Lidarnardi East and Lidarnardi West) located on either side of the point (Figure 2).

Lidarnardi East is a large shallow southeast facing ‘bay’ in the lee of a small sandbar (Figure 3). At high tide, the sparse fringing vegetation of mangroves is inundated. The substrate could be described as silty sand and whilst it generally appears sandy the feeding action of elasmobranchs reveals the presence of a significant proportion of finer material.

Figure 3. Section of site referred to as Lidarnardi East at high tide, with the spit (Record Point) inundated, corresponding to the area T1–T3 East in Figure 2.

Lidarnardi West is a northwest facing, gently sloping sandy beach (Figure 4) with a series of shallow gutters. These gutters are often targeted by recreational fishers because small bait fish are corralled into them by predators including large bony fish (e.g., Barramundi *Lates calcarifer*) and elasmobranchs as they are inundated. At high tide there is still a strip of exposed sand between the water’s edge and the surrounding savannah woodland. The substrate is similar to Lidarnardi East, but perhaps with slightly less silty material.

Figure 4. Section of Lidarnardi West (foreground), roughly corresponding to the area T1–T4 West in Figure 2.

3.3 Survey Techniques

Local observations from Garig Gunak Barlu National Park indicated that sawfish often occurred in shallow tidal habitats, particularly gently sloping beaches and shallow bays. They had been observed on the incoming tide, from half to the top of the tide, suggesting the main period of interest is from ~3–3.5 hours leading up to the high tide each day. Tide has been shown to a major factor influencing the short-term movements of sawfish (e.g., Smalltooth Sawfish *Pristis pectinata*; Simpfendorfer *et al.* 2010). Survey effort was focussed on these habitats and tide conditions, although some surveys were conducted on outgoing tides. The use of BRUVs in the intertidal zone is not commonplace, as this is a zone of disturbance given the water movement. In the hope of minimising disturbance from tidal movement field trips were undertaken around neap tides (Cappo *et al.* 2011).

3.3.1 Baited Remote Underwater Video (BRUVs)

Stereo BRUVs are a well-established survey tool for deriving a variety of data for marine research and has been found to be particularly appropriate for large predators and mobile species (Mallet & Pelletier 2014). Like drones, the non-invasive, non-destructive, and minimally disruptive nature of BRUVs means that they are also appropriate for use in protected areas (Langlois *et al.* 2018) and when dealing with rare and threatened species (White *et al.* 2013, Harasti *et al.* 2016). Data that can be derived from BRUVs include species community assemblage structure, relative biomass estimates, size estimates, and substrate evaluation.

Stereo BRUV rigs similar to those described in Langlois *et al.* (2018) were utilised although the rigs deployed here were collapsible rather than rigid. This facilitated easy transportation and deployment from a small vessel while targeting shallow waters. Rigs had a minimum operational depth of ~0.5–1 m. Each rig was fitted with GoPro Hero 4 cameras, and one rig per set was fitted with a water quality sensor to measure temperature, salinity, and depth.

BRUV footage was acquired in an attempt to:

1. Quantify the occurrence of sawfish;
2. Measure sawfish;
3. Identify other elasmobranchs; and,
4. Classify benthic composition and relief.

Each set comprised of 5 stereo BRUVs. On Survey Trip 1, these were deployed in a semi-random pattern and on Survey Trip 2, these were deployed within a pre-set transect area). The soak-time for each BRUV was a minimum 1-hour.

Pilchards/sardines are the most commonly used bait for BRUVs (Mallet & Pelletier 2014) and sardines were used during Survey Trip 1. However, White *et al.* (2013) postulated that these standard BRUV baits may not attract sawfishes and for Survey Trip 2 an equal mix of pilchards and prawns were used, since prawns are known to be a favoured prey type of sawfishes in northern Australia.

3.3.2 Drones

Traditional survey techniques for possible elasmobranch aggregation sites include fishing methods such as hook-and-line or gill nets or boat-based visual surveys (e.g., Vaudo & Heithaus 2009). These methods are either invasive or, where it would be necessary to be in close proximity to individuals, possibly prompt behaviour avoidance responses. The use of drones as a survey method is increasingly being applied to marine wildlife including mammals (Christiansen *et al.* 2016), sharks (Rieucau *et al.* 2018, Lea *et al*. 2019), and marine faunal assemblages (Hensel *et al*. 2018, Kelaher *et al*. 2019). Drones can be considerably less intrusive than traditional techniques, and furthermore, the functionality and affordability of hardware has improved substantially over the last decade (Colefax *et al*. 2018). Lea *et al.* (2019) suggest a major benefit of the drone is the lack of observer presence to affect behaviour and as such they are an effective, non-intrusive method to study the attendance and behaviour of large predators.

To fly drones in the national park, the necessary By-Law 32 Operation of Aircraft Permits were acquired (Permit DABL19/842 and DABL19/1104). Surveys used an off-the-shelf <2 kg DJI Mavic Pro. There are a number of standard operating conditions that were required to be observed including maximum flying height, maintaining line-of-sight, and distance from airfields. There are also several important limitations of this technology particularly relating to battery life and range. Flying time on a single battery was ~20 minutes and the range of the drone is theoretically several kilometres. Given surveys were conducted over water with drone launching and retrieval from a boat (small and moving location), a very conservative approach to battery usage was taken. High winds severely constrained the use of the drone during Survey Trip 1, with only limited windows of time with suitable conditions.

The optimal height was determined in accordance with local conditions, as per Kiszka *et al*. (2016) who flew transects over a known target at varying heights from 10–20 m. A submerged mock sawfish cut-out was used as the known target to test detectability at various heights (Figure 5), and to calibrate length measurements made using ImageJ software (see section 3.3.4).

Figure 5. The 1 m long mock sawfish (centre) with two live sharks (top right), photographed at 10 m drone height.

Transect (survey) flights were 200 m in length (Figure 2), flown at a height of 10 m (giving a strip width of 13.13 m) and a speed of ~2 m/s (with minor adjustments for wind and other factors).

Scoping flights did not follow a set path. They were generally at a height of 10 m, but this varied as the drone was periodically lowered to aid detection and identification with speed, distance, and time also varying.

There were multiple factors that contributed to overall visibility during drone surveys. Since a survey aim was to use drone footage to derive length measurements it was necessary to have to camera pointing directly down. Therefore, it wasn't possible to adjust the camera angle and polarising filter to reduce glare. Wind occasionally created surface waves and chop that reduced visibility, and water quality and depth affected the clarity.

3.3.3 Identification of Elasmobranch Species in Drone Footage

Drone footage was viewed in VLC Media Player, where it could be slowed down (which is particularly important in allowing for the detection of the better camouflaged and sometimes partially buried animals) and still photos could be captured. A snapshot was taken whenever an elasmobranch was in frame. Pups of both Green Sawfish and Giant Guitarfish (*Glaucostegus typus*) were well camouflaged against the sandy substrate, and many of the rays were observed to be partially buried in the substrate. Because of the prevalence of these difficult-to-detect species, footage for each transect was viewed multiple times. A transect was viewed repeatedly until the number of animals detected did not change in two subsequent viewings.

Elasmobranchs were identified to the lowest taxonomic level possible based on the field characteristics observable from directly above (the perspective provided by the drone). All sawfish seen in the drone footage were identified as Green Sawfish based on field characteristics. The Dwarf Sawfish (*Pristis clavata*) is known to occur in Port Essington and was possibly present during surveys but was not identified in drone footage.

For small sharks there are very few features visible from directly above that would confidently separate these to species-level and therefore all sharks were grouped (similar to Vaudo & Heithaus 2009). While true shark diversity was not characterised here, from casual observations the following species were confidently identified within the sampling area: Tawny Nurse Shark (*Nebrius ferrugineus*), Lemon Shark (*Negaprion acutidens*), and Blacktip Reef Shark (*Carcharhinus melanopterus*). In addition, Whitetip Reef Shark (*Triaenodon obesus*) was tentatively identified. These species have been confirmed to occur in the nearshore waters of GGBNP by both Gomelyuk (2009) and Yon *et al.* (2020). Given that 'shark' could represent four or more species, overall species diversity was not accurately determined in this study. There were also a number of 'unknown' rays where the available footage did now allow identification to species-level (using Last & Stevens 2009, Last *et al.* 2016).

3.3.4 Elasmobranch Measurements

The software package ImageJ (Abramoff *et al*. 2004) was used to measure the elasmobranchs from still photos captured from the video footage from transect flights. The technique relies on having a known drone height when calibrating the length measurement. The flying height of the drone is set relative to the water surface. If a ray is at the surface, the distance between drone and the ray is 10 m, the height the measurement was calibrated for, but if a ray is 2 m under the surface, the distance between the drone and the ray would be 12 m. It was not possible to know the exact depth an elasmobranch was at when it was recorded by the drone. Given this variability, all measurements are considered approximate. It was not possible to measure elasmobranchs observed during scoping flights as the elevation of the drone was variable.

3.3.5 Density Calculations

Sawfish density and combined elasmobranch density was calculated from the Survey Trip 2 transect flights as per Kiszka *et al.* (2016). Calculations were based on a transect length of 200 m and width of 13.13 m.

4. RESULTS

4.1 BRUVs

The use of BRUVs in Garig Gunak Barlu National Park proved problematic. Gomelyuk (2009) stated that the highest water transparency within the section of Port Essington sampled rarely exceeded 2 m at depths of 4–7 m and found 25% of their BRUV footage was unsuitable for analysis but still considered that BRUV sampling 'worked well in an area where diving visual surveys were impossible to implement because of high water turbidity'. It was apparent from preliminary examination of BRUV footage from Survey Trip 1 that visibility was poor throughout during this period of extremely high winds. At times the clarity from the drone looked quite good but the corresponding BRUV footage was unusable (Figure 6).

Figure 6. Aerial image showing a Tawny Nurse Shark (*Nebrius ferrugineus*) close to a deployed BRUV rig. Despite this shark coming within 3 m of the cameras, it was not visible in the BRUV footage.

With lower prevailing winds, BRUVs were again deployed during Survey Trip 2. However, water clarity proved insufficient for the successful application of this technique despite making all possible adjustments (brightness, contrast, etc.) and careful examination of footage. As a result, no elasmobranchs could be identified from BRUV footage acquired from either trip. Overall, the quality of the BRUVs footage was too poor to use in any analysis (including formal classification of the benthic habitat).

4.2 Drones

While a number of sites were scoped and trialled, Lidarnardi proved to be the most suitable for drone surveys and was the focus of Survey Trip 2. The results presented here relate to that site and trip only. Lidarnardi was surveyed on eight separate days with a total of seven scoping flights and 26 transect flights (Table 1). The number of flights varied daily and was influenced by weather and environmental conditions and boating travel times.

Table 1. The number of drone flights undertaken at Lidarnardi.

Survey day	Scoping flights	Transect flights
1	0	1
2	0	3
3	0	4
4	4	4
5	0	4
6	0	2
7	1	4
8	2	4
Total	**7**	**26**

4.2.1 Sawfish

All sawfish recorded during surveys were identified as Green Sawfish. This species was recorded on seven out of eight survey days (88%), on eight of 26 transect flights (31%), and on five of seven scoping flights (71%). Sawfish were more regularly recorded on the western side of Lidarnardi (n=5 transects) than the eastern side (n=3 transects).

Across all transect flights (n=26), the mean number of individual sawfish was 0.9 ± 1.9 (range: 0–8). When sawfish were recorded on transect flights (n=8), the mean number of individuals was 3.2 ± 2.1 (range: 1–8). Sawfish density ranged from 3.8 sawfish per hectare to 30.5 sawfish per hectare (Table 2). The size of individual sawfish was 57–167 cm total length (TL) with most in the size range 60–100 cm TL.

Water quality and habitat parameters where Green Sawfish were recorded are provided in Table 3. A full list of all Green Sawfish observations is provided in Appendix B.

Table 2. Number and density of Green Sawfish (*Pristis zijsron*) for each transect flight where the species was recorded. Refer to Figure 2 for transect location.

Survey day	Transect (T)	Number of Green Sawfish	Density (sawfish ha^{-1})
2	Lidarnardi East T1	8	30.5
3	Lidarnardi West T1	1	3.8
4	Lidarnardi East T1	2	7.6
5	Lidarnardi West T1	2	7.6
6	Lidarnardi West T1	4	15.2
6	Lidarnardi West T2	1	3.8
8	Lidarnardi East T1	4	15.2
9	Lidarnardi West T1	1	3.8

Table 3. Water quality and habitat parameters where Green Sawfish (*Pristis zijsron*) were recorded.

Temperature (°C)	Turbidity (NTU)	Salinity	Substrate	Depth (m)	Fringing vegetation
29.5–31.2	2.55–3.89	35.67–39.88	Sand or silty-sand	0–2	None or sparse mangroves

4.2.2 Elasmobranchs (All Species)

Seven species of ray were positively identified from the drone transects (Table 3). Given sharks were not identified beyond the category ‘unidentified sharks’ and some rays were also not identified (category: ‘unidentified rays’) true elasmobranch species diversity is unknown. The Broad Cowtail Ray (*Pastinachus ater*), Giant Guitarfish (*Glaucostegus typus*), Green Sawfish, and Mangrove Whipray (*Urogymnus granulatus*) represented the most commonly observed species (Table 4). Elasmobranch diversity and species-level density data will be analysed and reported elsewhere.

Table 4. Summary of elasmobranch species identified from transect and scoping drone flights during Survey Trip 2. Size measurements are approximate; for sawfish, sharks, and guitarfish, total length (TL) was recorded and for stingrays, disc width (DW) was recorded.

Common name	Species name	Total # seen in flights	Size range
Unidentified sharks	n/a	99	31–198 cm TL
Broad Cowtail Ray	*Pastinachus ater*	79	33–102 cm DW
Giant Guitarfish	*Glaucostegus typus*	63	34–141 cm TL
Green Sawfish	*Pristis zijsron*	41	56–167 cm TL
Mangrove Whipray	*Urogymnus granulatus*	31	30–91 cm DW
Unidentified rays	n/a	14	n/a
Pink Whipray	*Pateobatis fai*	8	n/a
Porcupine Ray	*Urogymnus asperrimus*	6	n/a
Australian Bluespotted Maskray	*Neotrygon australiae*	3	n/a

The combined density of elasmobranchs ranged from 3.8 (where a single animal was detected in the transect) to 133 animals per hectare (Table 5). In the highest density transects, rays were resting and feeding in aggregations in close physical proximity (Figure 7).

Table 5. Number and density of all elasmobranchs combined for each transect flight where elasmobranchs were recorded. Refer to Figure 2 for transect location.

Survey day	Transect (T)	Total number of elasmobranchs	Density (elasmobranchs ha^{-1})
1	Lidarnardi East T1	16	60.9
2	Lidarnardi West T1	2	7.6
2	Lidarnardi West T2	5	19.0
2	Lidarnardi West T3	3	11.4
3	Lidarnardi East T1	14	53.3
4	Lidarnardi West T1	15	57.1
4	Lidarnardi East T6	2	7.6
5	Lidarnardi West T1	13	49.5
5	Lidarnardi West T2	1	3.8
7	Lidarnardi East T1	35	133.3
7	Lidarnardi West T1	10	38.1
7	Lidarnardi West T2	2	7.6
8	Lidarnardi East T1	4	15.2
8	Lidarnardi East T2	1	3.8
8	Lidarnardi West T1	4	15.2
8	Lidarnardi West T2	2	7.6

Figure 7. Aggregating rays at Lidarnardi East.

5. DISCUSSION

5.1 Green Sawfish Aggregation

Despite challenging field conditions and the failed application of BRUVs, a Green Sawfish aggregation was documented by drone surveys in GGBNP. Green Sawfish were recorded on all but one survey day of Survey Trip 2 and were present in a third of transect flights. The maximum calculated density of Green Sawfish was remarkedly high (30.5 sawfish per hectare) and has not before been documented for any sawfish species. Sawfish density calculations are lacking from elsewhere within their range, probably due to their preference for turbid water systems combined with few known areas where multiple individuals can be located (given their highly threatened status). The highest sawfish density calculation is comparable to the maximum combined elasmobranch density that Vaudo & Heithaus (2009) found on the ‘pristine’ nearshore shallow sandflats of Shark Bay Marine Park in Western Australia, another remote protected marine area with multiple use zones.

Green Sawfish size-at-maturity is poorly-known but thought to be ~430 cm TL and size-at-birth is reported at ~80 cm TL (Last *et al.* 2016). The size of individual sawfish recorded during drone surveys was 57–167 cm TL with most in the size range 60–100 cm TL. These measurements indicate that all sawfish recorded were immature, were mostly young-of-year, and that the size-at-birth may be smaller than reported in the literature.

The national park is also noteworthy for the diversity of inshore tropical elasmobranchs. The maximum combined elasmobranch density (133 animals ha^{-1}) was many times higher than the maximum density of Blacktip Reef Shark and Pink Whipray (*Pateobatis fai*) which Kiszka *et al.* (2016) observed at shallow coral lagoon provisioning sites in French Polynesia. Aside from Green Sawfish (Critically Endangered), all but one identified elasmobranch species recorded in the surveys are globally threatened on the IUCN Red List of Threatened Species (IUCN 2022). These species and their global categories are: Broad Cowtail Ray (Vulnerable), Giant Guitarfish (Critically Endangered), Mangrove Whipray (Vulnerable), Pink Whipray (Vulnerable), and Porcupine Ray (*Urogymnus asperrimus*; Vulnerable). Despite their dire global status, these species are all considered Least Concern in Australia, highlighting the role of northern Australia as a global ‘lifeboat’ (Kyne *et al.* 2021).

5.2 Limitations of Drone Deployment

Typically drone surveys would only be undertaken during ideal conditions, when factors such as glare and wind do not impact on visibility (Kiszka *et al.* 2016, Schofield *et al.* 2017, Colefax *et al.* 2018, Hensel *et al*. 2018). Given available time was limited, in order to maximise the amount of footage, the drone was flown whenever wind and battery power permitted. With the camera pointing directly down to derive length measurements, it wasn’t possible to adjust the camera angle and polarising filter to reduce glare. Wind created surface waves and chop that reduced visibility, and turbidity and depth affected clarity. It is likely that in some transects there were elasmobranchs present, but they were not visible in the footage. Therefore, counts derived may be an underestimate of actual presence. Despite these limitations, drones were successfully deployed and provided data on the sawfish aggregation.

This survey method is likely to provide a valuable way to derive further knowledge about the marine biodiversity found in the shallow waters of GGBNP. There are several aspects of the technique applied that could be easily adjusted to derive better data in future. For example, operating from the land would mean longer flights could be made, as the operator would not need to keep a high level of battery power in reserve to account for the challenges of retrieving over water. This was not possible on the current field trips as BRUVs were deployed at the same time, and there was not sufficient time to land and relaunch the boat. If length measurements were not required, the angle of the camera and polarising filter could be adjusted to reduce glare.

5.3 Limitations of BRUV Deployment

BRUVs proved to be of poor utility in the intertidal zone where many elasmobranchs were aggregating. Despite capturing approximately 250 hours of footage from the stereo BRUVs, none of it was clear enough to derive quantitative data. In addition to weather and tides, bioturbation may have been a significant contributing factor to the poor visibility experienced during the survey periods. Most rays are benthic foragers that excavate pits in the sediment to feed on infauna (Vaudo & Heithaus 2011). This type of feeding mobilises sediment and leaves distinctive pits in the substrate (Takeuchi & Tamaki 2014). These pits were a very common feature at Lidarnardi (Figures 8 & 9), and many other sites visited. If this feeding was occurring whilst the BRUVs were in place, it would likely have resulted in localised patches of higher turbidity. This elevated turbidity may not have been reflected in the one-off turbidity measurements that were obtained for each BRUV set, which ranged 1.45–12.90 NTU on Survey Trip 1; and 2.55–11.40 NTU on Survey Trip 2, with the vast majority of readings ≤5 NTU. Yon *et al.* (2020) also noted particular difficulty identifying stingrays (compared to sharks) from their footage, suggesting their behaviour around the bait bags likely impacted visibility, and in general, they also considered most of their footage had less than ideal visibility.

This technique has been successfully deployed in GGBNP in the past. Yon *et al.* (2020) used BRUVs to describe the elasmobranch community of the nearshore coral reef habitat of GGBNP but did not detect Green Sawfish. Similarly, the species was not detected by Gomelyuk (2008) using the same sampling method within Port Essington itself, including at a site described as a sandy bank with low spatial heterogeneity, similar to the flats being sampled here (but not in the intertidal zone). White *et al.* (2013) suggested that Green Sawfish may not be attracted to baits used in BRUVs, possibly explaining their absence in the above studies. Alternatively, sawfish may actually be concentrating in the shallow to very shallow nearshore habitats, as Simpfendorfer *et al.* (2010) found Smalltooth Sawfish did in southwest Florida, USA.

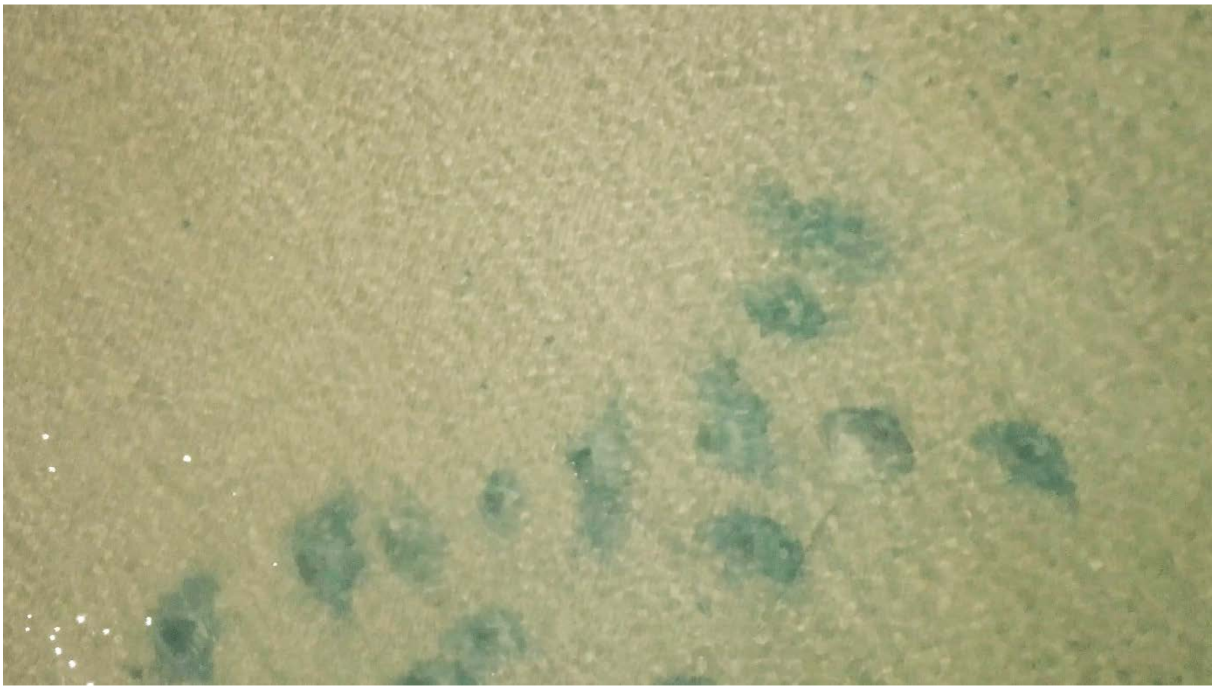

Figure 8. Ray feeding pits at Lidarnardi West with a feeding ray visible in the photo (second patch from right).

Figure 9. A multitude of small ray feeding pits at Lidarnardi East, exposed at low tide.

5.4 Management Implications & Future Directions

Shallow inshore waters are used as nursery areas by a variety of elasmobranchs (e.g., Vaudo & Heithaus 2009, Simpfendorfer *et al.* 2010). Elasmobranch nursery areas are defined when meeting three criteria (defined for sharks by Heupel *et al.* 2007 and extended to rays by Martins *et al.* 2018): '(1) sharks are more commonly encountered in the area than other areas; (2) sharks have a tendency to remain or return for extended periods; and (3) the area or habitat is repeatedly used across years.' (Heupel *et al.* 2007). This classification has been widely applied to shark and rays (Heupel *et al.* 2019). Given the one-off nature of the drone surveys reported here, the status of GGBNP (or more specifically, Lidarnardi) cannot be validated as a nursery area using this definition. Despite this, it seems likely that the location is a nursery area for Green Sawfish as well as Giant Guitarfish, given that young-of-the-year of these species were recorded in the surveys. Similarly, Yon *et al.* (2020) postulated that the area is a likely nursery area for Blacktip Reef Shark and possibly Tawny Nurse Shark. The validation of GGBNP as a nursery area, particularly for Green Sawfish should be the focus of future work.

While various sites around Port Essington were explored for this study, useful data was derived from only one site (Lidarnardi). There were numerous other sites within GGBNP that are likely to provide suitable habitat for sawfish aggregations, which were not able to be quantitatively sampled during this project. Within Port Essington this includes Knocker Bay and Kennedy Bay, and further afield, Gul and Nudaway (Davies *et al.* 2019). Drone surveys of these other sites (and additional surveys around Lidarnardi) would be prudent, in order to gain a full appreciation of the importance of the protected waters surrounding Cobourg Peninsula for Green Sawfish and many other elasmobranch species.

The project originally aimed to use the information derived from field sampling to model animal presence/counts based on variables (e.g., water temperature, salinity, turbidity, water depth, substrate type, fringing vegetation). Alternatively, if data were too limited for modelling, the aim was to identify similar habitat across the North Marine Bioregion using Landsat imagery. By extrapolating habitat type from the fine-scale of the survey area to the broad-scale of the seascape, it may be possible to map 'likely breeding' areas for the species. However, insufficient data were obtained for either of these approaches during the current surveys.

5.5 Conclusion

The Cobourg Peninsula Sanctuary and Marine Park Board (2011) called for research on the conservation and scientific values of the Park, including 'investigation of the significance of bays and estuaries as breeding areas for marine life.' The current surveys, combined with that of Yon *et al.* (2020) and Gomelyuk (2009), collectively suggest that the nearshore waters of GGBNP are of high importance to elasmobranchs, including species of high conservation value (e.g., Green Sawfish and Giant Guitarfish). Although it is not yet possible to formally categorise the area as a nursery area (following Heupel *et al.* 2007), the *Sawfish and River Sharks Multispecies Recovery Plan* (DOE 2015) states that 'all areas where aggregations of individuals have been recorded displaying biologically important behaviours such as breeding, foraging, resting or migrating, are considered critical to the survival of the species'. GGBNP waters clearly represent critical habitat for Green Sawfish. The ongoing legislative protection of the biologically and culturally important waters of GGBNP is therefore essential.

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APPENDIX A – OTHER SITES

Kennedy Bay

Kennedy Bay is a north facing bay located on the western side of Port Essington (Figure 2). It features extensive areas of shallow sandy habitat similar to that found at Lidarnardi East, including extensive shallow gutters where elasmobranchs can often be observed hunting (Figure 10). After observing suitable habitat during Survey Trip 1, Kennedy Bay was included as a sampling site for Survey Trip 2. However, the site was found to be experiencing an algal bloom during Survey Trip 2, resulting in both a thick surface layer and further algae suspended in the water column (Figure 11).

On day one of Survey Trip 2, a survey deploying BRUVs and transect drone flights was conducted. Despite the thick layer of surface algae, some sharks were detected on the drone footage but overall visibility was poor. Another attempt was made to survey Kennedy Bay on day two of Survey Trip 2 but despite a reduction in the surface layer algae, visibility was still very poor. This location was subsequently abandoned as a sampling site.

Figure 10. The extensive shallow sand flats of Kennedy Bay pictured at low tide during Survey Trip 1.

Figure 11. Kennedy Bay during Survey Trip 2 showing a thick layer of surface algae blanketing the water.

Knocker Bay

Knocker Bay lies on the western side of Port Essington to the south of Kennedy Bay (Figure 2). This area is covered by an active pearling lease and is excluded from the National Park. There are several sections with shallow sandy flats and spits that likely provide good sawfish habitat (Figure 12).

Figure 12. An area of shallow sand flat in Knocker Bay, where several ray species were observed during Survey Trip 1.

During Survey Trip 1, a Green Sawfish pup was observed feeding on a shallow sandy spit (Figure 13) and there were also a number of other rays observed during scoping drone flights along the shallow sand flat shown in Figure 12. However, water clarity was poorer than elsewhere, with turbidity precluding effective use of survey gear and the site was not formally surveyed.

Figure 13. A sandy spit in Knocker Bay where a sawfish pup was recorded in drone footage during Survey Trip 1.

Gumeragi

The site Gumeragi (the name of a nearby outstation) is in the shallow bay where the public boat ramp is located (Figure 2). There is a west facing sandy beach (Figure 14) with patches of rocky reef beyond the low tide mark. Locals living at the old school (known as Thunder Rock) which is positioned atop the cliff reported occasionally seeing quite large sawfish moving through the shallows of this bay.

Although this area did not have extensive areas of what may be considered to be ideal sawfish habitat (shallow sandy flat and gutters), it was considered during Survey Trip 1 because when winds were high (which prevented sampling elsewhere), conditions within this bay were often relatively calm.

Figure 14. Gumeragi, with beach section on right.

APPENDIX B – GREEN SAWFISH OBSERVATIONS

Table B1. All observations of Green Sawfish (*Pristis zijsron*) recorded from drone flights at Lidarnardi on Survey Trip 2. All observations were in the vicinity of -11.3242278°, 132.1735278° (see Figure 2 for transect locations).

Sampling day	Date	Drone flight	Location	Number of Green Sawfish	Temperature (°C)	Turbidity (NTU)	Salinity	Substrate	Maximum depth (m)	Fringing vegetation
1	18-Oct-19	Transect (T1)	Lidarnardi East	8	29.78	3.19	39.88	Silty sand	1	None
2	19-Oct-19	Transect (T1)	Lidarnardi West	1	31	3.45	39.26	Sand	1.5	None
3	20-Oct-19	Transect (T1)	Lidarnardi East	2	30.4	2.71	35.67	Silty sand	1	Sparse mangroves
4	21-Oct-20	Transect (T1)	Lidarnardi West	2	30.62	3.82	35.9	Sand	1.5	None
4	21-Oct-20	Scoping	Lidarnardi East	6	30.13	2.65	36.11	Silty sand	1	Sparse mangroves
4	21-Oct-20	Scoping	Lidarnardi East	5	30.13	2.65	36.11	Silty sand	1	Sparse mangroves
5	22-Oct-19	Transect (T1)	Lidarnardi West	4	29.5	2.55	36.22	Sand	1	None
5	22-Oct-19	Transect (T2)	Lidarnardi West	1	29.5	2.55	36.22	Sand	1	None
7	24-Oct-19	Transect (T1)	Lidarnardi East	4	30	2.89	36	Silty sand	1	Sparse mangroves
7	24-Oct-19	Scoping	Lidarnardi East	1	30	2.89	36	Silty sand	1	Sparse mangroves
8	25-Oct-19	Scoping	Lidarnardi East	3	30.75	2.63	36.3	Silty sand	1	Sparse mangroves
8	25-Oct-19	Scoping	Lidarnardi East	3	30.75	2.63	36.3	Silty sand	1	Sparse mangroves
8	25-Oct-19	Transect (T1)	Lidarnardi West	1	31.15	3.89	35.93	Sand	2	None

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