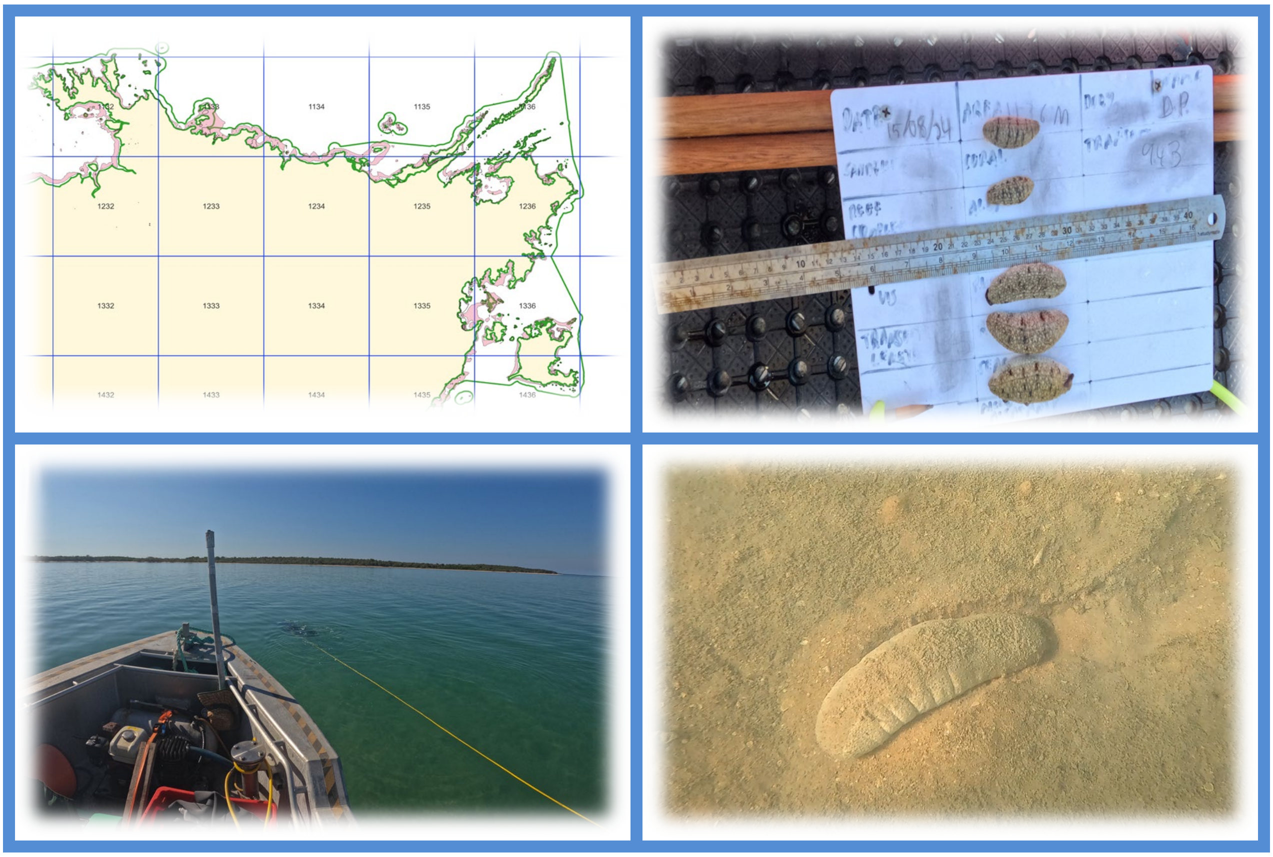
2024 surveys to estimate the density and biomass of Sandfish (*Holothuria scabra*) at Cobourg Peninsula and Groote Island



Matt Koopman and Ian Knuckey

2025

fishwell

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2025

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Contents

Executive Summary

Although other species of sea cucumber can be harvested in the Northern Territory (NT) Trepang fishery, only one species, the Sandfish (*Holothuria scabra*) is landed. This species inhabits the seafloor in shallow coastal waters (< 10m) where it can be hand-collected by divers licenced to operate in the fishery. Its high price on export markets and the relative ease of collection makes Sandfish vulnerable to over exploitation warranting cautious management given the declines in fisheries for this species elsewhere. Relatively little information is available on the status of the NT Trepang stocks, prompting development of survey methods suitable to support performance indicators for use in harvest strategies currently under development.

Historical catches are currently used to establish annual catch quotas applicable to 32 60 nm x 60 nm reporting grids. Although there are a large number of reporting grids covering the NT coastline, Sandfish are only harvested in a few grids, with much of the annual catch taken from three grids (including the Cobourg Peninsula and Groote Island). Nominal stock structure suggests that Cobourg Peninsula is part of a western stock and Groote Island an eastern stock. Within the three grids important to the fishery, fishery-independent surveys were designed to reflect spatial distribution of catches which are primarily taken within embayments, off archipelagos, and straits between islands. Sandfish are generally not found in habitat adjacent to exposed coastline. Thus, strata were assigned to cover the fishery with randomly allocated sites (transects) for survey by divers. Transects involved counts (including underwater videos) of Sandfish within a 2 m span along 100 m lines deployed on the seafloor. This survey method has been successfully employed in surveys of other species of sea cucumber in Australia. Densities and mean weights of Sandfish together with estimates of fished area yielded biomass estimates within strata which were then extrapolated to estimate biomass of Sandfish in each grid.

Survey design was affected by generally inaccurate bathymetric profiles available to assign transect sites within strata (< 10 m depth) in NT coastal waters. This and the high tidal range and inaccessibility of some Sandfish habitat affected survey execution and has compromised previous surveys. Nonetheless, current surveys off the Cobourg Peninsula and Groote Island yielded relatively precise estimates of density and biomass over relatively large spatial scales representative of the fishery. Importantly, the results can inform the design of further fishery-independent surveys addressing a need for improved performance indicators for the fishery.

Estimates of biomass for reporting grids 1132 (Cobourg Peninsula – western stock) and 1236, 1336 (Groote Island – eastern stock) were considered to be conservative as areas currently receiving no fishing effort, and not included in survey strata (including closed areas), are likely to have Sandfish. Annual catch limits applicable to each grid are much less than 10 % of estimated biomass: a yardstick generally deemed conservative as a basis for setting sustainable catch limits of sea cucumbers. Notably, the density of Sandfish recorded in the surveys was generally high (> 100 individuals/Ha) in comparison with densities of Sandfish recorded elsewhere but also in relation to other exploited populations of sea cucumbers. This suggests that the current spatial management (including annual catch limits applicable to grids) of the NT Trepang fishery is conservative. Other management measures include size limits (16 cm length). Surveys of both stocks revealed an accumulation of Sandfish above the size limit. Thus, the fishery-independent surveys of Sandfish described here can provide robust measures of biomass useful in the development and application of a harvest strategy for the fishery.

Introduction

Four species of sea cucumber have been recorded from NT waters but only Sandfish (*Holothuria scabra*) are commercially important (given their size, relative abundance and value) (Vail 1989). Sandfish (Trepang) have been harvested in northern Australian waters for centuries, first by Macassans (now Indonesia) (Shelley and Puig 2003, Grubert 2017) with the South Australian government issuing licences in 1907 (NT 2021), and more recently by Australian commercial fishers (Grubert 2017, 2019; Hamel *et al*. 2022). More generally, Sandfish are distributed widely throughout the Indo Pacific region (Kinch *et al.* 2008, Hamel *et al.* 2022) where they are highly valued on Asian seafood markets (Purcell *et al.* 2018). In Australia, Sandfish are found across the north coast and extend down the east coast to the Queensland/New South Wales border (Welch 2014) and down to the Pilbara in Western Australia.

The Northern Territory (NT) Trepang fishery is a limited-entry fishery (6 licences) with a minimum legal size of 16 cm (NT 2021). In 2004, the first assessment of the fishery under the *Environment Protection and Biodiversity Conservation* (EPBC) Act 1999 was undertaken and resulted in declaration of an approved Wildlife Trade Operation (WTO) (Grubert 2017). This assessment made recommendations including sustainable yield estimates and implementation of catch trigger limits to avoid localised depletion (NT 2021). A second assessment in 2007 resulted in implementation of an annual trigger limit of 300 t and, in 2016, spatial management was introduced with an annual total allowable catch of 246 t distributed over 32 60 nm x 60 nm grids ranging from 1 to 25 tonnes within each grid (Figure 1).

Sandfish inhabit soft benthic substrates (sand/mud) in intertidal and shallow waters (< 10 m). In the NT, they are harvested from these habitats by hand, by diving on hookah. Their relative ease of harvest and high value on global export markets makes Sandfish prone to overfishing (Hamel *et al*. 2022). Although further resolution of stock status is required, the available evidence supports the existence of two separate stocks of Sandfish in the NT Trepang fishery (Hart et al. 2024). Gardner *et al*., (2012) recorded two distinct genetic clusters of Sandfish suggesting an eastern stock in the Gulf of Carpentaria and a western stock in the Arafura Sea delineated somewhere between Millingimbi (12°06'27 S 134°55'34 E) and Nalwrung Strait (12°02'32 S 136°20'09 E).

Globally, Sandfish are not listed under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), but the species was added to the International Union for the Conservation of Nature (IUCN) Red List in 2013 as endangered. However, it is noted that currently, "*In Australia, this species is targeted in the Northern Territory, but is not considered to be overexploited, except possibly in the Torres Strait.*" (Hamel *et al.* 2013). In Australia, environmental approvals are based on assessments of the fishery's impacts on marine species protected under Part 13 of the EPBC Act, together with evaluation of fisheries for the purpose of export approval under Part 13A. The NT Trepang fishery is assessed as compliant with the Australian Government Guidelines for the Ecologically Sustainable Management of Fisheries – 2nd Edition (DEWR 2007). Accordingly, the fishery has export approval until 21 August 2026. Specific conditions were associated with the assessment and include resolution of stock status, alignment to relevant research conducted on sea cucumbers in other jurisdictions, and improved performance indicators for the fishery.

There is little information available to evaluate the efficacy of the current spatial management initiative for the NT Trepang fishery, particularly with respect to avoiding localised depletion of Sandfish. Thus, Fishwell Consulting was contracted to evaluate recent catches of Sandfish and to design a fishery-independent survey that could estimate the density and biomass of Sandfish in key commercial locations around the NT. The survey design was reviewed by industry and NT Fisheries, and this report describes the methods and results of the first two surveys undertaken off the Cobourg Peninsula (western stock) and Groote Island (eastern stock).

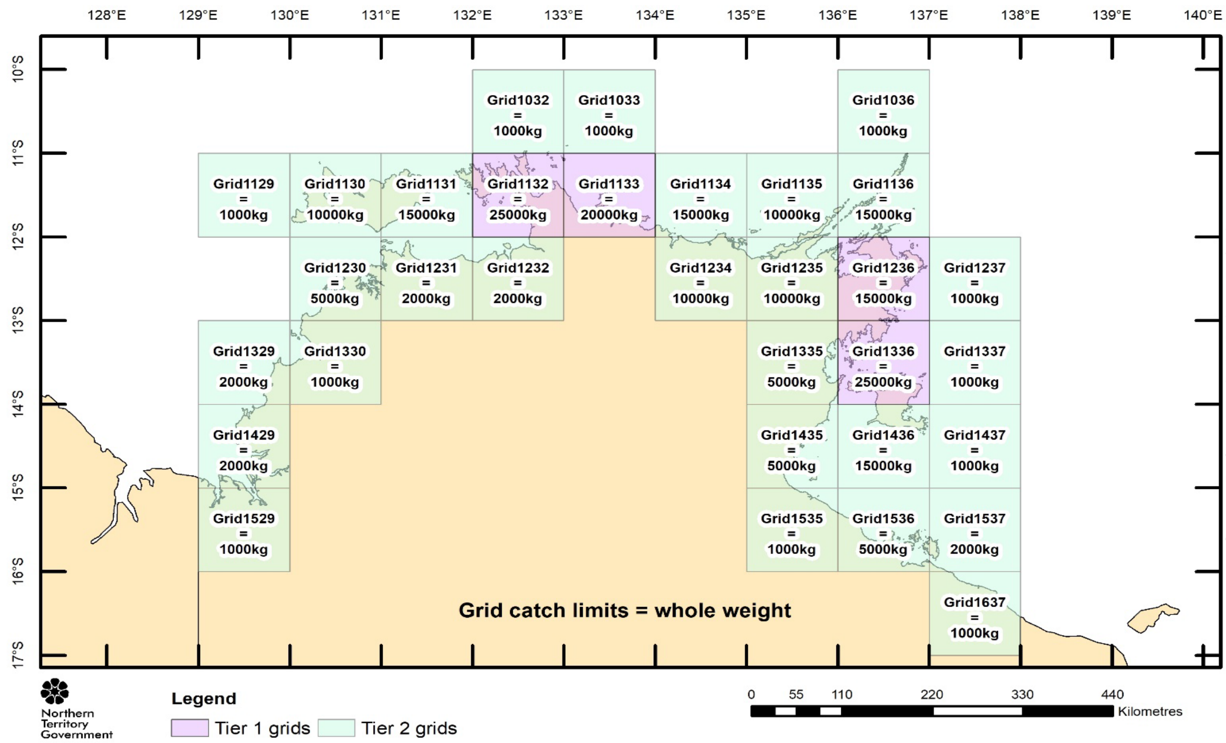


Figure 1. Area of the NT Trepang Fishery, reporting grids and catch limits (NT 2021).

Objectives

1. Undertake a fishery independent survey to estimate the density and biomass of Sandfish in grids 1132, 1336 and 1236.
2. Report the results to the Tasmanian Seafoods and NT Fisheries.

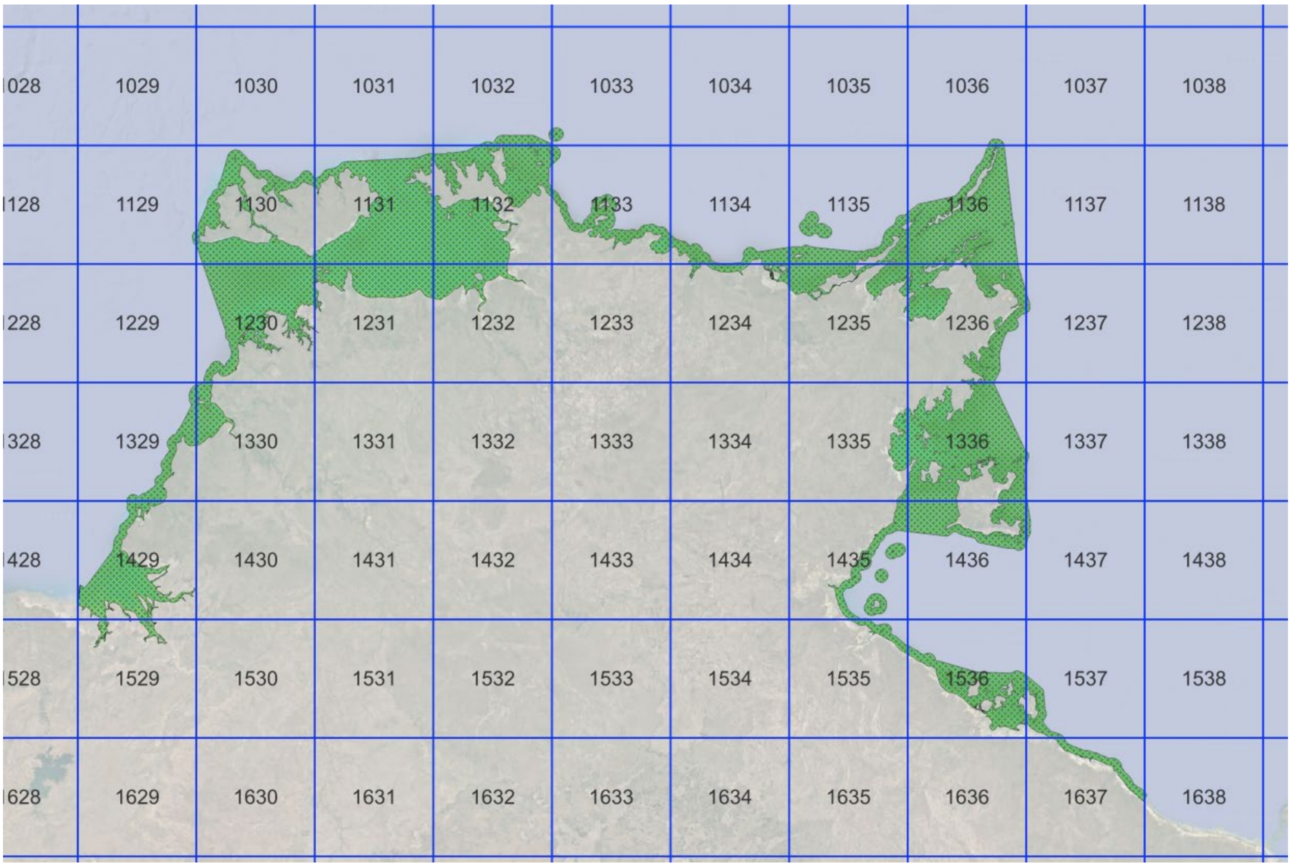


Figure 2. Area of the NT Trepang Fishery (green) and reporting grids used for spatial management.

Methods

Survey strata and extent

Sandfish inhabit depths from the intertidal zone to about 10 m. In fishing logbooks, the most common depth reported is 8 m. However, it is most likely that this is the depth of water in which the mother vessel was anchored, rather than where fishing took place. Surveys within reporting grids were therefore undertaken within 10 m depth.

In the NT, permits are required to access intertidal areas where traditional ownership is recognized. A decision was made that, rather than apply for permits to enter the intertidal areas, surveys would exclude intertidal areas. This occurred in three ways:

1. The shoreward boundary was set as the 0 m depth contour obtained from the AusBathyTopo 250m (Australia) 2023 Grid (Beaman, 2023) rasta from 1 m contours obtained using the QGIS Contour tool;
2. The shoreward boundary was clipped by the seaward extent of the Digital Earth Australia Intertidal Extents (Landsat)[1] layer indicating 0% chance of the area being intertidal; and
3. For the second survey (grids 1336 and 1236), the final survey areas were clipped using a 100 m buffer around entire polygons.

The seaward boundary was set as the 6 m contour obtained from the same data source as the 0 m contour. Polygons bound by the shoreward and seaward extents were made. We acknowledge that Sandfish inhabit waters deeper than the extent of our survey area (Purcel *et al.*, (2023) report

[1] https://ecat.ga.gov.au/geonetwork/srv/api/records/6e1e826e-90f1-41da-8346-1533c1e08097

that they are "found in shallow waters, but occasionally to about 20 m" depth), and shoreward of our survey area (in the intertidal area, pooling water and estuaries). We also acknowledge that during surveys it became apparent that the bathymetry used was not always accurate, and that the depth in some areas within polygons was deeper than 6 m.

Examination of logbook effort revealed that very little effort is reported along the open coastline, with most effort in embayments, straits and archipelagos. Polygons were cut at the headlands or entrances of each embayment, strait and archipelago. Each of these became a potential survey stratum. However, when the area was too large, multiple strata were assigned to embayments, straits or archipelagos (for example see 1132 – N, 1132 – O, 1132 – P and 1132 – Q in Figure 3). Strata that were surveyed within grids applicable to the fishery (Figure 2) were randomly selected from the pool of assigned strata (Figure 3, Figure 4).

Both random and gridded transect start points were allocated to each stratum.

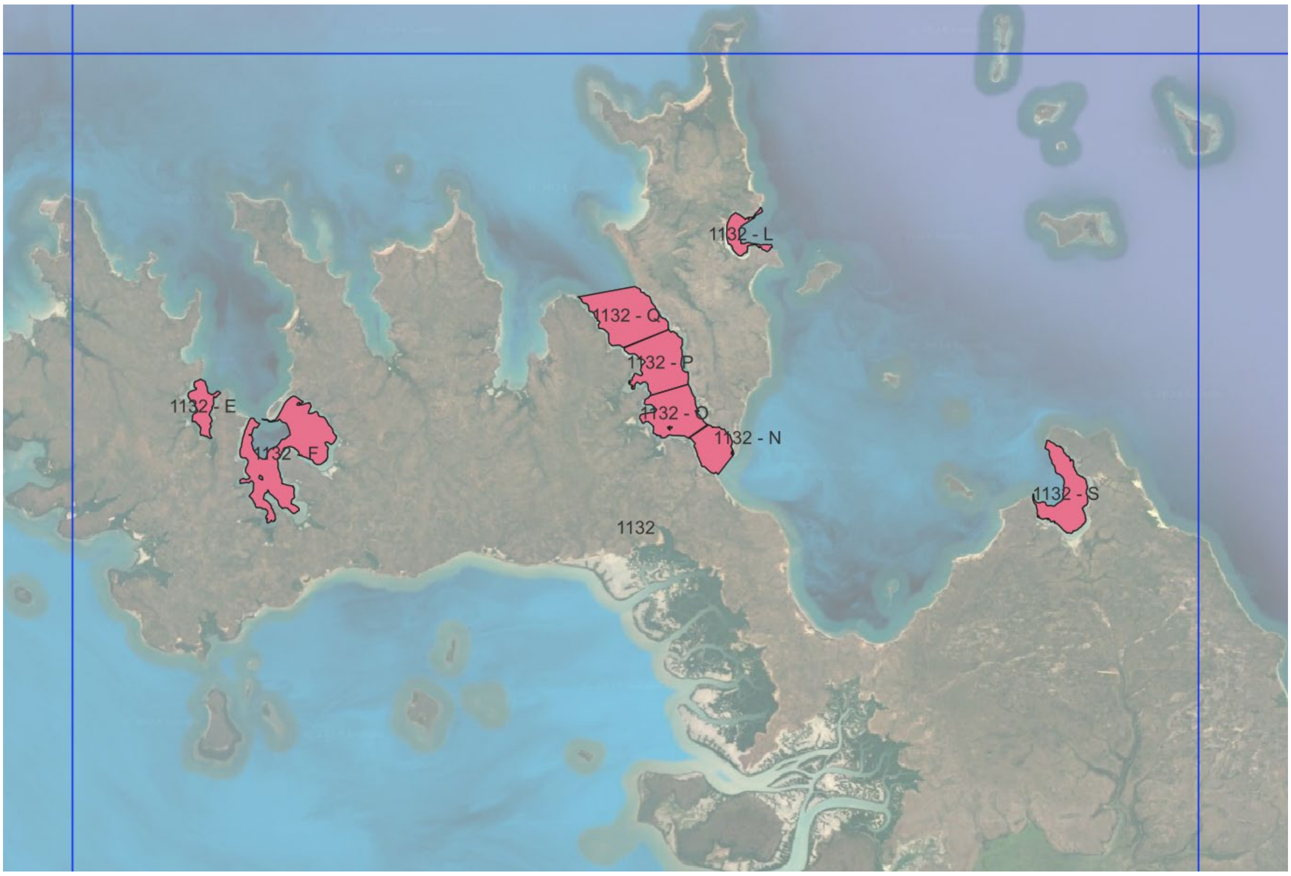


Figure 3. Strata surveyed within the 1132 grid.

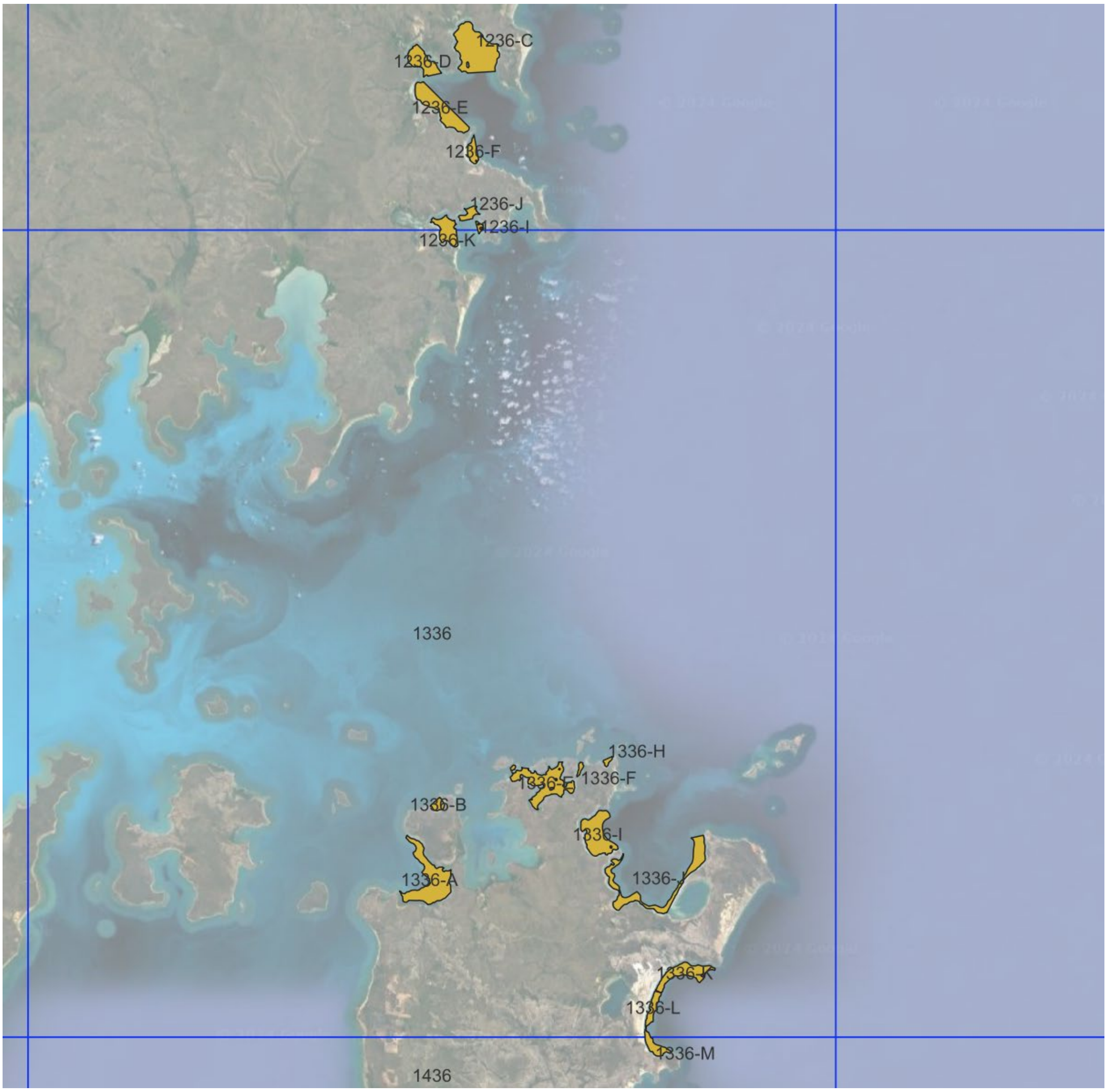


Figure 4. Strata surveyed within the 1236 and 1336 grids.

Transect sampling methods

Transect surveys were undertaken in accordance with SPECIAL PERMIT No 2024-2025 / S17/3605 and SPECIAL PERMIT No 2024-2025 / S17/3605 (2).

A daily survey plan was developed in consultation with the skipper and with divers reflecting diving conditions (wind strength and direction and prevailing ocean conditions and tides). Tenders were coordinated from a main vessel with separate dive teams operating from two or three tender vessels (dories). Generally, the main vessel anchored near the centre of the transect sites planned for each day and the dive teams operated independently to maximise safety and sampling efficiency.

Divers used surface-supplied breathing apparatus and followed the hip chain method as described by Leeworthy (2005) and Leeworthy and Skewes (2007). Accordingly, a 2 m pole was used to measure the width of the transect, and the hip chain measured the 100 m long transect. To control for edge effects, divers were instructed to count those Sandfish that were partially within the transect on the left-hand side of the pole, and to count only those that were completely inside the transect on the right-hand side of the pole. Start and end locations were recorded for each transect with the boat-mounted GPS in each dory. During each transect, the diver recorded depth, visibility, substrate/ major benthos type, benthic relief and abundance of Sandfish.

Measuring and weighing

For each transect, up to five Sandfish were collected for on-board measurement. Sandfish were allowed to drain for at least 2 minutes before being weighed to the nearest 10 g (Purcell *et al.* 2009). When the readout of the balance varied due to wave action, a median weight was inferred from the range in readouts over a 5–10 second period. Individuals were measured for length and width along the dorsal surface and to the nearest 0.5 cm. Sandfish were immediately returned to the water after weighing and measurement at the location of sampling (usually within 5 minutes).

Data analysis

All data processing and analysis was undertaken in R (R Core Team, 2024) and Microsoft Excel.

The mean density of Sandfish within each stratum was calculated as follows:

$$\overline{D}_s = \frac{\sum_{i=1}^{n_s} C_i/A_i}{n_s}$$

Where:

- $\overline{D}_s$= Mean density of sandfish in the stratum (*s*) (e.g., individuals per square meter);
- C_i = Count of sandfish observed in the *i*-th transect;
- A_i = Area of the *i*-th transect (e.g., in square meters); and
- n_s= Number of transects in the stratum.

The area (square meter) of each stratum was calculated using the “st_area” function in the R package “sf” (Pebesma and Bivand, 2023). The coordinate reference system (CRS) for all layers was WGS 84.

Abundance of Sandfish within each stratum was calculated as follows:

$$N_s = \overline{D}_s \cdot T_s$$

Where:

- N_s = Total abundance of sandfish in the stratum;
- $\overline{D}_s$ = Mean density of sandfish in the stratum (e.g., individuals per square meter); and
- T_s= = Total area of the stratum (in square meters).

Abundance was converted to biomass as follows:

$$B_{s=}N_s \cdot \overline{w}_c \cdot 1000$$

Where:

- B_s = Total biomass (t) of sandfish in the stratum;
- N_s = Total abundance of sandfish in the stratum; and
- $\overline{w}_c$ = Mean weight (kg) of Sandfish from grouped strata shown in Table 3 and Table 7 and descripted in the text before each table.

Bias corrected 95% confidence intervals for density, abundance and biomass were calculated using the “boot” package with either 5,000 replicated (Canty and Ripley 2019). Whole weights were converted to gutted and salted, weights were using the conversion factor 0.5 provided by the Department of Agriculture and Fisheries.

Biomass and associated uncertainty were also calculated using the parametric resampling analysis method of Hart *et al.* (2018) to account for the zero-inflated distribution of Sandfish counts in transect data (n = 10,000 resamples) (Manly 1997) for each stratum. Diagnostic graphs indicating sensitivity to the number of resamples in shown in Appendix 1. Estimates were generally unsensitive to the number of resamples, particularly for more than 8,000 resamples.

Outliers were not accounted for in biomass calculations for each stratum.

Extrapolated biomass estimates were calculated using two different methods:

1. Extrapolated biomass 1 - the mean density (across all strata combined) was scaled up to the area of all potential strata in the survey areas in which fishing effort had been recorded; and
2. Extrapolated biomass 2 - the combined biomass estimates for strata in which fishing effort had been recorded was scaled up to the area of all potential strata in the survey areas in which fishing effort had been recorded but that were not surveyed.

Quality assurance and quality control

A standard operation procedure (SOP) was developed to describe the methods, data sheets and type of information to be recorded. Before surveys were undertaken, a PowerPoint of the SOP was presented to all survey participants. SOPs were always available on each of the dories used in the surveys.

In dive surveys, issues of lack of detection, misidentification, and simple counting errors can compromise the quality of the data and may be influenced by differing diver experience, water clarity, light level, time of day, and type of benthic habitat. Thus, every transect was recorded by video for verification (accuracy of counts) and validation (completeness) of survey data.

Use of experienced commercial fishers for the survey is cost-effective and efficient because of their skills and experience in harvesting of sea cucumbers. However, commercial fishers may not be “independent”, which may lead to potential bias in the survey results. Thus, a random selection of 5–10% of transect videos was reviewed independently for validation. Experience from previous surveys (Koopman *et al.* 2019) showed that commercial divers identifying Sandfish counted in video footage helps with the accuracy and speed at which transect data can be processed.

Observational data were entered into an Access database and accuracy of entered data was error checked by comparison with original datasheets and by range checks. A subset of outputs was reproduced and compared using an alternative software package (Excel) to check accuracy and reproducibility.

Results

Cobourg Peninsula survey

Transects sampled

The survey vessel, FV Westmore, left Darwin on Sunday 14th July to survey stratum 1132-L on the morning of Monday 15th July 2024. The trip ended in Darwin on Sunday 21st July 2024.

Hip-chain transects were undertaken on a total of 165 sites across eight different strata (Table 1). Only three transects were undertaken at 1132 – N because most of the allocated transect start points were in deep water (up to 18 m depth). Throughout Croker Strait many of the transects were in water deeper than 6 m, revealing that the mapped bathymetry was inaccurate for shallow coastal NT. Following this, the survey methods were changed to better reflect the planned survey depth by:

- If the depth at a site was greater than 6 m, record the depth and chose a nearby backup site in shallower water; or
- Move directly inshore to less than 6 m and undertake the transect.

Average depth of transects ranged from 3.0 m in the 1132 - P stratum to 5.4 m in the 1132 – L and 1132 – O strata. Average transect length ranged from 86.3 m in the 1132 - L stratum to 102.4 m in the 1132 – P stratum (Table 1).

Table 1. Number of transects, average depth (m) and average transect length (m) in each stratum within grid 1132.

Stratum	N	Average depth (m)	Average transect length (m)
1132 - E	14	3.1	99.3
1132 - F	30	3.7	87.2
1132 - L	30	5.4	86.3
1132 - N	3	4.2	95.0
1132 - O	18	5.4	91.4
1132 - P	7	3.0	102.4
1132 - Q	19	4.9	100.8
1132 - S	44	5.1	96.6
Total	165	4.4	94.9

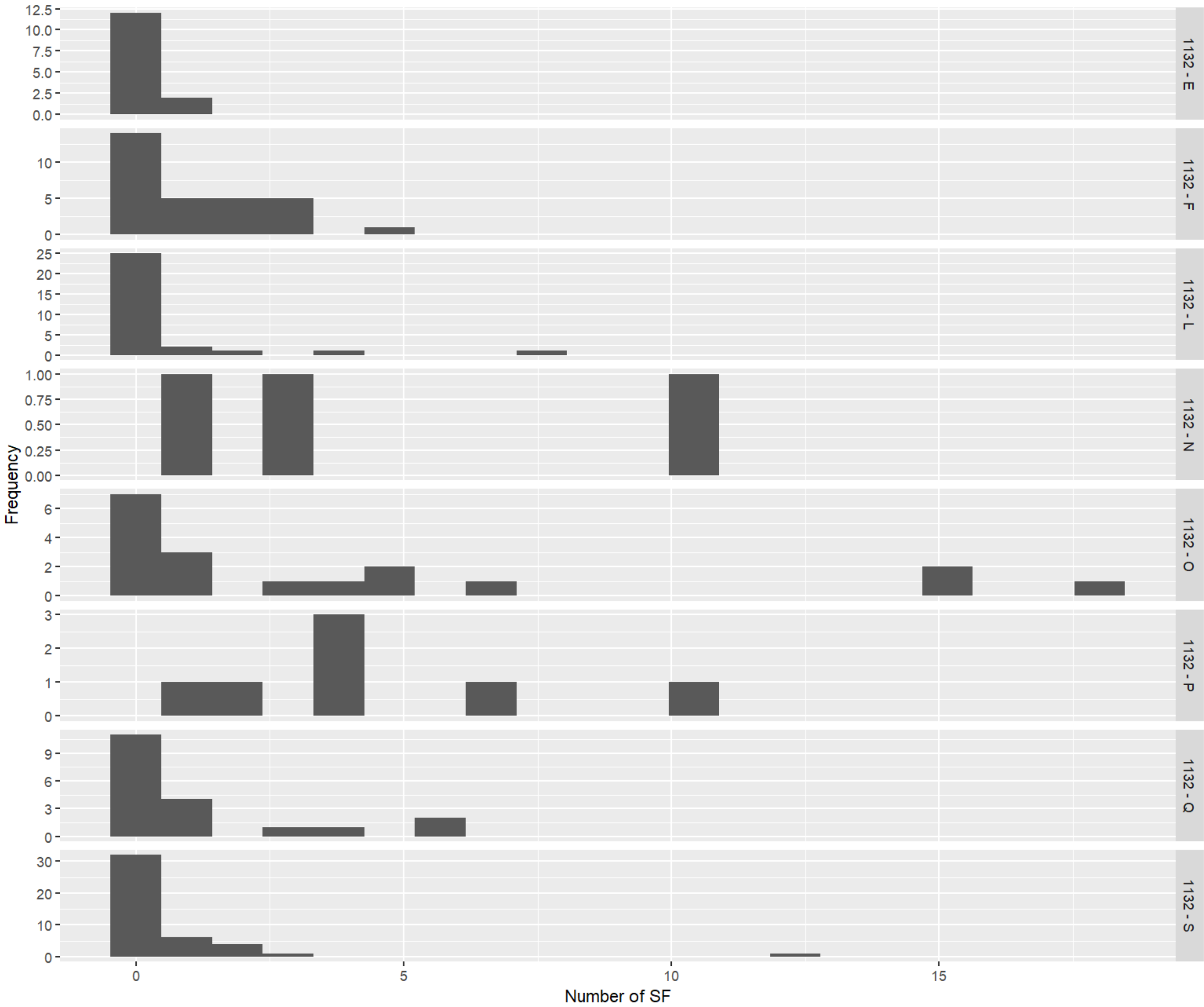


Figure 5. Histogram plot for Sandfish counts per transect for strata in grid 1132.

Length and weight

A total of 163 Sandfish was weighed, with individual weights ranging from 0.19 kg to 1.38 kg (Table 2, Figure 6, Figure 7). Mean weights ranged 0.36 kg at 1132 – N to 0.77 kg at 1132 – L, and was 0.56 kg overall. The smallest Sandfish recorded weighed 0.19 kg, whereas the largest was 1.38 kg. Mean lengths ranged from 17.3 cm at 1132 – E to 22.6 cm at 1132 – S.

Mean weights varied among strata ($P < 0.001$), with Tukey's multiple comparisons of means revealing that mean weights of Sandfish were significantly lower at the western strata (1132 - E and 1132 - F) and at 1132 – L and 1132 - N than the other four strata. However, sample size for 1132 – N was low, and as it was connected with the other three strata in Croker Strait, weights were combined from the strait and 1132 - S for biomass calculations (Figure 7). Overall, the mean whole and gutted weights of Sandfish were 0.75 kg and 0.28 kg respectively (Table 2). There was high variation among individuals for width at length (Figure 8). Length was a superior predictor of weight of Sandfish than width (Figure 8).

Table 2. Number of Sandfish measured, mean, minimum and maximum live weight and mean, minimum and maximum gutted, blanched and frozen weight (gutted, blanched and frozen weights were calculated using the conversion factor (0.5) used by NT Fisheries.

		Weight (kg)				
Stratum	N	Mean (StDev)	Min - max	Mean gutted, blanched and frozen (StDev)	Min/max gutted, blanched and frozen	Mean length (cm)
1132 - E	9	0.37 (0.08)	0.27 - 0.48	0.18 (0.04)	0.14 - 0.24	17.3
1132 - F	39	0.46 (0.14)	0.22 - 0.64	0.23 (0.07)	0.11 - 0.42	19.0
1132 - L	13	0.46 (0.19)	0.19 - 0.84	0.23 (0.09)	0.10 - 0.42	19.5
1132 - N	12	0.36 (0.15)	0.22 - 0.33	0.18 (0.07)	0.11 - 0.39	17.4
1132 - O	29	0.52 (0.15)	0.31 - 0.50	0.26 (0.07)	0.16 - 0.46	19.9
1132 - P	20	0.60 (0.20)	0.41 - 1.09	0.30 (0.10)	0.20 - 0.55	20.4
1132 - Q	21	0.62 (0.11)	0.41 - 0.51	0.31 (0.06)	0.20 - 0.42	21.8
1132 - S	20	0.77 (0.31)	0.22 - 1.38	0.38 (0.16)	0.11 - 0.69	22.6
Total	163	0.53 (0.21)	0.19 - 1.38	0.27 (0.11)	0.10 - 0.69	20.0

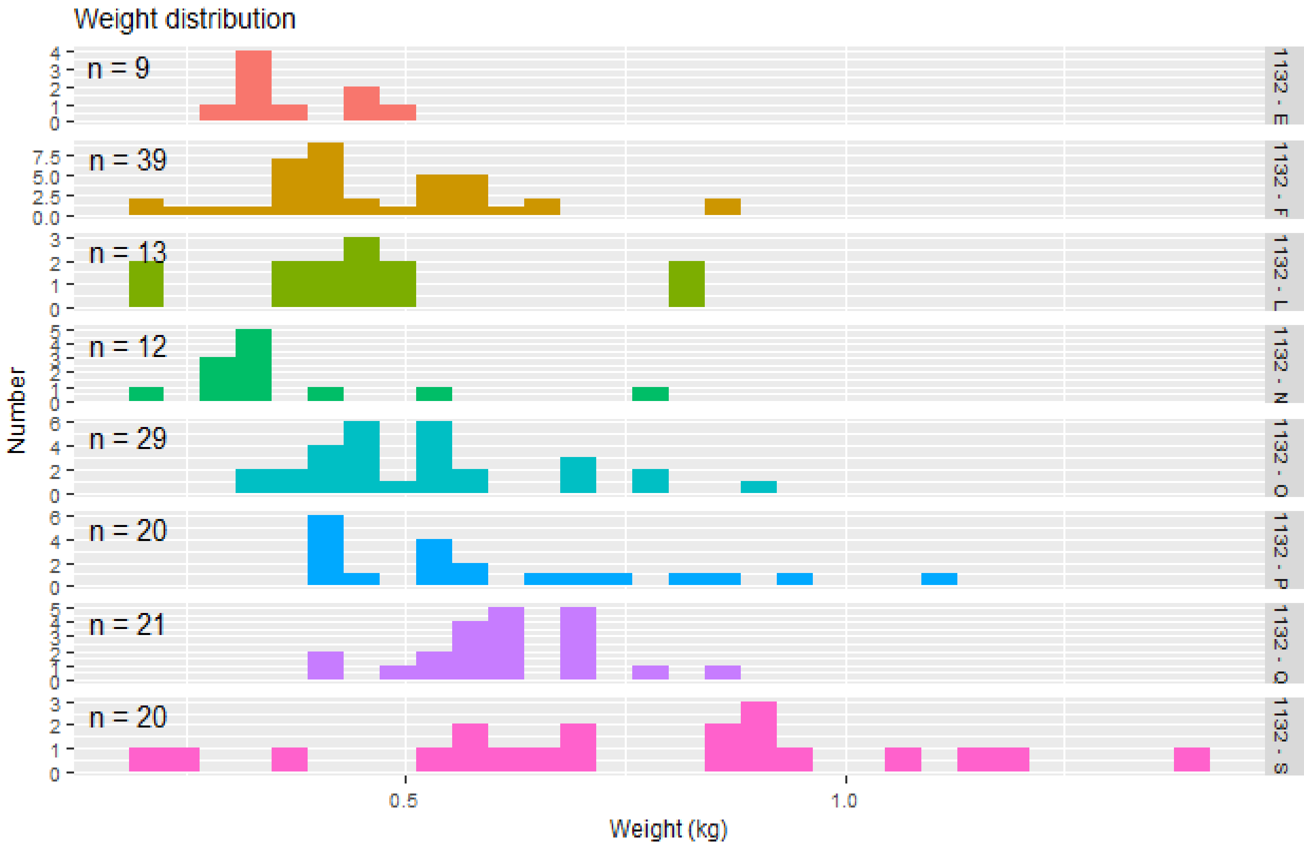


Figure 6. Histogram of Sandfish weights (kg) measured during survey in each stratum.

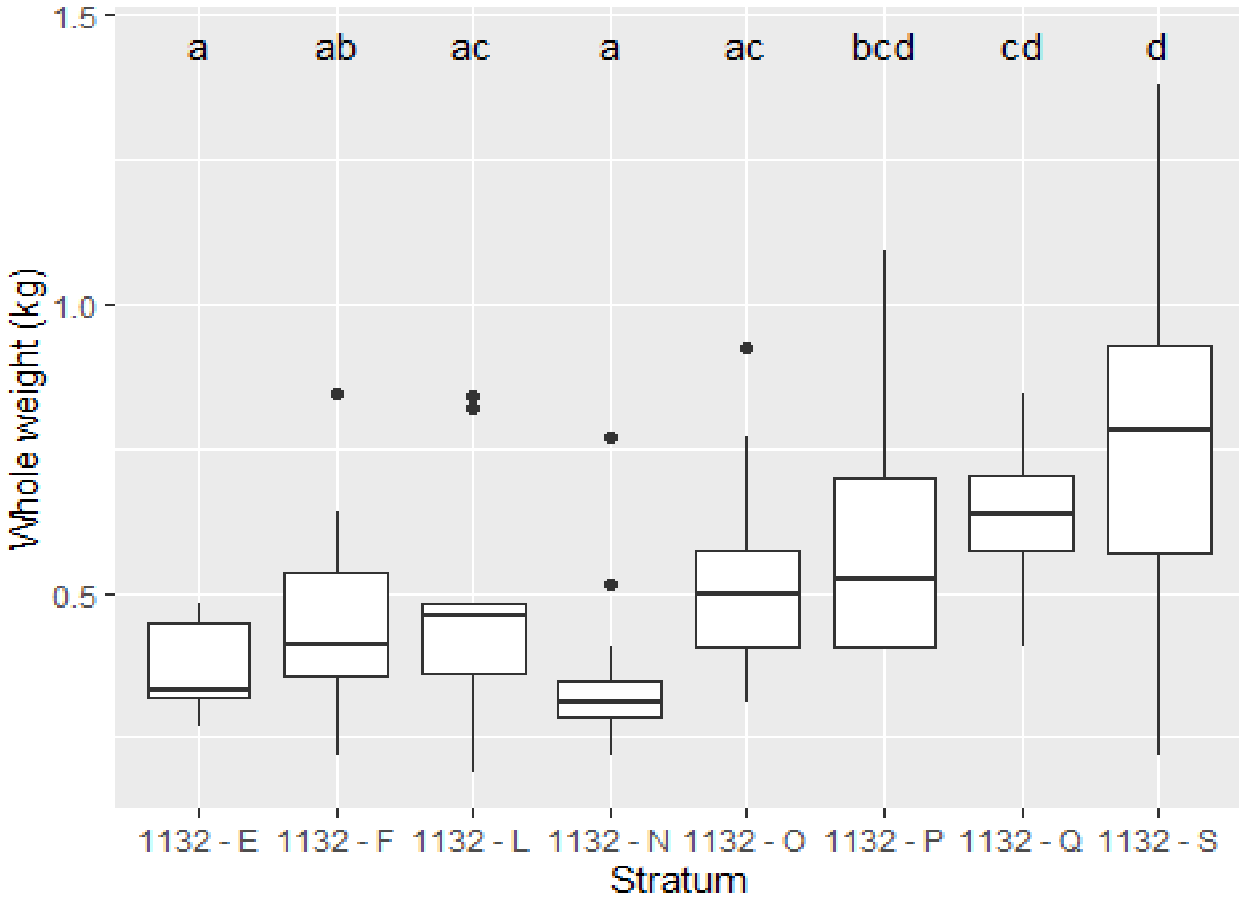


Figure 7. Box plot of whole weight of individual Sandfish from each stratum within grid 1132. Annotations denote strata with mean weights that were not significantly different (based on Tukey's HSD test) – strata that share a common letter are not different.

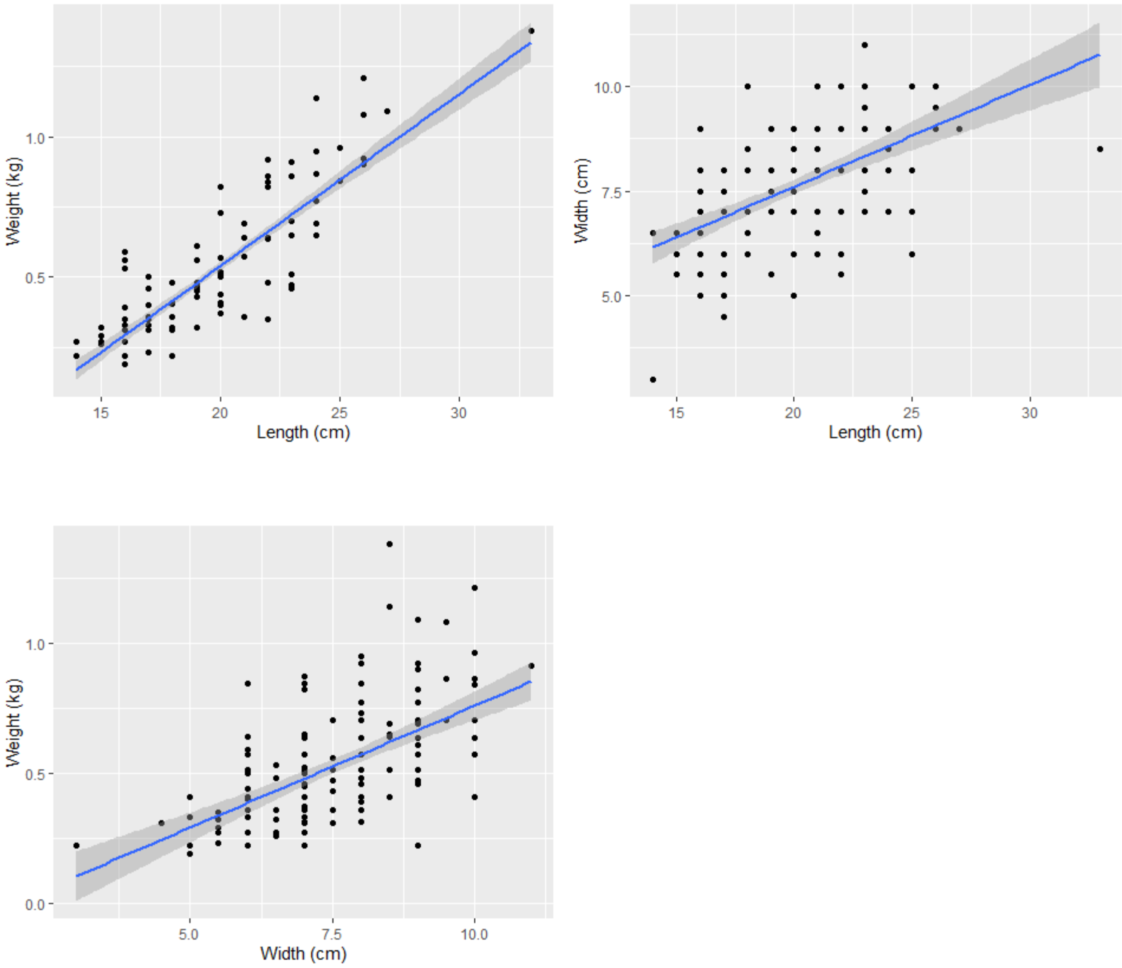


Figure 8. Relationship of length-weight, length-width and width-weight for Sandfish within grid 1132.

Biomass estimates

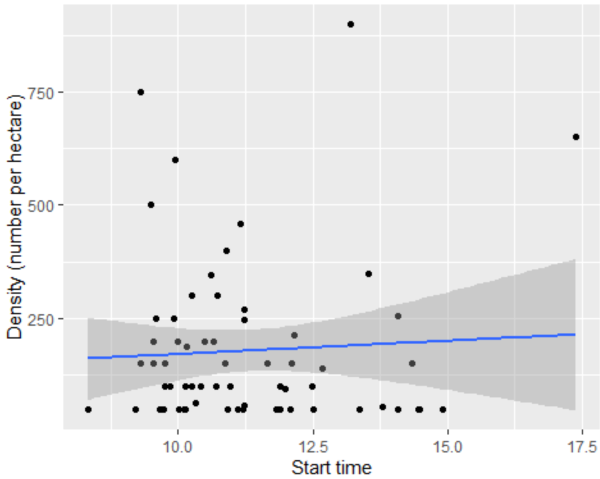
Sandfish burrow into the sediment and, according to anecdotal information from commercial fishers, they emerge during the afternoon. Fishers can find burrowed individuals either by the "burrowing scars" or by Sandfish being only partially covered. Detection rates may be lower while Sandfish are buried, raising concerns about the survey's accuracy and the timing of sampling. There was no significant effect of time-of-day on counts of Sandfish densities taken during this survey (Kruskal-Wallis test X^2 = 55, df = 54, *P* > 0.05 for non-zero transects; X^2 = 127, df = 133, *P* > 0.05 for all transects) (Figure 9). It is worth noting that most transects were completed by 3 pm on any day.

Mean density of Sandfish varied greatly among strata. Mean density was highest in three of the Croker Strait strata, 1132 – N (236.3 individuals per hectare), 1132 – P (220.5 individuals per hectare) and 1132 – O (206.8 individuals per hectare), whereas density at the forth Croker Strait stratum (1132 – Q) was 60.5 individuals per hectare (Figure 10, Table 3). Densities at 1132 – E and 1132 – F were 7.1 and 60.5 individuals per hectare respectively, and 31.9 individuals per hectare and 32.8 individuals per hectare at 1132 – L and 1132 – S. Spatial distribution of Sandfish densities from the current survey is shown in Figure 11.

The estimated total biomass of Sandfish in the survey area was 1042.7 t (95%CIs: 510.7 t–1747.2 t), comprising about 1.85 million individuals (Table 3). A similar biomass estimate was obtained using Hart's bootstrap method: 1,086 t (892 t–1,418 t) (Figure 12). Most of the estimated biomass

(317.7 t) was in the 1132 – P stratum, followed by the 1132 – 1132 – O stratum (259.4 t), the 1132 - N stratum (183.0 t), the 1132 - F stratum (120.1 t), the 1132 - Q stratum (108.8 t), the 1132 - S stratum (41.6 t), the 1132 - L stratum (9.4 t) and an estimated 2.7 t in the 1132 – E stratum. Estimated total gutted, blanched and frozen biomass was 500.6 t (258.2 t–887.9 t). The lower 90%CIs for whole and gutted, blanched and frozen biomass were 569.2 t and 284.6 t respectively (Table 3).

Strata surveyed were randomly selected from a pool of 19 different strata (Figure 13). Of those, 14 potential strata have logbook records within or nearby suggesting that harvesting has taken place. Using the overall mean density (69.3 individual per hectare) and overall mean weight (0.53 kg), estimated from strata surveyed (18,100 ha), biomass estimates were extrapolated to include the strata not surveyed but which had a history of fishing effort (11,300 ha) yielding a total estimated biomass of 1079.8t (Table 4). Scaling biomass directly up to the unsurveyed strata resulted in an estimated biomass of 1693.7 t (Table 4).



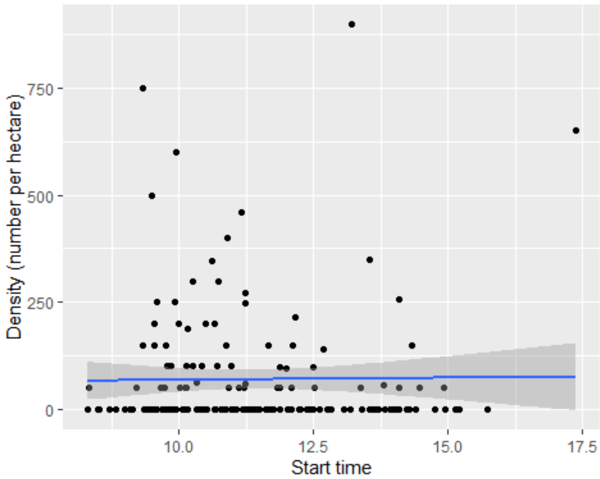


Figure 9. Density (number per hectare) of Sandfish by transect start time of non-zero transects (left) and with zero transects (right).

Table 3. Estimated biomass and 95% CI for each stratum surveyed within grid 1132.

	1132 - E	1132 - F	1132 - L	1132 - N	1132 - O	1132 - P	1132 - Q	1132 - S	Total
Stratum area (km^2)	9	45	7	13	21	25	31	22	164
Mean density (individuals per Ha) (95 $\pm$%CI)	7.1 (0-14.3)	60.5 (38.4-90.6)	31.9 (10-83.5)	236.3 (58.8-383.3)	206.8 (103.9-366.6)	220.5 (134-324.7)	60.5 (23.7-113.2)	32.8 (15.8-86.5)	69.3 (51.0-87.6)
Mean whole weight (kg)	0.44	0.44	0.44	0.58	0.58	0.58	0.58	0.58	
Mean gutted, blanched and frozen weight (kg)	0.22	0.22	0.22	0.29	0.29	0.29	0.29	0.29	
Total number (‘000)	6.1 (0-12)	270.1 (171-404)	21.1 (7-55)	313.6 (78-509)	444.4 (223-788)	544.3 (331-802)	186.4 (73-348)	71.3 (34-188)	1851.3 (917-2,702)
Whole biomass (t)	2.7 (0-5.4)	120.1 (76.2-179.8)	9.4 (2.9-24.6)	183.0 (45.6-296.9)	259.4 (130.3-459.8)	317.7 (193.1-467.8)	108.8 (42.6-203.3)	41.6 (20-109.6)	1042.7 (510.7-1747.2)
Gutted-and-salted weight (t)	1.4 (0-2.7)	60.1 (38.1-87.9)	4.7 (1.5-12.1)	91.5 (22.8-148.5)	129.7 (66.2-235.3)	158.8 (98.5-241.4)	54.4 (21.3-106.4)	20.8 (9.8-53.6)	521.4 (258.2-887.9)
Lower 90% CI Density	0	41.8	11.9	58.8	119.4	148.3	28.9	17	426.1
Lower 90% number (‘000)	0	187	8	78	257	366	89	37	1,022
Lower 90% Whole biomass (t)	0	83	3.5	45.6	149.8	213.7	52	21.6	569.2
Lower 90% Gutted-and-salted weight (t)	0	41.5	1.8	22.8	74.9	106.8	26	10.8	284.6

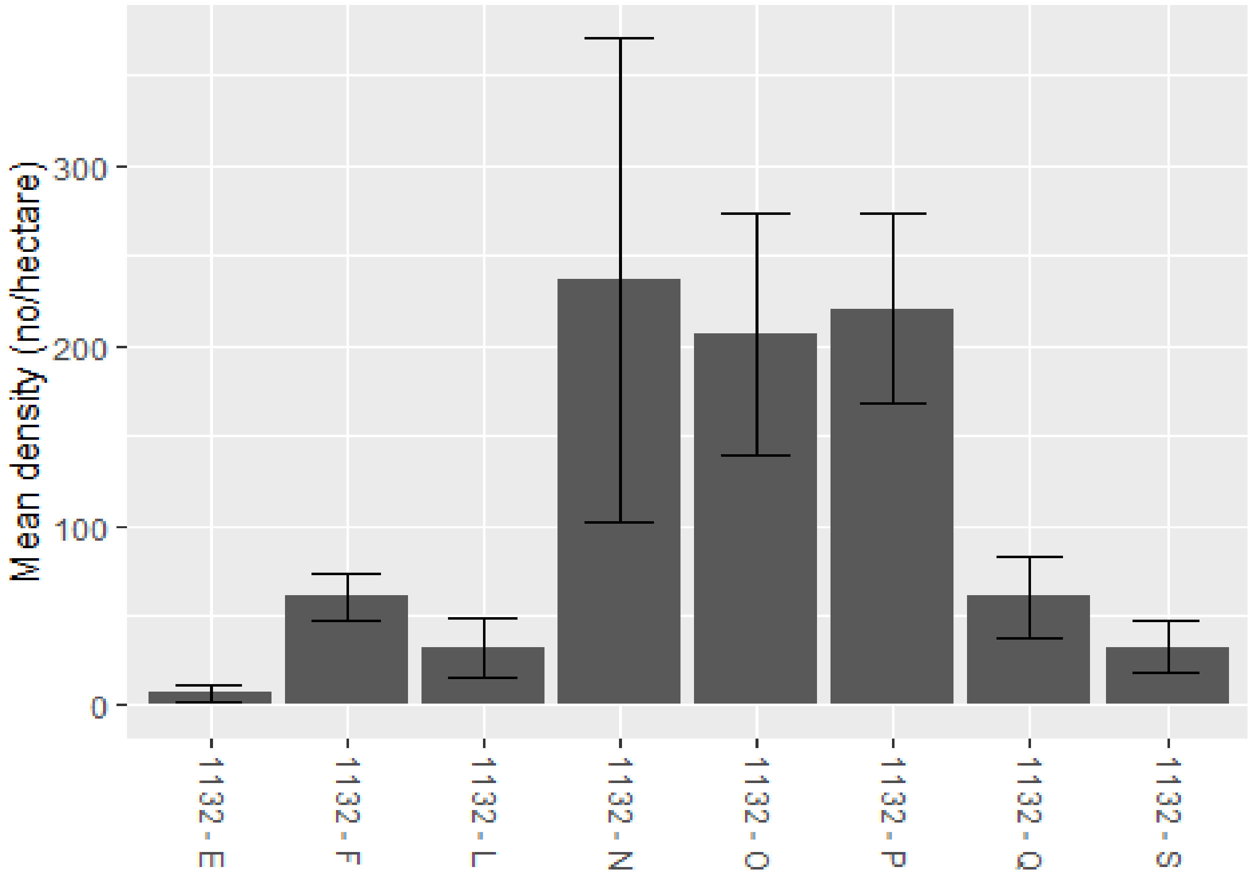


Figure 10. Mean density (number per hectare + SE) of Sandfish in each stratum within grid 1132.

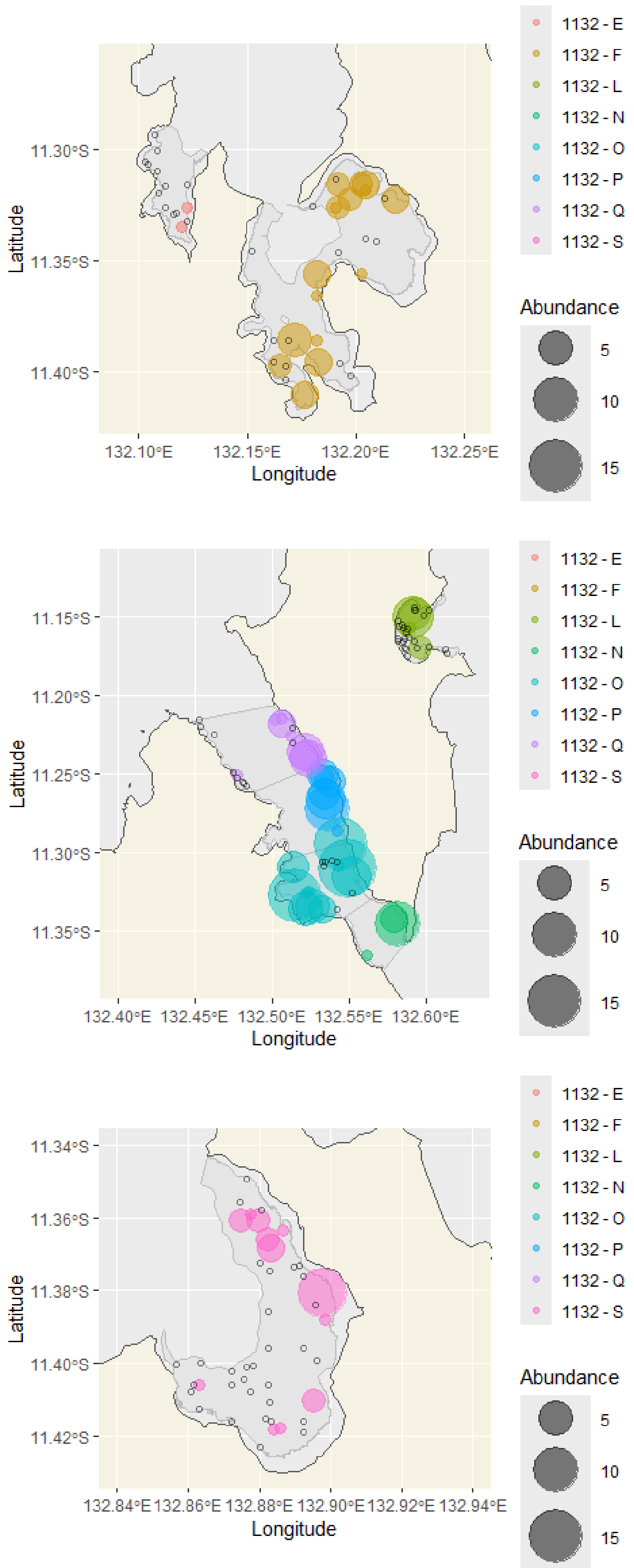


Figure 11. Abundance (raw counts per transect) of Sandfish at western strata (top), centre strata (middle) and eastern stratum (bottom) within grid 1132. Different colours indicate different strata.

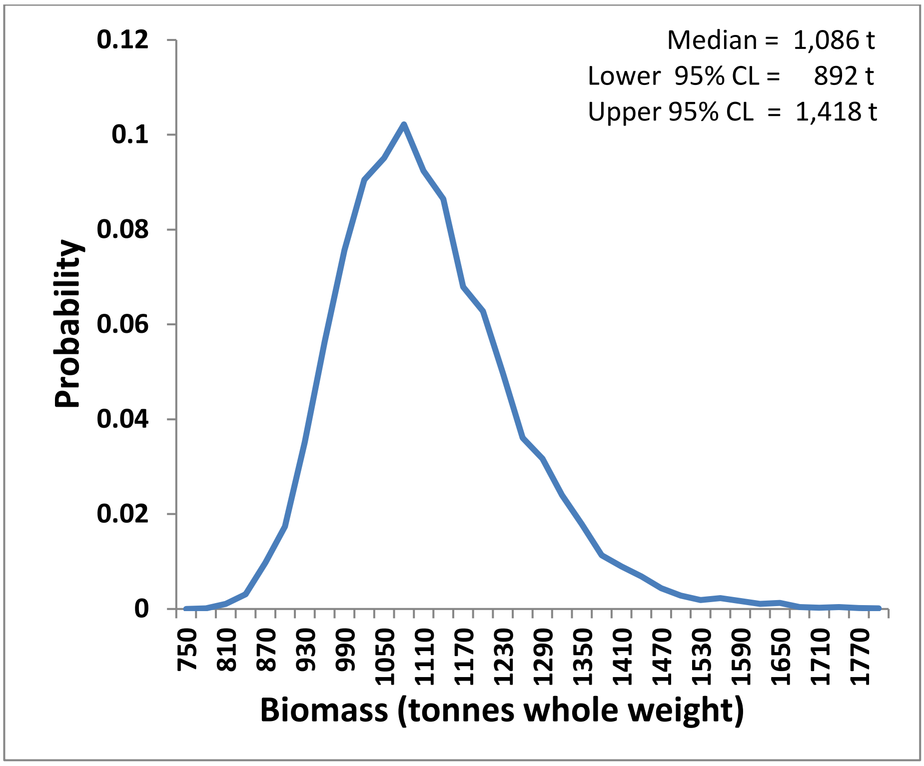


Figure 12. Probability estimates of the biomass of Sandfish for strata sampled within grid 1132. Note that no zero counts were recorded for 1132 – N and 1132 – P and so the CRITBINOM function returns the #NUM! error value. For those two strata, the estimated abundance was used instead.

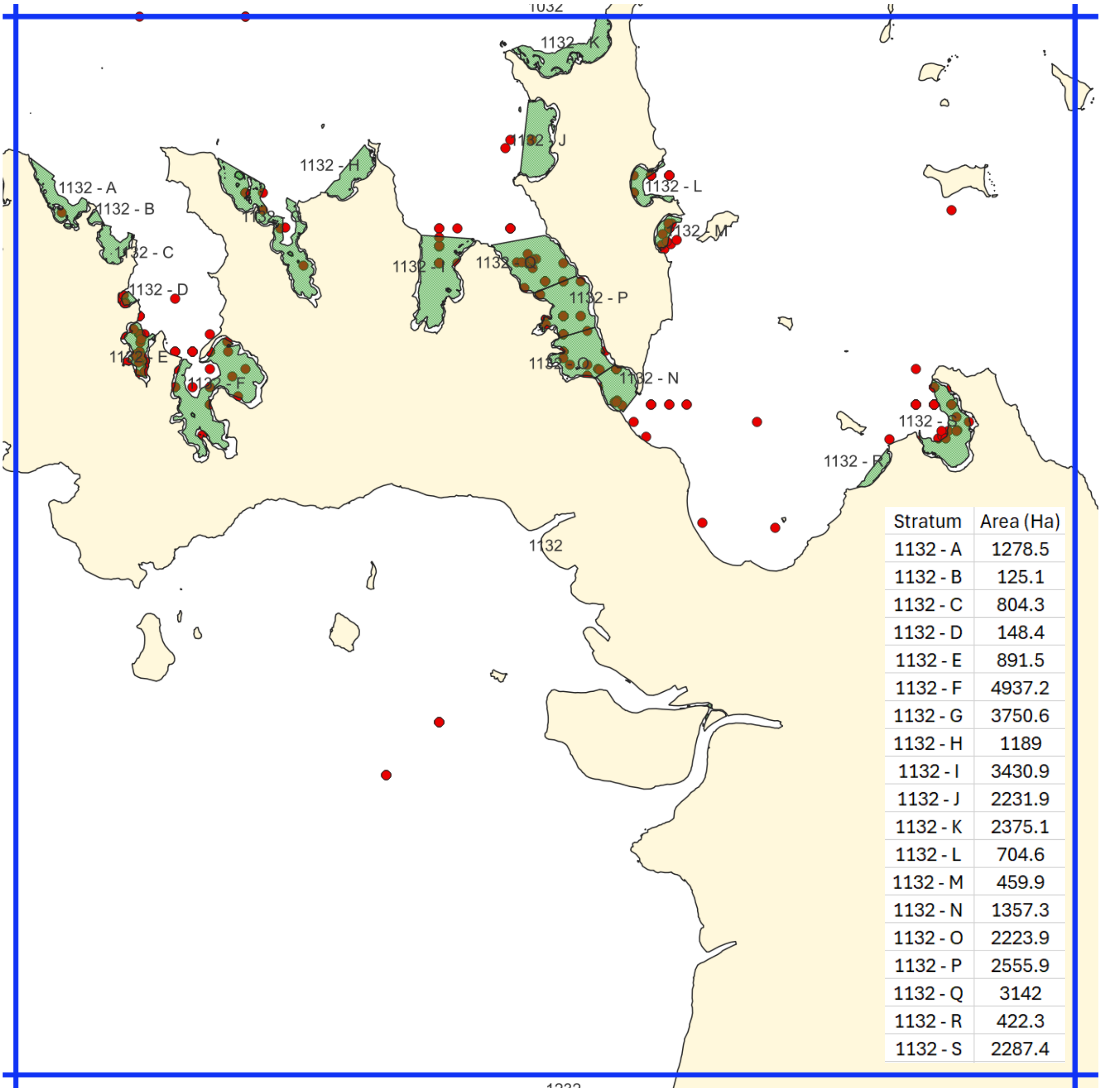


Figure 13. All potential strata in 1132 (green), location of logbook records (red dots) and the area (Ha) of each stratum.

Table 4. Extrapolated estimates of biomass of Sandfish by the proportional area of strata surveyed within grid 1132 compared with all non-surveyed and surveyed strata classified as having fishing effort present. See methods for description of how each estimate was calculated.

	Surveyed (Ha)	Surveyed biomass (t)	Not surveyed (Ha)	Total (Ha)	% surveyed in total	Extrapolated biomass 1 (t)	Extrapolated biomass 2 (t)
Effort present	18,100	1042.7	11,300	29,400	62%	1,079.8	1693.7
No effort present	0		4,916	4,916	38%	Not estimated	Not estimated
Total	18,100		16,216	34,316			

Groote Eylandt survey

Transects sampled

The survey vessel, FV Westmore, left Groote Eylandt on Sunday 12th August 2024 and the trip ended at Groote Eylandt on Monday 19th August 2024.

Hip-chain transects were undertaken on a total of 295 sites across 17 different strata within grids 1236 and 1336 (Table 5). As for the Cobourg Peninsula, many of the transects were in waters deeper than 6 m, with the same bathymetric approach used to define strata. The survey methods were changed to better reflect the planned survey depth by:

- If the depth at a site was great than 6 m, record the depth and chose a nearby backup site in shallower water; or
- Move directly inshore to less than 6 m and undertake the transect.

Average depth of transects ranged from 2.3 m in the 1336 - I stratum to 5.5 m in the 1336 – M strata. Average transect length ranged from 86.0 m in the 1336 - E stratum to 102.1 m in the 1336 – F stratum (Table 5).

Table 5. Number of transects, average depth (m) and average transect length (m) in each stratum within grids 1236 and 1336.

Stratum	N	Average depth (m)	Average transect length (m)
1236-C	38	4	97.0
1236-D	22	2.7	99.9
1236-E	32	3.8	95.5
1236-F	8	5.2	97.5
1236-I	9	2.3	94.2
1236-J	12	3.8	96.7
1236-K	27	4.8	97.9
1336-A	17	5.4	99.1
1336-B	10	3.1	101.4
1336-E	12	5.2	86.0
1336-F	14	3.2	102.1
1336-H	5	5.0	87.8
1336-I	11	4.2	97.3
1336-J	35	4.2	99.1
1336-K	15	4.5	96.3
1336-L	26	4.6	94.0
1336-M	15	5.5	95.3
Total	295	4.2	96.3

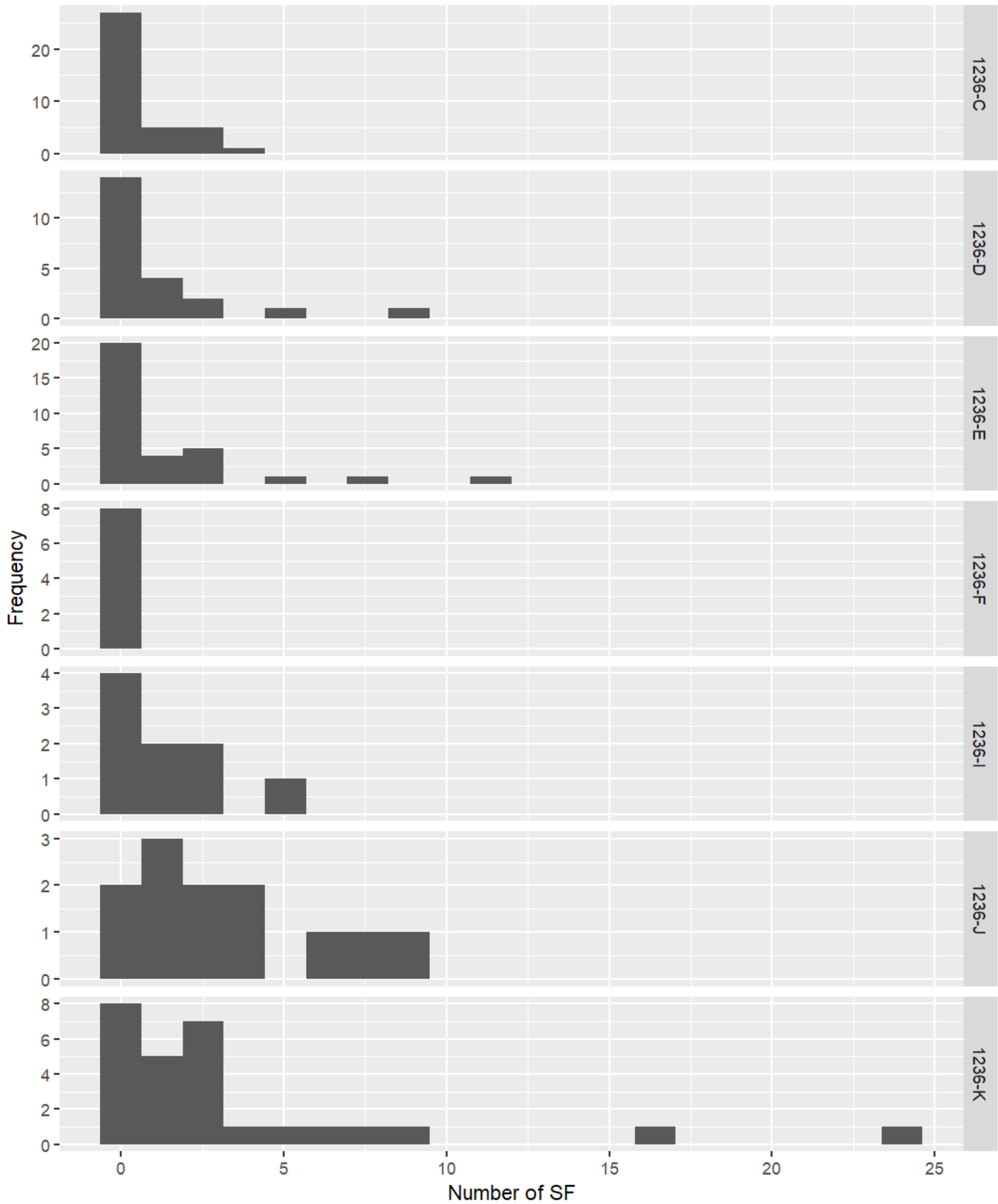


Figure 14. Histogram plot for Sandfish counts per transect for strata in grid 1236.

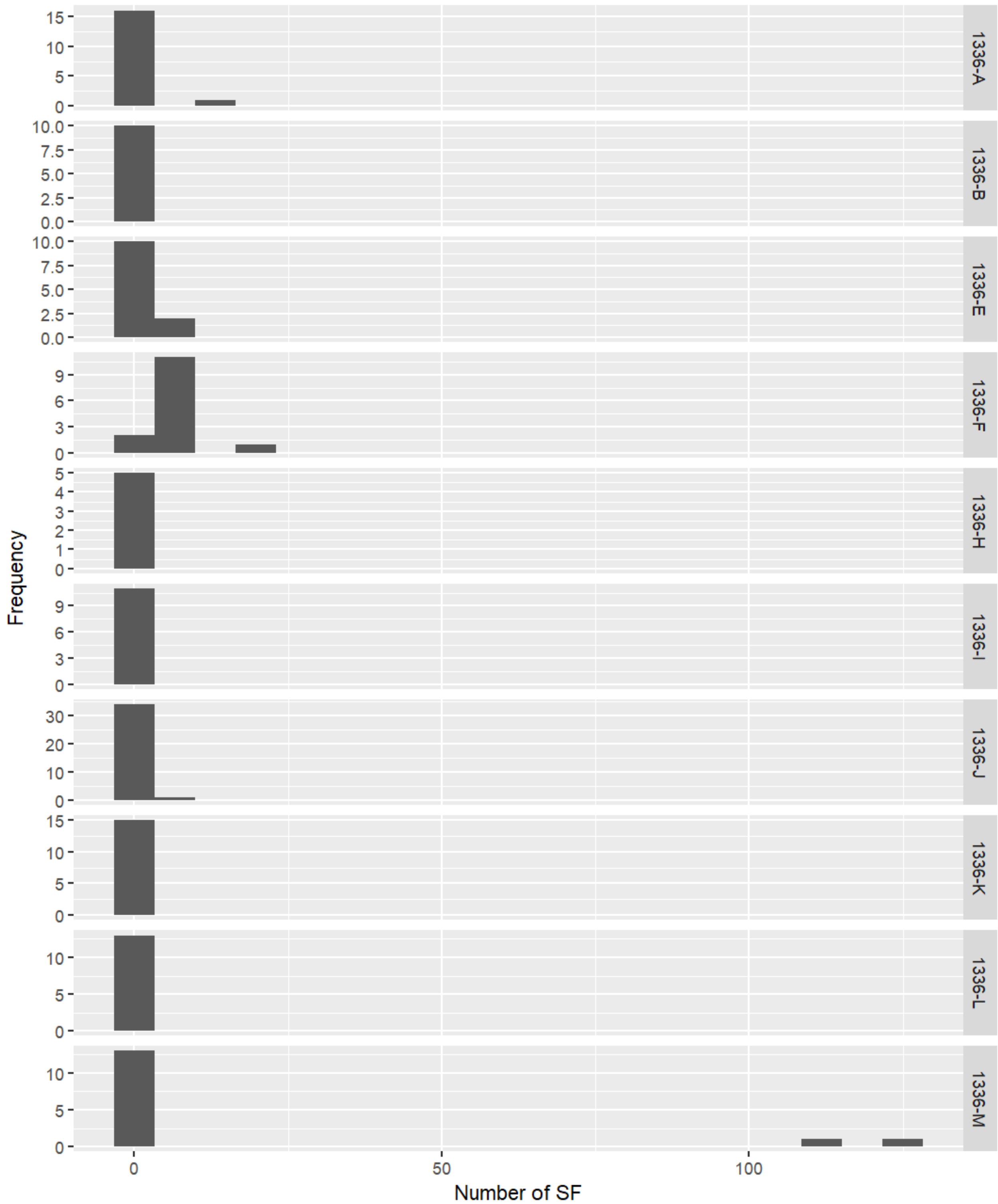


Figure 15. Histogram plot for Sandfish counts per transect for strata in grid 1336.

Length and weight

A total of 297 Sandfish was weighed, with individual weights ranging from 0.02 kg to 1.62 kg (Table 6, Figure 6, Figure 7). Mean weights ranged from 0.06 kg at 1336 – M to 0.81 kg at 1336 – B, and the mean weight was 0.40 kg overall. The smallest Sandfish weighed 0.02 kg and the largest was 1.62 kg. Mean lengths ranged from 7.3 cm at 1336 – M to 24.5 cm at 1336 – A.

Within grids 1236 and 1336, mean weights varied among strata (*P* < 0.001), with Tukey's multiple comparisons of means revealing that mean weights of Sandfish were significantly lower 1336 – L and 1336 – M than most other strata. Furthermore, given the large variability in weights at other sites, weights from many of the other combinations of strata were not significantly different (Figure 12). For biomass calculations, the average weight from strata within grids 1236 (0.43 kg) and 1336 (0.44 kg) were used. Overall, the mean whole and gutted weights of Sandfish were 0.40 kg and 0.20 kg respectively (Table 6). There was high variation among individuals for width at length., length at weight and width at weight (Figure 18).

Table 6. Summary weight and length data for strata sampled within grids 1236 and 1336 (gutted-and-salted weights were calculated using the conversion factor (0.5) used by NT Fisheries).

Stratum	N	Weight (kg)				Mean length (cm)
		Mean (StDev)	Min - max	Mean gutted-and-salted (StDev)	Min/max gutted-and-salted	
1236-C	21	0.47 (0.17)	0.16 - 0.79	0.23 (0.08)	0.08 - 0.40	18.6
1236-D	19	0.38 (0.14)	0.18 - 0.62	0.19 (0.07)	0.09 - 0.31	18.0
1236-E	32	0.46 (0.15)	0.24 - 0.97	0.23 (0.07)	0.12 - 0.49	18.8
1236-F	0					
1236-I	11	0.58 (0.11)	0.36 - 0.7	0.29 (0.06)	0.18 - 0.35	20.1
1236-J	29	0.49 (0.11)	0.28 - 0.72	0.25 (0.05)	0.14 - 0.36	18.2
1236-K	58	0.35 (0.12)	0.17 - 0.67	0.17 (0.06)	0.09 - 0.34	18.1
1336-A	12	0.36 (0.10)	0.15 - 0.46	0.18 (0.05)	0.08 - 0.23	24.5
1336-B	1	0.81 (0)	0.81 - 0.81	0.41 (0)	0.41 - 0.41	22.0
1336-E	12	0.54 (0.17)	0.34 - 0.81	0.27 (0.08)	0.17 - 0.41	21.3
1336-F	60	0.38 (0.11)	0.16 - 0.73	0.19 (0.06)	0.08 - 0.37	16.6
1336-H	0					
1336-I	0					
1336-J	13	0.62 (0.34)	0.32 - 1.62	0.31 (0.17)	0.16 - 0.81	19.0
1336-K	0					
1336-L	6	0.14 (0.06)	0.07 - 0.20	0.07 (0.03)	0.04 - 0.1	12.1
1336-M	23	0.06 (0.05)	0.02 - 0.25	0.03 (0.03)	0.01 - 0.13	7.3
Total	297	0.40 (0.19)	0.02 - 1.62	0.20 (0.09)	0.01 - 0.81	17.46

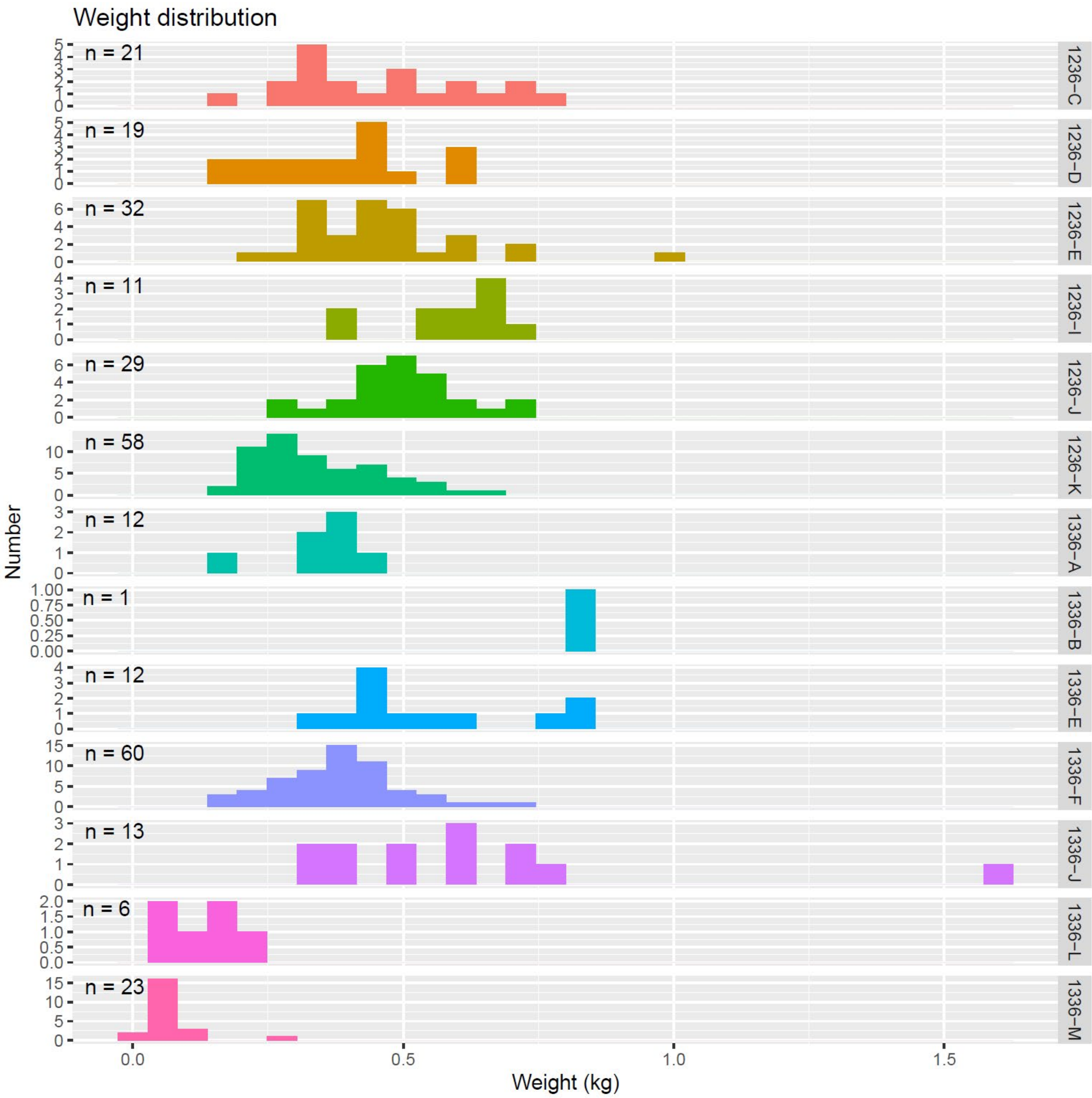


Figure 16. Histogram of Sandfish weights (kg) measured during survey in each stratum surveyed within grids 1236 and 1336.

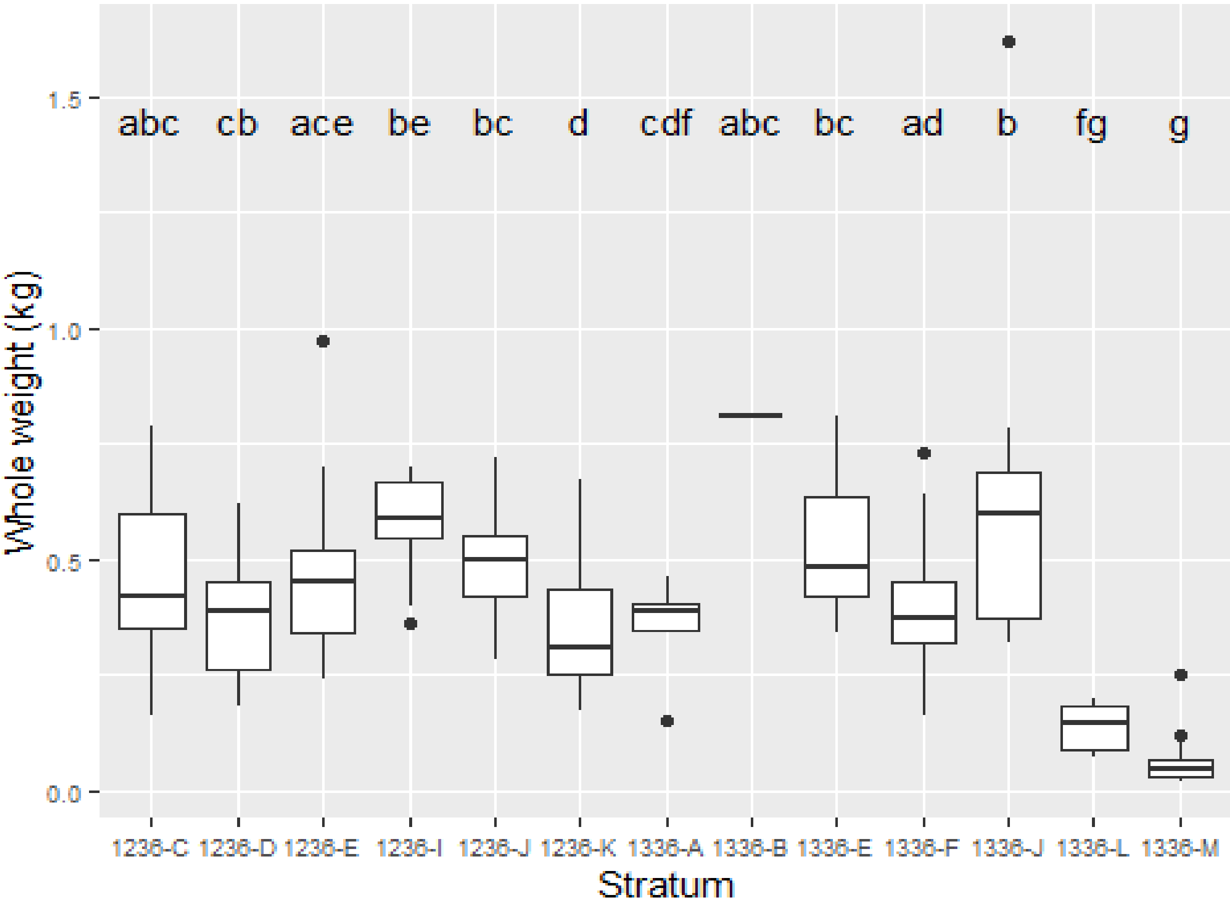


Figure 17. Box plot of Sandfish individual whole weight from each stratum sampled within grids 1236 and 1336. Annotations denote strata with mean weights that were not significantly different (based on Tukey's HSD test) – strata that share a common letter are not different.

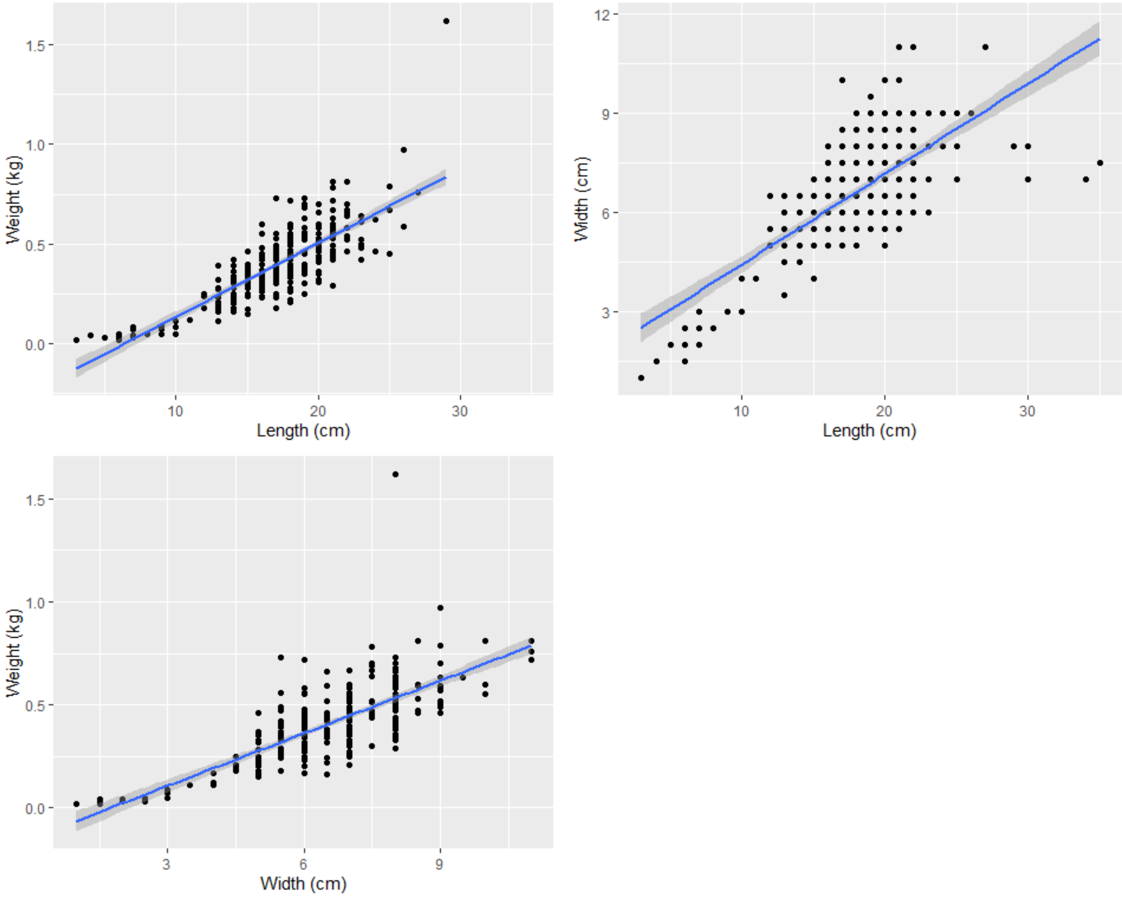


Figure 18. Relationship of length-weight, length-width and width-weight for Sandfish sampled within grids 1236 and 1336.

Biomass estimates

As in the Cobourg Peninsula survey, there was no significant effect of time-of-day on counts of Sandfish densities (Kruskal-Wallis test X^2 = 93, df = 96, $P > 0.05$ for non-zero count transects; X^2 = 213, df = 213, $P > 0.05$ for all transects) (Figure 19). However, most transects were completed by 4 pm on any day.

No Sandfish were recorded in transects undertaken at 1236 – F[2]. For other 1236 strata, mean densities ranged from 27.9 individuals per hectare to 169.9 individuals per hectare and averaged 76.9 individuals per hectare within the grid (Figure 20,Table 7.).

Estimated biomass was highest at 1236-K at 59.8 t (33.7 t-111.3 t) followed by 1236-E (44.9 t; 23 t-89.8 t) and 1236-C (33.5 t; 18.5 t-59.8 t) (Table 7). Total estimated whole biomass was 179.3 t (94.4 t-344.1 t) and gutted and salted biomass was 89.7 t (47.4 t-172.1 t) (Table 7). Estimated median biomass using Hart's bootstrap method was 186 t (Figure 22).

[2] 1236 – F is a small, open, east facing bay with a mangrove-lined freshwater input in the south-east. The stratum polygon misses the shallow area at the input, clipped by the 0 m contour and the 100 m buffer.

No Sandfish were recorded from three of the 1336 strata, 1336 - H, 1336 - I and 1336 – K (Table 8. , Table 9. , Figure 11)[3]. Densities at other strata ranged 4.9 individuals per hectare at 1336 – B to 796 individuals per hectare at 1336 – M, and overall averaged 90.9 individuals per hectare for the grid. Overall total whole biomass was 195.5 t (51.3 t - 419.4 t) and gutted and salted biomass was 97.8 t (25.6 t - 209.9 t). The very high numbers of Sandfish counted in two 1336 – M transects affected the precision of the estimate. Using Hart's bootstrap method, median total whole biomass was 401 t, but the probability distribution was heavily skewed right. Removing the 1136 – M transect data, resulted in a more normal distribution with a median biomass of 158 t and improved 95% confidence levels. Whole biomass was greatest at 1336 - A (49.8 t; 15.1 t - 154.6 t) and 1336 – E (49.1 t; 18 t – 100.7 t).

Survey strata within grid 1236 were randomly selected from a pool of 12 different strata (Figure 24). Of those, 7 potential strata have logbook records within or nearby suggesting that harvesting has taken place within the stratum. Using the overall mean density (76.9 individuals per Ha) and overall mean weight (0.42 kg), estimated from strata surveyed (4,950 Ha), biomass estimates were extrapolated to include the strata not surveyed but which had a history of fishing effort (1,866 Ha) yielding a total biomass of 220.1t (Table 10). Scaling biomass directly up to the unsurveyed strata resulted in an estimated biomass of 185.1 t (Table 10).

Survey strata within grid 1336 were randomly selected from a pool of 14 different strata (Figure 25). Of those, 12 potential strata have logbook records within or nearby suggesting that harvesting has taken place. Using the overall mean density (90.9 individuals per Ha) and overall mean weight (0.33 kg), biomass estimates from strata surveyed (9,748 Ha), biomass estimates were extrapolated to include the strata not surveyed but which had a history of fishing effort (7,560 Ha) yielding a total biomass of 520.3 t (Table 11). Scaling biomass directly up to the unsurveyed but fished strata resulted in an estimated biomass of 235.1 t (Table 11). The large difference in biomass estimates between extrapolation methods is likely due to the influence of very high density in the 1136 – M stratum, which was omitted from the calculation because there was no logbook effort recorded from that stratum.

[3] 1336-H is a small north facing bay on Grote Eylandt that is relatively open to the ocean. There is only two very small freshwater input and no mangroves. The bay has a relatively steep shoreline, and much of the polygon was deeper than 6 m. 1336 – I was an inlet within a larger bay. It is east facing and relatively open to the ocean and there are four small freshwater inputs. There are no mangroves 1336 – K is the northern third of a very large bay open to the ocean. Reef and coral were common in this stratum, particularly in the north. There are no freshwater inputs directly into this stratum and no mangroves. There are a number of freshwater inputs into the two strata to the south (1336 - L and 1336 - M), and Sandfish were found around the outlets of three of those. Sandfish found at two sites in 1336 – M had very high densities (>100 individuals per 200 m^2) of very small (3.5-14 cm) (Figure 12). These high densities resulted in very large confidence intervals for this stratum.

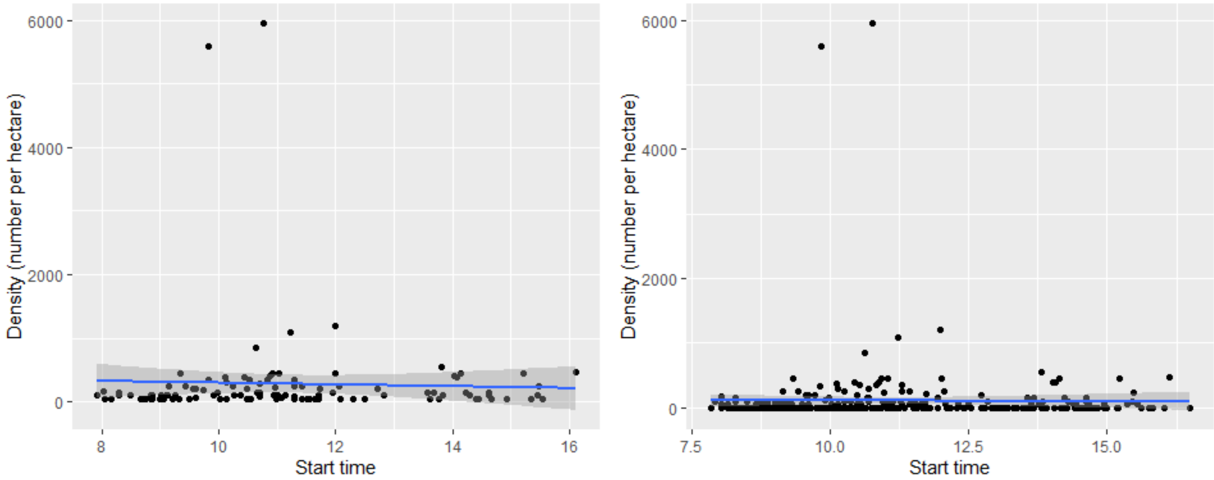


Figure 19. **Comparison of density (number per hectare) of Sandfish by transect start time for non-zero count transects (left) and with zero count transects (right).**

Table 7. Estimated biomass and 95% CI for each stratum within grid 1236.

	1236-C	1236-D	1236-E	1236-F	1236-I	1236-J	1236-K	Total
Stratum area (km^2)	28	9	16	4	1	3	8	69
Mean density (individuals per Ha) (95 $\pm$%CI)	27.9 (15.4-49.6)	52.7 (20.9-124.5)	64.1 (32.8-128.1)	0	74.3 (27.9-138.7)	154.4 (88.1-253.9)	169.9 (95.9-316.4)	76.9 (55.7-98.1)
Mean whole weight (kg)	0.43	0.43	0.43		0.43	0.43	0.43	
Mean gutted-and-salted weight (kg)	0.21	0.21	0.21		0.21	0.21	0.21	
Total number ('000)	78.7 (43-140)	49.3 (20-116)	105.4 (54-211)	0	6.3 (2-12)	40.8 (23-67)	140.2 (79-261)	420.55 (221-807)
Whole biomass (t)	33.5 (18.5-59.8)	21 (8.3-49.6)	44.9 (23-89.8)	0	2.7 (1-5)	17.4 (9.9-28.6)	59.8 (33.7-111.3)	179.3 (94.4-344.1)
Gutted-and-salted weight (t)	16.8 (9.3-29.9)	10.5 (4.2-24.8)	22.5 (11.5-44.9)	0	1.3 (0.5-2.5)	8.7 (5-14.3)	29.9 (16.9-55.7)	89.7 (47.4-172.1)
Lower 90% CI Density	17.1	25	35.9		33.9	97	104.8	313.7
Lower 90% number ('000)	48	23	59		3	26	86	245
Lower 90% Whole biomass (t)	20.5	10	25.2		1.2	10.9	36.9	104.7
Lower 90% Gutted-and-salted weight (t)	10.3	5	12.6		0.6	5.5	18.4	52.4

Table 8. Estimated biomass and 95% CI for each stratum within grid 1336.

	1336-A	1336-B	1336-E	1336-F	1336-H	1336-I
Stratum area (km^2)	24	2	20	1	1	17
Mean density (individuals per Ha) (95 +%CI)	48.3 (14.6-150)	4.9 (0-14.7)	56.7 (20.8-116.3)	355.7 (270.6-547.5)	0	0
Mean whole weight (kg)	0.44	0.44	0.44	0.44		
Mean gutted-and-salted weight (kg)	0.22	0.22	0.22	0.22		
Total number (‘000)	113.8 (35-354)	1 (0-3)	112.3 (41-231)	29.1 (22-45)	0	0
Whole biomass (t)	49.8 (15.1-154.6)	0.4 (0-1.3)	49.1 (18-100.7)	12.7 (9.7-19.5)	0	0
Gutted-and-salted weight (t)	24.9 (7.5-77.3)	0.2 (0-0.7)	24.5 (9-50.4)	6.4 (4.8-9.8)	0	0
Lower 90% CI Density	17.5	0	27.5	281.1		
Lower 90% number (‘000)	41	0	54	23		
Lower 90% Whole biomass (t)	18.1	0	23.8	10		
Lower 90% Gutted-and-salted weight (t)	9	0	11.9	5		

Table 9. Estimated biomass and 95% CI for each stratum within grid 1336 (continued).

	1336-J	1336-K	1336-L	1336-M	Total
Stratum area (km^2)	19	11	4	5	104
Mean density (individuals per Ha) (95 +%CI)	22.5 (8.4-68.3)	0	50.3 (11.5-162.9)	796 (30.3-2340.3)	90.9 (63.2-118.5)
Mean whole weight (kg)	0.44		0.08	0.08	
Mean gutted-and-salted weight (kg)	0.22		0.04	0.04	
Total number (‘000)	43.6 (16-133)	0	20.4 (5-66)	359.3 (14-1056)	679.49 (133-1888)
Whole biomass (t)	19 (7.1-57.9)	0	1.6 (0.4-5)	27.3 (1-80.4)	159.9 (51.3-419.4)
Gutted-and-salted weight (t)	9.5 (3.6-29)	0	0.8 (0.2-2.5)	13.7 (0.5-40.2)	97.8 (25.6-209.9)
Lower 90% CI Density	9.7		11.5	41.2	388.5
Lower 90% number (‘000)	19		5	19	161
Lower 90% Whole biomass (t)	8.2		0.4	1.4	61.9
Lower 90% Gutted-and-salted weight (t)	4.1		0.2	0.7	30.9

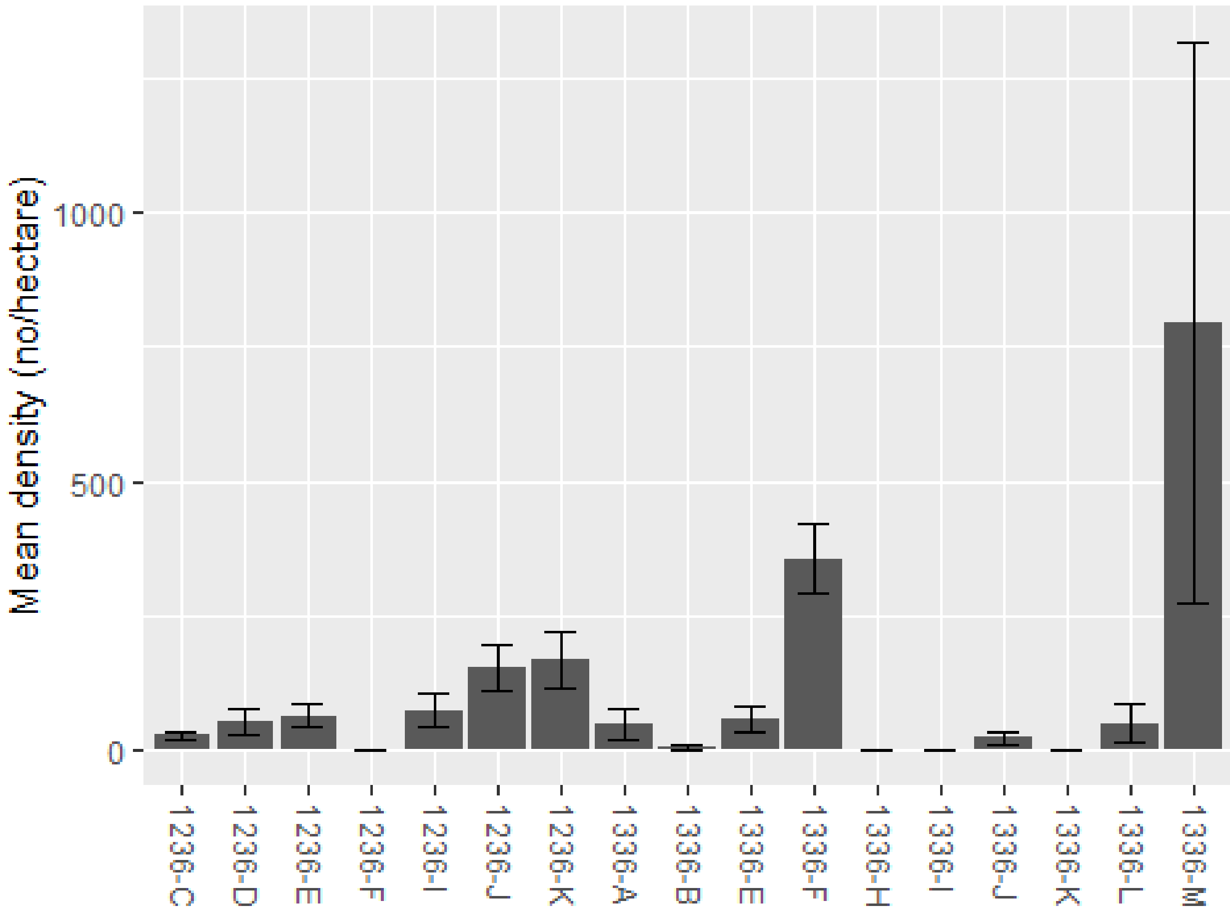


Figure 20. Mean density (number per hectare ± SE) of Sandfish in each stratum surveyed within grids 1236 and 1336.

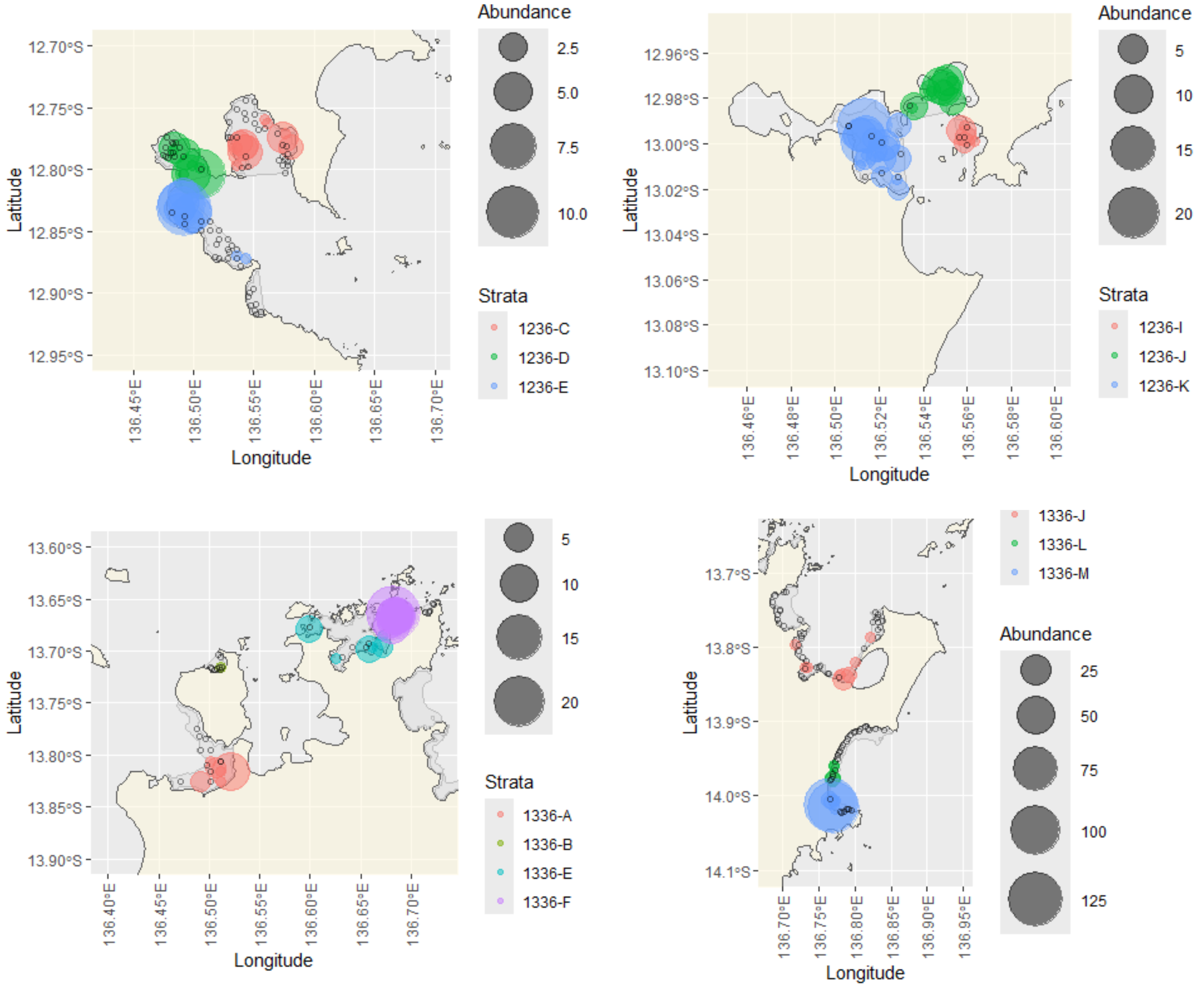


Figure 21. Abundance (raw counts per transect) of Sandfish at the northern 1236 strata (top left), southern 1236 strata (top right), western 1336 strata (bottom left), eastern 1336 strata (bottom right). Different colours indicate different strata.

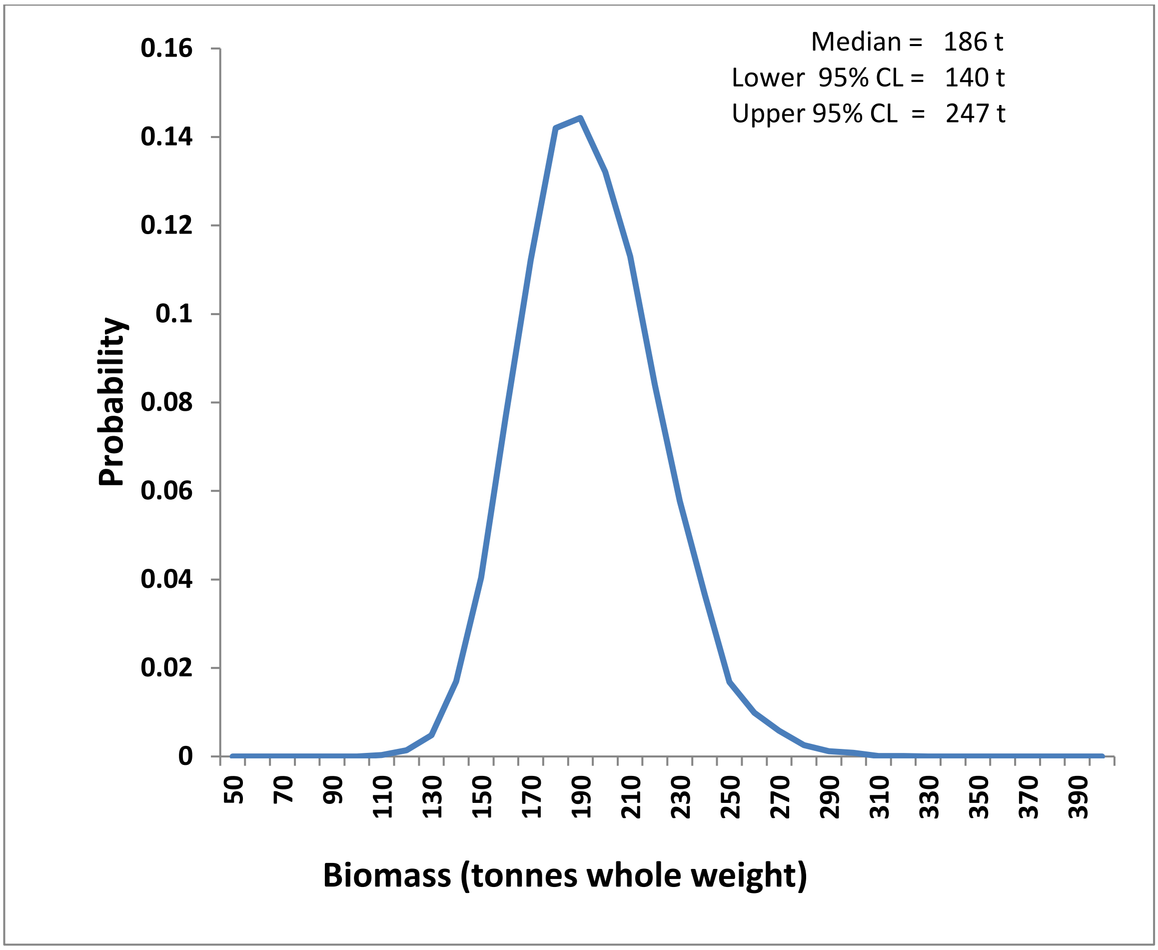
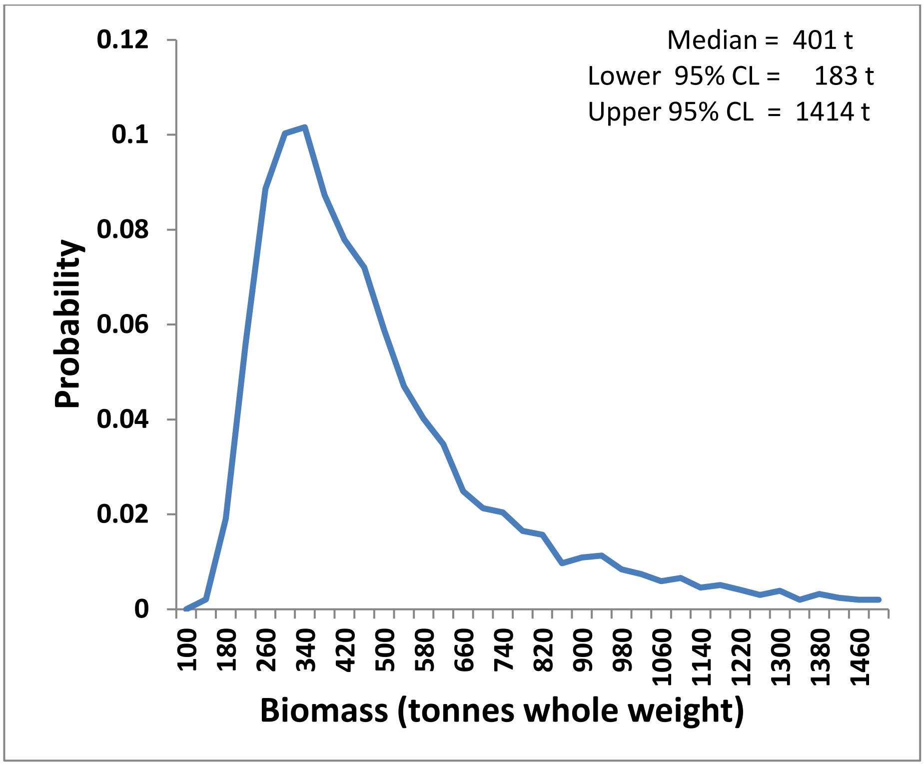


Figure 22. Probability estimates of the biomass of Sandfish within all survey strata sampled within grid 1236.



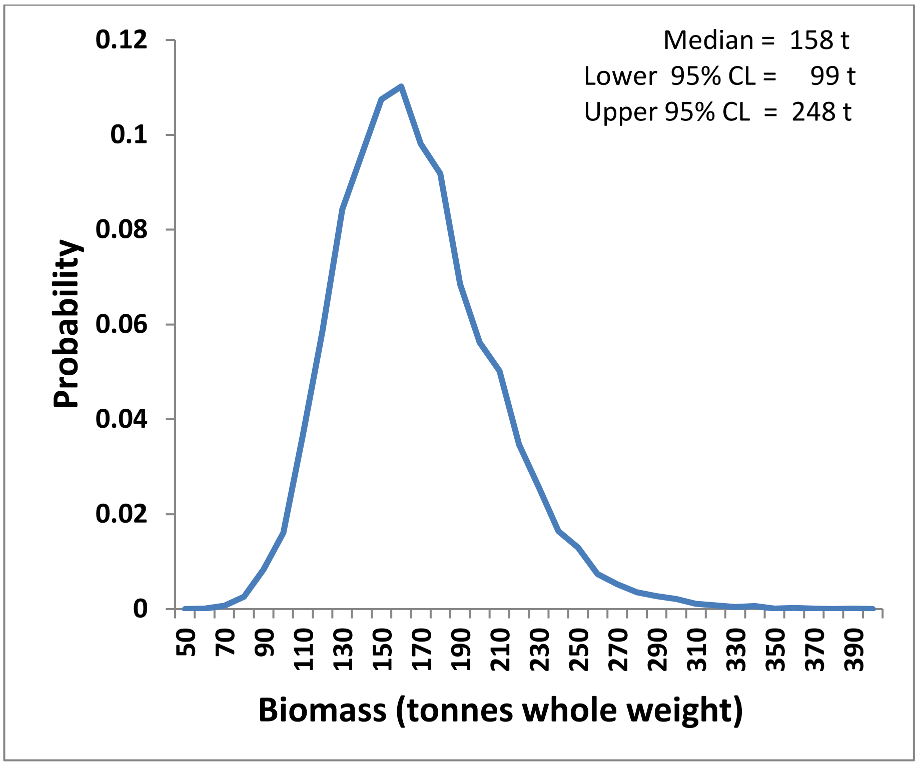
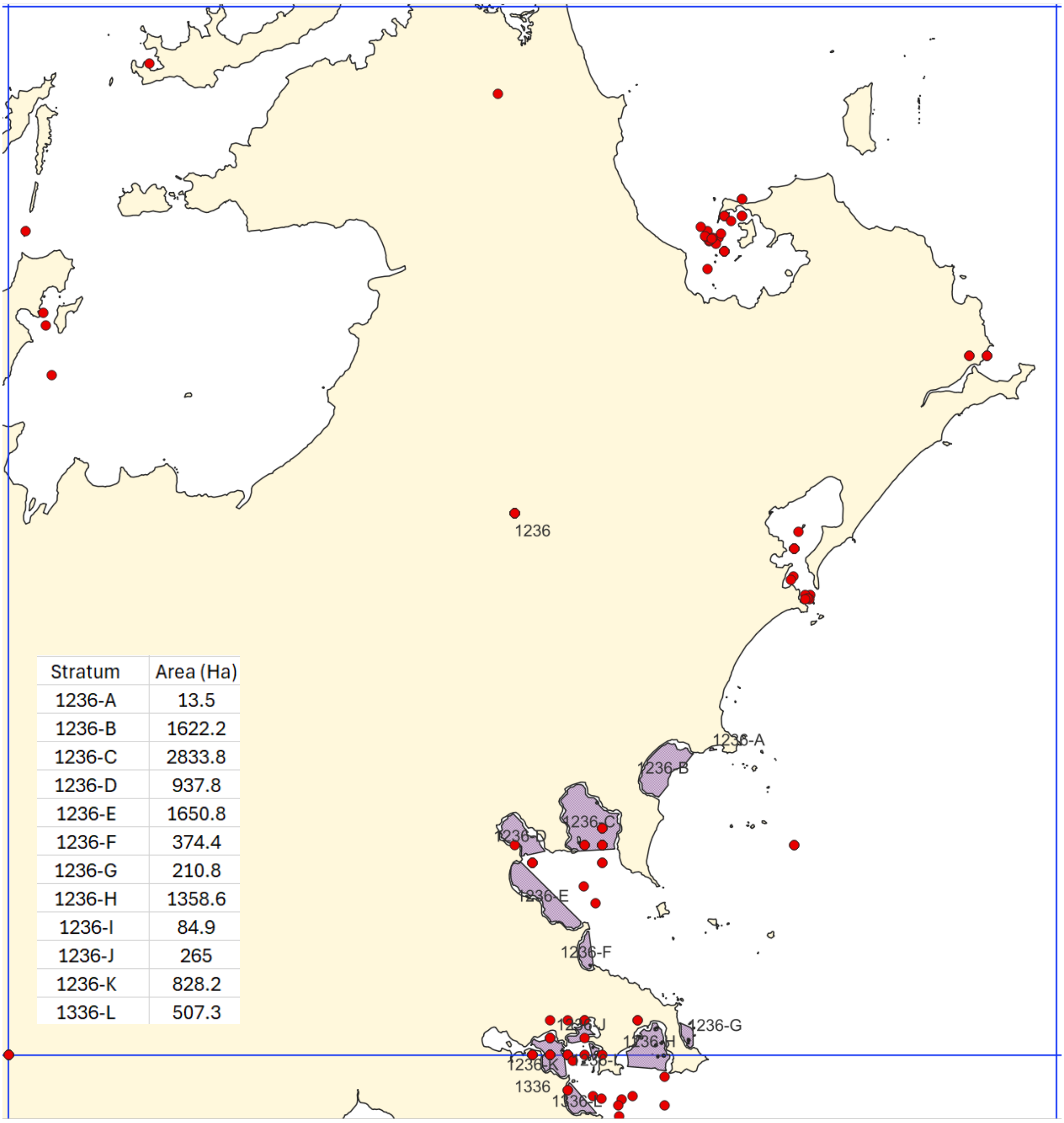


Figure 23. Probability estimates of the biomass of Sandfish within all survey strata sampled at within grid 1336 (top) and from all 1336 strata except for 1136 – L and 1136 – M (bottom). Note that no zero counts were recorded for 1136-F and so the CRITBINOM function returns the #NUM! error value. Similarly, there was only one non-zero record for 1336-F. For those two strata, the estimated abundance was used instead.



Stratum	Area (Ha)
1236-A	13.5
1236-B	1622.2
1236-C	2833.8
1236-D	937.8
1236-E	1650.8
1236-F	374.4
1236-G	210.8
1236-H	1358.6
1236-I	84.9
1236-J	265
1236-K	828.2
1336-L	507.3

Figure 24. All potential strata within grid 1236 (purple), location of logbook records (red dots) and the area (Ha) of each stratum.

Table 10. Extrapolated estimates of biomass of Sandfish by the proportional area of surveyed strata within grid 1236 compared with all potential and surveyed strata in those strata classified as having fishing effort present. See methods for description of how each estimate was calculated.

	Surveyed (Ha)	Surveyed biomass (t)	Not surveyed (Ha)	Total (Ha)	% surveyed in total	Extrapolated biomass 1 (t)	Extrapolated biomass 2 (t)
Effort present	4,950	134.4	1,866	6,816	73%	220.1	185.1
No effort present	2,025	44.9	1,846	3,872	27%	Not estimated	Not estimated
Total	6,975	179.3	3,712	10,687			

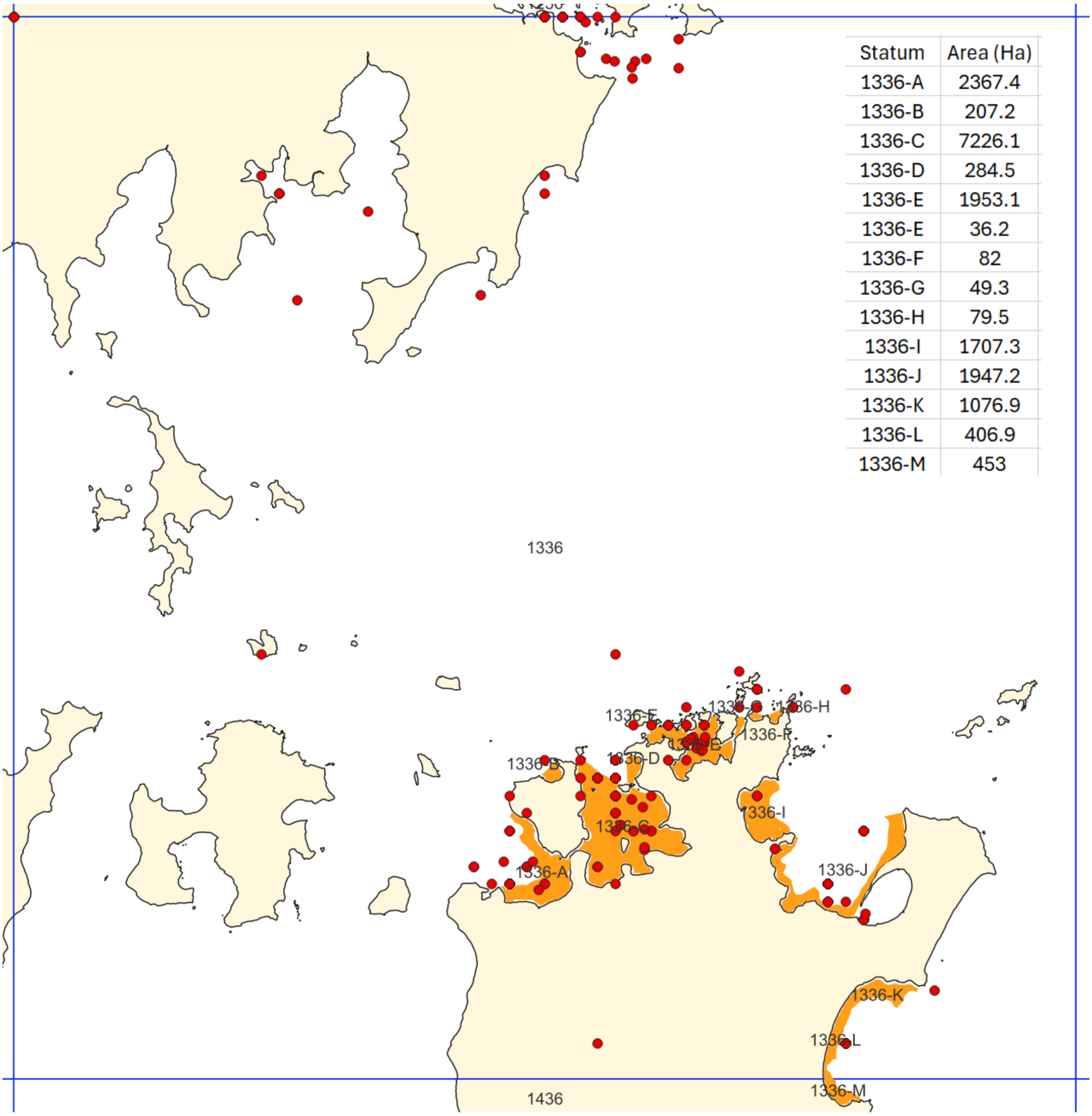


Figure 25. All potential strata within grid 1336 (orange), location of logbook records (red dots) and the area (Ha) of each stratum.

Table 11. Extrapolated estimates of biomass of Sandfish by the proportional area of surveyed strata within grid 1336 compared with all potential and surveyed strata in those strata classified as having fishing effort present. See methods for description of how each estimate was calculated.

	Surveyed (Ha)	Surveyed biomass (t)	Not surveyed (Ha)	Total (Ha)	% surveyed in total	Extrapolated biomass 1 (t)	Extrapolated biomass 2 (t)
Effort present	9,748	132.6	7,560	17,308	56%	520.3	235.1
No effort present	533	27.3		533	44%	Not estimated	Not estimated

Total	10,281	159.9	7,560	17,840

Discussion

Compared with other exploited populations of sea cucumbers that have been surveyed in the region (Uthicke and Benzie 2000; Skewes *et al*. 2004; Kinch *et al*. 2008; Purcell *et al.* 2013; Knuckey and Koopman 2016, Koopman and Knuckey 2021, 2022; Murphy *et al*. 2021), densities of Sandfish in the Northern Territory Trepang fishery are generally high (10s to 100s/Ha). Low densities of commercially-important sea cucumbers have prompted concerns of overfishing including those species harvested in Australia (Eriksson and Byrne 2015, Wolfe and Byrne 2022). Assessments of the NT Trepang fishery have also been in response to concerns of overfishing (Grubert 2017, 2019; NT 2021). Nominal thresholds below which reproduction of sea cucumbers may be compromised are suggested to be 10 individuals per Ha (Bell *et al.* 2008). However, little information is available to evaluate the reproductive ecology of sea cucumbers as it is affected by fishing (Uthicke *et al.* 2004, Wolfe and Byrne 2022, Waldie *et al.* 2024) and a lower threshold (4 individuals per Ha) has been proposed by Murphy *et al*. (2021).

There is little evidence of overfishing in the two stocks surveyed in the NT Trepang fishery. Previous surveys of Sandfish conducted off Croker Island (grid 1132) more than thirty years ago (Vial 1989) and off Cobourg Peninsula in 1996 (Carter 2001) revealed similar densities to those recorded in the current survey (~ 100 individuals/Ha). Vial (1989) recorded high densities of Sandfish along the northern shoreline of Bowen Strait and medium densities in Mission Bay (Figure 26). Survey methods employed by Vial (1989) differed from the current survey, primarily using beam trawls to sample Sandfish and to estimate density. He also used transect counts by walking on exposed habitat at low tide and by diving. Carter (2001) surveyed populations of Sandfish off the Cobourg Peninsula using towed video cameras covering habitat of between 160 m^2 and 320 m^2 in depths of ~ 6 m. Boat transects, intertidal walks and beam trawls were also used. The mean weight of Sandfish recorded in the 1989 study was 0.74 kg compared with 0.46 kg-0.62 kg in the current survey. The mean length of Sandfish off Croker Island was 23.4 cm in the 1989 survey compared with 17.4 cm-21.8 cm in the current survey. The comparative size distribution of Sandfish sampled from Croker Island is shown in Figure 27. These data indicate that the size distribution of Sandfish has contracted. However, both surveys revealed that most Sandfish sampled were above the current size limit (16 cm length) (Figure 27).

The total estimated biomass of Sandfish in each grid (for areas receiving fishing effort) was in the west (Cobourg Peninsula): 1132 - 1,079.8 t (or 1,693.7 t) and in the east (Groote Island): 1236 - 220.1 t (or 185.1 t), and 1336 - 520.3 t (or 235.1 t). These estimates are conservative as there may be Sandfish in areas of each grid that do not currently receive fishing effort but are nonetheless available to the fishery. Notably, Carter (2001) in surveys of Sandfish off the Cobourg Peninsula found no Sandfish on habitat adjacent to exposed coastline. In grid 1132, the survey strata included most of the potential habitat along the northern shore of Cobourg Peninsula, but did not cover the southern shore. There are logbook records of seven days of fishing effort off the southern shore with daily catches ranging from 178 kg to 970 kg. Off the southern shore there are many mangrove-lined freshwater inputs and large areas of shallow soft sediment likely to support Sandfish. For the eastern stock, in grid 1236, effort has been recorded in bays to the north of the area surveyed including Gove Harbour and around some of the islands to the west of Gove. Similarly in grid 1336, most fishing effort occurs in the survey area, but there is some effort off the mainland, and a lot of potentially suitable habitat around Blue Mud Bay with protected bays, mangrove lined freshwater inputs and shallow soft sediment. Furthermore, during the 2023 Blue Mud Bay enhancement area survey, Turner (2023) reported densities of 90 Sandfish per Ha and 120 Sandfish per Ha in areas remote from the hatchery release area. Accordingly, available biomass of Sandfish is likely to be greater than the estimates provided here for both stocks.

A draft harvest strategy is under development for the NT Trepang fishery. Under the current spatial management regime, the harvest strategy has target and trigger reference points based on the percent of the annual catch limit caught in each grid. The three grids in which these surveys were undertaken are all Tier 1 grids deemed as high priority for ongoing monitoring given regular fishing effort. For these Tier 1 grids, the annual catch limits (whole weight) are: 25 t (1132), 15 t (1236) and 25 t (1336). These are equivalent to 2.3%, 6.8%, and 4.8% of estimated biomass within the respective grids surveyed. Notably, these estimates are well below 10% of applicable annual catch limits particularly for the Cobourg Peninsula.

In the absence of formal stock assessments, 10% of available biomass is generally recommended as sustainable harvests for sea cucumber fisheries (DPIF 2008, Lovatelli et al. 2004, Skewes et al. 2010, Dissanyake and Athukorala 2009) suggesting that current harvests in the NT Trepang fishery are conservative for both eastern and western stocks. Thus, fishery independent surveys as reported here, can be used to set sustainable catch limits based on the conservative 10% of estimated biomass as applied in other spatially-managed sea cucumber fisheries (e.g. DPIF 2008, Skewes *et al*. 2014). This would also address some of the conditions applied to the fishery under the export approval process responsive to the EPBC Act including alignment to relevant research conducted on sea cucumbers in other jurisdictions, and improved performance indicators for the fishery.

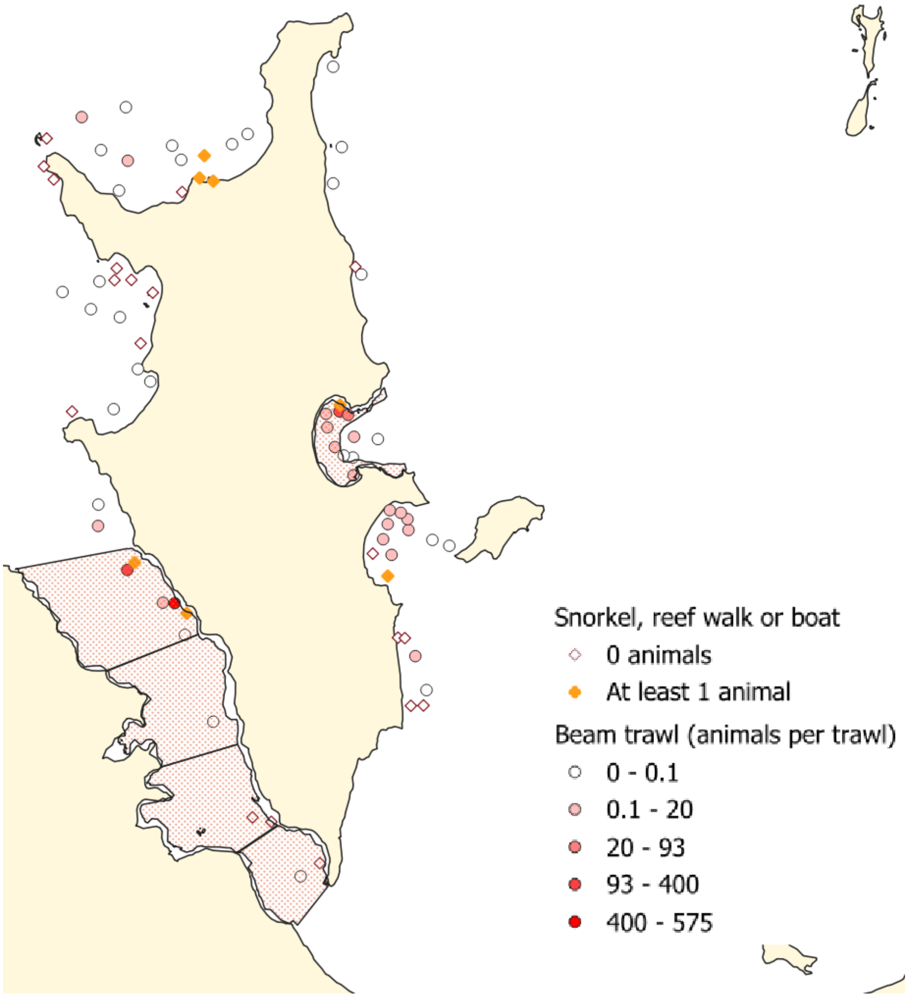
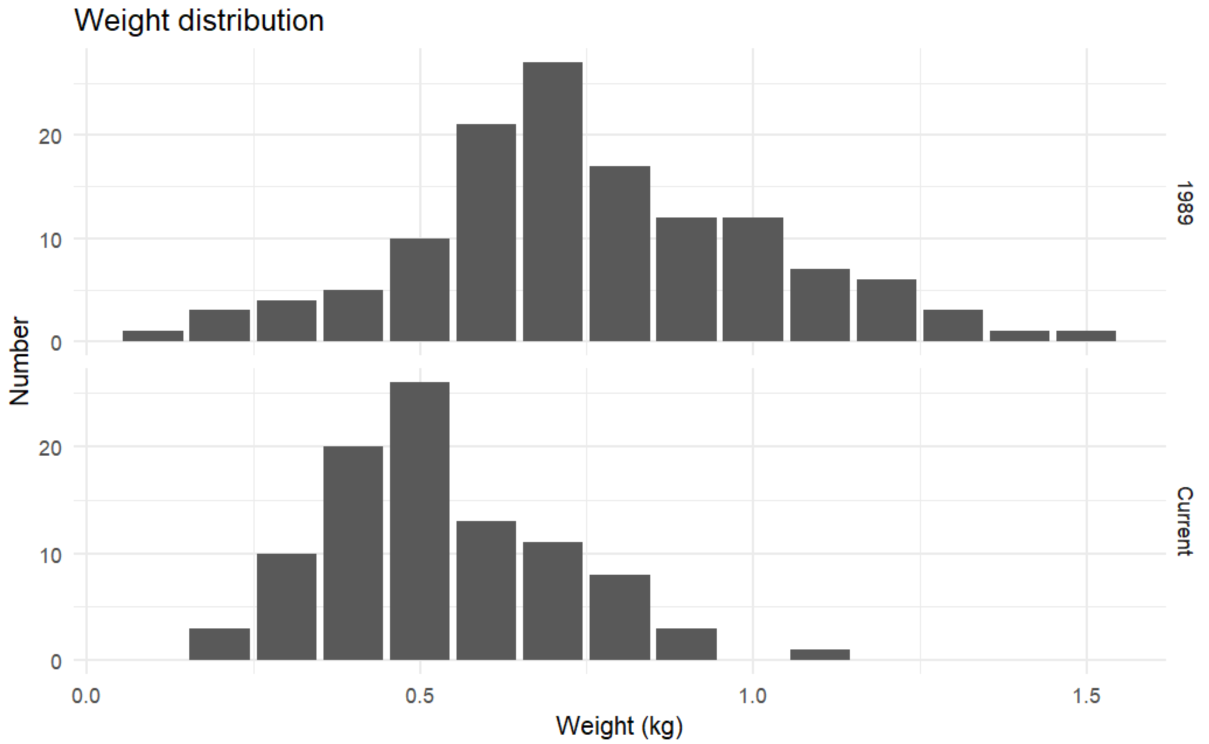


Figure 26. Results of a previous survey of Sandfish at Croker Island undertaken by Vail (1989). Current strata are overlaid. Open diamonds show snorkel, boat or reef walk transects with zero counts, closed diamonds show snorkel, boat or reef walk transects with non-zero counts, open circles show beam trawl transects with zero counts and closed circles show non-zero counts from beam trawls. Note that there was not enough information calculate densities that were comparable between transect methods.



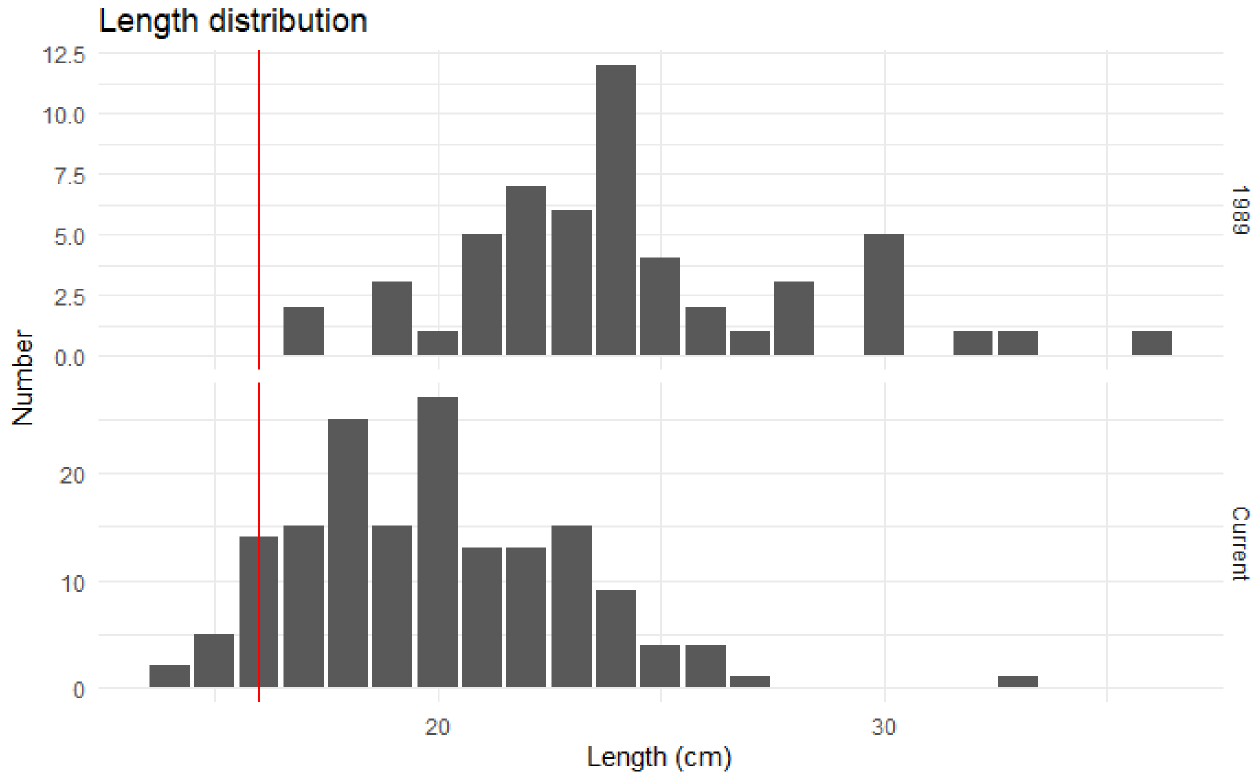


Figure 27. Weight (kg) and length frequency distribution reported by Vail (1989) and from the current survey (Croker Island sites only). The vertical red line shown in the length frequency distribution indicates the current legal minimum size (16cm).

Sandfish are broadcast spawners with a larval stage lasting 10-14 days (Ramofafia *et al.* 2002, Hamel *et al.* 2022). Gene flow is dependent on a number of factors including hydrological, ecological and physical barriers, the duration of the larval stage and larvae behaviour (Uthicke and Benzie 2001, Uthicke *et al.* 2004, Hamel *et al.* 2022). In Australia, spawning of Sandfish occurs from November to January (Harriott 1980, Morgan 2000). Modelled currents in November (Figure 28) head towards Gove Peninsula in a south-westerly direction, then heading either to the south or continuing south-east and then east. Prevailing currents would prohibit/limit gene flow between eastern and western populations, but potentially facilitate recruitment in both directions within each population.

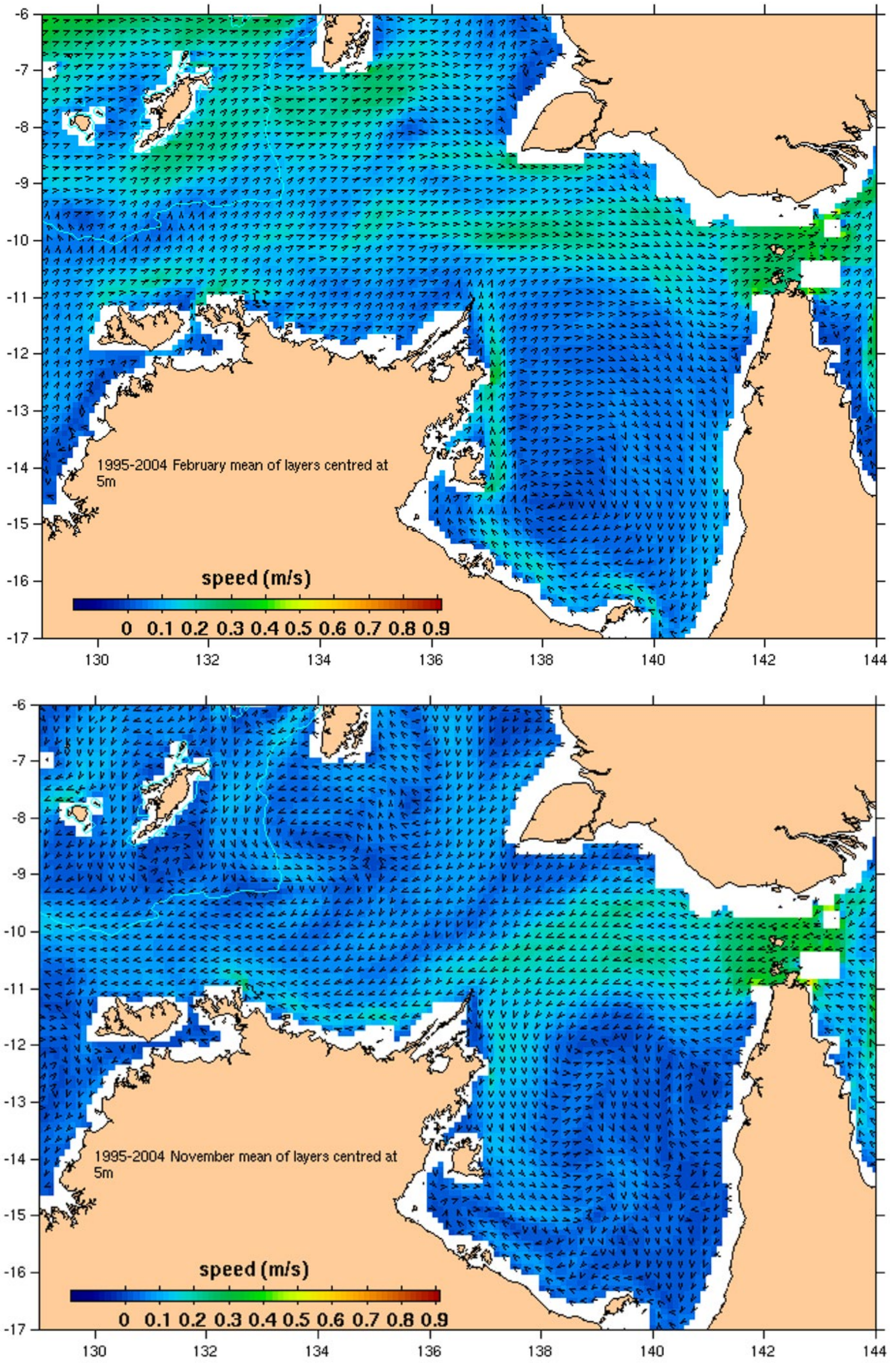


Figure 28. Map of northern Australia, showing the February (1995-2004) (top figure) and November (1995-2004) (lower figure) mean of surface layer (0-10m) as speed (see key) and direction (arrow heads). Taken directly from Griffen (2008).

Thus, although nominally separate stocks, the stock structure of Sandfish in the NT Trepang fishery requires further resolution and this is a condition of the current export approval under the EPBC Act.

Definition of the strata used in the current survey began with the AusBathyTopo 250m (Australia) 2023 Grid (Beaman, 2023) rasta to get the 0 m and 6 m contours. From the current survey, recorded bathymetry has low accuracy for both of those contours, with transects assigned in waters as deep as 18 m. Many sub-tidal areas were not included in strata and the 0 m contour often traversed land. Although more accurate data to define the 6 m contour was unavailable for the current survey, a more accurate inner boundary may be defined by the DEA Coastlines v2.2.0[4] layer (Bishop-Taylor *et al*., 2021). Examples of the differences between the 0 m contour used for the current survey strata and the 2023 coastline layer are shown in Figure 29. Figure 29A shows that the 0 m bathymetry cross the shoreline onto the beach and cross the headland whereas the coastline layer more accurately follows the shoreline. Figure 29A shows that 0 m contour crosses a bay in clearly deeper water. Figure 29C shows the inaccuracy of the 0 m contour around an island, missing a large part of a bay and crossing a headland. Figure 29D shows the 0 m contour crossing a beach, missing two sections of deeper water and crossing a headland. Thus, the coastline layer should be used in combination with the intertidal extent layer to define the shoreward boundaries of strata for future surveys.

Carter (2001) recommended broad-scale surveys from mother vessels from which smaller dories can operate (as employed in the current survey). She also recommended collaboration with commercial fishers which was a key success factor in the current survey. In contrast to previous surveys, the current survey using commercial divers operating in ~ 6m water depth supported by video cameras, was demonstrably successful in enumerating Sandfish in habitat important to the fishery. Similar methodology has been successfully employed in large-scale biomass surveys of other commercially-important species of sea cucumber particularly in Queensland (Koopman and Knuckey 2021, 2022). Nonetheless, the current surveys may be regarded as preliminary with counts of Sandfish highly variable. Thus, future surveys can use the available information on the distribution and abundance of Sandfish to refine strata so as to improve biomass estimates.

[4] DEA Coastlines — DEA Knowledge Hub (ga.gov.au)

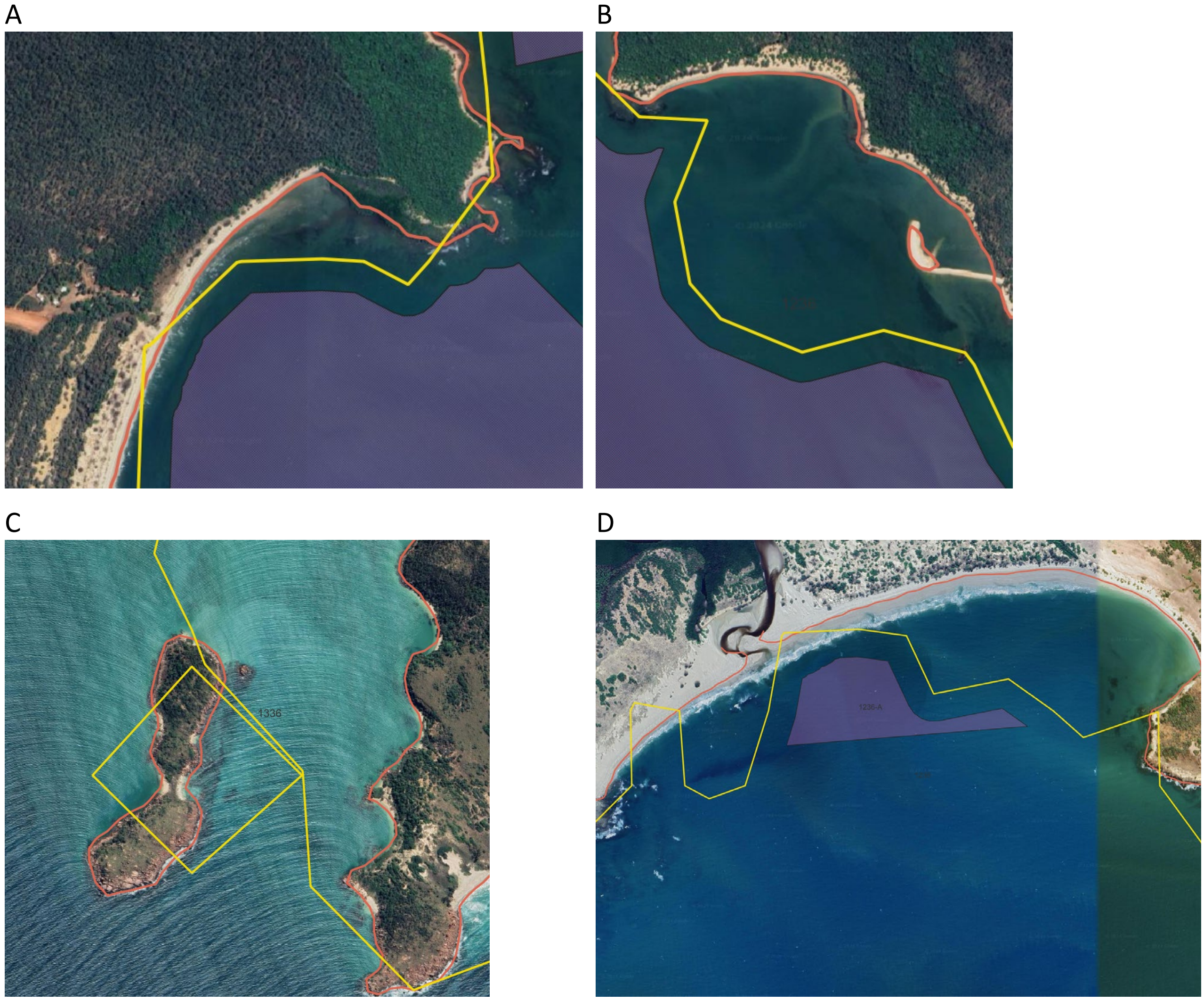


Figure 29. Comparison between the 0 m contour (yellow) and the 2023 coastline layer (orange). 2024 survey strata are also shown.

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Appendix 1 – Bootstrap diagnostics

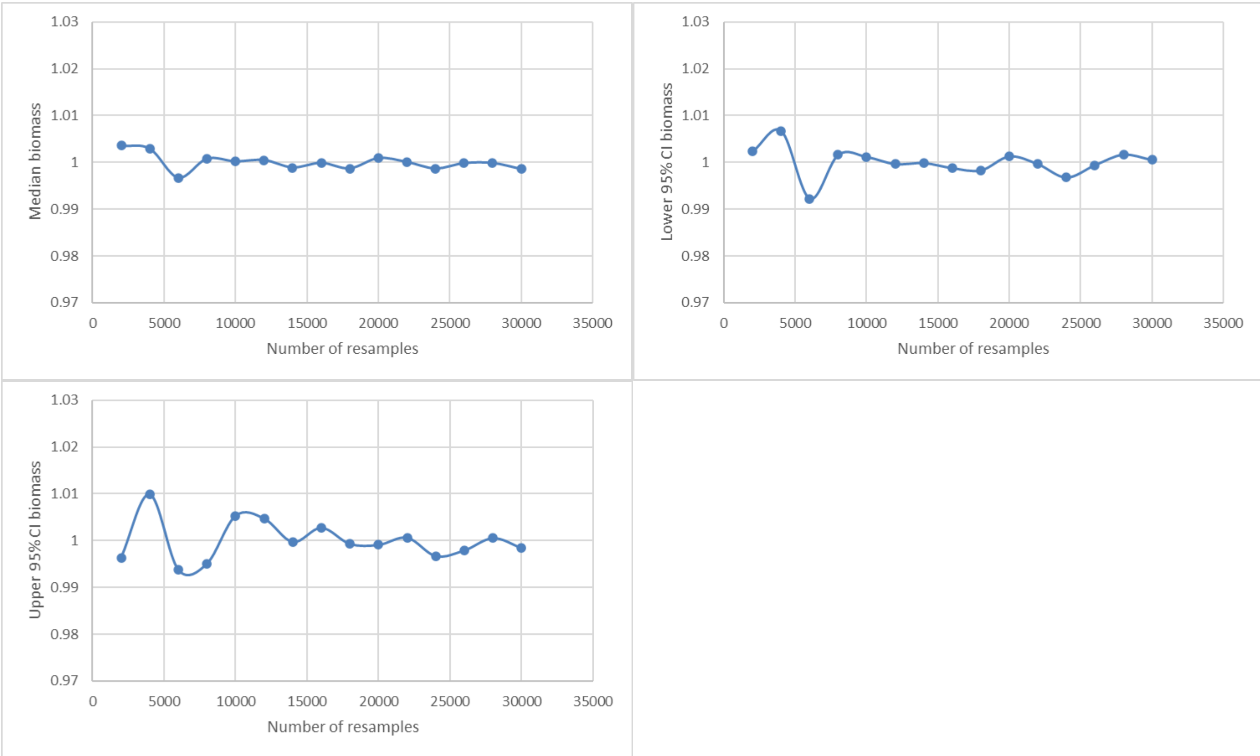

Figure 30. Diagnostic plots for biomass and lower and upper 95% confidence intervals over a range of number of resamples for the grid 1132 data. Data are standardised to the mean values.

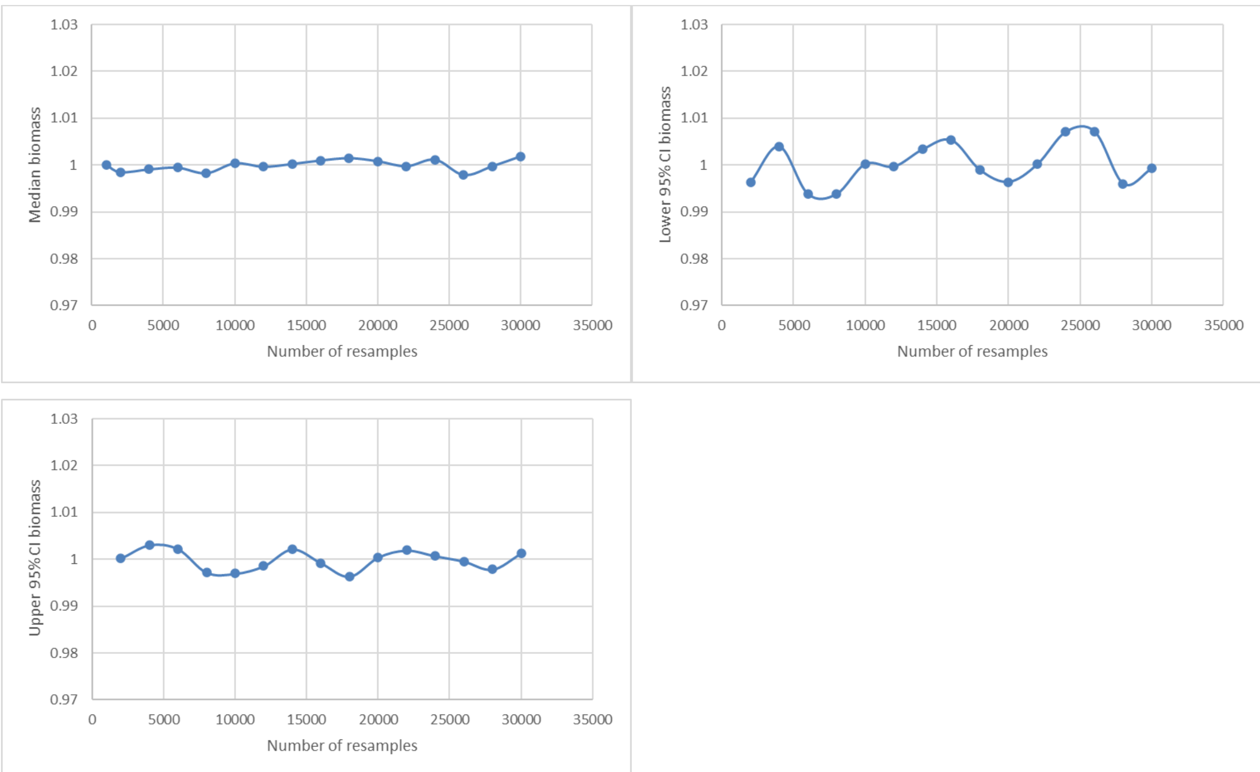

Figure 31. Diagnostic plots for biomass and lower and upper 95% confidence intervals over a range of number of resamples for the grid 1236 data. Data are standardised to the mean values.

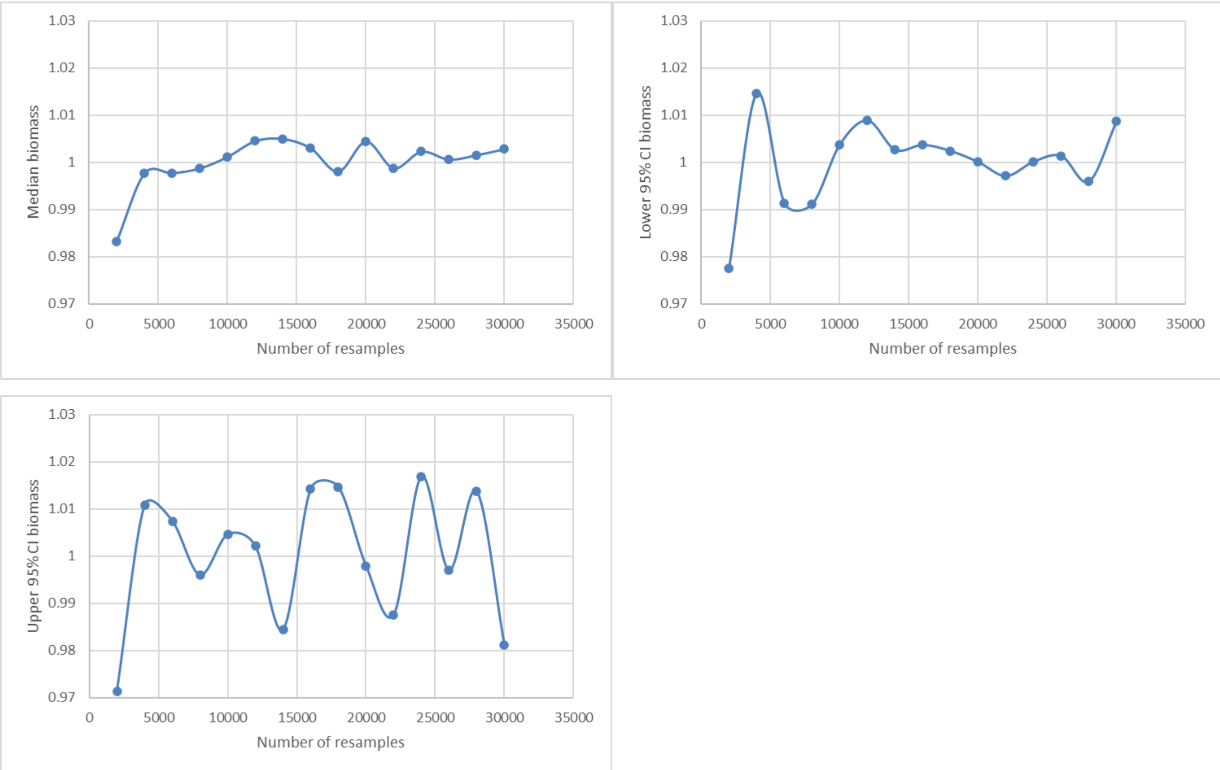

Figure 32. Diagnostic plots for biomass and lower and upper 95% confidence intervals over a range of number of resamples for the grid 1336 data. Data are standardised to the mean values.