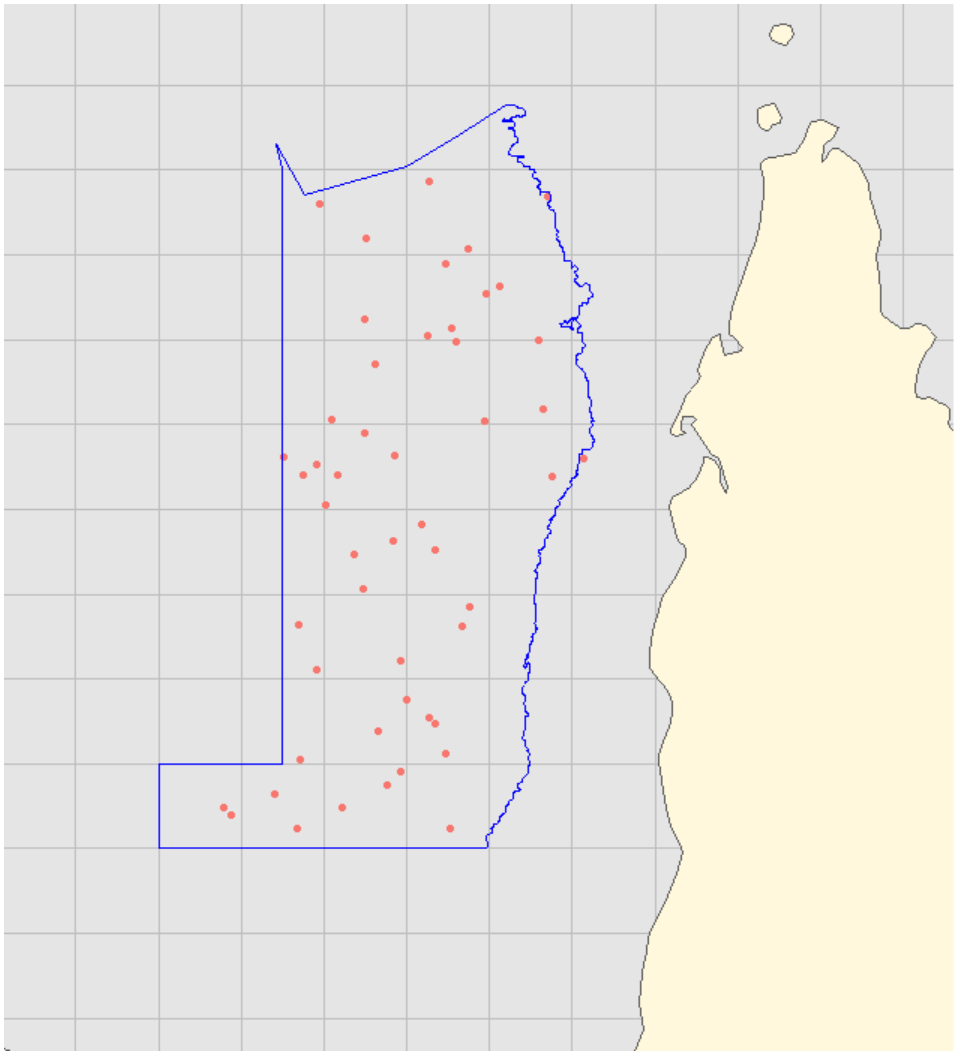
Survey of Tropical Snapper in Queensland Gulf of Carpentaria Developmental Fin Fish Trawl Fishery - 2021



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In submitting this report, the researcher has agreed to QDAF publishing this material in its edited form.

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Executive Summary

As part of a broader survey of tropical snapper across northern Australian waters, a fishery-independent survey of quota species and other species important to Queensland's Gulf of Carpentaria Developmental Fin Fish Trawl Fishery (GOCDFFTF) was conducted in April and May 2021. A total of 50 shots was undertaken in the Eastern Gulf of Carpentaria (GoC_East) stratum covering an area of 83,524 km^2.

Biomass estimates based on swept area are sensitive to assumed effective width of the trawl and vulnerability of fish to the gear. Biomass estimates based on door width are considered to be conservative (they potentially underestimate biomass), while estimates based on net width (or wing spread) are likely overestimates (particularly for species that respond to herding behaviour).

Biomass estimates are dependent on the assumptions of trawl swept area and the vulnerability of snapper to the trawl gear. Based on the most conservative assumption that the trawl swept area is the product of door width and tow distance (i.e. all snapper between the doors are caught in the net), biomass estimates (within the Eastern Gulf of Carpentaria stratum) for the five quota species are: Crimson Snapper (27,078 t), Saddletail Snapper (24,165 t), Red Emperor (738 t), Mangrove Jack (1,784 t) and Golden Snapper (2,775 t), and 27,714 t for the other species quota basket (OS GOC). Estimates were generally precise (coefficients of variation, CVs < 0.3) except for Mangrove Jack (CV 0.37) and Golden Snapper (CV 0.77). No CV was obtained for Black Jewfish because they were caught in only one shot.

Herding is known to occur for some tropical snapper species and effective trawl path width has been measured previously for Saddletail Snapper. Based on an estimated effective trawl path for trawl swept area (W_{eff}), biomass estimates (within the eastern Gulf of Carpentaria stratum) for the five quota species are: Crimson Snapper (46,205 t), Saddletail Snapper (40,996 t), Red Emperor (1,247 t), Mangrove Jack (3,051 t) and Golden Snapper (4,769 t), and 46,960 t for OS GOC. These estimates are considered conservative at least for Crimson Snapper, Red Emperor, Golden Snapper and Redspot Emperor, species that show no evidence of herding behaviour.

There was relatively little interaction of trawling with species of conservation interest. From the 50 shots undertaken, one Loggerhead Turtle, one unidentified turtle, two Elegant Seasnakes and one Pygmy Devilray were caught, with all except the Pygmy Devilray being released alive (note: to improve accuracy of data collected, this survey was conducted without a turtle excluder device TED).

Length frequency data were collected for eight species: Crimson Snapper, Saddletail Snapper, Goldband Snapper, Painted Sweetlips, Redspot Emperor, Red Emperor, Mangrove Jack and Golden Snapper. Lengths of Crimson Snapper ranged 22 cm – 47 cm, with most between 27cm – 37 cm. Saddletail Snapper were caught over a much wider range of lengths from 15 cm – 62 cm with peaks at about 30 cm and 46 cm. Golden Snapper and Mangrove Jack comprised larger fish mostly greater than 45 cm in length. A wide range of lengths was measured for Goldband Snapper, Painted Sweetlips and Red Emperor, but most fish measured were smaller than 35 cm. Length frequency of Redspot Emperor ranged from 21 cm – 41 cm.

DNA samples from a total 449 individuals of Crimson Snapper, Saddletail Snapper, Goldband Snapper, Red Emperor, Mangrove Jack and Golden Snapper were collected and provided to QDAF as part of a larger tropical snapper stock delineation project.

Introduction

Tropical snappers are important target and byproduct species of several northern Australian fisheries, including the Northern Territory (NT) Timor Reef Fishery and Demersal Fishery, and Queensland's Gulf of Carpentaria Developmental Fin Fish Trawl Fishery (GOCDFFTF). This report focuses solely on the GOCDFFTF.

The GOCDFFTF (Figure 1) is a limited-entry, quota-managed, semi-demersal trawl fishery and is managed as a developmental fishery under permit by the Queensland Department of Agriculture and Fisheries (QDAF). There are currently three permits to fish in the GOCDFFTF. These are held by three separate companies: Australia Bay Seafoods, ABS Queensland and A. Raptis & Sons Pty. Ltd. Until recently (2021), there had been no fishing undertaken in the fishery since 2016.

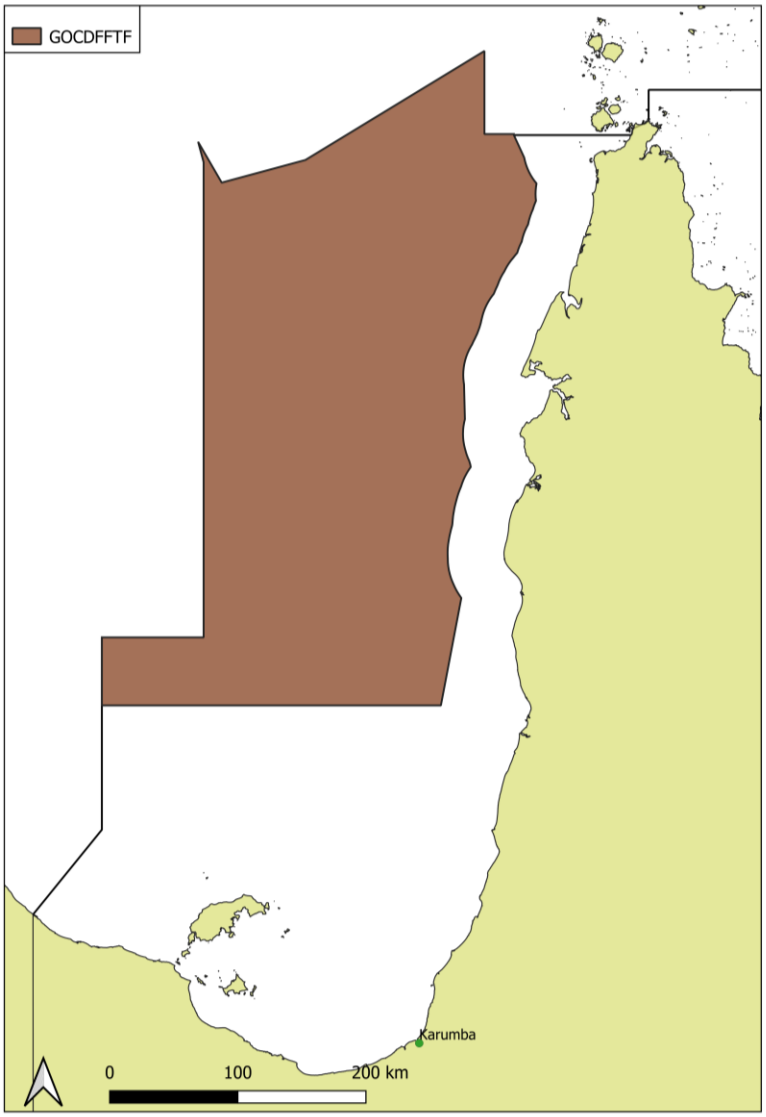

Figure 1. Area of the GOCDFFTF.

The fishery mainly targets tropical snappers (Family Lutjanidae): five Lutjanid species and all other teleost species are managed under quota. Quota species are: Crimson Snapper (*Lutjanus erythropterus*), Saddletail Snapper (*L. malabaricus*), Red Emperor (*L. sebae*), Golden Snapper (*L. johnii*) and Mangrove Jack (*L. argentimaculatus*), whereas all other teleost species are managed under a basket quota. Since 2010, catches in the GOCDFFTF have fluctuated from a high of 532 t in 2011 to a low of about 17 t in 2016. Effort has ranged from 282 days trawled in 2011 to 7 days trawled in 2013 and 2016. Although there was no fishing effort in the fishery from 2017 to 2020 the fishery has recommenced in 2021.

The GOCDFFTF was assessed under Part 13A of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) in November 2010 and the fishery was subsequently WTO-accredited until 24 November 2019. Several conditions and recommendations were made under the previous accreditation which were subsequently met or adopted during the period of the accreditation. After the accreditation lapsed, QDAF applied to the Department of Agriculture, Water and the Environment (DAWE) to renew export approval for the Fishery (QDAF 2020) and the application is currently being used to assess the operation of the fishery for the purposes of Part 13 and Part 13A with reference to the Guidelines for the Ecological Sustainable Management of Fisheries (DAWR 2007). As part of the DAWE assessment process, evidence of sustainability of the fishery is required to be provided to QDAF followed by an annual review done by QDAF. Part of the assessment involves conducting fishery-independent surveys.

The stock assessments for tropical snapper in this region rely on stochastic stock reduction analysis (SRA) models. Catch per unit effort (CPUE) from commercial catch and effort data forms the main index of abundance used in these models. The use of commercial CPUE as an indicator of relative abundance can be problematic for many reasons and can compromise the underlying assumption that commercial catch rates change linearly with abundance. Although some factors that are reported in logbooks can be used to standardise CPUE, there are other sources of variation including:

- modified fishing practices to target or avoid species to suit quota availability, meet market demands, or to comply with management arrangements;
- differences in selectivity of fishing gear and use of bycatch-reduction devices; and,
- the combined impacts of multiple management restrictions on a fishery.

Knuckey and Koopman (2020) designed a stratified random survey to provide a fishery-independent index of stock abundance for tropical snapper in Northern Territory and Queensland waters. Their stratification was based on analyses of commercial fishing effort, stock structure of the main target species, logbook catch records, and boundaries of bioregions. It was proposed that the use of commercial fishing vessels to undertake directed trawls with oversight by independent research scientists would provide a cost-effective and statistically-robust survey that could provide a fishery-independent estimate of relative biomass and coefficient of variation (CV) for target species, removing many of the sources of variation associated with fishery-dependent CPUE data. Fishery-independent surveys also provide the opportunity for collection of other important data such as DNA samples for stock structure, otoliths for age estimation, size-frequency, and reproductive condition of important species.

This report covers the survey undertaken in the Eastern Gulf of Carpentaria (GoC_East) stratum during April and May 2021.

Objectives

1. Undertake a demersal fish trawl survey of the GoC_East stratum, to provide relative indices of abundance (non-sex-specific) and CVs for:
    - Primary species (expected CVs <30%):
        i. Saddletail Snapper, (*Lutjanus malabaricus*);
        ii. Crimson Snapper, (*Lutjanus erythropterus*);
        iii. Goldband Snapper, (*Pristipomoides multidens*);
    - Secondary species (30<CVs<50%):
        i. Red Emperor, (*Lutjanus sebae*),
        ii. Painted Sweetlips, (*Diagramma pictum*),
        iii. Redspot Emperor (*Lethrinus lentjan*);
    - Additional species (poor CVs expected):
        i. Black Jewfish, (*Protonibea diacanthus*); and,
        ii. Mangrove Jack (*Lutjanus argentimaculatus*).
2. Collect length-frequency and other biological data on the main species caught;
3. Monitor any interactions with species of conservation concern.

Materials and Methods

Survey Design

The detailed survey design and sampling methods is described in Knuckey and Koopman (2020), but is summarised below.

The GoC_East stratum is a part of the GOCDFFTF, but is trimmed at the 50 m contour on its eastern boundary because of the difference in species composition in shallow water (Figure 2). The stratum has a total area of 83,524 km^2 and overlaps with about 1,632 km^2 of non-trawl marine protected areas. A minimum of 50 shots was required to achieve satisfactory CVs. Details of randomly-allocated shot locations across the stratum were provided to industry and a list of backup shot random shot locations was provided to be used in the event that the primary shot was deemed “untrawlable”.

Survey shots were undertaken at a speed ranging from 3.2 to 3.8 knots (average 3.5 knots), made with the tide abaft the beam (any direction more than 90 degrees from the current direction), and never trawling into the current. Tow duration was 1.5 hours from net on the bottom to the start of winch up. The start of a valid trawl shot (net on bottom) was restricted to between the hours of 06:00-18:00.

Following completion of the shot, the net was hauled aboard and the catch sorted on deck. Commercial species were gathered in fish bins and catches of target species and important byproduct species were weighed using calibrated motion-compensated scales. Discarded by-catch was identified to species where possible and an approximate weight of each species estimated. Length measurements and DNA samples of main target species were collected randomly during the survey. A small number of otoliths was collected from representative species.

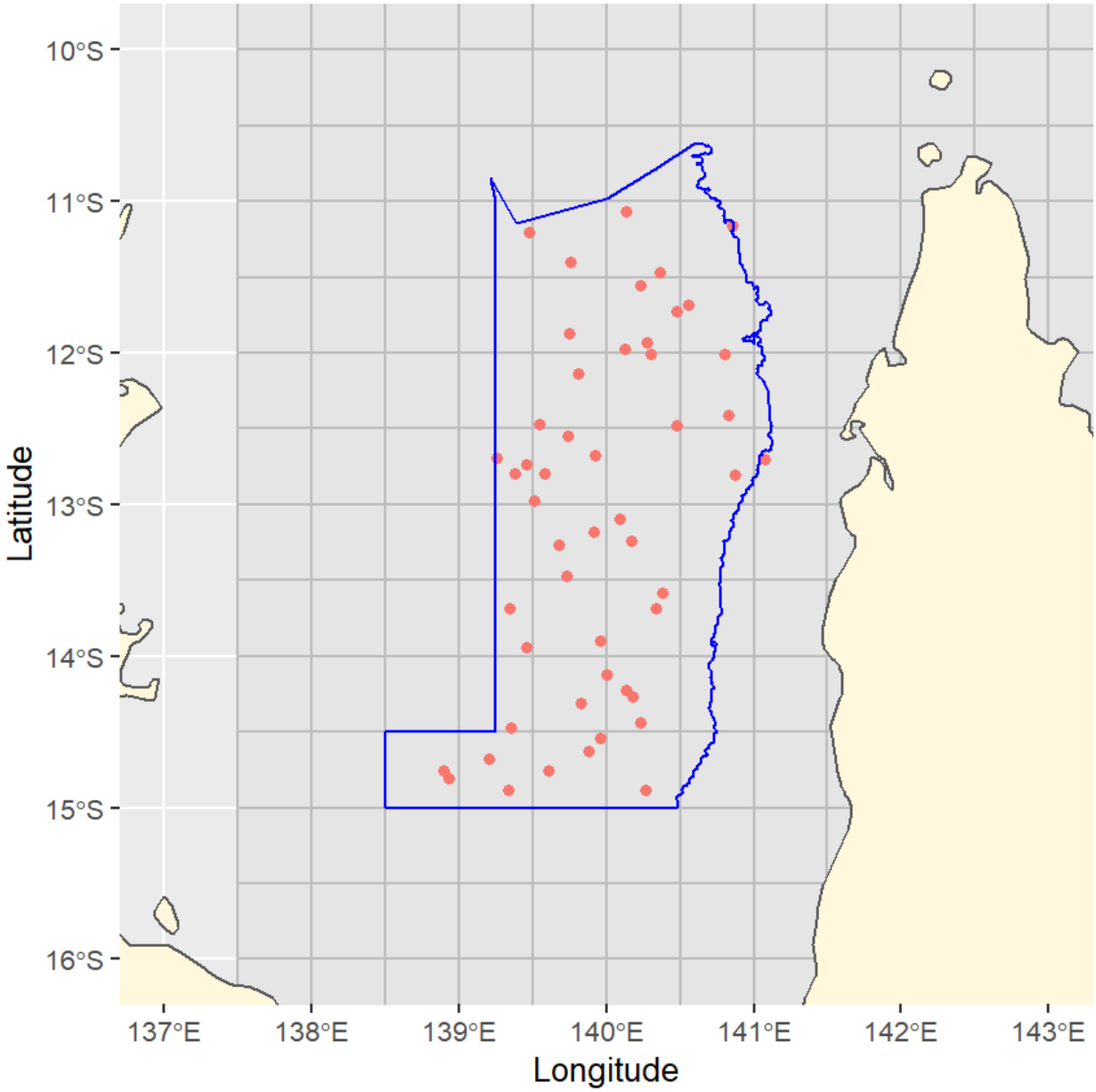

Figure 2. Survey start shot locations showing stratum boundary (blue). Note that the shot shown starting outside the stratum in the east was conducted within the stratum and considered a valid shot.

Calculation of Relative Biomass and CVs

Each survey shot provides a density estimate calculated by dividing the biomass of the catch of a particular species by the area swept. Mean density is then estimated with an associated coefficient of variation (CV) from all shots within each stratum:

$$Mean\ density = \frac{biomass\ captured}{area\ swept\ by\ net}$$

Total biomass can then be estimated (for each species) as the product of mean density and total area following a stratified random survey design (Schnute and Haigh, 2003; Knuckey *et al.*, 2021).

Determining the density

For shots where main species are present in the catch (non-zero measurements), the mean density for each stratum[1] (*h*) is

$$\mu_h = \frac{1}{n_h}\sum_{i=1}^{n_h}\mu_{hi}$$

The squared inverse of the coefficient of variation (CV) is

$$v_h = \mu_h^2 / s_h^2$$

The mean density of measurements for each stratum is

$$\delta_h = (1 - p_h)\mu_h$$

The variance of density of measurements each stratum is

$$\sigma_h = \sqrt{\left((1 - p_h)(1 + p_h v_h)\left(\mu_h^{\,2} / v_h\right)\right)}$$

The estimated biomass for each stratum *h* is

$$b_h = A_h \delta_h$$

The CV of the biomass estimate for each stratum is

$$cv_h = \sqrt{\sigma_h} / b_h\, n_h$$

Where p_h is the proportion of hauls with zero catch for the species in stratum *h*, μ_h is the mean weight in kilograms per area swept (m^2) of species where catch >zero, s_h is the standard kilograms per area swept (m^2) of species where catch >zero, A_h is the total area of stratum, n_h is the number of shots and b_h is the estimated relative biomass.

Total relative biomass (*B*) and CV for each species were calculated as follows:

[1] Note that this report includes the results of only one stratum of a larger survey that included numerous Northern Territory strata reported separately.

$$B = \sum_h b_h$$

$$cv = \sum_h cv_h$$

The number of shots, n_h, in each stratum that produced the desired coefficient of variation, cv_h, was randomly allocated within each stratum.

Relative biomass was estimated using the swept area method upscaling density of individual species caught and applying an estimate of the swept area of the trawl.

The density measure (weight per area swept) was estimated as follows:

$$\mu_{hi} = C_{hi} \Big/ v_{hi} d_{hi} E_{hi}$$

Where each shot *i* in stratum *h* has a known catch of C_{hi}, effort (shot duration hour) E_{hi}, vessel speed (m/hour) v_{hi} and effective trawl width d_{hi}. Thus, the biomass estimate is sensitive to the value of effective trawl width applied.

Swept area of the trawl

At its simplest, the swept area of a trawl tow can be calculated by multiplying the distance trawled by the width of the trawl. One of the greatest unknowns in most trawl fishing however, is the catchability of the gear, and the *effective* width of the trawl. These can be influenced by, among other factors, mesh size, the net configuration (including mesh size, headline height and length, footline length, ground gear configuration, floatation, sweeps, bridles, doors and warps) as well as the behaviour of fish (e.g. schooling, mobility, herding response) (Piasente et al., 2004). Two commonly used estimates for swept area are based on net width (the distance between the wings of the net or wing spread) and door width (the distance between the trawl doors). Both of these estimates can result in biased biomass estimates (Ramm and Xiao, 1995). Using wing spread (a smaller swept area) will overestimate biomass for species that are herded by the doors and sweeps, whereas using door width (a larger swept area) can under-estimate biomass. Both approaches are also potentially biased because they take no account of the fish that may swim over the headline, under the footline or escape through the meshes of the net.

Ramm (1992) considered catchability in his surveys as two different components, retention and effective trawl path. Based on information for lethrinids (family Lethrinidae) on the Northwest Shelf, the retention of large lutjanids may be high (90-100%), and herding may increase the effective path width of the trawl (30–60 m). He used these figures in estimations of biomass for Goldband Snapper and Saddletail Snapper, although he reported figures for effective trawl path-width ranging from 20–75 m and trawl retention from 10-100%.

In an experiment to measure effective trawl width (W_{eff}), Ramm and Xiao (1995) reported that for Saddletail Snapper caught with a trawl net with a door spread of 64 m and a wing spread of 15 m (headline = 26 m, footline 30 m (Ramm, 1997), the effective herding distance was 73.9 m and that the effective path width was 35.6 m. This was the only species for which a reliable estimate of herding parameters has been calculated.

In the absence of additional information on which to base the effective trawl path-width, we report values of biomass using three different options for calculating swept area (Figure 3):

1. Door spread. A conservative calculation that assumes all fish in the path of the trawl between the doors are caught;
2. Effective trawl path. An effective trawl path width calculated from equation 12 in Ramm and Xiao (1995), using their estimate of effective herd distance (73.9 m) for Saddletail Snapper only, calculated using the calculated wing spread and door spread from the current survey;
3. Wing spread. The least conservative calculation that assumes all fish in the path of the trawl between wings of the net are caught.

Further details are provided below.

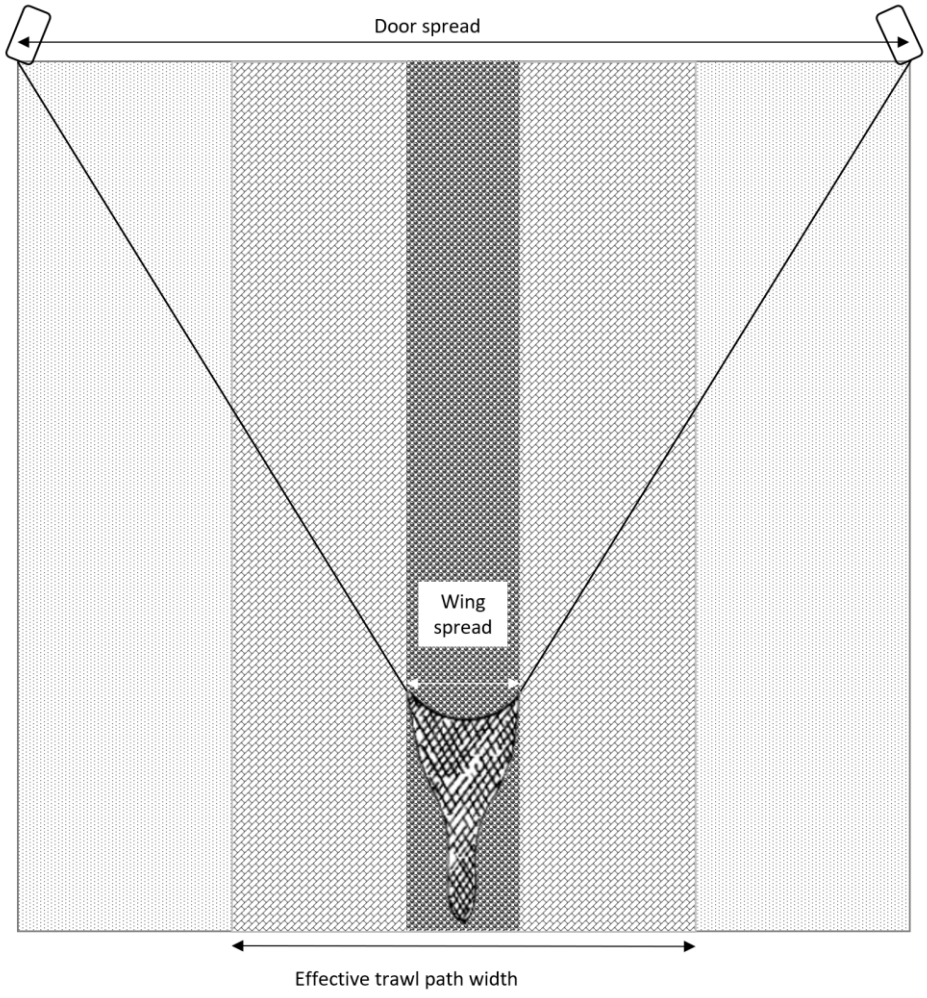

Figure 3. Illustration of the three options used to calculate swept area.

Door spread

This is often used in trawl surveys (e.g. MacGibbon, 2019), with the acknowledgement that the assumptions (that all fish in the water column are below the headline height and available to the net, that all fish in the area swept are caught and there is no escapement) are unlikely to be true, and therefore the biomass estimate is likely very conservative. In some studies where door spread is used to calculate absolute biomass (e.g. for Whiting (*Merlangius merlangus*) in Shephard *et al*.,

(2015)) a correction coefficient representing herding is applied. However, the correction coefficient needs to be measured experimentally.

During industry workshops two different figures for door spread were provided for two different depths: 70 m at a depth of 50 m and 96 m for a depth of 100 m.

The relationship between door spread and depth is often described by a simple logarithmic equation (e.g. see Arronte et al., 2021). A logarithmic equation was fitted to the two figures provided by industry resulting in the following:

$$DoorSpread = -76.74 + 37.51 \times \log(Depth)$$

Using the above relationship, door spread was calculated for each tow using the recorded depth.

Wing spread

Biomass estimates based on wing spread (the distance between the tips of the net wings) result in the largest biomass estimates. Wing spread is considered to be a realistic assumption of swept area for species which do not show herding behaviour (Walker et al., 2017).

The distance between wingtips was calculated using the following equation (from Seafish, 2010):

$$WingEndSpread = \frac{GroundGearLength \times DoorSpread}{BridleLength + GroundGearLength}$$

Where bridle length (135 m) was the combined bottom bridle (45 m) and sweep (90 m) lengths, door spread was as calculated above, and ground gear length was 33.6 m.

Effective trawl path

Ramm and Xiao (1995) showed an effect of herding on many tropical demersal species including Saddletail Snapper. From experiments where door width was changed, they calculated the "effective herding distance" to be 73.9 m for Saddletail Snapper (the only species for which reliable estimates of herding parameters could be obtained) over their range of experimental door widths (42.3 m to 80.6 m). From this, they calculated that the effective trawl path width W_{eff} for their net (headline length = 26 m, footrope = 30 m) when operating with a door spread of 60 m and a net opening (wing spread) of 15 m was 35.6 m for that species.

Using door spread and wing spread calculated from the methods described above, effective herding distance was calculated for each shot. Calculations were done using the R code below (based on code provided by Michael O'Neill, QDAF).

```
weffCum<-data.frame(Set.Id=numeric(), Weff = numeric())
for(i in 1:nrow(WeffDF)) {       # for-loop over rows
  shot <- WeffDF[i, ]
W=shot$W
D=shot$D
H=shot$H
      #We know 3 values to construct the linear line on the x-axis; 0 and H/2 here was the Ramm model;
  x=c(W, median(c(W, H)), H)
  y=c(1, 0.5, 0) #We know 3 retention probabilities to construct the linear line on the x-axis
    # Step 3
  # Integrate over the linear model to calculate effective trawl width
  d <- data.frame(x, y) #Put the data into a Table format
  mdl<-lm(data=d,y ~ x)#linear model
     pred<-data.frame(x=seq.int(from=0,to=H,by=.001))# Setup x-values for prediction. This is a sequence of numbers
from zero to H.
  pred$y<-predict(mdl,newdata =pred)
  pred$y<-with(pred, ifelse(y>1,1,
                            ifelse( x>D,0,y))) ##Restrict maximum of y to 1 for net width and sets y to 0 for outside of door spread
  retention =sum(pred$y)/length(pred$y)
    weff = H * 2 * retention
  weffadd<-c(Set.Id=c(shot[,c(1)]), Weff=weff)
     weffCum<-rbind(weffCum,weffadd)
}
colnames(weffCum) <- c('Set.Id', 'Weff')
```

This effective trawl width is used as a less conservative but more realistic biomass estimate than door width for at least for Saddletail Snapper. Although Ramm and Xiao (1995) did not provide estimates of herding distances to enable calculation of W_{eff} for other species, they did find evidence of herding in many other species including, of relevance for this study, Painted Sweetlips. Catches of Crimson Snapper, Golden Snapper, Red Emperor and Redspot Emperor showed no significant correlation with door spread (herding). For those species with no evidence of herding, the use of W_{eff} may still be conservative.

Other Species Quota Basket

Teleosts, other than quota species and restricted species are managed as a quota basket called OS GOC. We assigned species to the OS GOC category based on the following criteria:

- CSIRO code =>37053000 (the lowest of all teleosts caught in the survey) & CSIRO code <38000000
- Species is not in the following list: Crimson Snapper, Saddletail Snapper, Mangrove Jack, Golden Snapper, Red Emperor, Barramundi, Black Jewfish, Black Pomfret, Spanish Mackerel. Note, no tuna or tuna like species, billfish, Queenfish, King Salmon, Blue Salmon, or Grey Mackerel were caught during the survey.

Quality Assurance

All data were recorded in an observer version of ORLAC Dynamic Data Logger (DDL), which includes quality assurance protocols including automatic data capture (time, date and position), field restrictions, range checks, mandatory fields and lookup tables. All data were manually error checked against data sheets before loading into the shore version of ORLAC DDL. The database is regularly backed up and used to extract data for analyses.

All analyses were undertaken using R (R Core Team, 2022).

Results and their interpretations and conclusions were discussed amongst the research team and QDAF. Draft reports were reviewed by all co-authors and made available to QDAF members for comment. Where required, comments were addressed in preparation of the final report.

Results and Discussion

Survey Coverage

The GOCDFFTF tropical snapper survey was conducted over two trips between 26th April 2021 and 19th May 2021, involving 20 survey days (24 sea days) during which 50 shots were completed (Table 1). The total survey area was about 83,524 km^2 (Figure 2). The mean depth surveyed was 58.1 m, whereas the mean shot duration, speed, distance and swept areas (Weff) were 1.5 hours, 3.5 knots, 9.85 km and 0.438 km^2 respectively (Table 2).

Table 1. Ports of departure and return, start and end trip dates and shots undertaken during each trip.

Port of Departure	Start Trip Date	Port of Return	End Trip Date	Number of shots
Karumba	26/04/2021	Karumba	9/05/2021	32
Karumba	10/05/2021	Karumba	19/05/2021	18

Table 2. Mean and standard deviation (SD) depth fished (m), tow duration (hours), tow speed (knots), tow distance (km) and swept area (km^2) of shots during the 2021 survey. Area swept calculated using the three options described in methods.

Measure	Mean	SD
Depth (m)	58.1	3.5
Tow duration (hours)	1.5	0.0
Tow speed (kts)	3.5	0.1
Tow distance (km)	9.85	0.41
Area swept (km2) – Door Width	0.743	0.038
Area swept (km2) – Effective Path Width	0.438	0.018
Area swept (km2) – Wing Spread	0.148	0.007

Catch composition

The total catch from the 50 shots undertaken during the 2021 survey was 42.2 t, and comprised 196 different species or species groups. Catch of main species are shown in Table 3, while catches of all species are shown in Appendix 1. Quota species caught were Crimson Snapper 11.9 t (28.3%), Saddletail Snapper 10.6 t (25.1%), Red Emperor 0.3 t (0.8%), Golden Snapper 1.3 t (3%) and Mangrove Jack 0.8 t (1.9%). Other main species caught were Painted Sweetlips

2.1 t (5%), Goldband Snapper 1.7 t (3.9%) and Longnose Trevally 1.2 t (2.7%) (

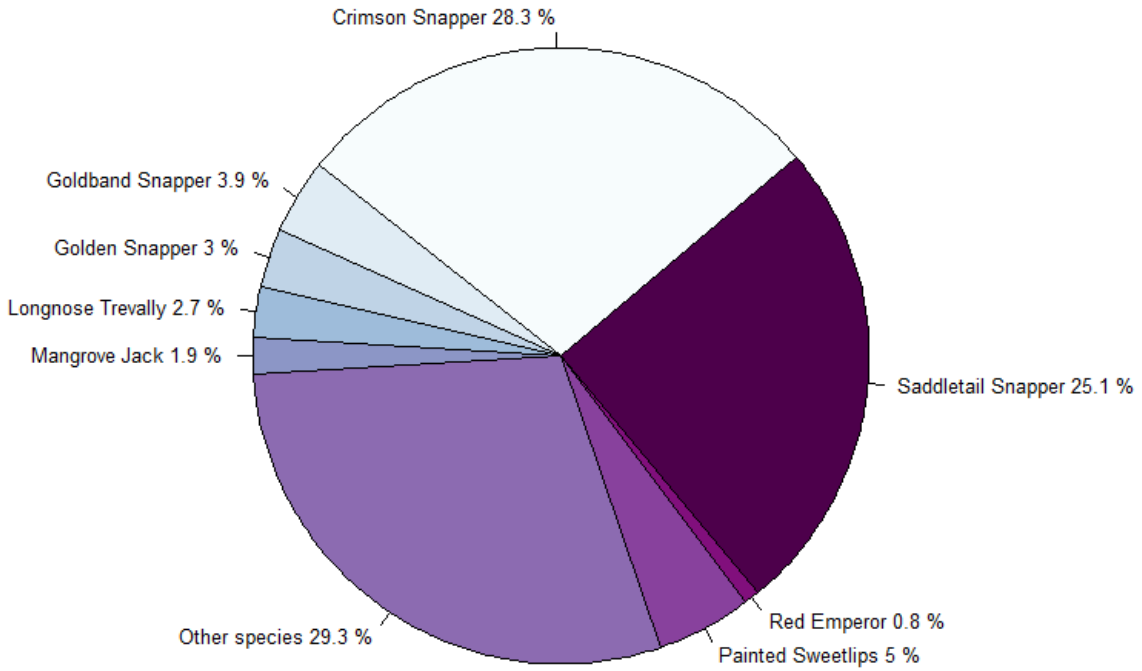

Figure 4). Densities of main species in each shot are shown in are shown in Figure 5 to Figure 9, and densities of each main species in each stratum is shown in Appendix 2. A map of percent composition of the six quota species/groups is shown in Figure 10.

Large single-shot catches (>500 kg) were recorded for Crimson Snapper, Saddletail Snapper and Golden Snapper and catches of all species were skewed right with numerous small catches (Figure 11). Of the main species caught, those that were observed in the greatest number of shots were Saddletail Snapper (48 shots), Painted Sweetlips (45), Goldband Snapper (43) and Redspot Emperor (37), whereas Black Jewfish were observed in only one shot (Table 4).

Table 3. Total catch (kg) of primary and secondary species caught during the 2021 survey.

COMMON NAME	SCIENTIFIC NAME	CAAB Code	Catch (kg)
Crimson Snapper	*Lutjanus erythropterus*	37346005	11942.1
Saddletail Snapper	*Lutjanus malabaricus*	37346007	10600.3
Painted Sweetlips	*Diagramma pictum*	37350003	2095.8
Goldband Snapper	*Pristipomoides multidens*	37346002	1658.3
Golden Snapper	*Lutjanus johnii*	37346030	1277.6
Mangrove Jack	*Lutjanus argentimaculatus*	37346015	802.9
Redspot Emperor	*Lethrinus lentjan*	37351007	628.3
Red Emperor	*Lutjanus sebae*	37346004	325.2
Black Jewfish	*Protonibea diacanthus*	37354003	4.0

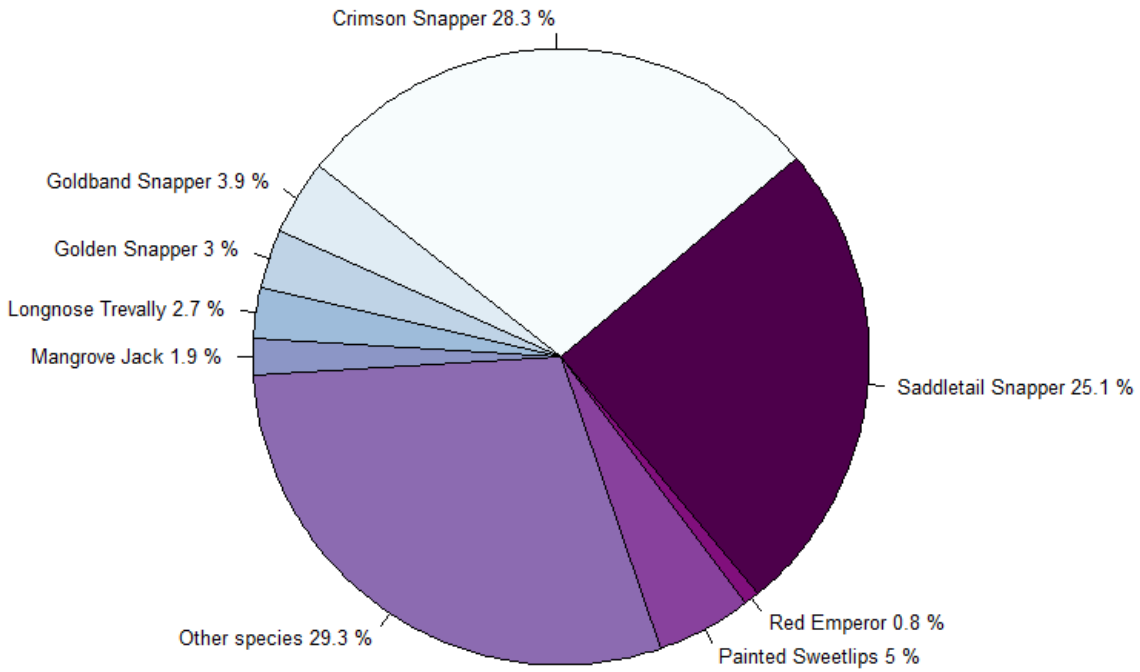

Figure 4. Percent weight (total catch 42.2 t) of species of interest and major species caught during the 2021 survey. Note that Black Jewfish is not shown here because they were only caught in one shot and made up a very small proportion of the catch.

Relative biomass

Using a swept area based on the calculated effective trawl width (Weff), biomass estimates were 46,205 t for Crimson Snapper, 40,996 t for Saddletail Snapper, 6,331 t for Goldband Snapper, 8,052 t for Painted Sweetlips, 2,385 t for Redspot Emperor, 1,247 t for Red Emperor, 3,051 t for Mangrove Jack, 4,769 t for Golden Snapper and 46,960 t for OS GOC (Table 4). This option is used to provide realistic estimates of biomass for quota Snapper species and other important byproduct species. However, for species such as Crimson Snapper, Golden Snapper, Red Emperor and Redspot Emperor, which do not show evidence of herding behaviour, the biomass estimates provided with this option may be considered conservative.

Using a swept area based on the calculated wing spread (i.e. no herding behaviour) yields biomass estimates of 135,875 t for Crimson Snapper, 121,257 t for Saddletail Snapper, 18,692 t for Goldband Snapper, 24,045 t for Painted Sweetlips, 7,114 t for Redspot Emperor, 3,704 t for Red Emperor, 8,950 t for Mangrove Jack, 13,926 t for Golden Snapper and 139,067 t for OS GOC (Table 4).

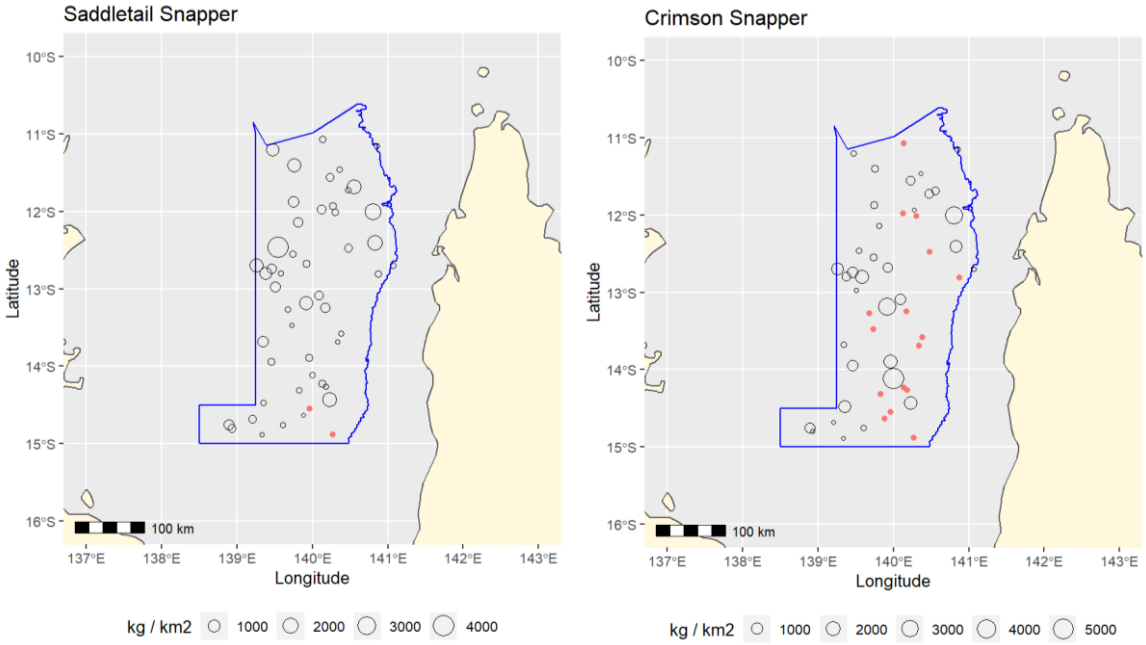

Figure 5. Density (kg/km2) of Saddletail Snapper and Crimson Snapper caught during the survey. Red dots show shot locations where 0 kg catches were recorded. Densities were calculated using W_{eff}.

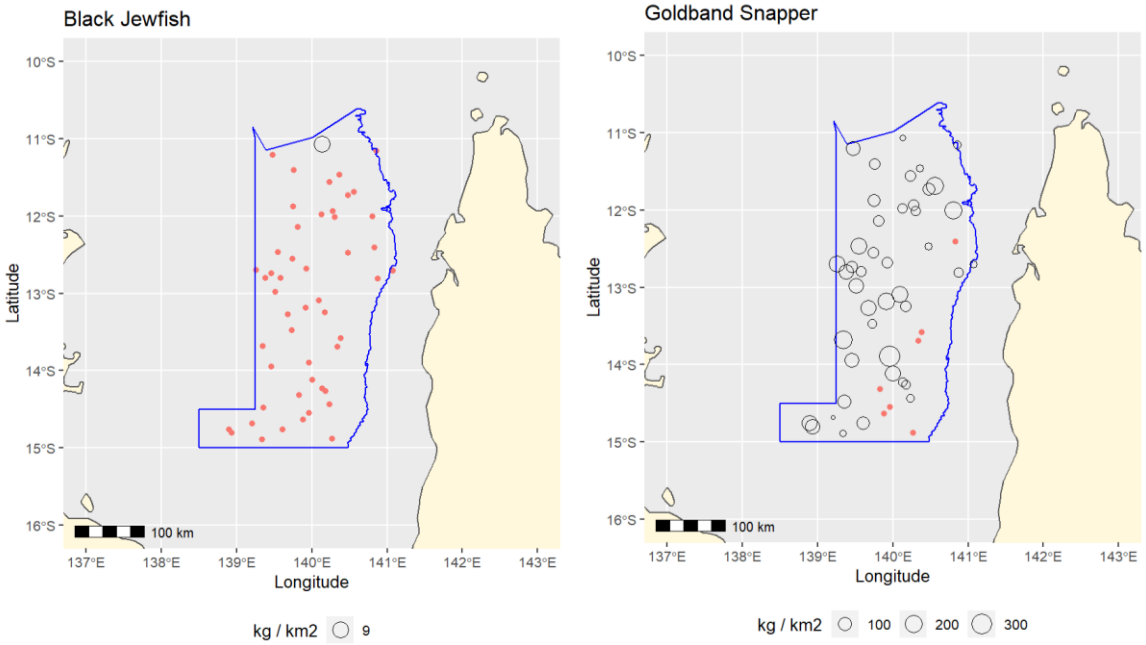

Figure 6. Density (kg/km2) of Black Jewfish and Goldband Snapper caught during the survey. Red dots show shot locations where 0 kg catches were recorded. Densities were calculated using W_{eff}.

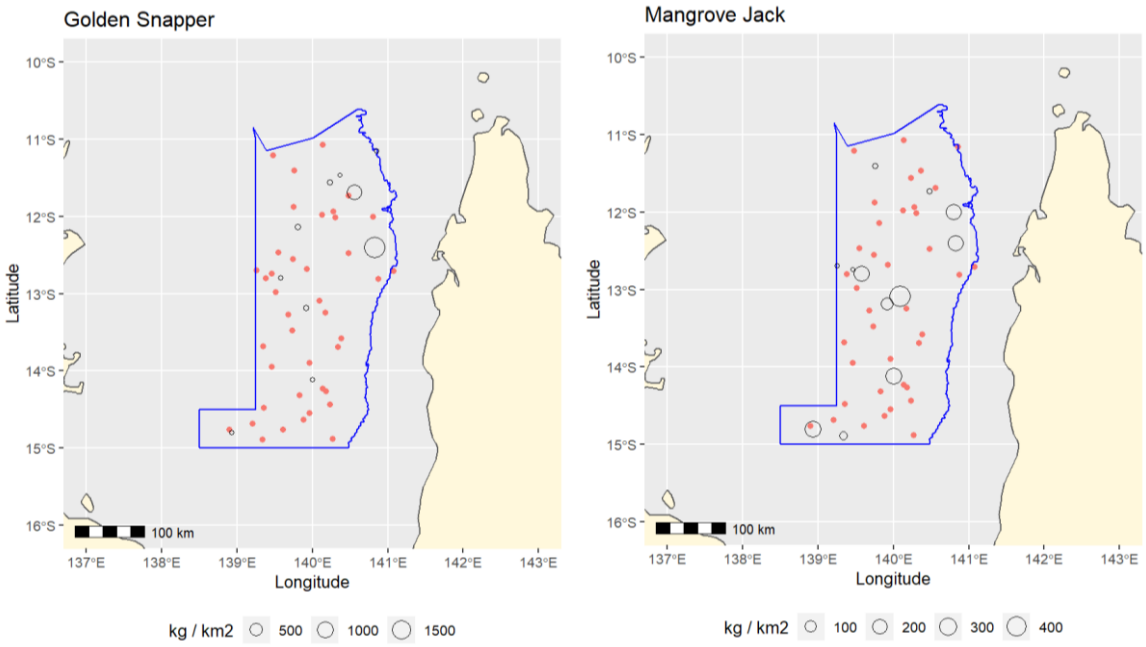

Figure 7. Density (kg/km2) of Golden Snapper and Mangrove Jack caught during the survey. Red dots show shot locations where 0 kg catches were recorded. Densities were calculated using W_{eff}.

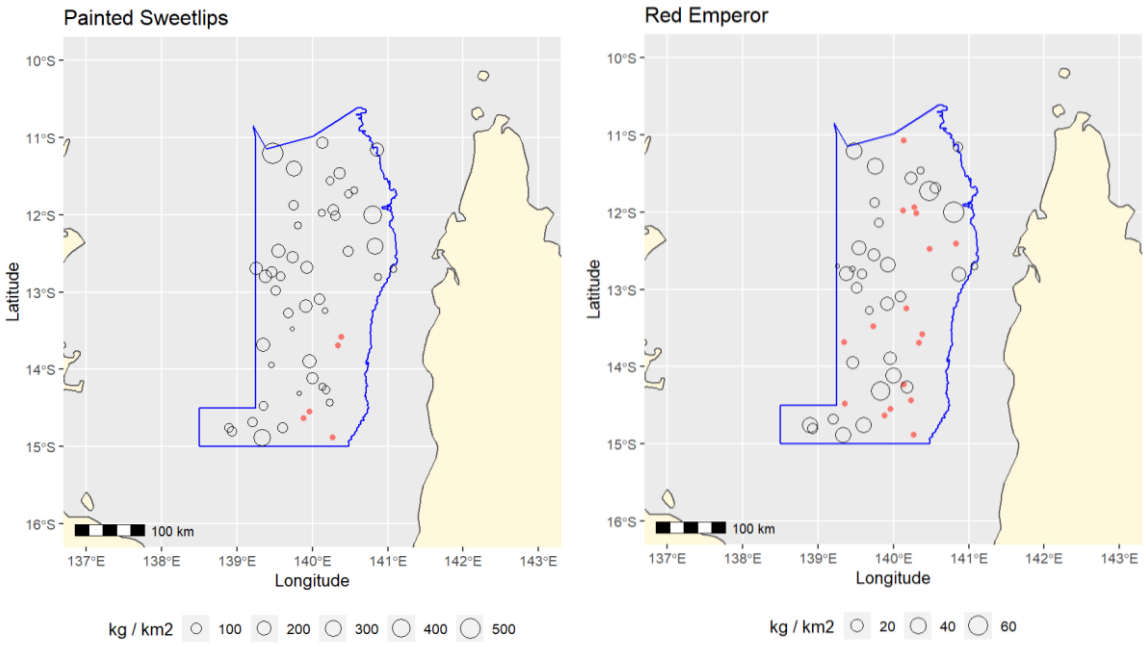

Figure 8. Density (kg/km2) of Painted Sweetlips and Red Emperor caught during the survey. Red dots show shot locations where 0 kg catches were recorded. Densities were calculated using Weff.

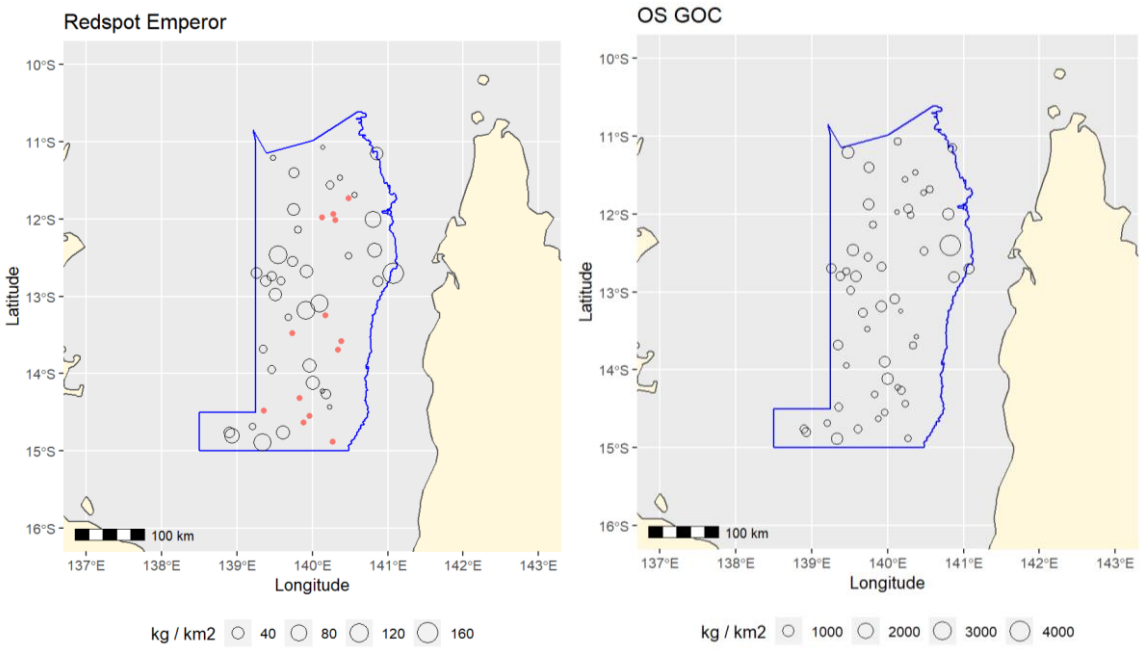

Figure 9. Density (kg/km2) of Redspot Emperor and OS GOCcaught during the survey. Red dots show shot locations where 0 kg catches were recorded. Densities were calculated using W_{eff}.

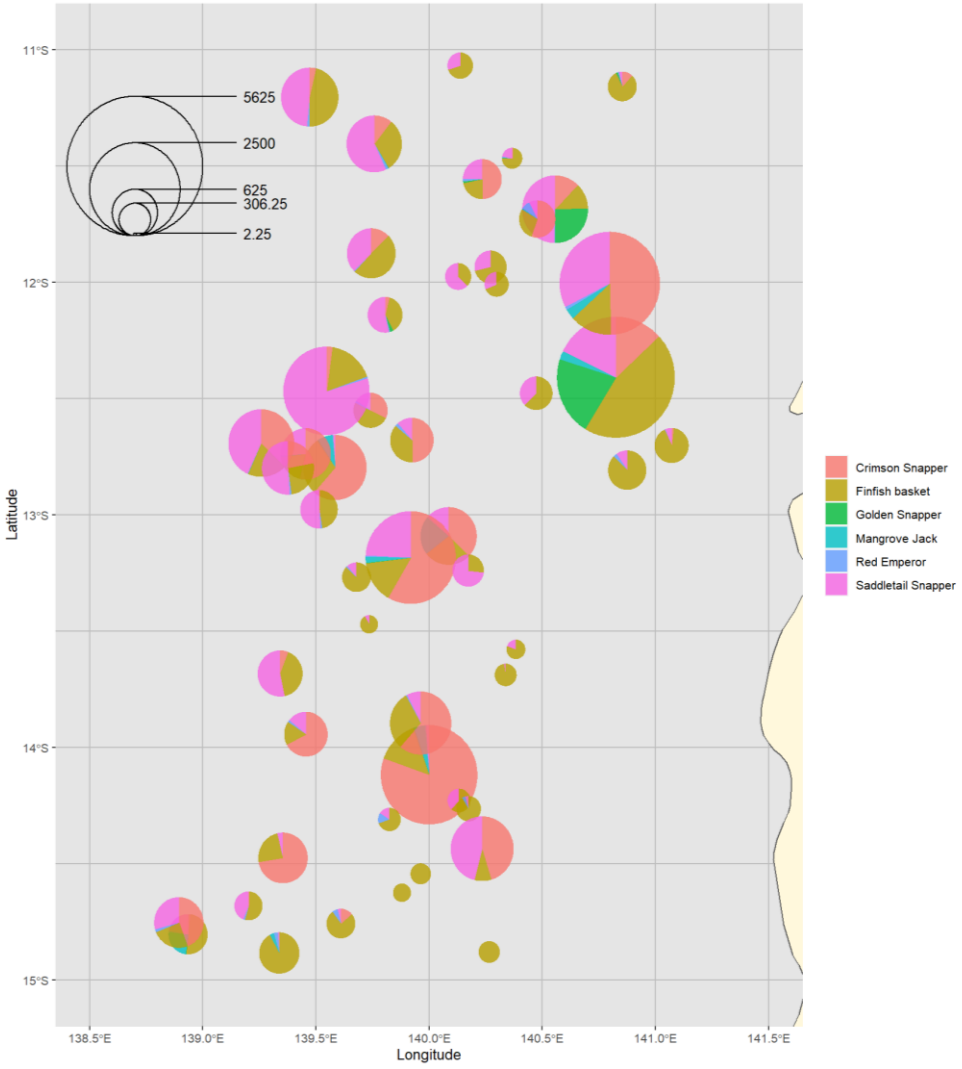

Figure 10. Relative percent composition of quota species and OS GOC in each shot. The size of pie charts is scaled by the total catch (kg) of those six quota species/groups.

Table 4. Estimated total relative biomass (t) with coefficient of variation (CV) of major commercial species within with the three different assumptions for trawl swept area.

Species	Number of shots caught	Relative biomass estimate (t) Door spread	Relative biomass estimate (t) Wing spread	Relative biomass estimate (t) W_{eff}	CV
Crimson Snapper	34	27,078	135,875	46,205	0.27
Saddletail Snapper	48	24,165	121,257	40,996	0.22
Goldband Snapper	43	3,725	18,692	6,331	0.14
Painted Sweetlips	45	4,792	24,045	8,052	0.16
Redspot Emperor	37	1,418	7,114	2,385	0.19
Red Emperor	33	738	3,704	1,247	0.17
Mangrove Jack	12	1,784	8,950	3,051	0.37
Black jewfish	1	9	47	16	NA
Golden Snapper	10	2,775	13,926	4,769	0.77
OS GOC	50	27,714	139,067	46,960	0.15

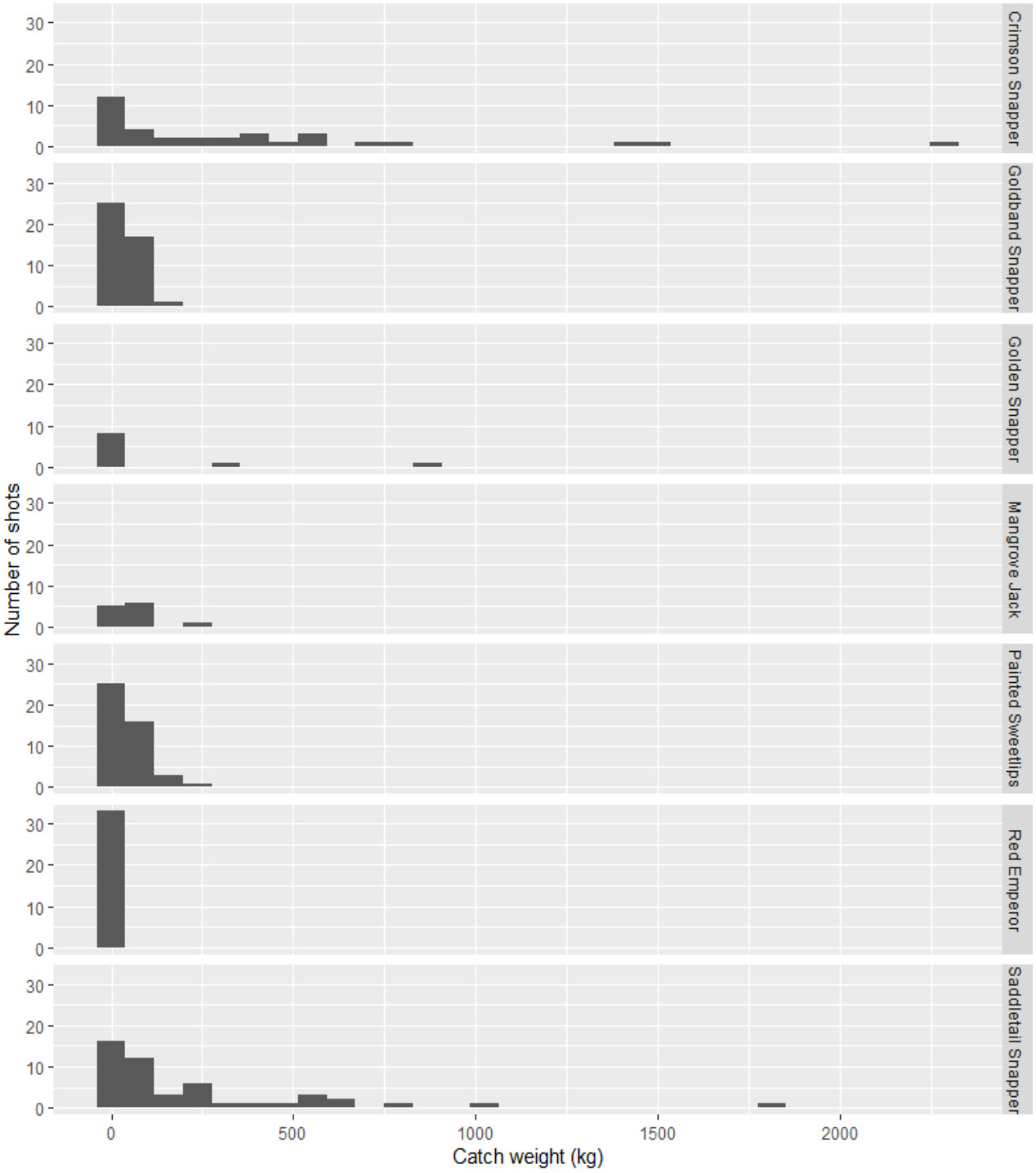

Figure 11. Frequency of catch weight of main species. Note that Black Jewfish is not shown here because they were only caught in one shot.

Length frequencies

The number of lengths of fish measured during the 2021 survey is shown in Table 5. Lengths of Crimson Snapper ranged 22 cm – 47 cm (Figure 12). Saddletail Snapper were caught over a much wider range of lengths from 15 cm – 62 cm. Golden Snapper and Mangrove Jack comprised mostly large fish greater than 45 cm and, although a wide range of lengths was recorded for Goldband Snapper, Painted Sweetlips and Red Emperor, most fish were smaller than 35 cm. Length frequency of Redspot Emperor ranged from 21 – 41 cm.

A total of 449 DNA samples was collected from six different species (Table 5). These samples have been provided to QDAF.

Table 5. Species and numbers of fish for which length was measured, and number of DNA samples collected and provided to QDAF during 2021 survey.

Species	Number of lengths measured	Number of DNA samples collected
Crimson Snapper	448	99
Saddletail Snapper	417	166
Goldband Snapper	380	129
Painted Sweetlips	222	
Redspot Emperor	154	
Red Emperor	150	97
Mangrove Jack	200	39
Golden Snapper	100	18

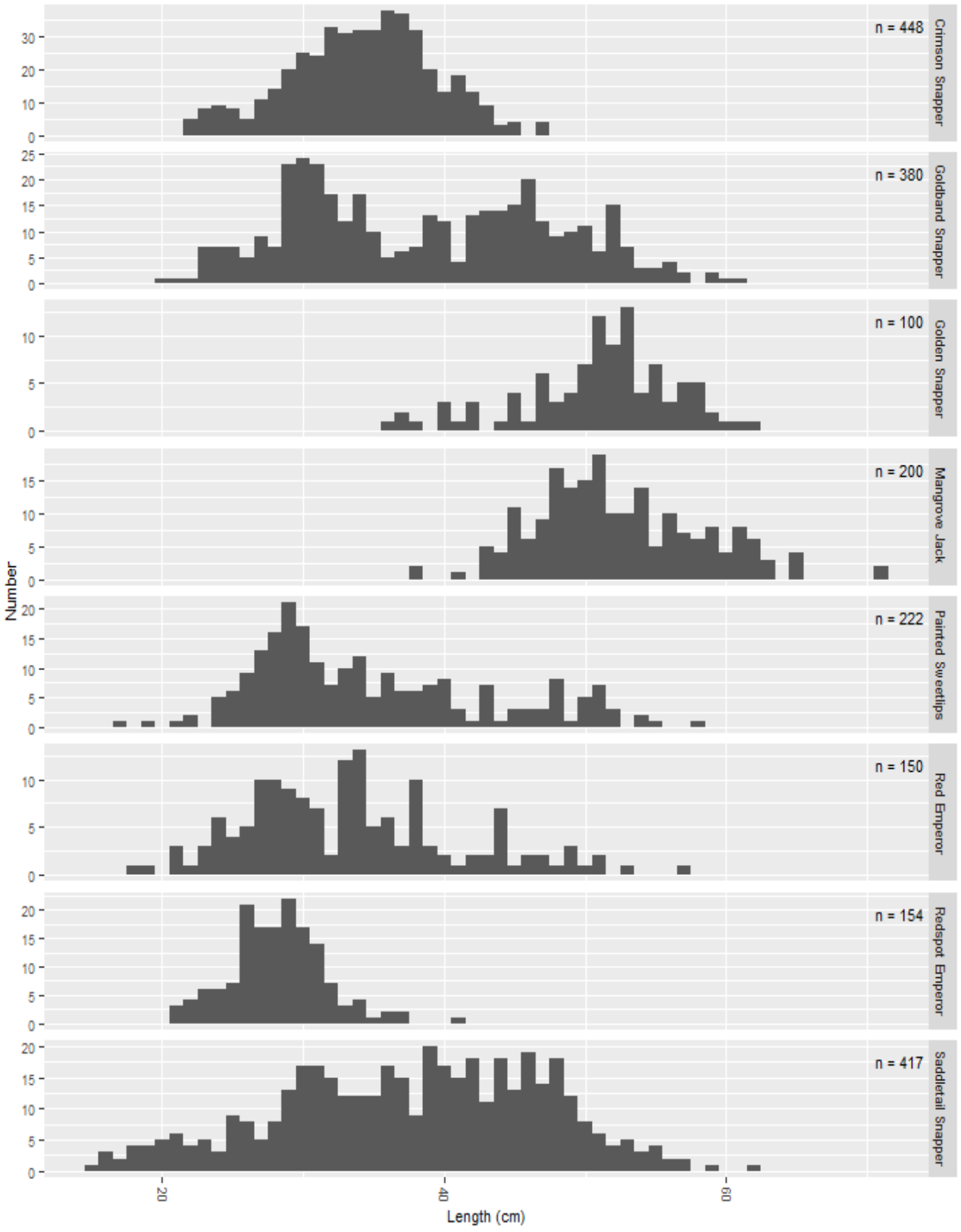

Figure 12. Length-frequencies (total length) of quota species and some other main species caught during the 2021 survey. Number of fish measured is annotated.

Species of Conservation Interest (SOCIs)

To improve accuracy of data collected during this survey, fishing was conducted without a turtle excluder device (TED). Species of conservation interest (SOCIs) were reported from four different shots (Table 6). From the shot undertaken on 26/4/2021 starting at 06:49, one Loggerhead Turtle weighing an estimated 30 kg was caught and released alive, and one Elegant Seasnake weighting an estimated 0.1 kg was caught and released alive. From the shot undertaken on 4/5/2021 starting at 16:13, one Elegant Seasnake weighing an estimated 0.1 kg was caught and released alive. From the shot undertaken on 7/5/2021 starting at 17:00, one unknown species of sea turtle weighing an estimated 50 kg was caught and released alive. From the shot undertaken on 16/5/2021 starting at 14:36, one Pygmy Devilray weighting an estimated 3 kg was caught and released dead.

Table 6. SOCI species caught during 2021 biomass survey.

Species	Scientific Name	Species Csiro	Start Date	Start Time	Start Latitude	Start Longitude	Green Weight (kg)
Loggerhead Turtle	*Caretta caretta*	39020001	2021-04-29	06:49	-12.70233	141.07164	30
Elegant Seasnake	*Hydrophis elegans*	39125021	2021-04-29	06:49	-12.70233	141.07164	0.1
Elegant Seasnake	*Hydrophis elegans*	39125021	2021-05-04	16:13	-12.00916	140.29863	0.1
Sea Turtles - und	*Cheloniidae & dermochelyidae*	39020000	2021-05-07	17:00	-14.31091	139.82493	50
Pygmy Devilray	*Mobula eregoodootenkee*	37041001	2021-05-16	14:36	-13.94383	139.45624	3

Conclusions

The 2021 biomass survey of eastern Gulf of Carpentaria within the GOCDFFTF was successfully undertaken with 50 valid shots completed in line with the survey design. The survey revealed abundant stocks of snapper with single-shot catches of at least two quota species (Crimson Snapper and Saddletail Snapper) often exceeding 500 kg.

Biomass estimates are dependent on the assumptions of trawl swept area and the vulnerability of snapper to the trawl gear. Based on the most conservative assumption — that the trawl swept area is equivalent to the door width (i.e. all snapper between the doors are caught in the net) — biomass estimates (within the eastern Gulf of Carpentaria stratum) for the five quota species are: Crimson Snapper (27,078 t), Saddletail Snapper (24,165 t), Red Emperor (738 t), Mangrove Jack (1,784 t), Golden Snapper (2,775 t), and OS GOC (27,714 t). Estimates were generally precise (CVs < 0.3) except for Mangrove Jack (CV 0.37) and Golden Snapper (CV 0.77).

Herding is known to occur for some tropical snapper species and effective trawl path width has been measured previously for Saddletail Snapper. Based on a calculated effective trawl path for trawl swept area, biomass estimates (within the eastern Gulf of Carpentaria stratum) for the five quota species are: Crimson Snapper (46,205 t), Saddletail Snapper (40,996 t), Red Emperor (1,247 t), Mangrove Jack (3,051 t), Golden Snapper (4,769 t) and OS GOC (46,960 t). These estimates are considered conservative at least for Crimson Snapper, Red Emperor, Golden Snapper and Redspot Emperor, species which show no evidence of herding behaviour.

The lengths of most quota species were within a relatively small range (e.g. Crimson Snapper 22-47 cm) except for Saddletail Snapper (which ranged from 15 to 62 cm in length).

There was little interaction of trawling with species of conservation interest with only four encounters recorded over 50 shots.

Acknowledgments

We thank the owners of Australia Bay 2 and the skipper Leigh Claydon and the crew for their professional approach to conducting the 2021 survey. We than Grant Johnson (NT DPI) who was the observer working with Russell Hudson, for assistance with data collection and help with organising the trip. Particular thanks to Australia Bay General Manager, Mike O'Brien for helping coordinate the vessel, survey gear and operation of the survey trip. Eddie Jebreen and Jason McGilvray from QDAF organised the DNA sampling equipment. Michael O'Neill (QDAF) provided comments on the draft including assistance with the code for calculation of effective trawl width.

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Appendix 1 Total catch (kg) of all species caught during the 2021 survey.

COMMON NAME	SCIENTIFIC NAME	CAAB Code	Catch (kg)
Crimson Snapper	*Lutjanus erythropterus*	37346005	11942.1
Saddletail Snapper	*Lutjanus malabaricus*	37346007	10600.3
Painted Sweetlips	*Diagramma pictum*	37350003	2095.8
Goldband Snapper	*Pristipomoides multidens*	37346002	1658.3
Golden Snapper	*Lutjanus johnii*	37346030	1277.6
Mangrove Jack	*Lutjanus argentimaculatus*	37346015	802.9
Redspot Emperor	*Lethrinus lentjan*	37351007	628.3
Red Emperor	*Lutjanus sebae*	37346004	325.2
Black Jewfish	*Protonibea diacanthus*	37354003	4.0
Longnose Trevally	*Carangoides chrysophrys*	37337011	1152.9
Sponge (U)	*Grantiidae - undifferentiated*	10216000	896.4
Jenkins' Whipray	*Pateobatis jenkinsii*	37035025	727.0
Malabar Trevally	*Carangoides malabaricus*	37337005	628.0
Bigeye Trevally	*Caranx sexfasciatus*	37337039	603.5
Common Saury	*Saurida tumbil*	37118028	561.4
Whitespotted Guitarfish	*Rhynchobatus australiae*	37026005	534.7
Whitecheek Shark	*Carcharhinus coatesi*	37018009	513.5
School Mackerel	*Scomberomorus queenslandicus*	37441014	446.6
Starry Triggerfish	*Abalistes stellatus*	37465011	438.3
Reticulate Whipray	*Himantura australis*	37035003	370.0
Black Pomfret	*Parastromateus niger*	37337072	351.1
Red Squirrelfish	*Sargocentron rubrum*	37261001	325.6
Catfish - Undifferentiated	*Arius* spp.	37188901	281.2
Frypan Bream	*Argyrops bleekeri*	37353006	263.5
Redtail Scad	*Decapterus kurroides*	37337056	248.6
Moses' Snapper	*Lutjanus russellii*	37346065	208.5
Shortfin Batfish	*Zabidius novemaculeatus*	37362003	188.9
Rough Golden Toadfish	*Lagocephalus lunaris*	37467012	175.7
Blackspotted Whipray	*Maculabatis astra*	37035020	155.3
Mouth Mackerel	*Rastrelliger kanagurta*	37441012	155.3
Barred Javelin	*Pomadasys kaakan*	37350011	142.0
Golden Trevally	*Gnathanodon speciosus*	37337012	132.2
Spot-Tail Shark	*Carcharhinus sorrah*	37018013	123.3
Brownstripe Snapper	*Lutjanus vitta*	37346003	121.7
Cobia	*Rachycentron canadum*	37335001	113.2
Weasel Shark	*Hemigaleus australiensis*	37018020	109.2
Blackbanded Amberjack	*Seriolina nigrofasciata*	37337014	107.0
Australian Butterfly Ray	*Gymnura australis*	37037001	106.4
Zebra Shark	*Stegostoma tigrinum*	37013006	105.0
Spanish Mackerel	*Scomberomorus commerson*	37441007	102.1
Purplespotted Bigeye	*Priacanthus tayenus*	37326003	99.9
Smalleye Stingray	*Megatrygon microps*	37035028	90.6
Goldspotted Rockcod	*Epinephelus coioides*	37311007	88.9
Spotted Sardine	*Amblygaster sirm*	37085006	88.7
Finny Scad	*Megalaspis cordyla*	37337028	81.9
Sea Turtles - Undifferentiated	Cheloniidae - undifferentiated	39020000	80.0
Mauvelip Threadfin Bream	*Nemipterus mesoprion*	37347026	79.2
Hardnose Shark	*Carcharhinus macloti*	37018025	77.5
Cuttlefish (U)	*Sepiidae* - undifferentiated	23607000	77.4
Unicorn Leatherjacket	*Aluterus monoceros*	37465022	72.6
Pickhandle Barracuda	*Sphyraena jello*	37382004	69.0
Bigeye Scad	*Selar crumenophthalmus*	37337009	67.8
Bug	*Ibacus* spp. & *Thenus* spp.	28821904	66.2
Opalescent Goatfish	*Parupeneus heptacanthus*	37355004	64.9
Oxeye Scad	*Selar boops*	37337008	61.3

COMMON NAME	SCIENTIFIC NAME	CAAB Code	Catch (kg)
Rosy Threadfin Bream	*Nemipterus furcosus*	37347005	59.4
Benthos	Undefined		56.3
Smallmouth Scad	*Alepes apercna*	37337010	54.6
Blacktip Tripodfish	*Trixiphichthys weberi*	37464001	52.7
Australian Blacktip Shark	*Carcharhinus tilstoni*	37018014	49.8
Silvermouth Trevally	*Ulua aurochs*	37337041	43.5
Rainbow Monocle Bream	*Scolopsis monogramma*	37347006	41.9
Shark Ray	*Rhina ancylostoma*	37026002	40.0
Bluespotted Maskray	*Neotrygon australiae*	37035004	34.4
Brassy Trevally	*Caranx papuensis*	37337064	33.4
Blacktip Sharks	*Carcharhinus limbatus* & *Carcharhinus tilstoni*	37018903	33.0
Swallowtail Seabream	*Gymnocranius elongatus*	37351010	30.9
Blackfin Barracuda	*Sphyraena qenie*	37382009	30.7
Stingray (U)	Dasyatidae - undifferentiated	37035000	30.0
Loggerhead Turtle	*Caretta caretta*	39020001	30.0
Eyebrow Wedgefish	*Rhynchobatus palpebratus*	37026004	27.7
Longspine Porcupinefish	*Tragulichthys jaculiferus*	37469004	27.2
Tasselled Wobbegong	*Orectolobus floridus*	37013021	27.0
Sunrise Goatfish	*Upeneus sulphureus*	37355007	25.6
Flutemouth (U)	*Fistulariidae* - undifferentiated	37278000	24.9
Yellowstripe Scad	*Selaroides leptolepis*	37337015	24.8
Whitemouth Trevally	*Uraspis uraspis*	37337020	23.5
Leopard Whipray	*Himantura leoparda*	37035026	22.8
Razor Moonfish	*Mene maculata*	37340001	21.5
Banded Eagle Ray	*Aetomylaeus caeruleofasciatus*	37039002	19.9
Shortnose Boxfish	*Ostracion nasus*	37466005	18.8
Black Rabbitfish	*Siganus fuscescens*	37438001	17.5
Milk Shark	*Rhizoprionodon acutus*	37018006	17.2
Barracuda - Undifferentiated	*Sphyraena* spp.	37382901	16.9
Fossil Shark	*Hemipristis elongata*	37018011	16.1
Soft Coral (U)	*Alcyoniidae* - undifferentiated	11176000	16.0
Scads (Decapterus) - Undifferentiated	*Decapterus* spp.	37337901	15.8
Onion Trevally	*Carangoides caeruleopinnatus*	37337021	14.9
Algae - Undifferentiated	Undefined		14.7
Spangled Emperor	*Lethrinus nebulosus*	37351008	12.3
Remoras - Undifferentiated	Echeneidae - undifferentiated	37336000	11.6
Spinycheek Grunter	*Terapon puta*	37321006	10.9
Lunartail Bigeye	*Priacanthus hamrur*	37326005	10.5
Bigeye Snapper	*Lutjanus lutjanus*	37346008	10.5
Trevally (U)	Carangidae - undifferentiated	37337000	10.0
Threadfin Leatherjacket	*Paramonacanthus filicauda*	37465024	9.5
Manyspot Leatherjacket	*Thamnaconus tessellatus*	37465026	9.3
Squid - Undifferentiated	*Loligo* spp.	23617907	9.2
Scalloped Hammerhead	*Sphyrna lewini*	37019001	8.7
Bigtooth Twinspot Flounder	*Pseudorhombus diplospilus*	37460015	8.5
Coral Trout - Undifferentiated	*Plectropomus* spp.	37311940	8.4
Giant Herring (U)	Elopidae - undifferentiated	37053000	7.9
Threadfin Bream - Undifferentiated	*Nemipterus* spp.	37347901	7.5
Common Silverbiddy	*Gerres subfasciatus*	37349005	7.2
Plain Porcupinefish	*Cyclichthys hardenbergi*	37469008	7.2
Australian Halibut	*Psettodes erumei*	37457001	7.1
Longraker Trevally	*Ulua mentalis*	37337048	6.8
Shell	Undefined		6.5
Paddletail	*Lutjanus gibbus*	37346028	6.2
Humpback Turretfish	*Tetrosomus gibbosus*	37466006	6.1
Smalltooth Flounder	*Pseudorhombus jenynsii*	37460002	6.0
Silver Trevally	*Pseudocaranx georgianus*	37337062	5.9
Silverbiddies - Undifferentiated	*Gerreidae* - undifferentiated	37349000	5.7
Whitecheek Monocle Bream	*Scolopsis vosmeri*	37347018	5.5
Goatfish (U)	*Mullidae* - undifferentiated	37355000	5.5
Humphead Batfish	*Platax batavianus*	37362002	5.4
Blackspot Whiptail	*Lucigadus nigromaculatus*	37232005	5.1

COMMON NAME	SCIENTIFIC NAME	CAAB Code	Catch (kg)
Yellowtail Scad	*Trachurus novaezelandiae*	37337003	4.9
Common Ponyfish	*Leiognathus equula*	37341014	4.5
Coralfish - Undifferentiated	Chaetodontidae - undifferentiated	37365900	4.3
Diamond Trevally	*Alectis indica*	37337038	4.3
Common Coral Trout	*Plectropomus leopardus*	37311078	4.2
Sixband Angelfish	*Pomacanthus sexstriatus*	37365010	4.2
Southern Ribbonfish	*Trachipterus jacksonensis*	37271001	4.1
Needleskin Queenfish	*Scomberoides tol*	37337044	3.8
Chinamanfish	*Symphorus nematophorus*	37346017	3.8
Tropical Rock Lobster - Undifferentiated	*Panulirus* spp. except *P. cygnus*	28820901	3.5
Pennantfish	*Alectis ciliaris*	37337018	3.5
Mixed Fish	Undefined	37999999	3.5
Pygmy Devilray	*Mobula kuhlii*	37041001	3.0
Leatherjackets - Undifferentiated	*Monacanthidae* - undifferentiated	37465903	3.0
Fusiliers - Undifferentiated	*Caesionidae* - undifferentiated	37346931	2.2
Slender Sardine	*Dussumieria elopsoides*	37085010	2.1
Goldstripe Sardinella	*Sardinella gibbosa*	37085013	1.9
Finespine Pufferfish	*Tylerius spinosissimus*	37467022	1.9
Plaintail Lionfish	*Pterois russelii*	37287012	1.9
Tille Trevally	*Caranx tille*	37337049	1.9
Seastar (U)	Class Asteroidea - undifferentiated	25102000	1.7
Coral Crab	*Charybdis feriata*	28911001	1.7
Bumpnose Trevally	*Carangoides hedlandensis*	37337042	1.6
Crab (U)	Infraorder Brachyura - undifferentiated	28850000	1.4
Goatfishes (Upeneus) - Undifferentiated	*Upeneus* spp.	37355903	1.3
Oxeye Herring	*Megalops cyprinoides*	37054001	1.2
Epaulette Trevally	*Carangoides humerosus*	37337031	1.2
Triggerfish & Leatherjacket (U)	*Balistidae, Monacanthidae* - undifferentiated	37465000	1.2
Starry Toadfish	*Arothron firmamentum*	37467005	1.2
Silver Toadfish	*Lagocephalus sceleratus*	37467007	1.1
Squirrelfish - Undifferentiated	*Myripristis* spp.	37261901	1.1
Monocle Bream - Undifferentiated	*Scolopsis* spp.	37347902	1.1
Java Rabbitfish	*Siganus javus*	37438005	1.1
Bluebarred Parrotfish	*Scarus ghobban*	37386001	1.0
Eye Gurnard	*Lepidotrigla argus*	37288032	0.9
Ponyfishes - Undifferentiated	*Leiognathidae* - undifferentiated	37341000	0.9
Round Batfish	*Platax orbicularis*	37362007	0.8
Smooth Golden Toadfish	*Lagocephalus inermis*	37467008	0.8
Longfin Bannerfish	*Heniochus acuminatus*	37365011	0.8
Pacific Bonefish	*Albula argentea*	37055001	0.7
Rough Flutemouth	*Fistularia petimba*	37278002	0.7
Sixbar Grouper	*Epinephelus sexfasciatus*	37311017	0.7
Sicklefish	*Drepane punctata*	37362005	0.6
Speckled Maskray	*Neotrygon picta*	37035029	0.6
Barred Yellowtail Scad	*Atule mate*	37337024	0.6
Ringtail Surgeonfish	*Acanthurus auranticavus*	37437005	0.6
Tripodfish & Deepwater Tripodfish (U)	*Triacanthidae, Triacanthodidae* - undifferentiated	37464000	0.6
Scallops - Undifferentiated	*Cypselurus poecilopterus*	37233010	0.6
Scribbled Angelfish	*Chaetodontoplus duboulayi*	37365009	0.5
Blackspot Butterfish	*Psenopsis humerosa*	37445007	0.5
Nudibranch (U)	Order Nudibranchia - undifferentiated	24420000	0.4
Batfish - Undifferentiated	*Platax* spp.	37362902	0.4
Ocellate Butterflyfish	*Parachaetodon ocellatus*	37365003	0.4
Tuskfishes - Undifferentiated	*Choerodon* spp.	37384902	0.4
False Bailer Shell	*Livonia mammilla*	24207001	0.3
Sea Urchin (U)	Class Echinoidea - undifferentiated	25200000	0.3
Threeline Rockcod	*Epinephelus heniochus*	37311019	0.3
Damselfishes - Undifferentiated	*Pomacentridae* - undifferentiated	37372000	0.3
Highfin Veilfin	*Velifer hypselopterus*	37269002	0.3
Spotted Stingerfish	*Inimicus sinensis*	37287020	0.2

COMMON NAME	SCIENTIFIC NAME	CAAB Code	Catch (kg)
Fiveline Snapper	*Lutjanus quinquelineatus*	37346006	0.2
Pufferfish (U)	*Triodontidae* - undifferentiated	37468000	0.2
Elegant Seasnake	*Hydrophis elegans*	39125021	0.2
Ditchelee	*Pellona ditchela*	37085009	0.2
Largespot Flying Gurnard	*Dactyloptena papilio*	37308001	0.2
Flying Fish	*Exocoetidae gen.* sp. unknown [Soviet Fishery Data, 1998]	99379760	0.2
Tasselled Leatherjacket	*Chaetodermis penicilligerus*	37465013	0.1
Goldband Goatfish	*Upeneus moluccensis*	37355003	0.1
Yellowtail Stargazer	*Uranoscopus cognatus*	37400008	0.1
Prawn (U)	*Penaeoidea & Caridea* - undifferentiated	28710000	0.1
Commercial Scallop	*Pecten fumatus*	23270007	0.1
Razorfish (U)	*Centriscidae - undifferentiated*	37280000	0.1
Toothed Ponyfish	*Gazza minuta*	37341007	0.1
Darkfin Puller	*Chromis atripes*	37372037	0.1
Demoiselle - Undifferentiated	*Chrysiptera* spp.	37372908	0.1
Darkspot Tuskfish	*Choerodon monostigma*	37384008	0.1
Spiny Eel Blenny	*Congrogadus spinifer*	37411001	0.1
Deep Pugnosed Ponyfish	*Leiognathus ruconius*	37341015	<0.0
Cardinalfish - Undifferentiated	*Apogon* spp.	37327901	<0.0
Total			**42,218.9**

Appendix 2 Density, biomass estimate and CV for each main species in each stratum.

Stratum	Species	Number of shots caught	Mean density (kg/km^2)	Standard error density (kg/km^2)	Relative biomass estimate (t)	CV	Mean density (kg/km^2) with zeros	Standard error density (kg/km^2) with zeros
GoC_East	Crimson Snapper	34	813.5	203.3	46205	0.27	553.2	147.9
GoC_East	Saddletail Snapper	48	511.3	110.7	40996	0.22	490.8	107.2
GoC_East	Painted Sweetlips	45	107.1	16.8	8052	0.16	96.4	15.8
GoC_East	Goldband Snapper	43	88.1	11.1	6331	0.14	75.8	10.5
GoC_East	Golden Snapper	10	285.5	203.1	4769	0.77	57.1	42.2
GoC_East	Mangrove Jack	12	152.2	41.6	3051	0.37	36.5	13.4
GoC_East	Redspot Emperor	37	38.6	6.4	2385	0.19	28.6	5.3
GoC_East	Red Emperor	33	22.6	3.0	1247	0.17	14.9	2.5
GoC_East	Black Jewfish	1	9.5	NA	16	NA	0.2	0.2
GoC_East	OS GOC	50	598.3	84.6	46,960	15	598.3	84.6

Note: Density is calculated based both on shots in which each species was caught, and also for all survey shots including zero catches. Calculation were made using the swept area calculated from Weff.